Preliminary Economic and Regulatory Flexibility Analysis for OSHA's Proposed Standard for Occupational Exposure to Respirable Crystalline Silica

Office of Regulatory Analysis

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And (For Chapter IV, Technological Feasibility)

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CHAPTER I: INTRODUCTION

OSHA's Preliminary Economic Analysis and Initial Regulatory Flexibility Analysis (PEA) addresses issues related to the costs, benefits, technological and economic feasibility, and the economic impacts (including impacts on small entities) of the proposed respirable crystalline silica rule and evaluates regulatory alternatives to the proposed rule. Executive Orders 13563 and 12866 direct agencies to assess all costs and benefits of available regulatory alternatives and, if regulation is necessary, to select regulatory approaches that maximize net benefits (including potential economic, environmental, public health and safety effects, distributive impacts, and equity). Executive Order 13563 emphasizes the importance of quantifying both costs and benefits, of reducing costs, of harmonizing rules and of promoting flexibility. OSHA has determined that this proposed rule governing occupational exposure to respirable crystalline silica (“silica”) is an economically significant regulatory action under section 3(f)(1) of Executive Order 12866. Accordingly, the Office of Regulatory Analysis within OSHA has prepared this preliminary economic analysis (PEA) for the proposed rule. In conducting this PEA, OSHA has endeavored to meet the requirements of OMB’s Circular A-4 (OMB, 2003), a guidance document for regulatory agencies preparing economic analyses under Executive Order 12866.

This rule has been reviewed by the Office of Information and Regulatory Affairs in the Office of Management and Budget, as required by Executive Order 12866.

The purpose of this Preliminary Economic and Initial Regulatory Flexibility Analysis is to:

- Identify the establishments and industries potentially affected by the proposed rule;
- Estimate current exposures and the technologically feasible methods of controlling these exposures;
- Estimate the benefits resulting from employers coming into compliance with the rule in terms of the reduction in fatal cases of lung cancer, fatal cases of non-malignant respiratory disease, fatal cases of end-stage renal disease, and cases of silicosis morbidity;
- Evaluate the costs and economic impacts that establishments in the regulated community will incur to achieve compliance with the proposed rule;
- Assess the economic feasibility of the rule for affected industries;
- Evaluate the principal regulatory alternatives to the proposed rule that OSHA has

considered; and

- Estimate the impacts of the final rule on small entities as defined by the Small Business Administration (in accordance with the Regulatory Flexibility Act, as amended in 1996).

The rest of this chapter is devoted to a description of the need for a silica rule, a discussion of the major provisions of the proposed rule, and a list of the chapters to follow in this PEA. To develop this PEA, OSHA relied considerably on the support of OSHA's contractor Eastern Research Group (ERG). ERG's individual work products are referenced throughout this PEA.

REASONS WHY ACTION BY THE AGENCY IS BEING CONSIDERED

When establishing the need for an occupational safety and health standard, OSHA must evaluate available data to determine whether or not workers will suffer a material impairment of their health or functional capacity as a result of being exposed to a particular safety or health hazard. Section 6(b)(5) of the Occupational Safety and Health Act (OSH Act) directs OSHA to set the standard ". . . which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life." 29 U.S.C. 655(b)(5).

The Supreme Court, in reviewing previous OSHA standards, has also directed the Agency to make a determination that ". . . significant risks are present and can be eliminated or lessened by a change in practices" before promulgating any health or safety standard. Indus. Union Dep't, AFL-CIO v. Am. Petroleum Inst., 448 U.S. 607, 642 (1980). While the Supreme Court did not specify what constituted a "significant risk" and considered that determination to be largely a policy decision for OSHA, the Court did offer guidance, stating that a reasonable person might well consider a 1 in 1000 risk of fatality to be significant. Id. at 655.

OSHA makes its material impairment and significant risk determinations by first evaluating available data to identify hazards to which employees are exposed in the workplace that are likely to induce material impairments of their health or functional capacity. The Agency looks at a broad array of scientific data and assesses the overall weight of evidence in making its significant risk determinations. In the next step, the Agency looks at the overall quality of the data to identify studies or other data that are useful in making quantitative estimates of the risk of those impairments of health among exposed workers over their working life (as mandated by the OSH Act). While many studies may add to the overall weight of evidence, often only select studies have suitable information for making quantitative estimates of risk. In the case of health risk analyses, the quantitative estimation of risk often involves the use of dose-response mathematical models. This is a common approach used in the field of health risk assessment that allows the Agency to extrapolate scientifically observable data, from humans or animals, to a variety of exposure scenarios that may be relevant to exposed workers.

In the case of respirable crystalline silica, OSHA has identified over 60 epidemiological studies (covering more than 30 occupational groups) that provide clear evidence that respirable crystalline silica is a human lung carcinogen. In addition, epidemiological evidence and case reports among exposed workers indicate that exposure to respirable crystalline silica leads to other adverse respiratory effects, such as fatal non-malignant silicosis and chronic obstructive pulmonary disease, and an elevated risk of end-stage renal disease. OSHA also identified seven studies that quantitatively described relationships between exposure to respirable crystalline silica and silicosis morbidity, as diagnosed from chest radiography (i.e., chest x-rays or computerized tomography).

Considering just respirable crystalline silica as a human lung carcinogen, OSHA believes that the strongest evidence for carcinogenicity comes from studies in five industry sectors (diatomaceous earth, pottery, granite, industrial sand, and coal mining) as well as a study by Steenland et al. (2001) that analyzed pooled data from 10 occupational cohort studies; each of these studies found a positive relationship between exposure to respirable crystalline silica and lung cancer mortality. Using data from a specific worker cohort to determine the risk to exposed workers has been upheld on judicial review in other standards regulating worker exposure to other toxic substances. It is also an accepted scientific approach used by other regulatory and non-regulatory entities in making decisions regarding public health.

Based on a variety of relative risk models fit to these data sets for death from lung cancer, OSHA estimates that the excess lifetime risk to workers exposed over a working life of 45 years at the current general industry permissible exposure limit (PEL) (approximately 100 $\mu g/m^3$ respirable crystalline silica) is between 13 and 60 deaths per 1,000 workers. For exposure over a working life at the current construction and shipyard employment PELs (estimated to range between 250 and 500 $\mu g/m^3$), the estimated excess risk lies between 37 and 653 deaths per 1,000. Reducing these PELs to the proposed PEL of 50 $\mu g/m^3$ respirable crystalline silica results in a substantial reduction of these risks, to a range estimated to be between 6 and 26 deaths from lung cancer per 1,000 workers.

Overall, OSHA estimates that the proposed rule would prevent between 579 and 796 fatalities annually—375 from non-malignant respiratory disease, 151 from end-stage renal disease, and between 53 and 271 from lung cancer—and an additional 1,585 cases of moderate-to-severe silicosis annually.

SUMMARY OF THE PROPOSED STANDARDS FOR RESPIRABLE CRYSTALLINE SILICA

OSHA has developed a comprehensive standard to protect employees from exposure to respirable crystalline silica in general industry and maritime and is proposing a separate standard for the construction industry. The proposed standards contains a permissible exposure limit (PEL) and other requirements, including: employee exposure assessment, regulated areas, methods of compliance, respiratory protection, medical surveillance, communication of silica hazards to employees, and recordkeeping. The text below summarizes the requirements contained in the proposed standards.

(a) Scope and application

One proposed standard would apply to all workplaces where there is occupational exposure to respirable crystalline silica within general industry and maritime. The other proposed standard would apply to all workplaces in construction industries where there is occupational exposure to respirable crystalline silica. Neither proposed standard would apply to agriculture.

(b) Definitions

The definitions section explains important terms used in the proposed standards, such as “action level,” “employee exposure,” “objective data,” “regulated area,” and others.

(c) Permissible Exposure Limit (PEL)

OSHA's proposed PEL is expressed in units of microgram(s) per cubic meter of air (μg/m^3), calculated as an 8-hour time-weighted average (TWA). The Agency is proposing a PEL of 50 μg/m^3 but for analytical purposes has also assessed the feasibility of an alternative PEL of 25 μg/m^3, as well as the economic impacts of an alternative PEL of 100 μg/m^3.

Health risk data and analyses indicate that the risk of non-malignant respiratory disease, end-stage renal disease, and lung cancer associated with exposure to 100 μg/m^3 respirable crystalline silica over a working lifetime is of a magnitude that would be considered significant by the Agency. Although OSHA is still evaluating the scientific evidence underlying these risk analyses, OSHA has made a preliminary decision not to consider an alternative PEL greater than 100 μg/m^3.

In this proposed rule, OSHA is also setting an action level of 25 μg/m^3. In these proposed standards, as in previous OSHA standards, the provisions for initial and periodic exposure monitoring are only triggered once the action level is reached or exceeded. Thus, employers may be able to considerably reduce the burden of complying with the proposed standards by reducing employee exposures below the action level.

(d) Exposure Assessment

This paragraph of the proposed standards has provisions for conducting an initial exposure assessment, for performing periodic and additional exposure monitoring, and for observing monitoring. Each employer is required to conduct an assessment of the work site to determine if employees are exposed to levels of respirable crystalline silica at or above the action level. The purpose of this assessment is to determine not only whether or not engineering and work practice controls are required to meet the PEL, but also whether certain provisions of the proposed standards—such as medical surveillance, periodic monitoring, training, or respiratory protection—would be needed. Airborne exposures would be measured by personal breathing zone air samples.

In cases where the employer has conducted exposure monitoring within the 12 months prior to the effective date of the rule, and has satisfied all other requirements within this section, the results of previous monitoring may be used to satisfy the initial monitoring provision. In addition, in cases where the employer has objective data demonstrating that respirable crystalline silica is not capable of being released in concentrations that exceed the action level, the employer may rely upon such data to satisfy the initial exposure assessment requirements of this section.

If the initial monitoring indicates that employee exposures are at or above the action level, the employer must comply with one of two requirements to re-evaluate exposures. Under an option that prescribes a fixed schedule, for airborne levels above the action level but below the PEL, monitoring is required every 6 months. For airborne levels above the PEL, monitoring is required every 3 months. However, if the periodic monitoring indicates that exposures are below the action level and the employer can confirm the results by two consecutive measurements taken at least seven days apart, then the employer may discontinue monitoring for employees covered by that monitoring. An alternative performance option permits the employer to assess the 8-hour TWA exposure for each employee on the basis of any combination of air monitoring data or objective data sufficient to accurately characterize employee exposure to respirable crystalline silica.

Additional monitoring is required when there is a change in the production process, control equipment, personnel, or work practices that may result in new or additional exposures to respirable crystalline silica.

The proposed construction standard requires employers to notify employees of the results of an exposure assessment within 5 days of completing an assessment. Employers in general industry and maritime are required to notify employees of the results of an exposure assessment within 15 days of completing an assessment. This notification may be made individually in writing or by posting the results in a location that is accessible to all affected employees. Where exposure levels are above the PEL, the employer is required to describe in the written notification the corrective action being taken to lower the exposure levels to below the PEL.

In addition, the proposed standard specifies the procedures and protocol to which laboratories must adhere when analyzing respirable crystalline silica exposure samples.

Employers are required to provide affected employees or their designated representatives with an opportunity to observe any monitoring of employees for exposure to respirable crystalline silica. The employer is also required to provide personal protective equipment (PPE) at no cost to all those observing the monitoring.

For construction, where employees perform operations listed in Table 1 in the proposed construction standard and the employer has fully implemented the engineering controls, work practices, and respiratory protection specified in Table 1 for that operation, the employer is not required to assess the exposure of employees performing such operations.

To implement this option, the employer must presume that each employee performing an operation listed in Table 1 is exposed at or above the action level, and that each employee performing an operation listed in Table 1 that requires a respirator is exposed above the PEL, unless the employer can demonstrate otherwise in accordance with the exposure assessment requirements in the standard.

(e) Regulated Areas

To minimize any unnecessary employee exposures, the proposed standard requires employers to establish either a regulated area or an access control plan wherever an employee’s exposure to airborne concentrations of respirable crystalline silica is, or can reasonably be expected to be, above the PEL.

Under the first option, the proposed standard requires that the regulated area include demarcating the boundaries of the regulated area (as separate from the rest of the workplace), limiting access to the regulated area, providing an appropriate respirator to each employee entering the regulated area, and providing protective clothing as needed in the regulated area.

Under the second option, the access control plan must include the following elements: competent person provisions, notification and demarcation procedures, multi-employer workplace procedures, provisions for limiting access, provisions for supplying respirators, and protective work clothing procedures. OSHA anticipates that employers will incur costs for labor, materials, and respiratory protection to comply with the proposed access control requirements.

(f) Methods of Compliance

The proposed standards would require that the employer use engineering controls and work practices to maintain exposures to levels at or below the PEL, unless the employer can demonstrate that such controls are not feasible. Wherever feasible engineering and work practice controls are not sufficient to reduce employee exposure to the PEL, the employer shall use them to reduce employee exposure to the lowest level achievable and then supplement them with respiratory protection.

The proposed standard cross-references other standards that address the unique conditions associated with abrasive blasting. Moreover, employers are prohibited from rotating employees to different jobs to achieve compliance with the PEL.

For operations listed in Table 1 in the proposed construction standard, employers who fully implement the engineering controls, work practices, and respiratory protection described in the table would be considered to be in compliance with the requirements in this section.

(g) Respiratory Protection

For all three affected major sectors (general industry, maritime, and construction), the proposed standards make reference to OSHA's respiratory protection standard for general industry (29 CFR 1910.134), which must be complied with when employees are required to use respirators for protection against respirable crystalline silica exposure. The respiratory protection standard requires written procedures for the proper selection, use, cleaning, storage, and maintenance of respirators. The proposed standards for respirable crystalline silica require the use of respirators in four situations: (1) periods necessary to install or implement feasible engineering and work practice controls; (2) work operations such as maintenance and repair activities where meeting the PEL with engineering and work practice controls is not feasible; (3) work operations in which an employer has implemented all feasible engineering and work practice controls and these controls do not reduce exposures to the PEL; and (4) during periods when the employee is in a regulated area, or, for construction, during periods when the employee is in an area where respirator use is required under an access control plan or under Table 1.

(h) Medical Surveillance

The proposed standards require employers to make medical surveillance available at no cost to the employee and at a reasonable time and place for those employees who will be exposed to silica above the PEL for 30 or more days a year. All medical examinations are to be performed by a physician or other licensed health care professional (PLHCP).

Medical examinations must be given within 30 days after initial assignment, unless the employer can demonstrate that the employee has already received a medical examination for respirable crystalline silica exposure within the past 12 months. Otherwise, medical examinations must be given: (1) every three years covering medical and work history, a chest x-ray and pulmonary function test, and a physical examination with special emphasis on the respiratory system; and (2) within 30 days if the PLHCP's written medical opinion indicates that an employee should be examined by a pulmonary specialist.

The initial medical examination must include a physical examination of the respiratory system, a chest x-ray, a pulmonary function test, testing for latent tuberculosis infection, and any other tests deemed appropriate by the PLHCP. The medical examination must also include an evaluation of the individual's medical and work history, with emphasis on past, present, and anticipated future exposure to respirable crystalline silica, dust, and other agents affecting the respiratory system; any history of respiratory system dysfunction, including signs and symptoms of respiratory disease (e.g., shortness of breath, cough, wheezing) and history of tuberculosis; and smoking status and history.

The employer is required to ensure the PLHCP has a copy of the standard. The PLHCP must be given information on the employee's work duties, levels of silica exposure, a description of all PPE used including duration of use, and previous medical records that are in the control of the employer, so that the PLHCP will have appropriate information to determine whether to recommend any limitations on the employee's exposure to silica or the use of PPE, such as respirators.

The employer is required to obtain a written medical opinion from the PLHCP within 30 days of the medical exam. The written opinion should explain: (1) whether the employee has any detected medical condition that would place the employee at increased risk of developing health problems from occupational exposure to respirable crystalline silica; (2) any limitations that the employee may have in the use of respirators or other PPE; (3) a statement that the employee should be examined by an American Board Certified Specialist in Pulmonary Disease (“pulmonary specialist”), if the chest X-ray provided in accordance with this section is classified as 1/0 or higher, or if referral to a pulmonary specialist is otherwise deemed appropriate by the PLHCP; and (4) a statement that the PLHCP has explained to the employee the results of the medical examination, including findings of any medical conditions related to respirable crystalline silica exposure that require further evaluation or treatment, and any special provisions for use of protective clothing or equipment.

If the PLHCP’s written medical opinion indicates that an employee should be examined by a pulmonary specialist, the proposed standards require that the employer provide a medical examination by a pulmonary specialist within 30 days after receiving the PLHCP’s written medical opinion. The employer must (1) ensure that the examining pulmonary specialist is provided with all of the information that the employer is obligated to provide to the PLHCP and (2) obtain a written medical opinion from the pulmonary specialist that meets the requirements of the proposed standards pertaining to the contents of the PLHCP’s written medical opinion.

(i) Communication of Respirable Crystalline Silica Hazards to Employees

This paragraph of the proposed standard includes a cross-reference to OSHA’s Hazard Communication Standard (HCS) (29 CFR 1910.1200) and requires that employers include respirable crystalline silica in their hazard communication program, implementation of which must include labels, material safety data sheets, and information and training. This is not a new requirement as the existing hazard communication standard already requires that hazardous chemicals such as respirable crystalline silica be included in the employer’s hazard communication program.

Under the proposed paragraph for communication of hazards, employers must ensure that each employee has access to labels on containers of respirable crystalline silica and material safety data sheets, has access to copies of the proposed standard without cost to employees, and is trained in accordance with the provisions of HCS and this communication section of the proposed standard. The employer must ensure that at least the following hazards are addressed: cancer, lung effects, immune system effects, and kidney effects.

Training must be tailored to operations at the work site and be designed to provide information on health hazards associated with silica exposure, operations that could result in exposures exceeding the PEL, principles of safe handling of silica materials, and methods used to minimize exposure. The employer must ensure that each affected employee can demonstrate knowledge of at least the following: (1) specific operations in the workplace that could result in exposure to respirable crystalline silica, especially operations where exposure may exceed the PEL; (2) specific procedures the employer has implemented to protect employees from exposure to respirable crystalline silica, including appropriate work practices and use of PPE such as respirators and protective clothing; (3) the contents of this section; and (4) the purpose and a description of the medical surveillance program required by the proposed standard.

(j) Recordkeeping

The employer is responsible for maintaining a record of employee exposure measurements, objective data, and employee medical surveillance information. Exposure and medical records must be maintained in accordance with 29 CFR 1910.1020.

For records of exposure measurements, the proposed standards require that the records include the date when each sample was taken; identification of the operation involving exposure to silica that was monitored; the sampling and analytical methods used; the number, duration and results of the samples; the identity of the laboratory that performed the analysis; type of PPE used; and name, social security number, and job classification of all employees represented by the monitoring, indicating which employees were actually monitored.

The proposed standard requires that employers maintain accurate records of objective data. The records maintained should include information on: the silica-containing material in question; the source of the objective data; the test protocol and results of testing, or analysis of the material for the release of respirable crystalline silica; a description of the process, operation, or activity and how the data support the assessment; and other data relevant to the process, operation, activity, material, or employee exposures. These records must be kept for as long as the objective data are relied upon.

The proposed standards require that all affected employers establish and maintain accurate records of each employee covered by medical surveillance. The information maintained should include: name and social security number of the employee; a copy of the written opinion of the physician or other licensed health care professional (PLHCP) and the pulmonary specialist; and a copy of the information provided to the PLHCPs and pulmonary specialists as required by the medical surveillance section of the proposed standards.

(k) Dates

Employers are required to comply with effective dates and start-up dates set forth in the proposed rule for certain provisions. The effective date is set for 60 days after publication of the final standard in the Federal Register. The start-up dates for most requirements are set at 180 days after the effective dates, except for engineering controls required by paragraph (f) of this standard, which must be implemented no later than one year after the effective date. The laboratory requirements commence two years after the effective date.

THE REST OF THIS PEA

Following this Introduction, the PEA contains the following chapters:

- Chapter II: Assessing the Need for Regulation
- Chapter III: Profile of Affected Industries
- Chapter IV: Technological Feasibility
- Chapter V: Costs of Compliance
- Chapter VI: Economic Feasibility Analysis and Regulatory Flexibility Determination
- Chapter VII: Benefits and Net Benefits
- Chapter VIII: Regulatory Alternatives
- Chapter IX: Initial Regulatory Flexibility Analysis
- Chapter X: Environmental Impacts

Subsequent to completion of the final draft of this PEA, OSHA identified an industry, hydraulic fracturing, that would be impacted by the proposed standard. Hydraulic fracturing, sometimes called “fracking”, is a process used to extract natural gas and oil deposits from shale and other tight geologic formations. Recent developments show that this industry routinely exposes workers to significant levels of silica. OSHA finds that there are now sufficient data to provide the main elements of the economic analysis for this rapidly growing industry and has done so in Appendix A to this PEA.

REFERENCES

U. S. Office of Management and Budget, 2003 (OMB, 2003). Circular A-4, Regulatory Analysis, September 17, 2003. Available at: http://www.whitehouse.gov/sites/default/files/omb/assets/regulatory_matters_pdf/a-4.pdf

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CHAPTER II: ASSESSING THE NEED FOR REGULATION

INTRODUCTION

The stated purpose of the Occupational Safety and Health Act of 1970 (OSH Act) is to "assure so far as possible every working man and woman in the Nation safe and healthful working conditions and to preserve our human resources . . . ." 29 U.S.C. 651(b). Section 2(b)(3) of the Act specifically authorizes "the Secretary of Labor to set mandatory occupational safety and health standards applicable to businesses affecting interstate commerce." 29 U.S.C. 651(b)(3). This congressional mandate provides the authority for OSHA's standard for respirable crystalline silica ("silica"), which is designed to mitigate the adverse health effects associated with occupational exposure to this hazardous substance.

Section 6(b)(5) of the Act requires the Secretary of Labor, when promulgating health standards, to set the standard at the level "which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity . . . ." 29 U.S.C. 655(b)(5). In its "Benzene" decision, the Supreme Court more precisely interpreted this language to mean that OSHA's health standards must reduce a "significant risk" of material impairment, subject to other regulatory constraints such as feasibility.[1] The Agency has determined that employees across a range of industries are exposed to levels of airborne silica that result in the development of lung cancer, silicosis, and end-stage renal disease—and premature death. The Agency's proposed standard would reduce these occupational risks of lung cancer, silicosis, and end-stage renal disease, with the result that an estimated 634 to 1,037 deaths annually will be prevented. Protecting employees from a significant risk of these diseases establishes the need for the Agency's remedy: to increase worker protection from exposure to silica.

Executive Order 12866 directs regulatory agencies to assess whether, from a legal or an economic view, a Federal regulation is needed:

Section 1. Statement of Regulatory Philosophy and Principles.

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[1] *Indus. Union Dep't*, *AFL-CIO v. Am. Petroleum Inst.*, 448 U.S. 607 (1980)).

> (a) The Regulatory Philosophy. Federal agencies should promulgate only such regulations as are required by law, are necessary to interpret the law, or are made necessary by compelling public need, such as material failures of private markets to protect or improve the health and safety of the public, the environment, or the well-being of the American people. 58 FR 51735 (Oct. 4, 1993).

OSHA believes there is a failure of private markets to protect the health of the public by exposing employees to unnecessarily high levels of silica. In making this statement, the Agency recognizes that many firms have responded to the risks posed by exposure to silica by implementing control programs for their employees. In fact, some existing control programs go beyond the requirements of the proposed rule, and information that OSHA has collected suggests that a significant percentage of all employees with silica present in the workplace are currently being protected against the risks posed by silica. For these firms and these employees, the economic incentives provided by private markets appear to be working effectively. Nevertheless, the effectiveness of private markets in protecting worker health and safety is far from universal. In particular, OSHA sampling data clearly indicate that many firms have not protected their workers from overexposure to silica.

The discussion below considers why private markets, as well as information dissemination programs, workers' compensation systems, and tort liability options, each may fail to protect employees from silica exposure, resulting in the need for a more protective OSHA silica rule.

PRIVATE MARKETS

In the United States, the preferred mechanism for making economic decisions and taking economic actions is the private market. Under suitable conditions, a market system is economically efficient in the following sense: resources are allocated where they are most highly valued; the appropriate mix of goods and services, embodying the desired bundle of characteristics, is produced; and further improvements in the welfare of any member of society cannot be attained without making at least one other member worse off.

In the job market, as ideally conceived, employers and employees bargain over the conditions of employment, including not only salary and other worker benefits, but also occupational risks to worker safety and health. Employers compete among themselves to attract workers. In order to induce workers to accept hazardous jobs, employers must offer a higher salary—termed a "wage premium for risk," or a "risk premium" for short—to compensate for the additional job risk.[2] Because they must pay higher wages for more hazardous work, employers have an incentive to make the workplace safer by making safety-related investments in equipment and training or by using more costly but safer work practices. According to economic theory, the operation of the private job market will provide the optimal level of occupational risk, where for each employer the additional cost of job safety just equals the avoided payout in risk premiums to workers.

For the job market to function in this idealized manner, however, four conditions must be satisfied. First, workers, as well as employers, must have perfect information—that is, they must be fully informed about their workplace options, including job hazards, or be able to costlessly acquire such information. Second, participants in the job market must directly bear all of the costs and obtain all of the benefits of their actions; that is, none of the direct impacts of job market transactions can be externalized to outside parties. Third, the relevant job market must be perfectly competitive; that is, it must contain such a large number of employers and such a large number of workers that no individual economic agent is able to influence the risk-adjusted wage. Fourth, since job market outcomes vary depending on the preexisting distribution of wealth and on other social parameters, for the market-derived level of occupational risk to be socially optimal (not just allocatively efficient), the social setting in which the job market operates cannot be unjust or unacceptably inequitable. In practice, each of these four conditions is violated in important ways. These are discussed below in the context of four specific types of market imperfections: (1) imperfect information, (2) externalities, (3) imperfect competition, and (4) market-transmitted inequities or injustices.[3]

Imperfect Information

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[2] The concept of compensating wage differentials for undesirable job characteristics, including occupational hazards, goes back to Adam Smith's *The Wealth of Nations*, which was originally published in 1776.

[3] Furthermore, other related market imperfections are identified and discussed in the section on workers' compensation insurance later in this chapter.

As described below, imperfect information about job hazards is present at several levels that reinforce each other: employers frequently lack knowledge about workplace hazards and how to reduce them; workers are often unaware of the workplace health and safety risks to which they are exposed; and workers typically have difficulty in understanding whatever risk information they are able to obtain. Imperfect information at these various levels has surely impeded the efficient operation of the job market as far as workplace risk is concerned. The reason is that workers unaware of job hazards do not seek, or receive, compensation for the risks they bear, and as a result, employers have insufficient incentive to invest in safer working conditions.

Lack of Employer Information

In the absence of regulation, employers have limited economic incentives to identify the health and safety risks that their workers bear.[4] Furthermore, employers have little incentive to share what information they possess about job hazards with their workers, whose response would be to demand higher wages to compensate for the risk. Similarly, employers who develop cost-effective methods of reducing workplace risk have little incentive to share information with their competitors about such methods (unless they are patentable).[5] As a result, without regulation, many employers are likely to be unaware of the magnitude of silica-related health risks in the workplace or of the availability of effective ways of ameliorating or eliminating these risks.

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[4] Other private parties also lack incentives to invest resources to collect and analyze occupational risk data due to the public-good nature of the information. See Ashford and Caldart (1996), p. 234.

[5] Relatedly, in the absence of regulation, employers, as well as third parties, have less incentive to develop new technological solutions to protect workers on the job. For evidence of regulatory stimuli inducing innovations to improve worker health and safety, see, for example, Ashford, Ayers, and Stone (1985), as well as more recent evidence from OSHA's 610 regulatory reviews.

Lack of Worker Information

Even without information from their employer, workers might reasonably be cognizant, at least at some simple qualitative level, of many occupational *safety* hazards. For example, workers can expect that activities involving explosive materials or working at heights in an open space are inherently dangerous. Furthermore, workers can develop some, admittedly limited, knowledge of safety hazards in their workplace from their own and their coworkers' on-the-job accident and injury experience.

The same cannot generally be said for occupational *health* hazards, such as worker exposure to respirable crystalline silica. Whereas the relationship between a workplace accident and the resultant injury is both immediate and obvious, the connection between exposure to an occupational health hazard and the resultant disease generally is not. Most diseases have multiple potential causes and may be the result of synergistic effects, making it virtually impossible to ascertain whether a worker's disease is job-related rather than an "ordinary disease of life" resulting from genetic, physiological, lifestyle, or non-occupational environmental factors.[6] Compounding this causation problem is the fact that there is frequently a long latency period—sometimes 20 years or more—between exposure to the occupational health hazard and the manifestation of the resultant disease. Consequently, workers usually cannot logically or intuitively draw a connection between work conditions and a chronic disease, as would be the case for an acute injury. For example, should workers attribute their lung cancer to cigarette smoking, to genetic predisposition, to exposure to silica in the workplace, or to other non-occupational exposures?

Even the preceding characterization fails to capture the extent to which imperfect information impairs the idealized job market's decision calculus, as workers supposedly weigh increased workplace safety or health hazards against wage increases. One reason is that the risk information available to the worker is typically crude and imprecise. For example, workers might reasonably be aware, at least over time, that their on-the-job exposure to silica increases their chance of contracting silicosis, but they could hardly be expected to know that, at an average silica exposure level of, say, 100 $\mu g/m^3$, they are increasing their risk of silicosis by 27 percent; furthermore, they probably would have no idea that they are increasing their risk of

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[6] It is true that, in rare circumstances, the cause of a disease is unique or nearly so. Examples of such "signature" diseases include mesothelioma and angiosarcoma, which are caused by exposure to asbestos and vinyl chloride, respectively. In some cases, silica can be uniquely identified as the dust causing a worker's pneumoconiosis, a restrictive lung disease due to inhalation of dust; in such cases, the disease is classified as silicosis. Silica cannot be uniquely identified, in individual cases, as the cause of other diseases arising from worker exposure to silica, such as lung cancer, tuberculosis, and renal failure.

lung cancer, much less that they are increasing their risk by 20 percent. Even more to the point, workers would have no way of ascertaining their average silica exposure without exposure monitoring, and the current silica rule does not require employers to conduct exposure monitoring. In addition to silicosis, moreover, how many affected workers would, *a priori*, be aware of the link between silica exposure and end-stage renal disease, let alone the risk of developing such an illness? A second, related reason is that workers are unlikely to know the workplace risks associated with their particular employer, or with one potential employer versus another, even if the types of work assignments are the same. For example, at a general level, how do workers know their level of silica exposure with a particular employer? More specifically, on tasks involving silica exposure, how do workers know whether adequate engineering controls are being applied or that the respirators the employer provides have adequate protection factors and have been properly fit-tested and maintained? In fact, even the assumption that the employer is using engineering controls and supplying respirators may not be warranted in the absence of regulation.

Inability to Process Risk Information

Equally problematic as the ability of workers to obtain workplace risk information is their ability to understand whatever workplace risk information they obtain.[7] Both experimental studies and observed market behavior suggest that individuals have considerable difficulty rationally processing information about low-probability, high-consequence events such as occupational injuries, illnesses, and fatalities. For example, most individuals are unable to comprehend or rationally act on risk information when presented, as risk analysis often is, in mathematical terms—a 0.0001 versus a 0.00001 versus a 0.000001 annual risk of death from occupational causes, for instance.

In order to cope with uncertain situations, individuals have developed various rules of thumb—termed "heuristics" (Tversky and Kahneman, 1974)—to aid in their decision-making. In many circumstances, these heuristics work quickly and effectively (which is their purpose), but sometimes they introduce unintentional cognitive biases that can lead to illogical, inconsistent, or otherwise poor decision-making.[8] Examples of these apparently almost universal human

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[7] The literature documenting risk perception problems is huge. See, in particular, the classic work of Tversky and Kahneman (1974). For a recent summary of risk perception problems and their causes, see Thaler and Sunstein (2008), pp. 17-37.

[8] These decision-making anomalies are the central theme in the growing field of behavioral economics, which has enriched economic modeling with insights from psychology (and which includes the

biases include framing effects;[9] biases due to representativeness, availability, and anchoring heuristics;[10] and the interrelated effects of prior endowment, status quo bias, and loss aversion.[11]

Furthermore, there is substantial evidence that most individuals are unrealistically optimistic, even in high-stakes, high-risk situations and even if they are aware of the statistical risks (Thaler and Sunstein, 2009, pp. 31-33). In the area of occupational safety and health, this means that most workers underestimate their own risk of work-related injury, disease, or fatality and, therefore, fail to demand adequate compensation for bearing those risks.

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seminal work of Tversky and Kahneman, 1974). For more information on developments in behavioral economics, see, for example, Camerer, Loewenstein, and Rabin (2004).

The emerging field of neuroeconomics has provided scientific evidence to buttress the findings of cognitive biases reported in the behavioral economics literature. Neuroeconomics combines neuroscience, economics, and psychology to study how people make decisions. Brain scans performed in neuroeconomic experiments compare the roles of the different brain areas that contribute to economic decision-making. Neuroeconomic research has shown that human behavior involves a fluid interaction between controlled (reflective) and automatic processes of the brain and between cognitive and affective (emotional) systems. So-called decision-making “anomalies” are therefore the result of simplistic modeling of human decision-making, in which only the reflective processes of the brain and cognitive systems are recognized. For more information on neuroeconomics, see, for example, Camerer, Loewenstein, and Prelec (2005).

[9] Framing effects arise when alternative representations of probabilistically identical decision problems lead to systematically different choices. For example, experiments have shown that subjects' choices in otherwise identical problems depend upon whether they are phrased as gambling or insurance decisions or whether the statistical outcomes are presented in terms of lives saved or lives lost. See, for example, Machina (1987), pp. 141-147.

[10] Representativeness refers to a probabilistic judgment—say, of person A belonging to category B—that is based on the similarity of A to a subject’s image or stereotype of B, often without reference to or contrary to statistical principles (such as regression towards the mean) or factors (such as known prior probabilities or sample size). Availability refers to probabilistic judgments based on how readily examples come to mind. Hence, more recent, more vivid, and more highly publicized causes of death tend to generate inflated estimates of likelihood of occurrence. Anchoring refers to an estimation process of adjustment from an initial value (the anchor). Problems arise due to faulty (e.g., sometimes random or externally imposed) anchors and inadequate adjustment. Characterization of these three heuristics, and the biased judgments associated with them, originated with Tversky and Kahneman (1974).

Externalities

Externalities arise when an economic transaction generates direct positive or negative spillover effects on parties not involved in the transaction. The resulting divergence between private and social costs undermines the efficient allocation of resources in the market because the market is imparting inaccurate cost and price signals to economic agents. Applied to the job market, when costs are externalized, they are not reflected in the decisions that employers and workers make—leading to allocative distortions in that market.

Negative externalities exist in the job market because many of the costs of occupational injury and illness are borne by parties other than individual employers or workers. The major source of these externalities, for chronic occupational diseases, has to do with those occupational illness costs not covered by workers' compensation.[12] Only a portion of these residual costs is borne either by workers or by their employers. Outside of workers' compensation, workers incapacitated by an occupational injury or illness and their families often receive health care, rehabilitation, retraining, direct income maintenance, and life insurance benefits, most of which are paid for by society through Social Security and other social insurance and social welfare programs.[13] Furthermore, the entire medical care system in the United States is heavily subsidized by government so that part of the medical cost of treating injured or ill workers is paid for by the rest of society (Nichols and Zeckhauser, 1977, pp. 44-45). To the extent that the costs of occupational injury and illness are not borne by employers or workers, they will ignore

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[11] The endowment effect reflects the fact that individuals often demand much more for an object they own than they would be willing to pay to acquire it. Loss aversion is a similar manifestation of asymmetric value in which the disutility of giving up an object is greater than the utility associated with acquiring it. Status quo bias is a preference by individuals for the current state such that they are induced neither to buy nor to sell an object. See, for example, Kahneman, Knetsch, and Thaler (1991).

[12] Workers' compensation is separately discussion later in this chapter. As described there, in many cases (particularly for smaller firms), the premiums that an individual employer pays for workers' compensation are only loosely related, or unrelated, to the occupational risks that that employer's workers bear. However, workers' compensation does not cover chronic occupational diseases in most instances. For that reason, negative externalities tend to be a more significant issue in the case of occupational injuries.

[13] In addition, many occupational injuries and illnesses are not processed through the workers' compensation system at all, with workers choosing to seek care from their own private physician rather than from their employer's physician.

these costs in their job market negotiations. The result will be an inefficiently high level of occupational risk.

Imperfect Competition

In the idealized job market, the actions of large numbers of buyers and sellers of labor services establish the market-clearing, risk-compensated wage, so that individual employers and workers effectively take that wage as given. In reality, however, the job market is not one market but many markets differentiated by location, occupation, and other factors; furthermore in wage negotiations with their own workers, employers are typically in an advantageous position relative to all other potential employers. In these situations, discussed below, employers may have sufficient power to influence or to determine the wage their workers receive. This violates the conditions necessary for perfect competition and can result in inadequate worker compensation for exposure to workplace hazards.

Some job markets are dominated by one or a few firms. The classic example would be a small town in a rural area whose entire economy is based on a single employer, such as a manufacturing plant or a mining operation. In the abstract these job markets are still competitive, since workers offered less than a competitive market wage could move to a higher-wage town, state, or region. After all, the United States is a very mobile country, with economic considerations—particularly wage increases—being the chief motivation for worker migration. However, the general mobility of the American population masks the fact that many individuals, particularly in rural or isolated communities, are in fact geographically immobile. These individuals may be bound by local family ties, the values and preferences they associate with their community, a lack of education or marketable job training, age, or other factors. Whatever the reason, some employers in isolated areas have a relatively captive labor pool and can exert their monopsony power in the job market to their advantage.

A more pervasive problem in the job market is that, contrary to the model of perfect competition, workers cannot costlessly quit their job and obtain a similar job at the same wage with another employer. Leaving one's current employer can entail the expense and uncertainty associated with relocating to take advantage of better employment opportunities,[14] the cost and

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[14] Two factors have made relocation for employment purposes much more difficult in recent decades in the United States. One is the significant increase in the number of married households in which both spouses are employed. One spouse, for example, wishing to relocate for a better job may be confronted with the prospect that the other spouse would have to give up a job for a worse job or no job at all. Second, the increased rate of home ownership has negative consequences for job mobility because

difficulty of upgrading job skills, and the risk of a prolonged period of unemployment. In addition, employers derive market power from the fact that a portion of the compensation their own workers receive is not transferable to other jobs. Examples include job-specific training and associated compensation, seniority rights and associated benefits, investments in a pension plan, and most important, in many cases—at least at the time of this writing[15]—health insurance[16] (which, even if provided by competing employers, would typically be subject to exclusions for pre-existing conditions).

Under the conditions described above, employers would not have to take the market-clearing wage as given, but could offer a lower wage than would be observed in a perfectly competitive market,[17] and less than full compensation for workplace health and safety risks. As a result, relative to the idealized competitive job market, employers would have less incentive to invest in workplace safety. OSHA welcomes comment and supporting evidence on the degree of competitiveness in the labor markets affected by the proposed silica standard and the extent to which competitive pressures, or the lack thereof, have affected worker health risks from exposure to respirable crystalline silica.

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a home is much more illiquid than an apartment.

[15] The Patient Protection and Affordable Care Act (PPACA) (Pub.L. 111-148, 124 Stat. 119), signed into law by President Obama on March 30, 2010, promises to comprehensively address the issue of health care availability in the United States. However, the key provisions in PPACA that would remove health-care-related competitive barriers in labor markets, such as exclusions or higher rates for individuals with pre-existing conditions, would not take effect until January 1, 2014.

[16] It should be noted, however, that the percentage of employers providing health insurance coverage in the United States has been steadily declining over time, both because of rising costs and because of the increased difficulty of obtaining such insurance. In any case, health insurers are only responsible for losses not covered by workers' compensation (and not subject to exclusions, such as for pre-existing conditions) within the life of the policy—normally one year. In future years, insurers can raise rates or cancel the health insurance policy with the employer if circumstances change.

[17] For a graphical demonstration that an employer with monopsony power will pay less than the competitive market wage, see Borjas (2000), pp. 187-189.

Market-Transmitted Inequities or Injustices

In the idealized market, it is impossible to reallocate resources in a way that makes one party better off without making at least one other party worse off. Economists refer to such an allocation of resources as “Pareto optimal” (or, more accurately, as “Pareto efficient”). However, market transactions do not take place in a vacuum. They occur in a societal environment with a preexisting distribution of wealth and a specified set of legal rights and constraints. The Pareto-efficient allocation of resources will vary depending on these societal conditions. If the initial endowment of wealth is distributed in an unjust or socially undesirable manner, the resulting market outcome, even if Pareto-efficient, will, in all likelihood, not be socially optimal.

In addition, some individual actions are circumscribed by rights and duties or other social purposes (OMB, 2003) that take precedence over market considerations. Market transactions in such circumstances may be legally forbidden or socially unacceptable on ethical grounds, even if there are willing parties to the transactions. For example, in the United States, one’s right to vote cannot be sold to another person, and the prison time a convicted criminal receives cannot be served by another person in exchange for a fee. In the context of the job market, individuals cannot sell themselves into slavery, and small children cannot work in factories.

The preceding points suggest that, because of important rights and duties or other social purposes, government intervention may sometimes improve the workings of the unfettered job market.   In fact, the American people, through their elected representatives, have made a determination to override the operation of the unfettered job market if necessary by assuring, in the OSH Act “so far as possible every working man and woman in the Nation safe and healthful working conditions . . . .” 29 U.S.C. 651(b). It is under this congressional mandate that OSHA has developed the proposed silica rule.

NON-MARKET AND QUASI-MARKET ALTERNATIVES TO REGULATION

The discussion in this section considers whether non-market and quasi-market alternatives to the proposed rule would be capable of protecting workers from the hazards of silica exposure.

The alternatives under consideration are information dissemination programs, workers' compensation systems, and tort liability options.

Information Dissemination Programs

An alternative to OSHA's proposed silica rule would be the dissemination of information, either voluntarily or through compliance with OSHA's hazard communication standard, about the health risks associated with workplace exposure to silica. Better informed workers could more accurately assess the occupational risks associated with different jobs, thereby facilitating, through labor market transactions, higher risk premiums for more hazardous work and inducing employers to make the workplace less hazardous. The proposed rule recognizes the link between the dissemination of information and workplace risks by requiring that workers engaged in jobs involving exposure to silica be provided with information and training about silica-related illnesses and ways to prevent them. There are several reasons, however, why reliance on information dissemination programs alone would not yield the level of worker protection achievable through the proposed silica rule.

First, in the context of OSHA's hazard communication standard, which requires employers to transmit information about the inherently hazardous properties of hazardous substances, insufficient information is provided to identify risks in specific workplaces. Silica-related risks, for instance, are highly specific to individual tasks and work environments. Accurate knowledge about these occupational health risks would thus require that individual employers make available specific information, beyond that required by OSHA's hazard communications standard, about the risks to workers at each particular worksite.

Second, in the case of voluntary information dissemination programs, there are no incentives or mechanisms, absent a regulation, to ensure that all appropriate information regarding worker risk—including, in particular, worksite-specific hazards—will actually be distributed to workers.

Third, even if workers were better informed about workplace risks and hazards, all of the defects in the functioning of the private job market previously discussed—the limited ability of workers to evaluate risk information, externalities, imperfect competition, and factors that transcend the market—would still apply. Better information, therefore, would not ensure that the job market will yield wage premiums for risk in a manner that is consistent with an efficient allocation of resources.

Thus, while improved access to information about silica-related hazards can provide for more rational decision-making in the private job market, information dissemination programs will not, by themselves, produce an adequate level of worker protection.

Workers' Compensation Systems

Another alternative to OSHA regulation is simply to use the various state workers' compensation programs to augment the workings of the private job market to limit occupational risks to worker safety and health. After all, one of the objectives of the workers' compensation system is to shift the costs of occupational injury and disease from workers to employers in order to induce employers to improve working conditions. Two other objectives are to provide fair and prompt compensation to workers for medical costs and lost wages resulting from workplace injury and disease and, through the risk-spreading features of the workers' compensation insurance pool, to prevent individual employers from suffering a catastrophic financial loss (Ashford, 2007, p. 1712).

However, there are three reasons, discussed below, why the workers' compensation system has fallen short of the goal of shifting, to employers, the costs of workplace injury and disease—and, in particular, the costs of worker exposure to silica—and would, therefore, result in inadequate worker protection in the absence of the proposed silica rule.

A Divergence between Workers' Compensation Premiums and Workplace Risk

The first reason is that the risk-spreading objective of workers' compensation conflicts with, and ultimately helps undermine, the cost-internalization objective.[18] For the 99 percent of employers who rely on workers' compensation insurance,[19] the payment of premiums represents their primary cost for silica-related illnesses and other types of occupational injuries and illnesses. However, the mechanism for determining an employer's workers' compensation insurance premium typically fails to reflect the actual occupational risk present in that employer's workplace.

Approximately 85 percent of employers have their premiums set on the basis of a "class rating," which is based on *industry* illness and injury history. Employers in this class are typically the smallest firms and represent only about 15 percent of workers (Ashford, 2007, p. 1713). Small firms are often ineligible for experience rating because of insufficient claims history or because of a high year-to-year variance in their claim rates. These firms are granted rate reductions only if the experience of the entire class improves. The remaining 14 percent of employers, representing approximately 70 percent of workers, have their premiums set on the basis of a combination of "class rating" and "experience rating," which adjusts the class rating to reflect a firm's individual claims experience. Furthermore, a firm's experience rating is generally based on the history of workers' compensation payments to workers injured at that firm's workplace, not on the quality of the firm's overall worker protection program and safety and health record. Thus, for example, the existence of circumstances that may lead to catastrophic future losses are not included in an experience rating—only actual past losses are.[20]

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[18] Recall from the earlier discussion of externalities that the failure to internalize costs leads to allocative distortions and inefficiencies in the market.

[19] Only the largest firms, constituting approximately 1 percent of employers and representing approximately 15 percent of workers, are self-insured. These individual firms accomplish risk-spreading as a result of the large number of workers they cover. See Ashford (2007), p. 1712.

[20] In order to spread risks in an efficient manner, it is critical that insurers have adequate information to set individual premiums that reflect each individual employer's risks. As the preceding discussion has made clear, by and large, they do not. In that sense, insurers can be added to employers and employees (as previously noted in the earlier discussion of private markets) as suffering from imperfect information about job hazards.

Insurance companies do have the right to refuse to provide workers' compensation insurance to an employer—and frequently exercise that right based on their inspections and evaluations of a firm's health and safety practices. However, almost all states have assigned risk pools that insist that any firm that cannot obtain workers' compensation policies from any insurer must be provided workers' compensation insurance at a state-mandated rate that reflects a combination of class and experience rating.

Workers' compensation insurance does protect individual employers against a catastrophic financial loss due to work-related injury or illness claims. As a result of risk spreading, however, efforts made by employers to reduce the incidence of occupational injuries and illnesses are not fully reflected in reduced workers' compensation premiums.

Conversely, employers that devote fewer resources to promoting worker safety and health may not incur commensurately higher workers' compensation costs. This creates a type of moral hazard, in that the presence of risk spreading in workers' compensation insurance may induce employers to make fewer investments in equipment and training to reduce the risk of workplace injuries and illnesses.

In short, the premiums most individual employers pay for workers' compensation insurance coverage do not reflect the actual cost burden those employers impose on the worker's compensation system. Consequently, employers considering measures to lower the incidence of workplace injuries and illnesses can expect to receive a less-than-commensurate reduction in workers' compensation premiums.

Failure to Provide Compensation for Most Occupational Diseases

The second, and most important, reason is that, as a practical matter, the various state workers' compensation programs tend not to provide benefits for most work-related diseases—including those resulting from silica exposure, such as cancer, renal disease, and chronic obstructive pulmonary disease. Several related factors account for this:

- Most occupational diseases have multiple causes and are indistinguishable from ordinary diseases of life. It would therefore be difficult for workers' compensation to trace the cause of these diseases to the workplace.

- Many occupational diseases have a long latency period, which tends to obscure the actual cause of the disease or the place of employment where exposure occurred.
- Workers (as well as medical personnel) often do not realize that a disease is work-related and, therefore, fail to file a workers' compensation claim.
- Most states have filing restrictions, such as a statute of limitations of ten years or less, that may preclude claims with a long latency period, and many states have a minimum time period of exposure before a disease can be attributed to an occupational cause.

As a result, excluding musculoskeletal disorders, only 5 percent of occupational diseases and 1.1 percent of occupational fatalities are actually covered by workers' compensation (Ashford, 2007, p. 1714). Silica-related occupational diseases face a similar lack of workers' compensation coverage. For instance, based on epidemiological estimates, workers' compensation covers only 3 percent of silicosis-related fatalities (Leigh and Robbins, 2004, p. 713), even though silicosis-related fatalities are the easiest fatalities to associate with silica exposure.

Limitations on Payouts

The third reason that employers do not fully pay for the costs of work-related injuries and diseases under the workers' compensation system is because, even for those claims that are accepted into the system, states have imposed significant limitations on payouts. Depending on the state, these include the following:

- Caps on wage replacement, based on the average wage in the state rather than the injured workers' actual wage;
- Restrictions on which medical care services are compensated and on the amount of compensation;
- No compensation for non-pecuniary losses, such as pain and suffering or impairment unrelated to earning power;
- Either no or limited cost-of-living increases;
- Restricted permanent, partial, and total disability benefits, either by specifying a maximum number of weeks for which benefits can be paid or by imposing an absolute ceiling on dollar payouts; and
- A low absolute ceiling on death benefits.

The last two restrictions may be the most important ones for occupational diseases with long-term health effects and possible fatal outcomes, such as those associated with worker exposure to silica. It would not be uncommon for the maximum workers' compensation cap on recovery for an accepted disease claim from worker exposure to silica to be less than 10 percent of economists' estimates of total disability costs or less than 2 percent of willingness-to-pay estimates of a lost (statistical) life.[21]

In summary, for all of the reasons discussed above, the worker's compensation system does not provide adequate incentives to employers to control occupational risks to worker safety and health.

Tort Liability Options

Another alternative to OSHA regulation would be for workers to use the tort system to seek redress for work-related injuries and diseases, including silica-related ones. A tort is a civil wrong (other than breach of contract), for which the courts provide a remedy in the form of an action for damages. The application of the tort system to occupationally related injury and disease would allow workers to sue their employer, or other responsible parties (so-called "third parties," such as suppliers of hazardous material or equipment used in the workplace), to recover damages. The tort system could thus shift the liability for the direct costs of occupational injury and disease from the worker to the employer or to other responsible parties—who would, in turn, be induced to improve worker on-the-job safety and health.

With limited exceptions, however, the tort system has not been a viable alternative to occupational safety and health regulation. The dominant reason is the "exclusive remedy" language in every state's workers' compensation statutes. Workers' compensation is essentially a type of no-fault insurance. In return for employers' willingness to provide, through workers' compensation, wage-loss and medical coverage for their workers' job-related injuries and diseases, regardless of fault, workers are barred from suing their employers for damages, except in cases of intentional harm or, in some states, gross negligence (Ashford and Caldart, 1996, p. 233). Thus, in most cases, the workers' compensation system is the exclusive legal remedy available to workers to recover damages from their employer.

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[21] On willingness-to-pay estimates of the value of a statistical life, and the logic underlying the concept, see Chapter VII of this PEA.

Workers may, in principle, attempt to recover damages for work-related injuries and disease from third parties through the tort system, but the process is adversarial and expensive and, particularly in a tort case involving a chronic occupational disease, the likelihood of prevailing in court and ultimately obtaining compensation is small:

- In a tort action, the burden of proof is on the plaintiff—the worker—to demonstrate by "a preponderance of the evidence" that the defendant owed a duty to the plaintiff, that the defendant breached that duty, and that such breach caused the worker's injury or disease.
- To establish third-party liability requires the worker to show that the third party's products or equipment or instructions for use were defective or negligently designed. Liability is often subject to dispute and difficult to prove by a preponderance of the evidence.
- Typically even more difficult to prove, in the case of chronic disease, is that the third-party was causally responsible. The worker must prove, based on a preponderance of the evidence, not only that the disease was not an ordinary disease of life and was the result of an occupational rather than a non-occupational exposure, but also that the causal exposure was due to the plaintiff's product at a particular worksite (rather than to some other third party's product at some other worksite). For diseases with long-latency periods and workers with long work histories, it may be almost impossible to establish causation based on a preponderance of the evidence.
- For chronic diseases, the potentially lengthy latency period between worker exposure and manifestation of the disease significantly lowers the probability that the responsible third party will still be in business when tort claims are ultimately filed and, furthermore, that the firm will have sufficient assets to cover the claims, particularly if there are many of them.[22]
- Workers may be deterred from filing tort actions because of the substantial costs involved—including attorney fees, court costs, and the costs of obtaining evidence and providing witnesses—and the lengthy period, often many years, before a final verdict is rendered.

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[22] The same qualification about the firm being in business and having sufficient assets to pay claims may also apply to liability insurers, in those cases where the firm has purchased liability insurance. For example, some liability insurers that provided asbestos coverage were unable to settle all claims and had to declare bankruptcy.

In sum, the use of the tort system as an alternative to regulation is severely limited because of the "exclusive remedy" provisions in workers' compensation statutes; because of the various legal and practical difficulties in seeking recovery from responsible third parties, particularly in cases of occupational disease such as those caused by on-the-job silica exposure; and because of the substantial costs associated with a tort action. The tort system, therefore, does not adequately serve to protect workers from exposure to hazards in the workplace.

SUMMARY

As shown in the preamble to the proposed silica rule, OSHA has determined that workers are exposed to a significant risk of incurring silicosis, lung cancer, and other silica-related diseases. The private market—augmented by information dissemination programs, workers' compensation systems, and tort liability options—has not been effective in reducing this level of risk for all workers due to a lack of information about health risks, the presence of externalities, imperfect competition, and other factors discussed above. The Agency has concluded that the private market will not provide the level of protection afforded by a silica health standard that adheres to the statutory requirements of the OSH Act.

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CHAPTER III: PROFILE OF AFFECTED INDUSTRIES

INTRODUCTION

In this chapter, OSHA presents profile data for industries potentially affected by the proposed silica standard. As a first step, OSHA identifies the North American Industrial Classification System (NAICS) industries, both in general industry and maritime and in the construction sector, with potential worker exposure to silica. Next, OSHA provides summary statistics for the affected industries, including the number of affected entities and establishments, the number of at-risk workers, and the average revenue for affected entities and establishments.[23] This information is provided for each affected industry in total, as well as for small entities as defined by SBA and for small entities with fewer than 20 employees in each affected industry. Finally, OSHA presents silica exposure profiles for at-risk workers. These data are presented by sector and job category. Summary data are also provided for the number of workers in each affected industry who are currently exposed above the proposed silica PEL of 50 $\mu g/m^3$, as well as above an alternative PEL of 100 $\mu g/m^3$ for economic analysis purposes.

The methodological basis for the industry and at-risk worker data presented in this chapter comes from ERG (2007a, 2007b, 2008a, and 2008b). The actual data used in this chapter come from the technological feasibility analyses presented in Chapter IV of this PEA and from ERG (2011), which updated ERG's earlier spreadsheets to reflect the most recent industry data available. The technological feasibility analyses identified the job categories with potential worker exposure to silica. ERG (2007a, 2007b) matched the BLS Occupational Employment Survey (OES) occupational titles in NAICS industries with the at-risk job categories and then calculated the percentages of production employment represented by each at-risk job title.[24] These percentages were then used to project the number of employees in the at-risk job categories by NAICS industry. OSHA welcomes additional information and data that might help improve the accuracy and usefulness of this industry profile.

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[23] An establishment is a single physical location at which business is conducted or services or industrial operations are performed. An entity is an aggregation of all establishments owned by a parent company within an industry with some annual payroll.

[24] Production employment includes workers in building and grounds maintenance; forestry, fishing, and farming; installation and maintenance; construction; production; and material handling occupations.

SELECTION OF NAICS INDUSTRIES FOR ANALYSIS

The technological feasibility analyses presented in Chapter IV of this PEA identify the general industry and maritime sectors and the construction activities potentially affected by the proposed silica standard.

General Industry and Maritime

Employees engaged in various activities in general industry and maritime routinely encounter crystalline silica as a molding material, as an inert mineral additive, as a refractory material, as a sandblasting abrasive, or as a natural component of the base materials with which they work. Some industries use various forms of silica for multiple purposes. As a result, employers are challenged to limit worker exposure to silica in dozens of job categories throughout the general industry and maritime sectors.

Job categories in general industry and maritime were selected for analysis based on data from the technical industrial hygiene literature, evidence from OSHA Special Emphasis Program (SEP) results, and, in several cases, information from ERG site visit reports. These data sources provided evidence of silica exposures in numerous sectors. While the available data are not entirely comprehensive, OSHA believes that silica exposures in other sectors are quite limited.

The 25 industry subsectors in the overall general industry and maritime sectors that OSHA identified as being potentially affected by the proposed silica standard are as follows:

- Asphalt Paving Products
- Asphalt Roofing Materials
- Industries with Captive Foundries[25]

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[25] Captive foundries is a subsector of the overall foundries industry described in Chapter IV of this PEA and includes establishments with foundry processes incidental to the primary products manufactured (e.g., heavy equipment manufacturing). Because the number of manufacturing establishments with

- Concrete Products
- Cut Stone
- Dental Equipment and Supplies
- Dental Laboratories

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captive foundry operations is not reported, ERG estimated the number of such establishments by industry using occupational employment information from BLS (2005) presenting, by industry, the number of employees in key foundry occupations. ERG identified those nonfoundry industries reporting employment in both the “pourers and casters, metal” and “foundry moldmakers and coremakers” occupational categories and then estimated overall employment in captive foundry operations by inflating the number of pourers and casters and foundry moldmakers and coremakers to account for other foundry workers. The Occupational Employment Survey (OES) 4-digit NAICS-based estimates for foundries were then converted to 73 6-digit NAICS industries with employment in the key foundry occupations. See ERG (2008) for further discussion of the identification of industries and the development of estimates of the numbers of establishments in this subsector.

- Flat Glass[26]
- Iron Foundries[27]
- Jewelry
- Mineral Processing
- Mineral Wool[28]
- Nonferrous Sand Casting Foundries[29]
- Non-Sand Casting Foundries[30]
- Other Ferrous Sand Casting Foundries[31]
- Other Glass Products[32]
- Paint and Coatings

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[26] Flat glass is a subsector of the glass industry described in Chapter IV of this PEA. See also ERG (2008).

[27] Iron foundries is a subsector of the overall foundries industry described in Chapter IV of this PEA. See also ERG (2008).

[28] Mineral wool is a subsector of the glass industry described in Chapter IV of this PEA. See also ERG (2008).

[29] Nonferrous sand casting foundries is a subsector of the overall foundries industry described in Chapter IV of this PEA. See also ERG (2008).

[30] Non-sand casting foundries is a subsector of the overall foundries industry described Chapter IV of this PEA. See also in ERG (2008).

[31] Other ferrous sand casting foundries is a subsector of the overall foundries industry described in Chapter IV of this PEA. See also ERG (2008).

[32] Other glass products is a subsector of the glass industry described in Chapter IV of this PEA. See also ERG (2008).

- Porcelain Enameling
- Pottery
- Railroads
- Ready-Mix Concrete
- Refractories
- Refractory Repair
- Shipyards
- Structural Clay

As described in ERG (2008b), OSHA identified the six-digit NAICS codes for these subsectors to develop a list of industries potentially affected by the proposed silica standard.[33] In some cases, such as in the foundry and glass sectors, affected sectors discussed in ERG (2008b) have been disaggregated to facilitate the cost and economic impact analysis. Table III-1 presents the sectors listed above with their corresponding six-digit NAICS industries.[34]

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[33] ERG (2008) also discussed potential silica exposures in the engineered stone and landscape contracting industries. These industries were judged to generate negligible levels of silica exposure in the United States and, as a result, no compliance costs were estimated for these industries. Accordingly, these industries are not shown in the following tables.

[34] As seen in this table, several NAICS industries (i.e., NAICS 331524, Aluminum foundries - except die-casting; NAICS 331525, Copper foundries – except die-casting; and NAICS 331528, Other nonferrous foundries – except die-casting) are contained in more than one sector (i.e., in both Nonferrous Sand Casting Foundries and Non-Sand Casting Foundries). This bifurcation of an industry into two sectors presents no special methodological or analytic difficulties. It merely reflects the fact that, within a particular NAICS industry (in the case of a few foundry industries), some establishments use sand-casting molds and some use non-sand-casting molds.

Table III-1
General Industry and Martime Sectors and Industries Potentially Affected by OSHA's Proposed Silica Rule

Sector	NAICS	Industry
Asphalt Paving Products	324121	Asphalt paving mixture and block mfg
Asphalt Roofing Materials	324122	Asphalt shingle and roofing materials
Captive Foundaries	331111	Iron & steel mills
	331112	Electrometallurgical ferroalloy product mfg
	331210	Iron & steel pipes & tubes mfg from purchased steel
	331221	Cold-rolled steel shape mfg
	331222	Steel wire drawing
	331314	Secondary smelting & alloying of aluminum
	331423	Secondary smelting, refining, & alloying of copper
	331492	Other nonferrous metal secondary smelting, refining, & alloying
	332111	Iron & steel forging
	332112	Nonferrous forging
	332115	Crown & closure mfg
	332116	Metal stamping
	332117	Powder metallurgy part mfg
	332211	Cutlery & flatware (except precious) mfg
	332212	Hand & edge tool mfg
	332213	Saw blade & handsaw mfg
	332214	Kitchen utensil, pot, & pan mfg
	332439	Other metal container mfg
	332510	Hardware mfg
	332611	Spring (heavy gauge) mfg
	332612	Spring (light gauge) mfg
	332618	Other fabricated wire product mfg
	332710	Machine shops
	332911	Industrial valve mfg
	332912	Fluid power valve & hose fitting mfg
	332913	Plumbing fixture fitting & trim mfg
	332919	Other metal valve & pipe fitting mfg
	332991	Ball & roller bearing mfg
	332996	Fabricated pipe & pipe fitting mfg
	332997	Industrial pattern mfg
	332998	Enameled iron & metal sanitary ware mfg
	332999	All other miscellaneous fabricated metal product mfg
	333319	Other commercial & service industry machinery mfg
	333411	Air purification equipment mfg
	333412	Industrial & commercial fan & blower mfg
	333414	Heating equipment (except warm air furnaces) mfg
	333511	Industrial mold mfg
	333512	Machine tool (metal cutting types) mfg
	333513	Machine tool (metal forming types) mfg
	333514	Special die & tool, die set, jig, & fixture mfg
	333515	Cutting tool & machine tool accessory mfg
	333516	Rolling mill machinery & equipment mfg
	333518	Other metalworking machinery mfg
	333612	Speed changer, industrial high-speed drive, & gear mfg
	333613	Mechanical power transmission equipment mfg
	333911	Pump & pumping equipment mfg
	333912	Air & gas compressor mfg
	333991	Power-driven handtool mfg
	333992	Welding & soldering equipment mfg
	333993	Packaging machinery mfg
	333994	Industrial process furnace & oven mfg
	333995	Fluid power cylinder & actuator mfg
	333996	Fluid power pump & motor mfg
	333997	Scale & balance (except laboratory) mfg
	333999	All other miscellaneous general-purpose machinery mfg
	334518	Watch, clock, & part mfg
	336111	Automobile mfg
	336112	Light truck & utility vehicle mfg
	336120	Heavy duty truck mfg
	336211	Motor vehicle body mfg
	336212	Truck trailer mfg

Table III-1
General Industry and Martime Sectors and Industries Potentially Affected by OSHA's Proposed Silica Rule
(Continued)

Sector	NAICS	Industry
	336213	Motor home mfg
	336311	Carburetor, piston, piston ring, & valve mfg
	336312	Gasoline engine & engine parts mfg
	336322	Other motor vehicle electrical & electronic equipment mfg
	336330	Motor vehicle steering & suspension component (except spring) mfg
	336340	Motor vehicle brake system mfg
	336350	Motor vehicle transmission & power train parts mfg
	336370	Motor vehicle metal stamping
	336399	All other motor vehicle parts mfg
	336992	Military armored vehicle, tank, & tank component mfg
	337215	Showcase, partition, shelving, & locker mfg
	339914	Costume jewelry & novelty mfg
Concrete Products	327331	Concrete block & brick mfg
	327332	Concrete pipe mfg
	327390	Other concrete product mfg
	327999	All other miscellaneous nonmetallic mineral product mfg
Cut Stone	327991	Cut stone & stone product mfg
Dental Equipment and Supplies	339114	Dental equipment and supplies, manufacturing
Dental Laboratories	339116	Dental laboratories
	621210	Offices of dentists
Flat Glass	327211	Flat glass mfg
Iron Foundries	331511	Iron foundries
Jewelry	339911	Jewelry (except costume) mfg
	339913	Jewelers' material & lapidary work mfg
	339914	Costume jewelry & novelty mfg
Mineral Processing	327992	Ground or treated mineral and earth manufacturing
Mineral Wool	327993	Mineral wool mfg
Nonferrous Sand Casting Foundries	331524	Aluminum foundries (except die-casting)
	331525	Copper foundries (except die-casting)
	331528	Other nonferrous foundries (except die-casting)
Non-Sand Casting Foundries	331512	Steel investment foundries
	331524	Aluminum foundries (except die-casting)
	331525	Copper foundries (except die-casting)
	331528	Other nonferrous foundries (except die-casting)
Other Ferrous Sand Casting Foundries	331513	Steel foundries (except investment)
Other Glass Products	327212	Other pressed & blown glass & glassware mfg
	327213	Glass container mfg
Paint and Coatings	325510	Paint & coating mfg [e]
Porcelain Enameling	332812	Metal coating and allied services
	332998	Enameled iron & metal sanitary ware mfg
	335211	Electric housewares and household fans
	335221	Household cooking appliance manufactruing
	335222	Household refrigerator and home freezer manufacturing
	332323	Ornamental and architectural metal work
	335224	Household laundry equipment manufacturing
	335228	Other major household appliance manufacturing
	339950	Sign manufacturing
Pottery	327111	Vitreous china plumbing fixture & bathroom accessories mfg
	327112	Vitreous china, fine earthenware, & other pottery product mfg
	327113	Porcelain electrical supply mfg
Railraods	482110	Rail transportation
Ready-Mix Concrete	327320	Ready-mix concrete mfg
Refractories	327124	Clay refractory mfg
	327125	Nonclay refractory mfg
Refractory Repair	423840	Industrial supplies - wholesale
Shipyards	336611	Ship building & repairing
	336612	Boat building
Structural Clay	327121	Brick & structural clay tile mfg
	327122	Ceramic wall & floor tile mfg
	327123	Other structural clay product mfg

Source: ERG, 2011

Construction

The construction sector is an integral part of the nation's economy, accounting for almost 6 percent of total employment. Establishments in this industry are involved in a wide variety of activities, including land development and subdivision, homebuilding, construction of nonresidential buildings and other structures, heavy construction work (including roadways and bridges), and a myriad of special trades such as plumbing, roofing, electrical, excavation, and demolition work.

Construction activities were selected for analysis based on historical data of recorded samples of construction worker exposures from the OSHA Integrated Management Information System (IMIS) and the National Institute for Occupational Safety and Health (NIOSH). In addition, OSHA reviewed the industrial hygiene literature across the full range of construction activities and focused on dusty operations where silica sand was most likely to be fractured or abraded by work operations. These physical processes have been found to cause the silica exposures that pose the greatest risk of silicosis for workers.

The 12 construction activities, by job category, that OSHA identified as being potentially affected by the proposed silica standard are as follows:

- Abrasive Blasters
- Drywall Finishers
- Heavy Equipment Operators
- Hole Drillers Using Hand-Held Drills
- Jackhammer and Impact Drillers
- Masonry Cutters Using Portable Saws
- Masonry Cutters Using Stationary Saws
- Millers Using Portable or Mobile Machines
- Rock and Concrete Drillers
- Rock-Crushing Machine Operators and Tenders
- Tuckpointers and Grinders
- Underground Construction Workers

As shown in the ERG Technological Feasibility Study for Construction (ERG, 2008a), these construction activities occur in the following construction industries, accompanied by their four-digit NAICS codes:[35]

2361	Residential Building Construction
2362	Nonresidential Building Construction
2371	Utility System Construction
2372	Land Subdivision
2373	Highway, Street, and Bridge Construction
2379	Other Heavy and Civil Engineering Construction
2381	Foundation, Structure, and Building Exterior Contractors
2382	Building Equipment Contractors
2383	Building Finishing Contractors
2389	Other Specialty Trade Contractors

In addition, some public employees in state and local governments are exposed to elevated levels of respirable crystalline silica. These exposures are included in the construction sector because they are the result of construction activities. OSHA requests comment on whether other industries—and, if so, which industries—perform construction work outside the construction sector that involves worker exposure to respirable crystalline silica. OSHA is also interested in the amount of construction work being performed in those industries that involves respirable crystalline silica.

CHARACTERISTICS OF AFFECTED INDUSTRIES

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[35] ERG and OSHA used the four-digit NAICS codes for the construction sector both because the BLS's Occupational Employment Statistics Survey only provides data at this level of detail and because, unlike the case in general industry and maritime, job categories in the construction sector are task-specific, not industry-specific. Furthermore, as far as economic impacts are concerned, IRS data on profitability are reported only at the four-digit NAICS code level of detail.

Table III-2 provides an overview of the industries and estimated number of workers affected by the proposed rule. Included in Table III-2 are summary statistics for each of the affected industries, subtotals for construction and for general industry and maritime, and grand totals for all affected industries combined.

The first five columns in Table III-2 identify each industry in which workers are routinely exposed to respirable crystalline silica (preceded by the industry's NAICS code) and the total number of entities, establishments, and employees for that industry.[36] Note that not all entities, establishments, and employees in these affected industries necessarily engage in activities involving silica exposure.

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[36] The source of these industry data is the U.S. Census Bureau, Statistics of U.S. Businesses, 2006.

Table III-2: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – All Entities

NAICS	Industry	Total Entities [a]	Total Establish-ments [a]	Total Employ-ment [a]	Total Affected Entities [b]	Total Affected Establish-ments [b]	Total Affected Employ-ment [b]	Total FTE Affected Employ-ees [b]	Total Revenues ($1,000) [c]	Revenues Per Entity	Revenues per Establish-ment
Construction											
236100	Residential Building Construction	197,600	198,912	966,198	54,973	55,338	55,338	27,669	$374,724,410	$1,896,379	$1,883,870
236200	Nonresidential Building Construction	43,634	44,702	741,978	43,634	44,702	173,939	34,788	$313,592,140	$7,186,876	$7,015,170
237100	Utility System Construction	20,236	21,232	496,628	20,236	21,232	217,070	96,181	$98,129,343	$4,849,246	$4,621,766
237200	Land Subdivision	12,383	12,469	77,406	6,466	6,511	6,511	3,255	$24,449,519	$1,974,442	$1,960,824
237300	Highway, Street, and Bridge Construction	11,081	11,860	325,182	11,081	11,860	204,899	66,916	$96,655,241	$8,722,610	$8,149,683
237900	Other Heavy and Civil Engineering Construction	5,326	5,561	90,167	5,326	5,561	46,813	18,835	$19,456,230	$3,653,066	$3,498,693
238100	Foundation, Structure, and Building Exterior Contractors	116,836	117,456	1,167,986	116,836	117,456	559,729	111,946	$157,513,197	$1,348,156	$1,341,040
238200	Building Equipment Contractors	179,051	182,368	1,940,281	19,988	20,358	20,358	10,179	$267,537,377	$1,494,196	$1,467,019
238300	Building Finishing Contractors	132,219	133,343	975,335	119,000	120,012	120,012	60,006	$112,005,298	$847,120	$839,979
238900	Other Specialty Trade Contractors	73,922	74,446	557,638	73,922	74,446	274,439	137,219	$84,184,953	$1,138,835	$1,130,819

Table III-2: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – All Entities

NAICS	Industry	Total Entities [a]	Total Establish-ments [a]	Total Employ-ment [a]	Total Affected Entities [b]	Total Affected Establish-ments [b]	Total Affected Employ-ment [b]	Total FTE Affected Employ-ees [b]	Total Revenues ($1,000) [c]	Revenues Per Entity	Revenues per Establish-ment
999000	State and local governments [d]	14,397	N/A	5,762,939	14,397	NA	170,068	85,034	N/A	N/A	N/A
	Subtotals - Construction	**806,685**	**802,349**	**13,101,738**	**485,859**	**477,476**	**1,849,175**	**652,029**	**$1,548,247,709**	**$1,954,148**	**$1,929,644**

Table III-2: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – All Entities (continued)

NAICS	Industry	Total Entities [a]	Total Establishments [a]	Total Employment [a]	Total Affected Entities [b]	Total Affected Establishments [b]	Total Affected Employment [b]	Total FTE Affected Employees [b]	Total Revenues ($1,000) [c]	Revenues Per Entity	Revenues Per Establishment
General Industry and Maritime											
324121	Asphalt paving mixture and block manufacturing	480	1,431	14,471	480	1,431	5,043		$8,909,030	$18,560,480	$6,225,737
324122	Asphalt shingle and roofing materials	121	224	12,631	121	224	4,395		$7,168,591	$59,244,556	$32,002,640
325510	Paint and coating manufacturing [e]	1,093	1,344	46,209	1,093	1,344	3,285		$24,113,682	$22,061,923	$17,941,728
327111	Vitreous china plumbing fixtures & bathroom accessories manufacturing	31	41	5,854	31	41	2,802		$818,725	$26,410,479	$19,968,899
327112	Vitreous china, fine earthenware, & other pottery product manufacturing	728	731	9,178	728	731	4,394		$827,296	$1,136,395	$1,131,731
327113	Porcelain electrical supply mfg	110	125	6,168	110	125	2,953		$951,475	$8,649,776	$7,611,802
327121	Brick and structural clay mfg	104	204	13,509	104	204	5,132		$2,195,641	$21,111,931	$10,762,945

Table III-2: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – All Entities (continued)

NAICS	Industry	Total Entities [a]	Total Establish-ments [a]	Total Employ-ment [a]	Total Affected Entities [b]	Total Affected Establish-ments [b]	Total Affected Employ-ment [b]	Total FTE Affected Employ-ees [b]	Total Revenues ($1,000) [c]	Revenues Per Entity	Revenues Per Establish-ment
327122	Ceramic wall and floor tile mfg	180	193	7,094	180	193	2,695		$1,217,597	$6,764,429	$6,308,794
327123	Other structural clay product mfg	45	49	1,603	45	49	609		$227,406	$5,053,461	$4,640,933
327124	Clay refractory manufacturing	108	129	4,475	108	129	1,646		$955,377	$8,846,082	$7,406,022
327125	Nonclay refractory manufacturing	81	105	5,640	81	105	2,075		$1,453,869	$17,948,999	$13,846,371
327211	Flat glass manufacturing	56	83	11,003	56	83	271		$3,421,674	$61,101,328	$41,224,993
327212	Other pressed and blown glass and glassware manufacturing	457	499	20,625	457	499	1,034		$3,395,635	$7,430,274	$6,804,880
327213	Glass container manufacturing	32	72	14,392	32	72	722		$4,365,673	$136,427,289	$60,634,351
327320	Ready-mixed concrete manufacturing	2,470	6,064	107,190	2,470	6,064	43,920		$27,904,708	$11,297,453	$4,601,700
327331	Concrete block and brick mfg	599	951	22,738	599	951	10,962		$5,127,518	$8,560,131	$5,391,712
327332	Concrete pipe mfg	194	385	14,077	194	385	6,787		$2,861,038	$14,747,620	$7,431,268

Table III-2: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – All Entities (continued)

NAICS	Industry	Total Entities [a]	Total Establish-ments [a]	Total Employ-ment [a]	Total Affected Entities [b]	Total Affected Establish-ments [b]	Total Affected Employ-ment [b]	Total FTE Affected Employ-ees [b]	Total Revenues ($1,000) [c]	Revenues Per Entity	Revenues Per Establish-ment
327390	Other concrete product mfg	1,934	2,281	66,095	1,934	2,281	31,865		$10,336,178	$5,344,456	$4,531,424
327991	Cut stone and stone product manufacturing	1,885	1,943	30,633	1,885	1,943	12,085		$3,507,209	$1,860,588	$1,805,048
327992	Ground or treated mineral and earth manufacturing	171	271	6,629	171	271	5,051		$2,205,910	$12,900,061	$8,139,891
327993	Mineral wool manufacturing	195	321	19,241	195	321	1,090		$5,734,226	$29,406,287	$17,863,633
327999	All other misc. nonmetallic mineral product mfg	350	465	10,028	350	465	4,835		$2,538,560	$7,253,028	$5,459,268
331111	Iron and steel mills	686	805	108,592	523	614	614		$53,496,748	$77,983,597	$66,455,587
331112	Electrometallurgical ferroalloy product manufacturing	22	22	2,198	12	12	12		$1,027,769	$46,716,774	$46,716,774
331210	Iron and steel pipe and tube manufacturing from purchased steel	186	240	21,543	94	122	122		$7,014,894	$37,714,484	$29,228,725

Table III-2: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – All Entities (continued)

NAICS	Industry	Total Entities [a]	Total Establish-ments [a]	Total Employ-ment [a]	Total Affected Entities [b]	Total Affected Establish-ments [b]	Total Affected Employ-ment [b]	Total FTE Affected Employ-ees [b]	Total Revenues ($1,000) [c]	Revenues Per Entity	Revenues Per Establish-ment
331221	Rolled steel shape manufacturing	150	170	10,857	54	61	61		$4,494,254	$29,961,696	$26,436,790
331222	Steel wire drawing	232	288	14,669	67	83	83		$3,496,143	$15,069,584	$12,139,387
331314	Secondary smelting and alloying of aluminum	119	150	7,381	33	42	42		$4,139,263	$34,783,724	$27,595,088
331423	Secondary smelting, refining, and alloying of copper	29	31	1,278	7	7	7		$765,196	$26,386,082	$24,683,755
331492	Secondary smelting, refining, and alloying of nonferrous metal (except cu & al)	195	217	9,383	48	53	53		$3,012,985	$15,451,203	$13,884,721
331511	Iron foundries	457	527	59,209	457	527	22,111		$9,753,093	$21,341,560	$18,506,818
331512	Steel investment foundries	115	132	16,429	115	132	5,934		$2,290,472	$19,917,147	$17,352,060
331513	Steel foundries (except investment)	208	222	17,722	208	222	6,618		$3,640,441	$17,502,121	$16,398,383
331524	Aluminum foundries (except die-casting)	441	466	26,565	441	466	9,633		$3,614,233	$8,195,541	$7,755,866

Table III-2: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – All Entities (continued)

NAICS	Industry	Total Entities [a]	Total Establish-ments [a]	Total Employ-ment [a]	Total Affected Entities [b]	Total Affected Establish-ments [b]	Total Affected Employ-ment [b]	Total FTE Affected Employ-ees [b]	Total Revenues ($1,000) [c]	Revenues Per Entity	Revenues Per Establish-ment
331525	Copper foundries (except die-casting)	251	256	6,120	251	256	2,219		$747,437	$2,977,835	$2,919,674
331528	Other nonferrous foundries (except die-casting)	119	124	4,710	119	124	1,708		$821,327	$6,901,910	$6,623,607
332111	Iron and steel forging	358	398	26,596	135	150	150		$5,702,872	$15,929,811	$14,328,825
332112	Nonferrous forging	67	77	8,814	43	50	50		$2,080,000	$31,044,783	$27,012,993
332115	Crown and closure manufacturing	50	59	3,243	15	18	18		$905,206	$18,104,119	$15,342,473
332116	Metal stamping	1,556	1,641	64,724	347	366	366		$10,418,233	$6,695,523	$6,348,710
332117	Powder metallurgy part manufacturing	111	129	8,362	41	47	47		$1,178,698	$10,618,900	$9,137,193
332211	Cutlery and flatware (except precious) manufacturing	138	141	5,779	32	33	33		$1,198,675	$8,686,049	$8,501,240
332212	Hand and edge tool manufacturing	1,056	1,155	36,622	189	207	207		$6,382,593	$6,044,123	$5,526,055
332213	Saw blade and handsaw	127	136	7,304	39	41	41		$1,450,781	$11,423,474	$10,667,509

Table III-2: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – All Entities (continued)

NAICS	Industry	Total Entities [a]	Total Establish-ments [a]	Total Employ-ment [a]	Total Affected Entities [b]	Total Affected Establish-ments [b]	Total Affected Employ-ment [b]	Total FTE Affected Employ-ees [b]	Total Revenues ($1,000) [c]	Revenues Per Entity	Revenues Per Establish-ment
	manufacturing										
332214	Kitchen utensil, pot, and pan manufacturing	64	70	3,928	20	22	22		$1,226,230	$19,159,850	$17,517,577
332323	Ornamental and architectural metal work	2,408	2,450	39,947	53	54	54		$6,402,565	$2,658,873	$2,613,292
332439	Other metal container manufacturing	364	401	15,195	78	86	86		$2,817,120	$7,739,340	$7,025,236
332510	Hardware manufacturing	734	828	45,282	227	256	256		$9,268,800	$12,627,793	$11,194,203
332611	Spring (heavy gauge) manufacturing	109	113	4,059	22	23	23		$825,444	$7,572,882	$7,304,815
332612	Spring (light gauge) manufacturing	270	340	15,336	69	87	87		$2,618,283	$9,697,344	$7,700,832
332618	Other fabricated wire product manufacturing	1,103	1,198	36,364	189	205	205		$5,770,701	$5,231,823	$4,816,946
332710	Machine shops	21,135	21,356	266,597	1,490	1,506	1,506		$32,643,382	$1,544,518	$1,528,534

Table III-2: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – All Entities (continued)

NAICS	Industry	Total Entities [a]	Total Establish-ments [a]	Total Employ-ment [a]	Total Affected Entities [b]	Total Affected Establish-ments [b]	Total Affected Employ-ment [b]	Total FTE Affected Employ-ees [b]	Total Revenues ($1,000) [c]	Revenues Per Entity	Revenues Per Establish-ment
332812	Metal coating and allied services	2,363	2,599	56,978	2,363	2,599	4,695		$11,010,624	$4,659,595	$4,236,485
332911	Industrial valve manufacturing	394	488	38,330	175	216	216		$8,446,768	$21,438,497	$17,308,951
332912	Fluid power valve and hose fitting manufacturing	306	381	35,519	161	201	201		$8,044,008	$26,287,608	$21,112,882
332913	Plumbing fixture fitting and trim manufacturing	126	144	11,513	57	65	65		$3,276,413	$26,003,281	$22,752,871
332919	Other metal valve and pipe fitting manufacturing	240	268	18,112	91	102	102		$3,787,626	$15,781,773	$14,132,931
332991	Ball and roller bearing manufacturing	107	180	27,197	91	154	154		$6,198,871	$57,933,374	$34,438,172
332996	Fabricated pipe and pipe fitting manufacturing	711	765	27,201	143	154	154		$4,879,023	$6,862,198	$6,377,808
332997	Industrial pattern manufacturing	459	461	5,281	30	30	30		$486,947	$1,060,887	$1,056,285
332998	Enameled iron and metal sanitary ware	72	76	5,655	72	76	96		$1,036,508	$14,395,940	$13,638,259

Table III-2: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – All Entities (continued)

NAICS	Industry	Total Entities [a]	Total Establishments [a]	Total Employment [a]	Total Affected Entities [b]	Total Affected Establishments [b]	Total Affected Employment [b]	Total FTE Affected Employees [b]	Total Revenues ($1,000) [c]	Revenues Per Entity	Revenues Per Establishment
	manufacturing										
332999	All other miscellaneous fabricated metal product manufacturing	3,043	3,123	72,201	397	408	408		$12,944,345	$4,253,811	$4,144,843
333319	Other commercial and service industry machinery manufacturing	1,253	1,349	53,012	278	299	299		$12,744,730	$10,171,373	$9,447,539
333411	Air purification equipment manufacturing	303	351	14,883	72	84	84		$2,428,159	$8,013,727	$6,917,833
333412	Industrial and commercial fan and blower manufacturing	142	163	10,506	52	59	59		$1,962,040	$13,817,181	$12,037,053
333414	Heating equipment (except warm air furnaces) manufacturing	377	407	20,577	108	116	116		$4,266,536	$11,317,071	$10,482,888
333511	Industrial mold manufacturing	2,084	2,126	39,917	221	226	226		$4,963,915	$2,381,917	$2,334,861

Table III-2: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – All Entities (continued)

NAICS	Industry	Total Entities [a]	Total Establish-ments [a]	Total Employ-ment [a]	Total Affected Entities [b]	Total Affected Establish-ments [b]	Total Affected Employ-ment [b]	Total FTE Affected Employ-ees [b]	Total Revenues ($1,000) [c]	Revenues Per Entity	Revenues Per Establish-ment
333512	Machine tool (metal cutting types) manufacturing	514	530	17,220	94	97	97		$3,675,264	$7,150,320	$6,934,461
333513	Machine tool (metal forming types) manufacturing	274	285	8,556	46	48	48		$1,398,993	$5,105,812	$4,908,746
333514	Special die and tool, die set, jig, and fixture manufacturing	3,172	3,232	57,576	319	325	325		$7,232,706	$2,280,172	$2,237,842
333515	Cutting tool and machine tool accessory manufacturing	1,482	1,552	34,922	188	197	197		$4,941,932	$3,334,637	$3,184,235
333516	Rolling mill machinery and equipment manufacturing	70	73	3,020	17	17	17		$652,141	$9,316,299	$8,933,437
333518	Other metalworking machinery manufacturing	362	383	12,470	67	70	70		$2,605,582	$7,197,740	$6,803,086
333612	Speed changer, industrial high-speed drive, and gear manufacturing	197	226	12,374	61	70	70		$2,280,825	$11,577,790	$10,092,145

Table III-2: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – All Entities (continued)

NAICS	Industry	Total Entities [a]	Total Establish-ments [a]	Total Employ-ment [a]	Total Affected Entities [b]	Total Affected Establish-ments [b]	Total Affected Employ-ment [b]	Total FTE Affected Employ-ees [b]	Total Revenues ($1,000) [c]	Revenues Per Entity	Revenues Per Establish-ment
333613	Mechanical power transmission equipment manufacturing	196	231	15,645	75	88	88		$3,256,010	$16,612,294	$14,095,280
333911	Pump and pumping equipment manufacturing	413	490	30,764	147	174	174		$7,872,517	$19,061,785	$16,066,362
333912	Air and gas compressor manufacturing	272	318	21,417	104	121	121		$6,305,944	$23,183,616	$19,830,011
333991	Power-driven handtool manufacturing	137	150	8,714	45	49	49		$3,115,514	$22,740,979	$20,770,094
333992	Welding and soldering equipment manufacturing	250	275	15,853	82	90	90		$4,257,678	$17,030,713	$15,482,466
333993	Packaging machinery manufacturing	583	619	21,179	113	120	120		$4,294,579	$7,366,345	$6,937,931
333994	Industrial process furnace and oven manufacturing	312	335	10,720	56	61	61		$1,759,938	$5,640,828	$5,253,548
333995	Fluid power cylinder and actuator	269	319	19,887	95	112	112		$3,991,832	$14,839,523	$12,513,579

Table III-2: Characteristics of Industries Affected by OSHA’s Proposed Standard for Silica – All Entities (continued)

NAICS	Industry	Total Entities [a]	Total Establish-ments [a]	Total Employ-ment [a]	Total Affected Entities [b]	Total Affected Establish-ments [b]	Total Affected Employ-ment [b]	Total FTE Affected Employ-ees [b]	Total Revenues ($1,000) [c]	Revenues Per Entity	Revenues Per Establish-ment
	manufacturing										
333996	Fluid power pump and motor manufacturing	146	178	13,631	63	77	77		$3,019,188	$20,679,367	$16,961,728
333997	Scale and balance (except laboratory) manufacturing	95	102	3,748	20	21	21		$694,419	$7,309,671	$6,808,027
333999	All other miscellaneous general purpose machinery manufacturing	1,630	1,725	52,454	280	296	296		$9,791,511	$6,007,062	$5,676,238
334518	Watch, clock, and part manufacturing	104	106	2,188	12	12	12		$491,114	$4,722,250	$4,633,151
335211	Electric housewares and household fans	99	105	7,425	20	22	22		$2,175,398	$21,973,717	$20,718,076
335221	Household cooking appliance manufacturing	116	125	16,033	43	47	47		$4,461,008	$38,456,968	$35,688,066
335222	Household refrigerator and home freezer manufacturing	18	26	17,121	18	26	50		$4,601,594	$255,644,105	$176,984,380

Table III-2: Characteristics of Industries Affected by OSHA’s Proposed Standard for Silica – All Entities (continued)

NAICS	Industry	Total Entities [a]	Total Establish-ments [a]	Total Employ-ment [a]	Total Affected Entities [b]	Total Affected Establish-ments [b]	Total Affected Employ-ment [b]	Total FTE Affected Employ-ees [b]	Total Revenues ($1,000) [c]	Revenues Per Entity	Revenues Per Establish-ment
335224	Household laundry equipment manufacturing	17	23	16,269	17	23	47		$4,792,444	$281,908,445	$208,367,112
335228	Other major household appliance manufacturing	39	45	12,806	32	37	37		$4,549,859	$116,663,058	$101,107,984
336111	Automobile manufacturing	167	181	75,225	167	181	425		$87,308,106	$522,803,033	$482,365,229
336112	Light truck and utility vehicle manufacturing	63	94	103,815	63	94	587		$139,827,543	$2,219,484,812	$1,487,527,055
336120	Heavy duty truck manufacturing	77	95	32,122	77	95	181		$17,387,065	$225,806,042	$183,021,739
336211	Motor vehicle body manufacturing	728	820	47,566	239	269	269		$11,581,029	$15,908,007	$14,123,206
336212	Truck trailer manufacturing	353	394	32,260	163	182	182		$6,313,133	$17,884,229	$16,023,179
336213	Motor home manufacturing	79	91	21,533	79	91	122		$5,600,569	$70,893,283	$61,544,718
336311	Carburetor, piston, piston ring, and valve manufacturing	102	116	10,537	52	60	60		$2,327,226	$22,815,945	$20,062,296

Table III-2: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – All Entities (continued)

NAICS	Industry	Total Entities [a]	Total Establish-ments [a]	Total Employ-ment [a]	Total Affected Entities [b]	Total Affected Establish-ments [b]	Total Affected Employ-ment [b]	Total FTE Affected Employ-ees [b]	Total Revenues ($1,000) [c]	Revenues Per Entity	Revenues Per Establish-ment
336312	Gasoline engine and engine parts manufacturing	810	876	66,112	345	373	373		$30,440,351	$37,580,680	$34,749,259
336322	Other motor vehicle electrical and electronic equipment manufacturing	643	697	62,016	323	350	350		$22,222,133	$34,560,082	$31,882,544
336330	Motor vehicle steering and suspension components (except spring) manufacturing	214	257	39,390	185	223	223		$10,244,934	$47,873,524	$39,863,557
336340	Motor vehicle brake system manufacturing	188	241	33,782	149	191	191		$11,675,801	$62,105,323	$48,447,306
336350	Motor vehicle transmission and power train parts manufacturing	432	535	83,756	382	473	473		$31,710,273	$73,403,409	$59,271,538
336370	Motor vehicle metal stamping	635	781	110,578	508	624	624		$24,461,822	$38,522,554	$31,321,154
336399	All other motor vehicle parts	1,189	1,458	149,251	687	843	843		$42,936,991	$36,111,851	$29,449,239

Table III-2: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – All Entities (continued)											
NAICS	Industry	Total Entities [a]	Total Establish-ments [a]	Total Employ-ment [a]	Total Affected Entities [b]	Total Affected Establish-ments [b]	Total Affected Employ-ment [b]	Total FTE Affected Employ-ees [b]	Total Revenues ($1,000) [c]	Revenues Per Entity	Revenues Per Establish-ment
	manufacturing										
336611	Ship building and repair	575	635	87,352	575	635	2,798		$14,650,189	$25,478,589	$23,071,163
336612	Boat building	1,066	1,129	54,705	1,066	1,129	1,752		$10,062,908	$9,439,876	$8,913,116
336992	Military armored vehicle, tank, and tank component manufacturing	47	57	6,899	32	39	39		$2,406,966	$51,212,047	$42,227,477
337215	Showcase, partition, shelving, and locker manufacturing	1,647	1,733	59,080	317	334	334		$8,059,533	$4,893,462	$4,650,625
339114	Dental equipment and supplies manufacturing	740	763	15,550	399	411	411		$3,397,252	$4,590,881	$4,452,493
339116	Dental laboratories	7,028	7,261	47,088	7,028	7,261	33,214		$3,852,293	$548,135	$530,546
339911	Jewelry (except costume) manufacturing	1,760	1,777	25,280	1,760	1,777	7,813		$6,160,238	$3,500,135	$3,466,650
339913	Jewelers' materials and lapidary work	261	264	5,199	261	264	1,607		$934,387	$3,580,028	$3,539,346

Table III-2: Characteristics of Industries Affected by OSHA’s Proposed Standard for Silica – All Entities (continued)

NAICS	Industry	Total Entities [a]	Total Establish-ments [a]	Total Employ-ment [a]	Total Affected Entities [b]	Total Affected Establish-ments [b]	Total Affected Employ-ment [b]	Total FTE Affected Employ-ees [b]	Total Revenues ($1,000) [c]	Revenues Per Entity	Revenues Per Establish-ment
	manufacturing										
339914	Costume jewelry and novelty manufacturing	590	590	6,775	590	590	1,088		$751,192	$1,273,206	$1,273,206
339950	Sign manufacturing	6,291	6,415	89,360	487	496	496		$11,299,429	$1,796,126	$1,761,407
423840	Industrial supplies, wholesalers	7,016	10,742	111,198	250	383	383		$19,335,522	$2,755,918	$1,799,993
482110	Rail transportation	N/A	N/A	N/A	N/A	N/A	16,895		N/A	N/A	N/A
621210	Dental offices	119,471	124,553	817,396	7,655	7,980	7,980		$88,473,742	$740,546	$710,330
	Subtotals – General Industry and maritime	**219,203**	**238,942**	**4,406,990**	**47,007**	**56,121**	**294,886**		**$1,101,555,989**	**$5,025,278**	**$4,610,140**
	Totals – All Industries	**1,025,888**	**1,041,291**	**17,508,728**	**532,866**	**533,597**	**2,144,061**	**652,029**	**$2,649,803,698**	**$2,619,701**	**$2,544,729**

[a] US Census Bureau, Statistics of US Businesses, 2006.

[b] OSHA estimates of employees potentially exposed to silica and associated entities and establishments. Affected entities and establishments constrained to be less than or equal to the number of affected employees.

[c] Estimates based on 2002 receipts and payroll data from US Census Bureau, Statistics of US Businesses, 2002, and payroll data from the US Census Bureau, Statistics of US Businesses, 2006. Receipts are not reported for 2006, but were estimated assuming the ratio of receipts to payroll remained unchanged from 2002 to 2006.

[d] State-plan states only. State and local governments are included under the construction sector because the silica risks for public employees are the result of construction-related activities.

[e] OSHA estimates that only one-third of the entities and establishments in this industry, as reported above, use silica-containing inputs.

Source: US Dept. of Labor, OSHA, Directorate of Evaluation and Analysis, Office of Regulatory Analysis, based on ERG, 2011.

The next three columns in Table III-2 show, for each affected industry, the number of entities and establishments in which workers are actually exposed to silica and the total number of workers exposed to silica.[37] The number of affected establishments was set equal to the total number of establishments in an industry (based on Census data) unless the number of affected establishments would exceed the number of affected employees in the industry. In that case, the number of affected establishments in the industry was set equal to the number of affected employees, and the number of affected entities in the industry was reduced so as to maintain the same ratio of entities to establishments in the industry.[38]

As shown in Table III-2, OSHA estimates that a total of 533,000 entities (486,000 in construction; 47,000 in general industry and maritime), 534,000 establishments (477,500 in construction; 56,100 in general industry and maritime), and 2.1 million workers (1.8 million in construction; 0.3 million in general industry and maritime) would be affected by the proposed silica rule. Note that only slightly more than 50 percent of the entities and establishments, and about 12 percent of the workers in affected industries, actually engage in activities involving silica exposure.[39]

It should be mentioned that a fraction of the workforce exposed to silica is likely exposed to other substances currently regulated by OSHA and therefore may benefit from existing controls. OSHA has not attempted to quantify the extent to which silica exposures, and exposure control,

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[37] Estimates of the numbers of affected employees in general industry and maritime were based on an assessment for each sector of the job categories of workers who perform tasks where silica exposures can occur. OSHA matched occupational titles from the 2008 BLS Occupational Employment Statistics (OES) survey with these at-risk job categories and then used OES occupational employment statistics to generate industry-specific estimates of the numbers of affected employees. To ensure data compatibility, OES occupational employment statistics were benchmarked to the 2006 County Business Pattern employment totals for each industry.

[38] OSHA determined that removing this assumption would have a negligible impact on total costs and would reduce the cost and economic impact on the average affected establishment or entity.

[39] It should be emphasized that these percentages vary significantly depending on the industry sector and, within an industry sector, depending on the NAICS industry. For example, about 14 percent of the workers in construction, but only 7 percent of workers in general industry, actually engage in activities involving silica exposure. As an example within construction, about 63 percent of workers in highway, street, and bridge construction, but only 3 percent of workers in state and local governments, actually engage in activities involving silica exposure.

overlap with other OSHA-regulated substances, but believes that any effect (for example, a reduction in compliance costs in relation to an OSHA silica standard) would be minor. OSHA requests comment on the effect of overlapping exposures on OSHA's estimates of the costs and benefits of the proposed silica rule.

The ninth column in Table III-2, with data only for construction, shows for each affected NAICS construction industry the number of full-time-equivalent (FTE) affected workers that corresponds to the total number of affected construction workers in the previous column.[40] This distinction is necessary because affected construction workers may spend large amounts of time working on tasks with no risk of silica exposure. As shown in Table III-2, the 1.8 million affected workers in construction converts to approximately 652,000 FTE affected workers. In contrast, OSHA based its analysis of the affected workers in general industry and maritime on the assumption that they were engaged full time in activities with some silica exposure.

The last three columns in Table III-2 show combined total revenues for all entities (not just affected entities) in each affected industry and the average revenue per entity and per establishment in each affected industry.[41] Because OSHA did not have data to distinguish revenues for affected entities and establishments in any industry, average revenue per entity and average revenue per affected entity (as well as average revenue per establishment and average revenue per affected establishment) are estimated to be equal in value.

Similar information to that provided in Table III-2 for all entities in each affected industry is also provided for all small entities, as defined by SBA, in each affected industry (in Table III-3) and for all small entities with fewer than 20 employees in each affected industry (in Table III-4).

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[40] FTE affected workers becomes a relevant variable in the estimation of control costs in the construction industry in Chapter V of this PEA. The reason is that, consistent with the costing methodology, control costs depend only on how many worker-days there are in which exposures are above the PEL. These are the worker-days in which controls are required. For the derivation of FTEs, see Tables IV-8 and IV-22 and the associated text in ERG (2007a).

[41] Revenue estimates are based on 2002 receipts and payroll data from the U.S. Census Bureau, Statistics of U.S. Businesses, 2002, and payroll data from U.S. Census Bureau, Statistics of U.S. Businesses, 2006. Receipts are not reported for 2006, but were estimated assuming that the ratio of receipts to payroll remained unchanged between 2002 and 2006.

Table III-3: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Small Entities

NAICS	Industry	SBA Small Business Classification (Limit for revenues or employment) [a]	Small Business or Gov. Entities [b]	Establishments for SBA Entities [b]	SBA Entity Employment [b]	Affected Small Business or Gov. Entities [c]	Affected Employment (at risk) for SBA Entities [c]	Affected FTE Employees (at risk) for SBA Entities[c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity	Revenues per SBA Establishment
Construction											
236100	Residential Building Construction	$33.5 million	196,920	197,028	772,357	44,236	44,236	22,118	$241,430,957	$1,226,036	$1,225,364
236200	Nonresidential Building Construction	$33.5 million	42,536	42,680	445,279	42,536	104,385	20,877	$164,773,960	$3,873,753	$3,860,683
237100	Utility System Construction	$33.5 million	20,069	20,244	315,725	20,069	138,000	61,146	$61,322,564	$3,055,586	$3,029,172
237200	Land Subdivision	$7 million	11,642	11,652	36,125	3,039	3,039	1,519	$13,314,383	$1,143,651	$1,142,669
237300	Highway, Street, and Bridge Construction	$33.5 million	10,350	10,397	138,783	10,350	87,448	28,559	$37,505,489	$3,623,719	$3,607,338
237900	Other Heavy and Civil Engineering Construction	$33.5 million	5,260	5,320	66,063	5,260	34,298	13,800	$12,795,638	$2,432,631	$2,405,195
238100	Foundation, Structure, and Building Exterior Contractors	$14 million	115,345	115,489	813,345	115,345	389,776	77,955	$107,561,550	$932,520	$931,358
238200	Building Equipment Contractors	$14 million	176,705	177,064	1,330,657	13,962	13,962	6,981	$181,594,976	$1,027,673	$1,025,589
238300	Building Finishing	$14 million	131,123	131,244	710,648	87,443	87,443	43,721	$91,025,950	$694,203	$693,563

Table III-3: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Small Entities

NAICS	Industry	SBA Small Business Classification (Limit for revenues or employment) [a]	Small Business or Gov. Entities [b]	Establishments for SBA Entities [b]	SBA Entity Employ-ment [b]	Affected Small Business or Gov. Entities [c]	Affected Employment (at risk) for SBA Entities [c]	Affected FTE Employees (at risk) for SBA Entities[c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity	Revenues per SBA Establishment
	Contractors										
238900	Other Specialty Trade Contractors	$14 million	73,291	73,395	435,959	73,291	214,555	107,278	$69,405,885	$946,991	$945,649
999000	State and local governments [e]	Population of 50,000 or less	13,482	N/A	739,795	13,482	21,832	10,916	N/A	N/A	N/A
	Subtotals - Construction		**796,723**	**784,513**	**5,804,736**	**429,012**	**1,138,973**	**394,870**	**$980,731,352**	**$1,252,145**	**$1,250,115**

Table III-3: Characteristics of Industries Affected by OSHA’s Proposed Standard for Silica – Small Entities (continued)

NAICS	Industry	SBA Small Business Classification (Limit for revenues or employment) [a]	Small Business or Gov. Entities [b]	Establishments for SBA Entities [b]	SBA Entity Employment [b]	Affected Small Business or Gov. Entities [c]	Affected Employment (at risk) for SBA Entities [c]	Affected FTE Employees (at risk) for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity	Revenues per SBA Establishment
General Industry and Maritime											
324121	Asphalt paving mixture and block manufacturing	500 employees	431	713	8,091	431	2,819		$4,228,380	$9,810,627	$5,930,407
324122	Asphalt shingle and roofing materials	750 employees	106	131	3,491	106	1,215		$1,402,794	$13,233,907	$10,708,353
325510	Paint and coating manufacturing [f]	500 employees	1,042	1,121	20,147	1,042	1,432		$6,266,578	$6,013,990	$5,590,168
327111	Vitreous china plumbing fixtures & bathroom accessories manufacturing	750 employees	25	25	818	25	392		$35,505	$1,420,219	$1,420,219
327112	Vitreous china, fine earthenware, & other pottery product manufacturing	500 employees	717	719	6,242	717	2,988		$467,868	$652,535	$650,720

Table III-3: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Small Entities (continued)

NAICS	Industry	SBA Small Business Classification (Limit for revenues or employment) [a]	Small Business or Gov. Entities [b]	Establishments for SBA Entities [b]	SBA Entity Employment [b]	Affected Small Business or Gov. Entities [c]	Affected Employment (at risk) for SBA Entities [c]	Affected FTE Employees (at risk) for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity	Revenues per SBA Establishment
327113	Porcelain electrical supply mfg	500 employees	97	106	3,381	97	1,619		$417,430	$4,303,399	$3,938,016
327121	Brick and structural clay mfg	500 employees	93	107	5,153	93	1,958		$810,661	$8,716,789	$7,576,275
327122	Ceramic wall and floor tile mfg	500 employees	173	177	3,684	173	1,399		$526,758	$3,044,845	$2,976,035
327123	Other structural clay product mfg	500 employees	42	46	860	42	327		$102,418	$2,438,515	$2,226,470
327124	Clay refractory manufacturing	500 employees	96	100	1,869	96	688		$544,243	$5,669,203	$5,442,435
327125	Nonclay refractory manufacturing	750 employees	68	74	1,962	68	722		$469,975	$6,911,400	$6,351,017
327211	Flat glass manufacturing	1,000 employees	56	83	11,003	56	271		$3,421,674	$61,101,328	$41,224,993
327212	Other pressed and blown glass and glassware manufacturing	750 employees	432	440	4,623	228	232		$380,129	$879,928	$863,929

Table III-3: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Small Entities (continued)

NAICS	Industry	SBA Small Business Classification (Limit for revenues or employment) [a]	Small Business or Gov. Entities [b]	Establishments for SBA Entities [b]	SBA Entity Employment [b]	Affected Small Business or Gov. Entities [c]	Affected Employment (at risk) for SBA Entities [c]	Affected FTE Employees (at risk) for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity	Revenues per SBA Establishment
327213	Glass container manufacturing	750 employees	24	24	1,099	24	55		$229,887	$9,578,637	$9,578,637
327320	Ready-mixed concrete manufacturing	500 employees	2,401	3,791	63,259	2,401	25,920		$16,366,671	$6,816,606	$4,317,244
327331	Concrete block and brick mfg	500 employees	567	690	14,003	567	6,751		$3,370,132	$5,943,795	$4,884,249
327332	Concrete pipe mfg	500 employees	181	221	7,052	181	3,400		$1,337,014	$7,386,815	$6,049,835
327390	Other concrete product mfg	500 employees	1,876	2,002	43,172	1,876	20,814		$6,215,690	$3,313,267	$3,104,740
327991	Cut stone and stone product manufacturing	500 employees	1,874	1,902	27,472	1,874	10,838		$3,051,218	$1,628,185	$1,604,216
327992	Ground or treated mineral and earth manufacturing	500 employees	132	164	2,937	132	2,238		$780,856	$5,915,575	$4,761,317
327993	Mineral wool manufacturing	750 employees	175	193	5,118	175	290		$1,017,676	$5,815,293	$5,272,934

Table III-3: Characteristics of Industries Affected by OSHA’s Proposed Standard for Silica – Small Entities (continued)

NAICS	Industry	SBA Small Business Classification (Limit for revenues or employment) [a]	Small Business or Gov. Entities [b]	Establishments for SBA Entities [b]	SBA Entity Employment [b]	Affected Small Business or Gov. Entities [c]	Affected Employment (at risk) for SBA Entities [c]	Affected FTE Employees (at risk) for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity	Revenues per SBA Establishment
327999	All other misc. nonmetallic mineral product mfg	500 employees	326	337	5,528	326	2,665		$1,318,597	$4,044,776	$3,912,751
331111	Iron and steel mills	1,000 employees	686	805	108,592	523	614		$53,496,748	$77,983,597	$66,455,587
331112	Electrometallurgical ferroalloy product manufacturing	750 employees	18	18	1,278	7	7		$408,459	$22,692,159	$22,692,159
331210	Iron and steel pipe and tube manufacturing from purchased steel	1,000 employees	186	240	21,543	94	122		$7,014,894	$37,714,484	$29,228,725
331221	Rolled steel shape manufacturing	1,000 employees	150	170	10,857	54	61		$4,494,254	$29,961,696	$26,436,790
331222	Steel wire drawing	1,000 employees	232	288	14,669	67	83		$3,496,143	$15,069,584	$12,139,387
331314	Secondary smelting and alloying of aluminum	750 employees	107	120	3,921	20	22		$1,861,853	$17,400,493	$15,515,440

Table III-3: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Small Entities (continued)

NAICS	Industry	SBA Small Business Classification (Limit for revenues or employment) [a]	Small Business or Gov. Entities [b]	Establishments for SBA Entities [b]	SBA Entity Employment [b]	Affected Small Business or Gov. Entities [c]	Affected Employment (at risk) for SBA Entities [c]	Affected FTE Employees (at risk) for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity	Revenues per SBA Establishment
331423	Secondary smelting, refining, and alloying of copper	750 employees	26	27	1,088	6	6		$502,924	$19,343,215	$18,626,799
331492	Secondary smelting, refining, and alloying of nonferrous metal (except cu & al)	750 employees	167	178	4,662	25	26		$1,494,647	$8,949,982	$8,396,894
331511	Iron foundries	500 employees	408	422	19,421	408	7,253		$2,251,262	$5,517,799	$5,334,744
331512	Steel investment foundries	500 employees	101	103	6,204	101	2,241		$806,662	$7,986,753	$7,831,670
331513	Steel foundries (except investment)	500 employees	192	195	9,220	192	3,443		$2,163,437	$11,267,900	$11,094,547
331524	Aluminum foundries (except die-casting)	500 employees	412	420	15,641	412	5,671		$1,565,556	$3,799,894	$3,727,515
331525	Copper foundries (except die-casting)	500 employees	246	251	5,785	246	2,098		$658,948	$2,678,652	$2,625,292

Table III-3: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Small Entities (continued)

NAICS	Industry	SBA Small Business Classification (Limit for revenues or employment) [a]	Small Business or Gov. Entities [b]	Establishments for SBA Entities [b]	SBA Entity Employment [b]	Affected Small Business or Gov. Entities [c]	Affected Employment (at risk) for SBA Entities [c]	Affected FTE Employees (at risk) for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity	Revenues per SBA Establishment
331528	Other nonferrous foundries (except die-casting)	500 employees	112	112	2,248	112	815		$278,178	$2,483,733	$2,483,733
332111	Iron and steel forging	500 employees	317	327	11,442	63	65		$2,478,449	$7,818,452	$7,579,356
332112	Nonferrous forging	500 employees	54	56	3,165	17	18		$1,112,135	$20,595,086	$19,859,547
332115	Crown and closure manufacturing	500 employees	44	44	1,233	7	7		$277,248	$6,301,099	$6,301,099
332116	Metal stamping	500 employees	1,498	1,553	51,247	279	290		$7,554,099	$5,042,790	$4,864,198
332117	Powder metallurgy part manufacturing	500 employees	98	102	4,246	23	24		$583,445	$5,953,519	$5,720,048
332211	Cutlery and flatware (except precious) manufacturing	500 employees	129	130	2,522	14	14		$346,209	$2,683,788	$2,663,143
332212	Hand and edge tool manufacturing	500 employees	1,025	1,081	21,182	113	120		$3,278,282	$3,198,324	$3,032,639

Table III-3: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Small Entities (continued)

NAICS	Industry	SBA Small Business Classification (Limit for revenues or employment) [a]	Small Business or Gov. Entities [b]	Establishments for SBA Entities [b]	SBA Entity Employment [b]	Affected Small Business or Gov. Entities [c]	Affected Employment (at risk) for SBA Entities [c]	Affected FTE Employees (at risk) for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity	Revenues per SBA Establishment
332213	Saw blade and handsaw manufacturing	500 employees	114	117	2,223	12	13		$577,563	$5,066,344	$4,936,437
332214	Kitchen utensil, pot, and pan manufacturing	500 employees	56	61	2,525	13	14		$545,534	$9,741,680	$8,943,181
332323	Ornamental and architectural metal work	500 employees	2,378	2,400	31,781	42	43		$4,629,638	$1,946,862	$1,929,016
332439	Other metal container manufacturing	500 employees	342	366	10,628	56	60		$1,692,546	$4,948,965	$4,624,443
332510	Hardware manufacturing	500 employees	682	704	18,979	104	107		$2,850,379	$4,179,442	$4,048,834
332611	Spring (heavy gauge) manufacturing	500 employees	103	106	3,401	19	19		$641,639	$6,229,509	$6,053,202
332612	Spring (light gauge) manufacturing	500 employees	261	297	8,909	44	50		$1,105,090	$4,234,063	$3,720,843

Table III-3: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Small Entities (continued)

NAICS	Industry	SBA Small Business Classification (Limit for revenues or employment) [a]	Small Business or Gov. Entities [b]	Establishments for SBA Entities [b]	SBA Entity Employment [b]	Affected Small Business or Gov. Entities [c]	Affected Employment (at risk) for SBA Entities [c]	Affected FTE Employees (at risk) for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity	Revenues per SBA Establishment
332618	Other fabricated wire product manufacturing	500 employees	1,065	1,113	27,446	148	155		$3,447,000	$3,236,620	$3,097,035
332710	Machine shops	500 employees	21,020	21,176	249,538	1,399	1,410		$28,957,294	$1,377,607	$1,367,458
332812	Metal coating and allied services	500 employees	2,301	2,422	45,444	2,301	3,745		$6,287,992	$2,732,721	$2,596,198
332911	Industrial valve manufacturing	500 employees	344	353	12,938	71	73		$1,890,247	$5,494,903	$5,354,807
332912	Fluid power valve and hose fitting manufacturing	500 employees	264	273	10,076	55	57		$1,610,940	$6,102,046	$5,900,880
332913	Plumbing fixture fitting and trim manufacturing	500 employees	115	118	4,596	25	26		$993,520	$8,639,301	$8,419,657
332919	Other metal valve and pipe fitting manufacturing	500 employees	210	219	7,411	40	42		$1,863,531	$8,873,957	$8,509,274
332991	Ball and roller bearing	750 employees	83	88	3,452	18	20		$460,076	$5,543,088	$5,228,140

Table III-3: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Small Entities (continued)											
NAICS	Industry	SBA Small Business Classification (Limit for revenues or employment) [a]	Small Business or Gov. Entities [b]	Establishments for SBA Entities [b]	SBA Entity Employment [b]	Affected Small Business or Gov. Entities [c]	Affected Employment (at risk) for SBA Entities [c]	Affected FTE Employees (at risk) for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity	Revenues per SBA Establishment
	manufacturing										
332996	Fabricated pipe and pipe fitting manufacturing	500 employees	680	700	18,055	99	102		$2,800,361	$4,118,178	$4,000,516
332997	Industrial pattern manufacturing	500 employees	453	455	5,006	28	28		$480,407	$1,060,502	$1,055,840
332998	Enameled iron and metal sanitary ware manufacturing	750 employees	60	60	1,284	22	22		$180,350	$3,005,840	$3,005,840
332999	All other miscellaneous fabricated metal product manufacturing	500 employees	2,959	2,999	55,806	311	315		$8,085,145	$2,732,391	$2,695,947
333319	Other commercial and service industry machinery manufacturing	500 employees	1,190	1,218	29,926	165	169		$5,553,611	$4,666,900	$4,559,615

Table III-3: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Small Entities (continued)

NAICS	Industry	SBA Small Business Classification (Limit for revenues or employment) [a]	Small Business or Gov. Entities [b]	Establishments for SBA Entities [b]	SBA Entity Employment [b]	Affected Small Business or Gov. Entities [c]	Affected Employment (at risk) for SBA Entities [c]	Affected FTE Employees (at risk) for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity	Revenues per SBA Establishment
333411	Air purification equipment manufacturing	500 employees	278	284	6,538	36	37		$1,163,708	$4,185,999	$4,097,563
333412	Industrial and commercial fan and blower manufacturing	500 employees	126	136	6,556	34	37		$939,848	$7,459,115	$6,910,651
333414	Heating equipment (except warm air furnaces) manufacturing	500 employees	352	356	10,936	61	62		$1,876,671	$5,331,452	$5,271,548
333511	Industrial mold manufacturing	500 employees	2,042	2,072	34,594	193	196		$4,075,012	$1,995,598	$1,966,705
333512	Machine tool (metal cutting types) manufacturing	500 employees	491	500	10,852	60	61		$1,910,885	$3,891,823	$3,821,770
333513	Machine tool (metal forming types) manufacturing	500 employees	263	272	7,341	40	41		$1,078,246	$4,099,796	$3,964,141
333514	Special die and tool, die set, jig, and	500 employees	3,126	3,171	49,262	274	278		$6,126,103	$1,959,726	$1,931,915

Table III-3: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Small Entities (continued)

NAICS	Industry	SBA Small Business Classification (Limit for revenues or employment) [a]	Small Business or Gov. Entities [b]	Establishments for SBA Entities [b]	SBA Entity Employment [b]	Affected Small Business or Gov. Entities [c]	Affected Employment (at risk) for SBA Entities [c]	Affected FTE Employees (at risk) for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity	Revenues per SBA Establishment
	fixture manufacturing										
333515	Cutting tool and machine tool accessory manufacturing	500 employees	1,453	1,479	25,229	140	142		$2,846,376	$1,958,965	$1,924,528
333516	Rolling mill machinery and equipment manufacturing	500 employees	63	64	2,289	13	13		$493,725	$7,836,908	$7,714,456
333518	Other metalworking machinery manufacturing	500 employees	343	358	9,270	50	52		$1,832,815	$5,343,484	$5,119,595
333612	Speed changer, industrial high-speed drive, and gear manufacturing	500 employees	179	190	6,061	32	34		$1,015,097	$5,670,934	$5,342,617
333613	Mechanical power transmission equipment manufacturing	500 employees	172	177	6,332	35	36		$1,471,611	$8,555,877	$8,314,185

Table III-3: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Small Entities (continued)											
NAICS	**Industry**	**SBA Small Business Classification (Limit for revenues or employment) [a]**	**Small Business or Gov. Entities [b]**	**Establishments for SBA Entities [b]**	**SBA Entity Employment [b]**	**Affected Small Business or Gov. Entities [c]**	**Affected Employment (at risk) for SBA Entities [c]**	**Affected FTE Employees (at risk) for SBA Entities [c]**	**Total Revenues for SBA Entities ($1,000) [d]**	**Revenues Per SBA Entity**	**Revenues per SBA Establishment**
333911	Pump and pumping equipment manufacturing	500 employees	368	383	9,987	54	56		$2,153,602	$5,852,179	$5,622,982
333912	Air and gas compressor manufacturing	500 employees	234	242	5,786	32	33		$1,384,829	$5,918,075	$5,722,436
333991	Power-driven handtool manufacturing	500 employees	120	120	2,379	13	13		$430,821	$3,590,179	$3,590,179
333992	Welding and soldering equipment manufacturing	500 employees	233	237	5,584	31	32		$1,235,324	$5,301,818	$5,212,335
333993	Packaging machinery manufacturing	500 employees	551	558	13,273	74	75		$2,197,889	$3,988,910	$3,938,870
333994	Industrial process furnace and oven manufacturing	500 employees	302	312	8,316	45	47		$1,270,055	$4,205,481	$4,070,690
333995	Fluid power cylinder and actuator	500 employees	245	253	7,795	43	44		$1,343,729	$5,484,609	$5,311,183

Table III-3: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Small Entities (continued)											
NAICS	**Industry**	**SBA Small Business Classification (Limit for revenues or employment) [a]**	**Small Business or Gov. Entities [b]**	**Establishments for SBA Entities [b]**	**SBA Entity Employ-ment [b]**	**Affected Small Business or Gov. Entities [c]**	**Affected Employment (at risk) for SBA Entities [c]**	**Affected FTE Employees (at risk) for SBA Entities [c]**	**Total Revenues for SBA Entities ($1,000) [d]**	**Revenues Per SBA Entity**	**Revenues per SBA Establishment**
	manufacturing										
333996	Fluid power pump and motor manufacturing	500 employees	130	137	3,688	20	21		$538,330	$4,141,001	$3,929,417
333997	Scale and balance (except laboratory) manufacturing	500 employees	92	96	2,941	16	17		$431,691	$4,692,298	$4,496,785
333999	All other miscellaneous general purpose machinery manufacturing	500 employees	1,547	1,574	29,810	166	168		$4,747,476	$3,068,828	$3,016,186
334518	Watch, clock, and part manufacturing	500 employees	101	101	1,598	9	9		$273,509	$2,708,008	$2,708,008
335211	Electric housewares and household fans	750 employees	89	89	1,773	5	5		$509,756	$5,727,593	$5,727,593
335221	Household cooking appliance manufacturing	750 employees	104	105	3,476	10	10		$1,023,414	$9,840,520	$9,746,801

Table III-3: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Small Entities (continued)

NAICS	Industry	SBA Small Business Classification (Limit for revenues or employment) [a]	Small Business or Gov. Entities [b]	Establishments for SBA Entities [b]	SBA Entity Employment [b]	Affected Small Business or Gov. Entities [c]	Affected Employment (at risk) for SBA Entities [c]	Affected FTE Employees (at risk) for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity	Revenues per SBA Establishment
335222	Household refrigerator and home freezer manufacturing	1,000 employees	18	26	17,121	18	50		$4,601,594	$255,644,105	$176,984,380
335224	Household laundry equipment manufacturing	1,000 employees	17	23	16,269	17	47		$4,792,444	$281,908,445	$208,367,112
335228	Other major household appliance manufacturing	500 employees	26	26	980	3	3		$202,255	$7,779,055	$7,779,055
336111	Automobile manufacturing	1,000 employees	167	181	75,225	167	425		$87,308,106	$522,803,033	$482,365,229
336112	Light truck and utility vehicle manufacturing	1,000 employees	63	94	103,815	63	587		$139,827,543	$2,219,484,812	$1,487,527,055
336120	Heavy duty truck manufacturing	1,000 employees	77	95	32,122	77	181		$17,387,065	$225,806,042	$183,021,739
336211	Motor vehicle body manufacturing	1,000 employees	728	820	47,566	239	269		$11,581,029	$15,908,007	$14,123,206

Table III-3: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Small Entities (continued)

NAICS	Industry	SBA Small Business Classification (Limit for revenues or employment) [a]	Small Business or Gov. Entities [b]	Establishments for SBA Entities [b]	SBA Entity Employment [b]	Affected Small Business or Gov. Entities [c]	Affected Employment (at risk) for SBA Entities [c]	Affected FTE Employees (at risk) for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity	Revenues per SBA Establishment
336212	Truck trailer manufacturing	500 employees	329	336	13,076	72	74		$2,791,165	$8,483,783	$8,307,038
336213	Motor home manufacturing	1000 employees	79	91	21,533	79	122		$5,600,569	$70,893,283	$61,544,718
336311	Carburetor, piston, piston ring, and valve manufacturing	500 employees	92	94	2,482	14	14		$194,045	$2,109,189	$2,064,313
336312	Gasoline engine and engine parts manufacturing	750 employees	758	769	16,812	94	95		$3,027,205	$3,993,675	$3,936,548
336322	Other motor vehicle electrical and electronic equipment manufacturing	750 employees	586	597	18,259	101	103		$3,719,120	$6,346,622	$6,229,682
336330	Motor vehicle steering and suspension components (except spring) manufacturing	750 employees	176	180	6,522	36	37		$1,281,978	$7,283,967	$7,122,101

Table III-3: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Small Entities (continued)

NAICS	Industry	SBA Small Business Classification (Limit for revenues or employment) [a]	Small Business or Gov. Entities [b]	Establishments for SBA Entities [b]	SBA Entity Employment [b]	Affected Small Business or Gov. Entities [c]	Affected Employment (at risk) for SBA Entities [c]	Affected FTE Employees (at risk) for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity	Revenues per SBA Establishment
336340	Motor vehicle brake system manufacturing	750 employees	157	161	8,409	46	47		$968,024	$6,165,756	$6,012,570
336350	Motor vehicle transmission and power train parts manufacturing	750 employees	374	384	11,991	66	68		$2,131,769	$5,699,918	$5,551,482
336370	Motor vehicle metal stamping	500 employees	550	595	38,474	201	217		$5,938,434	$10,797,152	$9,980,561
336399	All other motor vehicle parts manufacturing	750 employees	1,038	1,080	43,308	235	245		$6,820,940	$6,571,233	$6,315,685
336611	Ship building and repair	1,000 employees	575	635	87,352	575	2,798		$14,650,189	$25,478,589	$23,071,163
336612	Boat building	500 employees	1,041	1,048	25,582	814	819		$5,194,492	$4,989,906	$4,956,576
336992	Military armored vehicle, tank, and tank component manufacturing	1,000 employees	47	57	6,899	32	39		$2,406,966	$51,212,047	$42,227,477

Table III-3: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Small Entities (continued)

NAICS	Industry	SBA Small Business Classification (Limit for revenues or employment) [a]	Small Business or Gov. Entities [b]	Establishments for SBA Entities [b]	SBA Entity Employ-ment [b]	Affected Small Business or Gov. Entities [c]	Affected Employment (at risk) for SBA Entities [c]	Affected FTE Employees (at risk) for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity	Revenues per SBA Establishment
337215	Showcase, partition, shelving, and locker manufacturing	500 employees	1,600	1,641	42,750	235	241		$5,475,456	$3,422,160	$3,336,658
339114	Dental equipment and supplies manufacturing	500 employees	729	738	11,186	292	296		$1,796,269	$2,464,017	$2,433,968
339116	Dental laboratories	500 employees	7,011	7,060	39,244	7,011	27,681		$3,514,294	$501,254	$497,775
339911	Jewelry (except costume) manufacturing	500 employees	1,751	1,758	20,447	1,751	6,319		$4,309,089	$2,460,930	$2,451,131
339913	Jewelers' materials and lapidary work manufacturing	500 employees	258	261	3,779	258	1,168		$673,700	$2,611,240	$2,581,225
339914	Costume jewelry and novelty manufacturing	500 employees	588	588	6,326	588	1,016		$537,493	$914,103	$914,103
339950	Sign manufacturing	500 employees	6,261	6,339	78,049	428	434		$9,676,242	$1,545,479	$1,526,462

Table III-3: Characteristics of Industries Affected by OSHA’s Proposed Standard for Silica – Small Entities (continued)

NAICS	Industry	SBA Small Business Classification (Limit for revenues or employment) [a]	Small Business or Gov. Entities [b]	Establishments for SBA Entities [b]	SBA Entity Employment [b]	Affected Small Business or Gov. Entities [c]	Affected Employment (at risk) for SBA Entities [c]	Affected FTE Employees (at risk) for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity	Revenues per SBA Establishment
423840	Industrial supplies, wholesalers	100 employees	6,885	8,489	80,884	226	278		$32,394,611	$4,705,100	$3,816,069
482110	Rail transportation	N/A	NA	NA	NA	NA	NA		NA	NA	NA
621210	Dental offices	$6 million	119,272	121,934	777,326	7,423	7,589		$74,497,933	$624,605	$610,969
	Subtotals – General Industry and Maritime		**216,079**	**224,419**	**3,036,008**	**41,136**	**171,282**		**$719,209,398**	**$3,328,456**	**$3,204,762**
	Totals – All Industries		**1,012,802**	**1,008,932**	**8,840,744**	**470,148**	**1,310,254**		**$1,699,940,750**	**$1,701,097**	**$1,684,891**

[a] Data were not available specifically for small entities with more than 500 employees. For SBA small business classifications specifying 750 or fewer employees, OSHA used data for small businesses with 500 or fewer employees. For SBA small business classifications specifying 1,000 or fewer employees, OSHA used data for all entities in the industry.

[b] US Census Bureau, Statistics of US Businesses, 2006.

[c] OSHA estimates of employees potentially exposed to silica and associated entities and establishments. Affected entities and establishments constrained to be less than or equal to the number of affected employees.

[d] Estimates based on 2002 receipts and payroll data from US Census Bureau, Statistics of US Businesses, 2002, and payroll data from the US Census Bureau, Statistics of US Businesses, 2006. Receipts are not reported for 2006, but were estimated assuming the ratio of receipts to payroll remained unchanged from 2002 to 2006.

[e] State-plan states only. State and local governments are included under the construction sector because the silica risks for public employees are the result of construction-related activities.

[f] OSHA estimates that only one-third of the entities and establishments in this industry, as reported above, use silica-containing inputs.

Source: US Dept. of Labor, OSHA, Directorate of Evaluation and Analysis, Office of Regulatory Analysis, based on ERG, 2011.

Table III-4: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Entities with Fewer than 20 Employees										
NAICS	Industry	Entities with <20 Employees [a]	Estab. For Entities with <20 Employees [a]	Employment for Entities with <20 Employees[a]	Affected Entities with <20 Employees [b]	Affected Employees for Entities with <20 Employees [b]	Affected FTE Employees for Entities with <20 Employees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employees	Revenue per Estab. For Entities with <20 Employees
Construction										
236100	Residential Building Construction	190,863	190,876	559,487	32,044	32,044	16,022	$165,597,421	$867,625	$867,565
236200	Nonresidential Building Construction	35,746	35,773	187,254	35,746	43,897	8,779	$63,990,139	$1,790,134	$1,788,783
237100	Utility System Construction	16,113	16,118	84,361	16,113	36,873	16,338	$15,033,541	$933,007	$932,718
237200	Land Subdivision	11,642	11,652	36,125	3,039	3,039	1,519	$13,314,383	$1,143,651	$1,142,669
237300	Highway, Street, and Bridge Construction	8,080	8,085	43,108	8,080	27,163	8,871	$12,536,864	$1,551,592	$1,550,633
237900	Other Heavy and Civil Engineering Construction	4,436	4,440	19,031	4,436	9,880	3,975	$3,480,614	$784,629	$783,922
238100	Foundation, Structure, and Building Exterior Contractors	105,227	105,237	421,630	105,227	202,056	40,411	$59,028,342	$560,962	$560,909

Table III-4: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Entities with Fewer than 20 Employees

NAICS	Industry	Entities with <20 Employ-ees [a]	Estab. For Entities with <20 Employ-ees [a]	Employ-ment for Entities with <20 Employ-ees[a]	Affected Entities with <20 Employ-ees [b]	Affected Employ-ees for Entities with <20 Employ ees [b]	Affected FTE Employ-ees for Entities with <20 Employ-ees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employ-ees	Revenue per Estab. For Entities with <20 Employ-ees
238200	Building Equipment Contractors	159,965	160,012	694,285	7,285	7,285	3,642	$87,240,419	$545,372	$545,212
238300	Building Finishing Contractors	123,229	123,241	412,476	50,754	50,754	25,377	$49,750,510	$403,724	$403,685
238900	Other Specialty Trade Contractors	68,075	68,093	243,192	68,075	119,686	59,843	$38,466,840	$565,066	$564,916
999000	State and local governments [d]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Subtotals - Construction	**723,376**	**723,527**	**2,700,949**	**330,798**	**532,676**	**184,778**	**$508,439,073**	**$702,870**	**$702,723**

Table III-4: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Entities with Fewer than 20 Employees (continued)										
NAICS	**Industry**	**Entities with <20 Employ-ees [a]**	**Estab. For Entities with <20 Employ-ees [a]**	**Employ-ment for Entities with <20 Employ-ees[a]**	**Affected Entities with <20 Employ-ees [b]**	**Affected Employ-ees for Entities with <20 Employ ees [b]**	**Affecte d FTE Employ-ees for Entities with <20 Employ-ees[b]**	**Total Revenues for Entities with <20 Employees ($1,000) [c]**	**Revenues Per Entity with <20 Employ-ees**	**Revenue per Estab. For Entities with <20 Employ-ees**
General Industry and Maritime										
324121	Asphalt paving mixture and block manufacturing	260	265	1,547	260	539		$1,060,478	$4,078,763	$4,001,806
324122	Asphalt shingle and roofing materials	57	57	300	57	104		$215,229	$3,775,939	$3,775,939
325510	Paint and coating manufacturing [e]	740	743	4,578	325	325		$1,302,704	$1,760,410	$1,753,302
327111	Vitreous china plumbing fixtures & bathroom accessories manufacturing	19	19	84	19	40		$5,851	$307,970	$307,970
327112	Vitreous china, fine earthenware, & other pottery product	645	646	2,358	645	1,129		$94,208	$146,058	$145,832

Table III-4: Characteristics of Industries Affected by OSHA’s Proposed Standard for Silica – Entities with Fewer than 20 Employees (continued)

NAICS	Industry	Entities with <20 Employees [a]	Estab. For Entities with <20 Employees [a]	Employment for Entities with <20 Employees[a]	Affected Entities with <20 Employees [b]	Affected Employees for Entities with <20 Employees [b]	Affected FTE Employees for Entities with <20 Employees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employees	Revenue per Estab. For Entities with <20 Employees
	manufacturing									
327113	Porcelain electrical supply mfg	57	57	252	57	120		$32,244	$565,684	$565,684
327121	Brick and structural clay mfg	31	31	126	31	48		$20,854	$672,724	$672,724
327122	Ceramic wall and floor tile mfg	136	136	629	136	239		$103,286	$759,454	$759,454
327123	Other structural clay product mfg	25	25	110	25	42		$18,403	$736,137	$736,137
327124	Clay refractory manufacturing	55	55	243	55	89		$78,722	$1,431,313	$1,431,313
327125	Nonclay refractory manufacturing	40	40	277	40	102		$56,676	$1,416,902	$1,416,902
327211	Flat glass manufacturing	37	37	168	4	4		$31,520	$851,902	$851,902
327212	Other pressed and blown glass and glassware	373	373	1,583	79	79		$130,107	$348,811	$348,811

Table III-4: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Entities with Fewer than 20 Employees (continued)

NAICS	Industry	Entities with <20 Employ-ees [a]	Estab. For Entities with <20 Employ-ees [a]	Employ-ment for Entities with <20 Employ-ees[a]	Affected Entities with <20 Employ-ees [b]	Affected Employ-ees for Entities with <20 Employ ees [b]	Affected FTE Employ-ees for Entities with <20 Employ-ees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employ-ees	Revenue per Estab. For Entities with <20 Employ-ees
	manufacturing									
327213	Glass container manufacturing	19	19	86	4	4		$48,082	$2,530,632	$2,530,632
327320	Ready-mixed concrete manufacturing	1,429	1,454	10,356	1,429	4,243		$2,584,674	$1,808,729	$1,777,630
327331	Concrete block and brick mfg	339	340	2,499	339	1,205		$636,496	$1,877,568	$1,872,046
327332	Concrete pipe mfg	67	69	535	67	258		$149,703	$2,234,377	$2,169,613
327390	Other concrete product mfg	1,326	1,328	8,646	1,326	4,168		$1,215,695	$916,814	$915,433
327991	Cut stone and stone product manufacturing	1,471	1,473	8,855	1,471	3,493		$1,309,890	$890,476	$889,267
327992	Ground or treated mineral and earth manufacturing	78	78	514	78	392		$119,980	$1,538,203	$1,538,203

Table III-4: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Entities with Fewer than 20 Employees (continued)

NAICS	Industry	Entities with <20 Employ-ees [a]	Estab. For Entities with <20 Employ-ees [a]	Employ-ment for Entities with <20 Employ-ees[a]	Affected Entities with <20 Employ-ees [b]	Affected Employ-ees for Entities with <20 Employ ees [b]	Affected FTE Employ-ees for Entities with <20 Employ-ees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employ-ees	Revenue per Estab. For Entities with <20 Employ-ees
327993	Mineral wool manufacturing	118	118	808	46	46		$155,219	$1,315,417	$1,315,417
327999	All other misc. nonmetallic mineral product mfg	235	236	1,430	235	689		$322,146	$1,370,834	$1,365,026
331111	Iron and steel mills	467	469	2,137	12	12		$1,835,440	$3,930,278	$3,913,518
331112	Electrometallurgical ferroalloy product manufacturing	6	6	33	0	0		$6,788	$1,131,348	$1,131,348
331210	Iron and steel pipe and tube manufacturing from purchased steel	72	72	390	2	2		$143,147	$1,988,148	$1,988,148
331221	Rolled steel shape manufacturing	72	72	368	2	2		$142,816	$1,983,557	$1,983,557
331222	Steel wire drawing	128	128	672	4	4		$100,600	$785,939	$785,939
331314	Secondary smelting and alloying of	51	51	288	2	2		$97,843	$1,918,495	$1,918,495

Table III-4: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Entities with Fewer than 20 Employees (continued)

NAICS	Industry	Entities with <20 Employ-ees [a]	Estab. For Entities with <20 Employ-ees [a]	Employ-ment for Entities with <20 Employ-ees[a]	Affected Entities with <20 Employ-ees [b]	Affected Employ-ees for Entities with <20 Employ ees [b]	Affected FTE Employ-ees for Entities with <20 Employ-ees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employ-ees	Revenue per Estab. For Entities with <20 Employ-ees
	aluminum									
331423	Secondary smelting, refining, and alloying of copper	10	10	42	0	0		$25,674	$2,567,427	$2,567,427
331492	Secondary smelting, refining, and alloying of nonferrous metal (except cu & al)	103	103	661	4	4		$149,834	$1,454,703	$1,454,703
331511	Iron foundries	201	201	1,144	201	427		$194,991	$970,105	$970,105
331512	Steel investment foundries	27	27	165	27	60		$46,518	$1,722,873	$1,722,873
331513	Steel foundries (except investment)	102	102	563	102	210		$151,386	$1,484,181	$1,484,181
331524	Aluminum foundries (except die-casting)	235	235	1,726	235	626		$193,232	$822,265	$822,265
331525	Copper foundries (except die-casting)	164	164	1,270	164	460		$125,674	$766,307	$766,307

Table III-4: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Entities with Fewer than 20 Employees (continued)

NAICS	Industry	Entities with <20 Employ-ees [a]	Estab. For Entities with <20 Employ-ees [a]	Employ-ment for Entities with <20 Employ-ees[a]	Affected Entities with <20 Employ-ees [b]	Affected Employ-ees for Entities with <20 Employ ees [b]	Affected FTE Employ-ees for Entities with <20 Employ-ees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employ-ees	Revenue per Estab. For Entities with <20 Employ-ees
331528	Other nonferrous foundries (except die-casting)	77	77	556	77	202		$60,663	$787,832	$787,832
332111	Iron and steel forging	197	197	935	5	5		$217,882	$1,106,000	$1,106,000
332112	Nonferrous forging	26	26	180	1	1		$35,023	$1,347,027	$1,347,027
332115	Crown and closure manufacturing	29	29	228	1	1		$46,812	$1,614,205	$1,614,205
332116	Metal stamping	814	815	6,211	35	35		$877,879	$1,078,476	$1,077,153
332117	Powder metallurgy part manufacturing	50	50	475	3	3		$74,365	$1,487,293	$1,487,293
332211	Cutlery and flatware (except precious) manufacturing	101	101	508	3	3		$37,244	$368,754	$368,754
332212	Hand and edge tool manufacturing	758	758	4,472	25	25		$549,687	$725,180	$725,180
332213	Saw blade and	84	84	524	3	3		$77,102	$917,882	$917,882

Table III-4: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Entities with Fewer than 20 Employees (continued)

NAICS	Industry	Entities with <20 Employ-ees [a]	Estab. For Entities with <20 Employ-ees [a]	Employ-ment for Entities with <20 Employ-ees[a]	Affected Entities with <20 Employ-ees [b]	Affected Employ-ees for Entities with <20 Employ ees [b]	Affecte d FTE Employ-ees for Entities with <20 Employ-ees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employ-ees	Revenue per Estab. For Entities with <20 Employ-ees
	handsaw manufacturing									
332214	Kitchen utensil, pot, and pan manufacturing	30	30	169	0	0		$23,323	$777,440	$777,440
332323	Ornamental and architectural metal work	1,946	1,946	10,169	14	14		$1,274,104	$654,730	$654,730
332439	Other metal container manufacturing	213	217	1,211	7	7		$205,891	$966,624	$948,806
332510	Hardware manufacturing	438	440	2,714	15	15		$320,154	$730,945	$727,622
332611	Spring (heavy gauge) manufacturing	61	62	441	2	2		$101,835	$1,669,429	$1,642,503
332612	Spring (light gauge) manufacturing	148	148	1,136	6	6		$151,107	$1,020,992	$1,020,992

Table III-4: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Entities with Fewer than 20 Employees (continued)

NAICS	Industry	Entities with <20 Employ-ees [a]	Estab. For Entities with <20 Employ-ees [a]	Employ-ment for Entities with <20 Employ-ees[a]	Affected Entities with <20 Employ-ees [b]	Affected Employ-ees for Entities with <20 Employ ees [b]	Affected FTE Employ-ees for Entities with <20 Employ-ees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employ-ees	Revenue per Estab. For Entities with <20 Employ-ees
332618	Other fabricated wire product manufacturing	714	714	4,562	26	26		$523,160	$732,717	$732,717
332710	Machine shops	17,619	17,632	95,210	538	538		$10,770,479	$611,299	$610,848
332812	Metal coating and allied services	1,652	1,654	10,754	886	886		$936,503	$566,890	$566,205
332911	Industrial valve manufacturing	202	202	1,347	8	8		$246,078	$1,218,210	$1,218,210
332912	Fluid power valve and hose fitting manufacturing	151	151	1,027	6	6		$191,842	$1,270,476	$1,270,476
332913	Plumbing fixture fitting and trim manufacturing	67	67	344	2	2		$51,137	$763,242	$763,242
332919	Other metal valve and pipe fitting manufacturing	112	113	621	4	4		$228,107	$2,036,674	$2,018,650
332991	Ball and roller bearing	44	44	259	1	1		$74,848	$1,701,096	$1,701,096

Table III-4: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Entities with Fewer than 20 Employees (continued)

NAICS	Industry	Entities with <20 Employees [a]	Estab. For Entities with <20 Employees [a]	Employment for Entities with <20 Employees[a]	Affected Entities with <20 Employees [b]	Affected Employees for Entities with <20 Employees [b]	Affected FTE Employees for Entities with <20 Employees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employees	Revenue per Estab. For Entities with <20 Employees
	manufacturing									
332996	Fabricated pipe and pipe fitting manufacturing	437	437	2,852	16	16		$508,646	$1,163,949	$1,163,949
332997	Industrial pattern manufacturing	386	386	2,035	12	12		$182,760	$473,471	$473,471
332998	Enameled iron and metal sanitary ware manufacturing	47	47	280	5	5		$32,078	$682,501	$682,501
332999	All other miscellaneous fabricated metal product manufacturing	2,149	2,149	12,813	72	72		$1,887,691	$878,404	$878,404
333319	Other commercial and service industry machinery manufacturing	804	804	4,525	26	26		$853,167	$1,061,153	$1,061,153
333411	Air purification equipment	180	180	1,087	6	6		$195,185	$1,084,359	$1,084,359

Table III-4: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Entities with Fewer than 20 Employees (continued)

NAICS	Industry	Entities with <20 Employ-ees [a]	Estab. For Entities with <20 Employ-ees [a]	Employ-ment for Entities with <20 Employ-ees[a]	Affected Entities with <20 Employ-ees [b]	Affected Employ-ees for Entities with <20 Employ ees [b]	Affecte d FTE Employ-ees for Entities with <20 Employ-ees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employ-ees	Revenue per Estab. For Entities with <20 Employ-ees
	manufacturing									
333412	Industrial and commercial fan and blower manufacturing	55	55	383	2	2		$75,247	$1,368,128	$1,368,128
333414	Heating equipment (except warm air furnaces) manufacturing	227	228	1,391	8	8		$192,527	$848,137	$844,417
333511	Industrial mold manufacturing	1,538	1,539	10,002	57	57		$1,036,687	$674,049	$673,611
333512	Machine tool (metal cutting types) manufacturing	326	327	2,006	11	11		$279,661	$857,856	$855,233
333513	Machine tool (metal forming types) manufacturing	164	164	1,068	6	6		$201,919	$1,231,215	$1,231,215
333514	Special die and tool, die set, jig, and fixture	2,425	2,427	15,077	85	85		$1,863,802	$768,578	$767,945

Table III-4: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Entities with Fewer than 20 Employees (continued)

NAICS	Industry	Entities with <20 Employ-ees [a]	Estab. For Entities with <20 Employ-ees [a]	Employ-ment for Entities with <20 Employ-ees[a]	Affected Entities with <20 Employ-ees [b]	Affected Employ-ees for Entities with <20 Employ ees [b]	Affecte d FTE Employ-ees for Entities with <20 Employ-ees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employ-ees	Revenue per Estab. For Entities with <20 Employ-ees
	manufacturing									
333515	Cutting tool and machine tool accessory manufacturing	1,107	1,109	7,191	41	41		$803,091	$725,466	$724,158
333516	Rolling mill machinery and equipment manufacturing	35	35	307	2	2		$73,880	$2,110,852	$2,110,852
333518	Other metalworking machinery manufacturing	207	207	1,548	9	9		$188,053	$908,471	$908,471
333612	Speed changer, industrial high-speed drive, and gear manufacturing	100	100	759	4	4		$131,130	$1,311,301	$1,311,301
333613	Mechanical power transmission equipment manufacturing	96	96	713	4	4		$190,842	$1,987,939	$1,987,939

Table III-4: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Entities with Fewer than 20 Employees (continued)

NAICS	Industry	Entities with <20 Employ-ees [a]	Estab. For Entities with <20 Employ-ees [a]	Employ-ment for Entities with <20 Employ-ees[a]	Affected Entities with <20 Employ-ees [b]	Affected Employ-ees for Entities with <20 Employ ees [b]	Affected FTE Employ-ees for Entities with <20 Employ-ees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employ-ees	Revenue per Estab. For Entities with <20 Employ-ees
333911	Pump and pumping equipment manufacturing	235	235	1,648	9	9		$297,095	$1,264,236	$1,264,236
333912	Air and gas compressor manufacturing	154	154	967	5	5		$238,270	$1,547,208	$1,547,208
333991	Power-driven handtool manufacturing	89	89	505	3	3		$180,704	$2,030,378	$2,030,378
333992	Welding and soldering equipment manufacturing	156	156	876	5	5		$195,409	$1,252,620	$1,252,620
333993	Packaging machinery manufacturing	365	365	2,231	13	13		$277,950	$761,507	$761,507
333994	Industrial process furnace and oven manufacturing	186	186	1,288	7	7		$231,810	$1,246,288	$1,246,288
333995	Fluid power cylinder and actuator	148	148	905	5	5		$127,620	$862,298	$862,298

Table III-4: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Entities with Fewer than 20 Employees (continued)

NAICS	Industry	Entities with <20 Employ-ees [a]	Estab. For Entities with <20 Employ-ees [a]	Employ-ment for Entities with <20 Employ-ees[a]	Affected Entities with <20 Employ-ees [b]	Affected Employ-ees for Entities with <20 Employ ees [b]	Affected FTE Employ-ees for Entities with <20 Employ-ees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employ-ees	Revenue per Estab. For Entities with <20 Employ-ees
	manufacturing									
333996	Fluid power pump and motor manufacturing	91	91	611	3	3		$121,353	$1,333,551	$1,333,551
333997	Scale and balance (except laboratory) manufacturing	63	63	447	3	3		$90,539	$1,437,128	$1,437,128
333999	All other miscellaneous general purpose machinery manufacturing	1,141	1,141	7,465	42	42		$935,673	$820,046	$820,046
334518	Watch, clock, and part manufacturing	71	71	301	2	2		$39,164	$551,606	$551,606
335211	Electric housewares and household fans	66	66	265	0	0		$52,615	$797,194	$797,194
335221	Household cooking appliance manufacturing	74	74	355	1	1		$155,125	$2,096,278	$2,096,278

Table III-4: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Entities with Fewer than 20 Employees (continued)

NAICS	Industry	Entities with <20 Employ-ees [a]	Estab. For Entities with <20 Employ-ees [a]	Employ-ment for Entities with <20 Employ-ees[a]	Affected Entities with <20 Employ-ees [b]	Affected Employ-ees for Entities with <20 Employ ees [b]	Affecte d FTE Employ-ees for Entities with <20 Employ-ees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employ-ees	Revenue per Estab. For Entities with <20 Employ-ees
335222	Household refrigerator and home freezer manufacturing	7	7	58	0	0		$32,383	$4,626,121	$4,626,121
335224	Household laundry equipment manufacturing	8	8	24	0	0		$13,304	$1,663,024	$1,663,024
335228	Other major household appliance manufacturing	13	13	45	0	0		$20,876	$1,605,841	$1,605,841
336111	Automobile manufacturing	108	108	491	3	3		$153,123	$1,417,805	$1,417,805
336112	Light truck and utility vehicle manufacturing	40	40	182	1	1		$41,009	$1,025,224	$1,025,224
336120	Heavy duty truck manufacturing	33	33	216	1	1		$135,707	$4,112,321	$4,112,321
336211	Motor vehicle body manufacturing	394	394	2,830	16	16		$637,726	$1,618,593	$1,618,593

Table III-4: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Entities with Fewer than 20 Employees (continued)

NAICS	Industry	Entities with <20 Employ-ees [a]	Estab. For Entities with <20 Employ-ees [a]	Employ-ment for Entities with <20 Employ-ees[a]	Affected Entities with <20 Employ-ees [b]	Affected Employ-ees for Entities with <20 Employ ees [b]	Affected FTE Employ-ees for Entities with <20 Employ-ees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employ-ees	Revenue per Estab. For Entities with <20 Employ-ees
336212	Truck trailer manufacturing	188	188	1,177	7	7		$478,649	$2,546,006	$2,546,006
336213	Motor home manufacturing	35	35	273	2	2		$71,923	$2,054,950	$2,054,950
336311	Carburetor, piston, piston ring, and valve manufacturing	62	62	304	2	2		$50,773	$818,914	$818,914
336312	Gasoline engine and engine parts manufacturing	612	612	2,673	15	15		$499,567	$816,287	$816,287
336322	Other motor vehicle electrical and electronic equipment manufacturing	382	382	1,972	11	11		$497,299	$1,301,831	$1,301,831
336330	Motor vehicle steering and suspension components (except spring)	104	104	658	4	4		$151,006	$1,451,978	$1,451,978

Table III-4: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Entities with Fewer than 20 Employees (continued)

NAICS	Industry	Entities with <20 Employees [a]	Estab. For Entities with <20 Employees [a]	Employment for Entities with <20 Employees[a]	Affected Entities with <20 Employees [b]	Affected Employees for Entities with <20 Employees [b]	Affected FTE Employees for Entities with <20 Employees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employees	Revenue per Estab. For Entities with <20 Employees
	manufacturing									
336340	Motor vehicle brake system manufacturing	91	91	546	3	3		$118,026	$1,296,989	$1,296,989
336350	Motor vehicle transmission and power train parts manufacturing	261	261	1,462	8	8		$212,325	$813,505	$813,505
336370	Motor vehicle metal stamping	182	183	1,318	7	7		$260,226	$1,429,814	$1,422,000
336399	All other motor vehicle parts manufacturing	615	615	3,666	21	21		$792,101	$1,287,970	$1,287,970
336611	Ship building and repair	370	371	2,041	65	65		$268,330	$725,215	$723,261
336612	Boat building	782	783	3,773	121	121		$810,202	$1,036,064	$1,034,741
336992	Military armored vehicle, tank, and tank component	20	20	138	0	0		$21,559	$1,077,970	$1,077,970

Table III-4: Characteristics of Industries Affected by OSHA’s Proposed Standard for Silica – Entities with Fewer than 20 Employees (continued)

NAICS	Industry	Entities with <20 Employ-ees [a]	Estab. For Entities with <20 Employ-ees [a]	Employ-ment for Entities with <20 Employ-ees[a]	Affected Entities with <20 Employ-ees [b]	Affected Employ-ees for Entities with <20 Employ ees [b]	Affecte d FTE Employ-ees for Entities with <20 Employ-ees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employ-ees	Revenue per Estab. For Entities with <20 Employ-ees
	manufacturing									
337215	Showcase, partition, shelving, and locker manufacturing	1,013	1,013	6,459	36	36		$826,194	$815,591	$815,591
339114	Dental equipment and supplies manufacturing	610	610	3,277	87	87		$377,132	$618,249	$618,249
339116	Dental laboratories	6,664	6,667	24,555	6,664	17,320		$2,048,372	$307,379	$307,241
339911	Jewelry (except costume) manufacturing	1,532	1,533	6,761	1,532	2,090		$971,176	$633,927	$633,513
339913	Jewelers' materials and lapidary work manufacturing	218	218	1,096	218	339		$188,557	$864,940	$864,940
339914	Costume jewelry and novelty manufacturing	514	514	2,289	368	368		$219,669	$427,372	$427,372

Table III-4: Characteristics of Industries Affected by OSHA's Proposed Standard for Silica – Entities with Fewer than 20 Employees (continued)

NAICS	Industry	Entities with <20 Employ-ees [a]	Estab. For Entities with <20 Employ-ees [a]	Employ-ment for Entities with <20 Employ-ees[a]	Affected Entities with <20 Employ-ees [b]	Affected Employ-ees for Entities with <20 Employ ees [b]	Affected FTE Employ-ees for Entities with <20 Employ-ees[b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employ-ees	Revenue per Estab. For Entities with <20 Employ-ees
339950	Sign manufacturing	5,312	5,316	25,236	140	140		$2,606,147	$490,615	$490,246
423840	Industrial supplies, wholesalers	5,707	5,881	28,505	98	98		$13,059,089	$2,288,258	$2,220,556
482110	Rail transportation	N/A	N/A	N/A	N/A	N/A		N/A	N/A	N/A
621210	Dental offices	115,748	117,076	674,036	6,581	6,581		$61,302,763	$529,623	$523,615
	Subtotals – General Industry and Maritime	189,475	191,063	1,077,459	25,625	48,771		$128,486,243	$678,117	$672,481
	Totals – All Industries	912,851	914,590	3,778,408	356,424	581,447		$636,925,316	**$697,732**	**$696,405**

[a] US Census Bureau, Statistics of US Businesses, 2006.

[b] OSHA estimates of employees potentially exposed to silica and associated entities and establishments. Affected entities and establishments constrained to be less than or equal to the number of affected employees.

[c] Estimates based on 2002 receipts and payroll data from US Census Bureau, Statistics of US Businesses, 2002, and payroll data from the US Census Bureau, Statistics of US Businesses, 2006. Receipts are not reported for 2006, but were estimated assuming the ratio of receipts to payroll remained unchanged from

2002 to 2006.

[d] State-plan states only. State and local governments are included under the construction sector because the silica risks for public employees are the result of construction-related activities.

[e] OSHA estimates that only one-third of the entities and establishments in this industry, as reported above, use silica-containing inputs.

Source: US Dept. of Labor, OSHA, Directorate of Evaluation and Analysis, Office of Regulatory Analysis, based on ERG, 2011.

SILICA EXPOSURE PROFILE OF AT-RISK WORKERS

The technological feasibility analyses presented in Chapter IV of this PEA contain data and discussion of worker exposures to silica throughout industry. Exposure profiles, by job category, were developed from individual exposure measurements that were judged to be substantive and to contain sufficient accompanying description to allow interpretation of the circumstance of each measurement. The resulting exposure profiles show the job categories with current overexposures to silica and, thus, the workers for whom silica controls would be implemented under the proposed rule.

Table III-5 summarizes, from the exposure profiles, the number of workers at risk from silica exposure and the distribution of 8-hour TWA respirable crystalline silica exposures by job category for general industry and maritime sectors and for construction activities. Exposures are grouped into the following ranges: less than 25 µg/m^3; ≥ 25 µg/m^3 and ≤ 50 µg/m^3; > 50 µg/m^3 and ≤ 100 µg/m^3; > 100 µg/m^3 and ≤ 250 µg/m^3; and greater than 250 µg/m^3. These frequencies represent the percentages of production employees in each job category and sector currently exposed at levels within the indicated range.

Table III-6 presents data by NAICS code—for each affected general, maritime, and construction industry—on the estimated number of workers currently at risk from silica exposure, as well as the estimated number of workers at risk of silica exposure at or above 25 µg/m^3, above 50 µg/m^3, and above 100 µg/m^3. As shown, an estimated

1,026,000 workers (851,000 in construction; 176,000 in general industry and maritime) currently have silica exposures at or above the proposed action level of 25 µg/m^3; an estimated 770,000 workers (648,000 in construction; 122,000 in general industry and maritime) currently have silica exposures above the proposed PEL of 50 µg/m^3; and an estimated 501,000 workers (420,000 in construction; 81,000 in general industry and maritime) currently have silica exposures above 100 µg/m^3—an alternative PEL investigated by OSHA for economic analysis purposes.

Table III-5
Distribution of Silica Exposures by Sector and Job Category or Activity

Sector	Job Category/Activity	Silica Exposure Range					Total
		<25 μg/m^3	25-50 μg/m^3	50-100 μg/m^3	100-250 μg/m^3	>250 μg/m^3	
Construction							
	Abrasive Blasters	18.6%	11.9%	16.9%	20.3%	32.2%	100.0%
	Drywall Finishers	86.7%	6.7%	6.7%	0.0%	0.0%	100.0%
	Heavy Equipment Operators	79.2%	8.3%	8.3%	4.2%	0.0%	100.0%
	Hole Drillers Using Hand-Held Drills	14.3%	28.6%	35.7%	14.3%	7.1%	100.0%
	Jackhammer and Impact Drillers	18.3%	8.3%	15.6%	24.8%	33.0%	100.0%
	Masonry Cutters Using Portable Saws	24.2%	9.9%	12.1%	38.5%	15.4%	100.0%
	Masonry Cutters Using Stationary Saws	21.4%	25.0%	25.0%	3.6%	25.0%	100.0%
	Millers Using Portable or Mobile Machines	54.3%	20.0%	20.0%	2.9%	2.9%	100.0%
	Rock and Concrete Drillers	35.9%	17.9%	17.9%	17.9%	10.3%	100.0%
	Rock-Crushing Machine Operators and Tenders	0.0%	0.0%	0.0%	20.0%	80.0%	100.0%
	Tuckpointers and Grinders	10.0%	8.5%	11.9%	18.4%	51.2%	100.0%
	Underground Construction Workers	59.3%	18.5%	11.1%	7.4%	3.7%	100.0%
General Industry/Maritime							
Asphalt Paving Products	Front-end loader operator	50.0%	0.0%	50.0%	0.0%	0.0%	100.0%
	Maintenance worker	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%
	Plant operator	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%
Asphalt Roofing Materials	Material handler	0.0%	28.6%	42.9%	28.6%	0.0%	100.0%
	Production operator	0.0%	60.0%	20.0%	20.0%	0.0%	100.0%
Captive Foundries	Abrasive blasting operator	6.6%	24.6%	27.9%	27.9%	13.1%	100.0%
	Cleaning/Finishing operator	15.5%	21.6%	19.2%	21.1%	22.5%	100.0%
	Coremaker	25.5%	32.1%	29.2%	9.4%	3.8%	100.0%
	Furnace operator	37.5%	25.0%	0.0%	12.5%	25.0%	100.0%
	Housekeeping worker	14.3%	14.3%	42.9%	14.3%	14.3%	100.0%
	Knockout operator	10.8%	35.1%	18.9%	24.3%	10.8%	100.0%
	Maintenance operator	16.7%	25.0%	25.0%	12.5%	20.8%	100.0%
	Material handler	28.1%	18.8%	31.3%	21.9%	0.0%	100.0%
	Molder	26.3%	24.3%	28.9%	19.1%	1.3%	100.0%
	Pouring operator	25.0%	25.0%	16.7%	29.2%	4.2%	100.0%
	Sand systems operator	17.2%	15.5%	25.9%	27.6%	13.8%	100.0%
	Shakeout operator	14.4%	25.8%	29.9%	17.5%	12.4%	100.0%
Concrete Products	Abrasive blasting operator	13.3%	6.7%	20.0%	26.7%	33.3%	100.0%
	Finishing operator	45.9%	16.2%	10.8%	16.2%	10.8%	100.0%
	Forming Line operator	83.3%	7.1%	7.1%	2.4%	0.0%	100.0%
	Material handler	41.9%	22.6%	19.4%	9.7%	6.5%	100.0%
	Mixer Operator	46.2%	15.4%	0.0%	30.8%	7.7%	100.0%
	Packaging operator	33.3%	0.0%	33.3%	16.7%	16.7%	100.0%
Cut Stone	Abrasive blasting ops	14.3%	28.6%	14.3%	14.3%	28.6%	100.0%
	Fabricator	16.7%	33.3%	8.3%	25.0%	16.7%	100.0%
	Machine operator	11.8%	17.6%	23.5%	35.3%	11.8%	100.0%
	Sawyer	17.4%	26.1%	39.1%	17.4%	0.0%	100.0%
	Splitter/chipper	17.2%	13.8%	20.7%	48.3%	0.0%	100.0%
Dental Equipment	Production operator	33.3%	0.0%	33.3%	33.3%	0.0%	100.0%
Dental Laboratories	Dental technician	83.9%	12.9%	3.2%	0.0%	0.0%	100.0%
Flat Glass	Batch operator	50.0%	0.0%	33.3%	0.0%	16.7%	100.0%
	Material handler	0.0%	16.7%	33.3%	33.3%	16.7%	100.0%
Iron Foundries	Abrasive blasting operator	6.6%	24.6%	27.9%	27.9%	13.1%	100.0%
	Cleaning/Finishing operator	15.5%	21.6%	19.2%	21.1%	22.5%	100.0%
	Coremaker	25.5%	32.1%	29.2%	9.4%	3.8%	100.0%
	Furnace operator	37.5%	25.0%	0.0%	12.5%	25.0%	100.0%
	Housekeeping worker	14.3%	14.3%	42.9%	14.3%	14.3%	100.0%
	Knockout operator	10.8%	35.1%	18.9%	24.3%	10.8%	100.0%
	Maintenance operator	16.7%	25.0%	25.0%	12.5%	20.8%	100.0%
	Material handler	28.1%	18.8%	31.3%	21.9%	0.0%	100.0%
	Molder	26.3%	24.3%	28.9%	19.1%	1.3%	100.0%
	Pouring operator	25.0%	25.0%	16.7%	29.2%	4.2%	100.0%
	Sand systems operator	17.2%	15.5%	25.9%	27.6%	13.8%	100.0%
	Shakeout operator	14.4%	25.8%	29.9%	17.5%	12.4%	100.0%
Jewelry	Jewelry workers	37.5%	18.8%	12.5%	18.8%	12.5%	100.0%
Mineral Processing	Production worker	0.0%	82.4%	11.8%	5.9%	0.0%	100.0%
Mineral Wool	Batch operator	50.0%	0.0%	33.3%	0.0%	16.7%	100.0%
	Material handler	0.0%	16.7%	33.3%	33.3%	16.7%	100.0%
Nonferrous Sand Casting Foundries	Abrasive blasting operator	6.6%	24.6%	27.9%	27.9%	13.1%	100.0%
	Cleaning/Finishing operator	15.5%	21.6%	19.2%	21.1%	22.5%	100.0%
	Coremaker	25.5%	32.1%	29.2%	9.4%	3.8%	100.0%

Table III-5
Distribution of Silica Exposures by Sector and Job Category or Activity
(Continued)

Sector	Job Category/Activity	Silica Exposure Range <25 μg/m³	25-50 μg/m³	50-100 μg/m³	100-250 μg/m³	>250 μg/m³	Total
	Furnace operator	37.5%	25.0%	0.0%	12.5%	25.0%	100.0%
	Housekeeping worker	14.3%	14.3%	42.9%	14.3%	14.3%	100.0%
	Knockout operator	10.8%	35.1%	18.9%	24.3%	10.8%	100.0%
	Maintenance operator	16.7%	25.0%	25.0%	12.5%	20.8%	100.0%
	Material handler	28.1%	18.8%	31.3%	21.9%	0.0%	100.0%
	Molder	26.3%	24.3%	28.9%	19.1%	1.3%	100.0%
	Pouring operator	25.0%	25.0%	16.7%	29.2%	4.2%	100.0%
	Sand systems operator	17.2%	15.5%	25.9%	27.6%	13.8%	100.0%
	Shakeout operator	14.4%	25.8%	29.9%	17.5%	12.4%	100.0%
Non-Sand Casting Foundries	Abrasive blasting operator	6.6%	24.6%	27.9%	27.9%	13.1%	100.0%
	Cleaning/Finishing operator	15.5%	21.6%	19.2%	21.1%	22.5%	100.0%
	Coremaker	25.5%	32.1%	29.2%	9.4%	3.8%	100.0%
	Furnace operator	37.5%	25.0%	0.0%	12.5%	25.0%	100.0%
	Housekeeping worker	14.3%	14.3%	42.9%	14.3%	14.3%	100.0%
	Knockout operator	10.8%	35.1%	18.9%	24.3%	10.8%	100.0%
	Maintenance operator	16.7%	25.0%	25.0%	12.5%	20.8%	100.0%
	Material handler	28.1%	18.8%	31.3%	21.9%	0.0%	100.0%
	Molder	26.3%	24.3%	28.9%	19.1%	1.3%	100.0%
	Pouring operator	25.0%	25.0%	16.7%	29.2%	4.2%	100.0%
	Sand systems operator	17.2%	15.5%	25.9%	27.6%	13.8%	100.0%
	Shakeout operator	14.4%	25.8%	29.9%	17.5%	12.4%	100.0%
Other Ferrous Sand Casting Foundries	Abrasive blasting operator	6.6%	24.6%	27.9%	27.9%	13.1%	100.0%
	Cleaning/Finishing operator	15.5%	21.6%	19.2%	21.1%	22.5%	100.0%
	Coremaker	25.5%	32.1%	29.2%	9.4%	3.8%	100.0%
	Furnace operator	37.5%	25.0%	0.0%	12.5%	25.0%	100.0%
	Housekeeping worker	14.3%	14.3%	42.9%	14.3%	14.3%	100.0%
	Knockout operator	10.8%	35.1%	18.9%	24.3%	10.8%	100.0%
	Maintenance operator	16.7%	25.0%	25.0%	12.5%	20.8%	100.0%
	Material handler	28.1%	18.8%	31.3%	21.9%	0.0%	100.0%
	Molder	26.3%	24.3%	28.9%	19.1%	1.3%	100.0%
	Pouring operator	25.0%	25.0%	16.7%	29.2%	4.2%	100.0%
	Sand systems operator	17.2%	15.5%	25.9%	27.6%	13.8%	100.0%
	Shakeout operator	14.4%	25.8%	29.9%	17.5%	12.4%	100.0%
Other Glass Products	Batch operator	50.0%	0.0%	33.3%	0.0%	16.7%	100.0%
	Material handler	0.0%	16.7%	33.3%	33.3%	16.7%	100.0%
Paint and Coatings	Material handler	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%
	Mixer operator	80.0%	0.0%	0.0%	0.0%	20.0%	100.0%
Porcelain Enameling	Enamel preparer	33.3%	33.3%	33.3%	0.0%	0.0%	100.0%
	Porcelain applicator	52.2%	13.0%	21.7%	0.0%	13.0%	100.0%
Pottery	Coatings operator	18.9%	10.8%	16.2%	32.4%	21.6%	100.0%
	Coatings preparer	5.3%	5.3%	31.6%	26.3%	31.6%	100.0%
	Finishing operator	15.4%	34.6%	19.2%	30.8%	0.0%	100.0%
	Forming Line operator	25.6%	40.0%	14.4%	20.0%	0.0%	100.0%
	Material handler	38.1%	19.0%	19.0%	9.5%	14.3%	100.0%
Railroads	Ballast dumper	50.0%	26.9%	7.7%	7.7%	7.7%	100.0%
	Machine operator	21.0%	38.0%	23.0%	11.0%	7.0%	100.0%
Ready mix	Batch operator	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%
	Maintenance operator	60.0%	20.0%	20.0%	0.0%	0.0%	100.0%
	Material handler	75.0%	0.0%	25.0%	0.0%	0.0%	100.0%
	Quality control technician	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%
	Truck driver	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%
Refractories	Ceramic fiber furnace operator	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%
	Finishing operator	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%
	Forming operator	45.5%	27.3%	13.6%	13.6%	0.0%	100.0%
	Material handler	33.3%	22.2%	22.2%	18.5%	3.7%	100.0%
	Packaging operator	50.0%	41.7%	0.0%	8.3%	0.0%	100.0%
Refractory Repair	Production operator	20.0%	40.0%	20.0%	20.0%	0.0%	100.0%
Shipyards	Abrasive blasters	0.0%	28.6%	14.3%	14.3%	42.9%	100.0%
Structural Clay	Forming line operator/Coatings blender	10.0%	10.0%	50.0%	30.0%	0.0%	100.0%
	Forming line operator/Formers	27.0%	16.2%	16.2%	29.7%	10.8%	100.0%
	Forming Line operator/Pug mill operator	0.0%	14.3%	14.3%	28.6%	42.9%	100.0%
	Grinding operator	21.4%	7.1%	21.4%	28.6%	21.4%	100.0%
	Material handler/Loader operator	42.9%	0.0%	28.6%	28.6%	0.0%	100.0%
	Material handler/post-production	70.3%	16.2%	10.8%	2.7%	0.0%	100.0%
	Material handler/production	30.0%	20.0%	30.0%	15.0%	5.0%	100.0%

Source: Technological feasibility analysis in Chapter IV in this PEA.

Table III-6: Numbers of Workers Exposed to Silica (by Affected Industry and Exposure Level (µg/m^3))								
				Numbers exposed to Silica				
NAICS	**Industry**	**Number of Establishments**	**Number of Employees**	**>=0**	**>=25**	**>=50**	**>=100**	**>=250**
Construction								
236100	Residential Building Construction	198,912	966,198	55,338	32,260	24,445	14,652	7,502
236200	Nonresidential Building Construction	44,702	741,978	173,939	83,003	63,198	39,632	20,504
237100	Utility System Construction	21,232	496,628	217,070	76,687	53,073	28,667	9,783
237200	Land Subdivision	12,469	77,406	6,511	1,745	1,172	560	186
237300	Highway, Street, and Bridge Construction	11,860	325,182	204,899	58,441	39,273	19,347	7,441
237900	Other Heavy and Civil Engineering Construction	5,561	90,167	46,813	12,904	8,655	4,221	1,369
238100	Foundation, Structure, and Building Exterior Contractors	117,456	1,167,986	559,729	396,582	323,119	237,537	134,355
238200	Building Equipment Contractors	182,368	1,940,281	20,358	6,752	4,947	2,876	1,222
238300	Building Finishing Contractors	133,343	975,335	120,012	49,202	37,952	24,662	14,762
238900	Other Specialty Trade Contractors	74,446	557,638	274,439	87,267	60,894	32,871	13,718
999000	State and local governments [d]	NA	5,762,939	170,068	45,847	31,080	15,254	5,161
	Subtotals - Construction	**802,349**	**13,101,738**	**1,849,175**	**850,690**	**647,807**	**420,278**	**216,003**

General Industry and Maritime								
324121	Asphalt paving mixture and block manufacturing	1,431	14,471	5,043	48	48	0	0
324122	Asphalt shingle and roofing materials	224	12,631	4,395	4,395	1,963	935	0
325510	Paint and coating manufacturing	1,344	46,209	3,285	404	404	404	404
327111	Vitreous china plumbing fixtures & bathroom accessories manufacturing	41	5,854	2,802	2,128	1,319	853	227
327112	Vitreous china, fine earthenware, & other pottery product manufacturing	731	9,178	4,394	3,336	2,068	1,337	356
327113	Porcelain electrical supply mfg	125	6,168	2,953	2,242	1,390	898	239
327121	Brick and structural clay mfg	204	13,509	5,132	3,476	2,663	1,538	461
327122	Ceramic wall and floor tile mfg	193	7,094	2,695	1,826	1,398	808	242
327123	Other structural clay product mfg	49	1,603	609	412	316	182	55
327124	Clay refractory manufacturing	129	4,475	1,646	722	364	191	13
327125	Nonclay refractory manufacturing	105	5,640	2,075	910	459	241	17
327211	Flat glass manufacturing	83	11,003	271	164	154	64	45

Table III-6: Numbers of Workers Exposed to Silica (by Affected Industry and Exposure Level (µg/m^3)) (continued)								
				Numbers exposed to Silica				
NAICS	**Industry**	**Number of Establishments**	**Number of Employees**	**>=0**	**>=25**	**>=50**	**>=100**	**>=250**
327212	Other pressed and blown glass and glassware manufacturing	499	20,625	1,034	631	593	248	172
327213	Glass container manufacturing	72	14,392	722	440	414	173	120
327320	Ready-mixed concrete manufacturing	6,064	107,190	43,920	32,713	32,110	29,526	29,526
327331	Concrete block and brick mfg	951	22,738	10,962	5,489	3,866	2,329	929
327332	Concrete pipe mfg	385	14,077	6,787	3,398	2,394	1,442	575
327390	Other concrete product mfg	2,281	66,095	31,865	15,957	11,239	6,769	2,700
327991	Cut stone and stone product manufacturing	1,943	30,633	12,085	10,298	7,441	4,577	1,240
327992	Ground or treated mineral and earth manufacturing	271	6,629	5,051	5,051	891	297	0
327993	Mineral wool manufacturing	321	19,241	1,090	675	632	268	182
327999	All other misc. nonmetallic mineral product mfg	465	10,028	4,835	2,421	1,705	1,027	410
331111	Iron and steel mills	805	108,592	614	456	309	167	57
331112	Electrometallurgical ferroalloy product manufacturing	22	2,198	12	9	6	3	1
331210	Iron and steel pipe and tube manufacturing from purchased steel	240	21,543	122	90	61	33	11
331221	Rolled steel shape manufacturing	170	10,857	61	46	31	17	6

Table III-6: Numbers of Workers Exposed to Silica (by Affected Industry and Exposure Level (μg/m^3)) (continued)

				Numbers exposed to Silica				
NAICS	Industry	Number of Establishments	Number of Employees	>=0	>=25	>=50	>=100	>=250
331222	Steel wire drawing	288	14,669	83	62	42	23	8
331314	Secondary smelting and alloying of aluminum	150	7,381	42	31	21	11	4
331423	Secondary smelting, refining, and alloying of copper	31	1,278	7	5	4	2	1
331492	Secondary smelting, refining, and alloying of nonferrous metal (except cu & al)	217	9,383	53	39	27	14	5
331511	Iron foundries	527	59,209	22,111	16,417	11,140	6,005	2,071
331512	Steel investment foundries	132	16,429	5,934	4,570	3,100	1,671	573
331513	Steel foundries (except investment)	222	17,722	6,618	4,914	3,334	1,797	620
331524	Aluminum foundries (except die-casting)	466	26,565	9,633	7,418	5,032	2,712	931
331525	Copper foundries (except die-casting)	256	6,120	2,219	1,709	1,159	625	214
331528	Other nonferrous foundries (except die-casting)	124	4,710	1,708	1,315	892	481	165
332111	Iron and steel forging	398	26,596	150	112	76	41	14
332112	Nonferrous forging	77	8,814	50	37	25	13	5
332115	Crown and closure manufacturing	59	3,243	18	14	9	5	2
332116	Metal stamping	1,641	64,724	366	272	184	99	34

Table III-6: Numbers of Workers Exposed to Silica (by Affected Industry and Exposure Level (μg/m^3)) (continued)

				Numbers exposed to Silica				
NAICS	**Industry**	**Number of Establishments**	**Number of Employees**	**>=0**	**>=25**	**>=50**	**>=100**	**>=250**
332117	Powder metallurgy part manufacturing	129	8,362	47	35	24	13	4
332211	Cutlery and flatware (except precious) manufacturing	141	5,779	33	24	16	9	3
332212	Hand and edge tool manufacturing	1,155	36,622	207	154	104	56	19
332213	Saw blade and handsaw manufacturing	136	7,304	41	31	21	11	4
332214	Kitchen utensil, pot, and pan manufacturing	70	3,928	22	17	11	6	2
332323	Ornamental and architectural metal work	2,450	39,947	54	26	19	7	7
332439	Other metal container manufacturing	401	15,195	86	64	43	23	8
332510	Hardware manufacturing	828	45,282	256	190	129	69	24
332611	Spring (heavy gauge) manufacturing	113	4,059	23	17	12	6	2
332612	Spring (light gauge) manufacturing	340	15,336	87	64	44	24	8
332618	Other fabricated wire product manufacturing	1,198	36,364	205	153	104	56	19
332710	Machine shops	21,356	266,597	1,506	1,118	759	409	141
332812	Metal coating and allied services	2,599	56,978	4,695	2,255	1,632	606	606
332911	Industrial valve manufacturing	488	38,330	216	161	109	59	20
332912	Fluid power valve and hose fitting manufacturing	381	35,519	201	149	101	55	19

Table III-6: Numbers of Workers Exposed to Silica (by Affected Industry and Exposure Level (μg/m³)) (continued)								
				Numbers exposed to Silica				
NAICS	**Industry**	**Number of Establishments**	**Number of Employees**	**>=0**	**>=25**	**>=50**	**>=100**	**>=250**
332913	Plumbing fixture fitting and trim manufacturing	144	11,513	65	48	33	18	6
332919	Other metal valve and pipe fitting manufacturing	268	18,112	102	76	51	28	10
332991	Ball and roller bearing manufacturing	180	27,197	154	114	77	42	14
332996	Fabricated pipe and pipe fitting manufacturing	765	27,201	154	114	77	42	14
332997	Industrial pattern manufacturing	461	5,281	30	22	15	8	3
332998	Enameled iron and metal sanitary ware manufacturing	76	5,655	96	56	38	16	11
332999	All other miscellaneous fabricated metal product manufacturing	3,123	72,201	408	303	205	111	38
333319	Other commercial and service industry machinery manufacturing	1,349	53,012	299	222	151	81	28
333411	Air purification equipment manufacturing	351	14,883	84	62	42	23	8
333412	Industrial and commercial fan and blower manufacturing	163	10,506	59	44	30	16	6
333414	Heating equipment (except warm air furnaces) manufacturing	407	20,577	116	86	59	32	11
333511	Industrial mold manufacturing	2,126	39,917	226	168	114	61	21
333512	Machine tool (metal cutting types)	530	17,220	97	72	49	26	9

Table III-6: Numbers of Workers Exposed to Silica (by Affected Industry and Exposure Level (µg/m^3)) (continued)

				Numbers exposed to Silica				
NAICS	**Industry**	**Number of Establishments**	**Number of Employees**	**>=0**	**>=25**	**>=50**	**>=100**	**>=250**
	manufacturing							
333513	Machine tool (metal forming types) manufacturing	285	8,556	48	36	24	13	5
333514	Special die and tool, die set, jig, and fixture manufacturing	3,232	57,576	325	241	164	88	30
333515	Cutting tool and machine tool accessory manufacturing	1,552	34,922	197	146	99	54	18
333516	Rolling mill machinery and equipment manufacturing	73	3,020	17	13	9	5	2
333518	Other metalworking machinery manufacturing	383	12,470	70	52	35	19	7
333612	Speed changer, industrial high-speed drive, and gear manufacturing	226	12,374	70	52	35	19	7
333613	Mechanical power transmission equipment manufacturing	231	15,645	88	66	44	24	8
333911	Pump and pumping equipment manufacturing	490	30,764	174	129	88	47	16
333912	Air and gas compressor manufacturing	318	21,417	121	90	61	33	11
333991	Power-driven handtool manufacturing	150	8,714	49	37	25	13	5
333992	Welding and soldering equipment manufacturing	275	15,853	90	67	45	24	8

Table III-6: Numbers of Workers Exposed to Silica (by Affected Industry and Exposure Level (μg/m^3)) (continued)

				Numbers exposed to Silica				
NAICS	**Industry**	**Number of Establishments**	**Number of Employees**	**>=0**	**>=25**	**>=50**	**>=100**	**>=250**
333993	Packaging machinery manufacturing	619	21,179	120	89	60	32	11
333994	Industrial process furnace and oven manufacturing	335	10,720	61	45	31	16	6
333995	Fluid power cylinder and actuator manufacturing	319	19,887	112	83	57	31	11
333996	Fluid power pump and motor manufacturing	178	13,631	77	57	39	21	7
333997	Scale and balance (except laboratory) manufacturing	102	3,748	21	16	11	6	2
333999	All other miscellaneous general purpose machinery manufacturing	1,725	52,454	296	220	149	80	28
334518	Watch, clock, and part manufacturing	106	2,188	12	9	6	3	1
335211	Electric housewares and household fans	105	7,425	22	10	8	3	3
335221	Household cooking appliance manufacturing	125	16,033	47	22	16	6	6
335222	Household refrigerator and home freezer manufacturing	26	17,121	50	24	17	7	7
335224	Household laundry equipment manufacturing	23	16,269	47	23	17	6	6
335228	Other major household appliance manufacturing	45	12,806	37	18	13	5	5
336111	Automobile manufacturing	181	75,225	425	316	214	115	40
336112	Light truck and utility vehicle manufacturing	94	103,815	587	436	296	159	55

Table III-6: Numbers of Workers Exposed to Silica (by Affected Industry and Exposure Level (μg/m^3)) (continued)								
				Numbers exposed to Silica				
NAICS	**Industry**	**Number of Establishments**	**Number of Employees**	**>=0**	**>=25**	**>=50**	**>=100**	**>=250**
336120	Heavy duty truck manufacturing	95	32,122	181	135	91	49	17
336211	Motor vehicle body manufacturing	820	47,566	269	200	135	73	25
336212	Truck trailer manufacturing	394	32,260	182	135	92	50	17
336213	Motor home manufacturing	91	21,533	122	90	61	33	11
336311	Carburetor, piston, piston ring, and valve manufacturing	116	10,537	60	44	30	16	6
336312	Gasoline engine and engine parts manufacturing	876	66,112	373	277	188	101	35
336322	Other motor vehicle electrical and electronic equipment manufacturing	697	62,016	350	260	176	95	33
336330	Motor vehicle steering and suspension components (except spring) manufacturing	257	39,390	223	165	112	60	21
336340	Motor vehicle brake system manufacturing	241	33,782	191	142	96	52	18
336350	Motor vehicle transmission and power train parts manufacturing	535	83,756	473	351	238	128	44
336370	Motor vehicle metal stamping	781	110,578	624	464	315	170	58
336399	All other motor vehicle parts manufacturing	1,458	149,251	843	626	425	229	79

Table III-6: Numbers of Workers Exposed to Silica (by Affected Industry and Exposure Level (μg/m^3)) (continued)

				Numbers exposed to Silica				
NAICS	**Industry**	**Number of Establishments**	**Number of Employees**	**>=0**	**>=25**	**>=50**	**>=100**	**>=250**
336611	Ship building and repair	635	87,352	2,798	2,798	1,998	1,599	1,199
336612	Boat building	1,129	54,705	1,752	1,752	1,252	1,001	751
336992	Military armored vehicle, tank, and tank component manufacturing	57	6,899	39	29	20	11	4
337215	Showcase, partition, shelving, and locker manufacturing	1,733	59,080	334	248	168	91	31
339114	Dental equipment and supplies manufacturing	763	15,550	411	274	274	137	0
339116	Dental laboratories	7,261	47,088	33,214	5,357	1,071	0	0
339911	Jewelry (except costume) manufacturing	1,777	25,280	7,813	4,883	3,418	2,442	977
339913	Jewelers' materials and lapidary work manufacturing	264	5,199	1,607	1,004	703	502	201
339914	Costume jewelry and novelty manufacturing	590	6,775	1,088	685	479	338	135
339950	Sign manufacturing	6,415	89,360	496	249	172	57	57
423840	Industrial supplies, wholesalers	10,742	111,198	383	306	153	77	0
482110	Rail transportation	NA	NA	16,895	11,248	5,629	2,852	1,233
621210	Dental offices	124,553	817,396	7,980	1,287	257	0	0

Table III-6: Numbers of Workers Exposed to Silica (by Affected Industry and Exposure Level (µg/m^3)) (continued)								
				Numbers exposed to Silica				
NAICS	Industry	Number of Establishments	Number of Employees	>=0	>=25	>=50	>=100	>=250
	Subtotals – General Industry and Maritime	**238,942**	**4,406,990**	**294,886**	**175,801**	**122,472**	**80,731**	**48,956**
	Totals	**1,041,291**	**17,508,728**	**2,144,061**	**1,026,491**	**770,280**	**501,009**	**264,959**

Source: U.S. Dept. of Labor, OSHA, Directorate of Evaluation and Analysis, Office of Regulatory Analysis, based on Table III-5 and the technological feasibility analysis presented in Chapter IV of this PEA.

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CHAPTER IV: TECHNOLOGICAL FEASIBILITY

METHODOLOGY

Data Sources

Defining “Silica” Data

This technological feasibility analysis covers respirable crystalline silica, hereinafter termed “silica.” Unless specifically indicated otherwise, all silica exposure data, samples, and results discussed in this technological feasibility analysis refer to measurements of personal breathing zone (PBZ) respirable crystalline silica. The term “respirable crystalline silica” is used as defined in the proposed rule (see “Definitions”).

Polymorphs of Crystalline Silica in Air Samples

Silica occurs in multiple forms (polymorphs). OSHA is proposing the same permissible exposure limits (PELs) for all three of the major polymorphs of crystalline silica (quartz, cristobalite, and tridymite). On the rare occasions when more than one form of silica was present in the results available to OSHA, the concentrations of the detected forms were added together.

The vast majority of crystalline silica encountered by workers in the United States is in the quartz form, to such an extent that investigators often use the two terms (crystalline silica and quartz) interchangeably. Nevertheless, the data available to OSHA contain a few samples in which detectable levels of cristobalite were reported, either alone or in addition to quartz. These results, when discussed individually, are specifically identified as including detectable cristobalite. Tridymite was not reported as a component of silica samples available to OSHA.

The exposure profiles and technological feasibility analysis are based on silica results (i.e., PBZ respirable crystalline silica). However, this report also occasionally discusses the results of other types of samples, including area samples and respirable dust samples, when these values contribute information on the effectiveness of engineering controls. In each case where a sample result is other than PBZ respirable crystalline silica, the sample type or analyte is clearly identified to avoid confusion with silica results.

Sources of Silica in Workplace Air Samples

The silica content of materials used or processed in the workplace influences the level of airborne silica. Silica is a natural component of sand, rock, clay, and other mineral products. The amount of silica in these natural materials varies from location to location.

Silica is also a component of man-made materials produced with these mineral products. The silica content of man-made materials also varies based on the silica content of the minerals incorporated. For example, concrete (made with cement, sand, and rock aggregate) contains crystalline silica from the sand and also from the rock aggregate. The percentage of silica in concrete varies by the amount of sand in the specific formulation and the type of rock used as the aggregate. The percentage of silica in bricks, tiles, pottery, stone products, refractory materials, paints, enamels, and asphalt also varies for similar reasons.

OSHA recognizes that the silica content of rock varies greatly, based on the type of rock and the geographic area. The quantity of silica in rocks in the Earth is not something over which construction contractors have control. In contrast, the amount of silica in purchased rock and mineral products (e.g., obtained from the mining industry or other sources) for use in construction or general industry can be determined and potentially controlled through product selection.

Updated Contractor Reports

For this technological feasibility analysis, OSHA has primarily relied on reports developed by OSHA's contractor Eastern Research Group, Inc. (ERG). ERG initially acquired silica exposure data and related information between 1999 and 2002 using literature search and retrieval processes; records provided by OSHA; and communications with representatives of the National Institute for Occupational Safety and Health (NIOSH), state agencies, identified industries, and other groups.

ERG analyzed the available data using the methods described below and produced reports in 2003 on general industry and construction. These reports were reviewed that same year by a panel convened under the Small Business Regulatory Enforcement Fairness Act (SBREFA) and were entered in the associated silica rulemaking docket.[42]

In 2008, ERG produced updated reports on construction and general industry (ERG-C, 2008; ERG-GI, 2008). OSHA has independently reviewed ERG's *Technological Feasibility Study of Regulatory Alternatives for a Proposed Crystalline Silica Standard for Construction* (ERG-C, 2008) and *Technological Feasibility Study of Regulatory Alternatives for a Proposed Crystalline Silica Standard for General Industry* (ERG-GI, 2008), which review the literature, available worker exposure data, and exposure controls for affected industries. In general, OSHA finds the logic and methodology of these studies to be sound, the data complete to the extent available, and the analysis compelling. Unless otherwise noted here, OSHA concurs with ERG's findings.

OSHA's present technological feasibility analysis is primarily based on information presented in ERG-C (2008) and ERG-GI (2008). Where additional data and information are available from sources not previously evaluated by ERG, OSHA has considered and referenced them as updates in the present analysis.

Sources of Data

This technological feasibility analysis relies on information from a wide variety of sources available to OSHA and reviewed in ERG's reports (ERG-GI, 2008; ERG-C, 2008):

- Published literature.
- OSHA silica Special Emphasis Program (SEP) inspection reports.[43]

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[42] ERG's *Cost and Economic Impact Analysis of the Draft Crystalline Silica Standard for General Industry* (September 23, 2003) appears in the docket as OSHA-H006A-2006-0800-0020, while ERG's *Technological Feasibility Study and Cost and Impact Analysis of the Draft Crystalline Silica Standard for Construction* (August 19, 2003) appears as exhibit OSHA-H006A-2006-0800-0002.

[43] The OSHA SEP inspection reports, provided by OSHA area offices, primarily include files closed between 1994 and 1999 that were identified as containing silica sample results. Two additional reports, provided as

- NIOSH reports, including health hazard evaluations [HHE], control technology [CT] assessments, in-depth surveys, recommendations for exposure control, and engineering control feasibility studies.
- Workplace evaluation reports related to programs on "sentinel event notification system for occupational risks" (SENSOR) for silica from the states of Michigan, New Jersey, and Ohio.[44]
- ERG and OSHA site visits.
- Unpublished information (e.g., unpublished data and research obtained through personal communications, meetings, and presentations).
- Information available from other federal agencies, state agencies, labor organizations, industry associations, and other groups.

ERG also obtained OSHA Integrated Management Information System (IMIS) data from 1979 through mid-2002, which were used primarily to identify the industries initially considered for inclusion in this technological feasibility analysis.[45]

ERG contractor reports primarily relied on information sources published from 1990 through 2001, updated with some information through 2007. In a few cases, where sources more recent than 1990 were limited and earlier information existed, information from the 1980s was used. Some sources of exposure data span several years, or even decades, and provide valuable insight into how exposure levels change as processes and controls are upgraded.

As noted above, OSHA has primarily relied on the contractor reports, ERG-C (2008) and ERG-GI (2008); however, OSHA has considered and referenced additional material where available.

The exposure profiles only include silica exposure data for workers in the United States. Information on international exposure levels is occasionally offered for perspective or in discussion of control options.

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separate supplemental submissions, were closed in 2001 (OSHA SEP inspection Report 303207518, discussed in Section IV.C.8 – Foundries) and in 2007 (OSHA SEP Inspection Report 311079172 discussed in Section IV.C.7 – Engineered Stone Products).

[44] ERG assigned these reports case file numbers beginning with "ERG #" and followed by the prefix MI-, NJ-, or OH- and a unique 4-digit number [e.g., ERG #MI-1485]; the reports are cited under these designations.

[45] ERG obtained records for IMIS data for the period May 1, 1979, through April 29, 1998, supplemented by an update in 2002 containing data from January 1, 1998, through May 1, 2002. To ensure that the silica records were interpreted correctly, ERG took steps to check records for conditions that indicated apparent inconsistencies within the record or for which the presence of silica could not be confirmed in the work area. Regardless of the hazard being evaluated, this type of examination is conducted as a first step in detailed data analysis as a means of overcoming inherent limitations of the IMIS database (Linch et al., 1998; Middendorf, 2004). Although a sizable and valuable database, Yassin et al. (2005) point out some of the inherent limitations of IMIS data for analysis beyond the level of a general overview.

Notes on Data Sources and Characteristics

Integrated Management Information System Limitations

For purposes of this analysis, the documentation for individual results in OSHA's IMIS data (1979 through mid-2002) is incomplete. The IMIS record reports the Standard Industrial Classification (SIC), but not the product formed, action performed, or materials used. Furthermore, the IMIS does not include information on the sample duration; thus it was not possible to confirm whether samples were obtained over 60 minutes or 360 minutes or 480 minutes of the worker's shift (or any other time period). The IMIS record reports the worker's job title (a free text field subject to infinite variability, and therefore difficult to sort into job categories), but not the worker's actual activities during the sampling period or the presence of exposure controls.

As intended, the IMIS system is useful as a management tool for observing trends and identifying industries in which exposures occur. However, for the detailed industry-by-industry technological feasibility analyses, more completely documented data sources were used. Industry sector exposure profiles also were based on other sources, if available.

OSHA Special Emphasis Program Inspection Reports

OSHA silica SEP inspection reports contain silica exposure data that were also entered in the IMIS system. However, in contrast to the IMIS data, these reports include substantial additional information about worker activities, air sampling methods, and silica results, including the compliance safety and health officer's (CSHO's) notes on working conditions, sample duration, and in some cases post-abatement follow-up results. OSHA relied heavily on information from the 191 OSHA SEP inspection reports referenced in the contractor reports (ERG-C, 2008; ERG-GI, 2008).

Limits of Detection for Silica Data

Investigators performing data analysis usually follow the common practice of assigning a value to samples with concentrations reported as "none detected" (sometimes designated as "ND"). The assigned value is typically related to the reported limit of detection (LOD) and permits the investigator to account for these sample results in quantitative analysis, such as when calculating the mean and median.

The LOD indicates the smallest quantity of crystalline silica that can be detected. This practical limitation of the laboratory analysis (procedures and analytical equipment) is typically a fixed value for each analytical method. The silica LOD can be presented in two formats: as the analytical method LOD, which refers to the smallest mass of silica, in micrograms (µg), that can be detected on the filter; or as the concentration LOD, which refers to a calculated value representing the smallest airborne concentration, in µg/cubic meter (m^3) of air, that can be detected.

Results below the limit of quantitation (LOQ) are those in which silica was detected, but not in sufficient quantity to offer an accurate analytical result (this range is sometimes reported non-quantitatively as "trace"). Like the LOD, the LOQ is a function of the laboratory analytical method. OSHA handled results reported as below the LOQ in the same manner as LOD values were handled (e.g., by assigning the reported value of the LOQ to results reported as the LOQ).

The silica analytical method LOD is presented as the number of µg of silica that can be detected on an individual filter used to collect an air sample. For example, OSHA's crystalline silica analytical method (ID-142) has a reported LOD value of 10 µg. If dust on a filter contains less than 10 µg of silica, the analytical process will not be able to measure it. The laboratory technician cannot tell whether the filter holds no silica at all, or if it bears some small amount between 0 µg and the LOD of 10 µg. The only certainty is that the amount of silica on that filter is less than the LOD. Although historically other LODs have been published for other silica analytical methods (NIOSH-1994-7500, 1994), most laboratories currently report an LOD of 10 µg or lower for quartz samples (ERG-LOD, 2009). When a laboratory finds that the mass of silica on a filter is not detectable, the laboratory report will generally indicate that the mass is "less than 10 µg" (<10 µg). In some instances laboratories will not analyze filters that bear such a small amount of respirable dust that the dust level cannot be accurately quantified (regardless of the amount of silica in that dust) or if the dust level was so low that it was not important to measure silica for the purposes of the particular air sampling effort. The results of these samples are also typically reported as not detectable. Silica reporting methods for many sources do not differentiate between results for which the dust level or the silica amount was below the LOD.

When a laboratory reports that the gravimetric result[46] is not detectable because there is not enough silica on the sample filter, the analytical LOD is used to represent the silica mass in the concentration calculation. The concentration LOD is calculated by dividing the analytical LOD by the volume of air sampled (measured in cubic meters). For example, if the analytical LOD is 10 µg and the air volume sampled is 816 liters (0.816 m^3), the concentration LOD would be calculated as 10 µg/0.816 m^3 or about 12 µg/m^3 (see Table IV.A-1 for examples of the concentration LOD for silica results analyzed using a method with an analytical LOD of 10 µg).

The resulting concentration LOD indicates the minimum concentration of airborne silica that could have been detected. Because silica was not detected, the true airborne concentration is less than the concentration LOD. These LODs vary depending on the volume of air sampled. For respirable dust samples obtained with a nylon cyclone at 1.7 liters per minute (lpm), a shorter sampling period will always result in a smaller volume of air that is sampled. Thus, a sample collected over a short period will result in a higher LOD than a sample collected over a longer period of time. Two results obtained on the same date at the same location, but involving different volumes of sampled air, will have different LODs.

Practical examples of the concentration LOD for silica results analyzed using a method with an analytical LOD of 10 µg appear in Table IV.A-1.

Table IV.A-1
LOD Practical Examples of Concentration LODs for Silica Results Obtained Using a Method With an Analytical LOD of 10 µg

Sample Duration*	Air Volume Sampled	Calculated Concentration LOD
480 minutes (8 hours)	816 Liters (0.816 m^3)	12 µg/m^3
360 minutes (6 hours)	612 Liters (0.612 m^3)	16 µg/m^3
180 minutes (3 hours)	306 Liters (0.306 m^3)	32 µg/m^3
30 minutes (½ hour)	51 Liters (0.051 m^3)	196 µg/m^3

* Also assumes that the air sample was obtained at 1.7 lpm, the rate used for a standard nylon cyclone.

Several different approaches are available for assigning a value to sample results below the LOD (e.g., assigning a value of one-half the LOD concentration, assigning the unmodified LOD concentration value) (Flanagan et al., 2006; Hornung and Reed, 1990; NIOSH ECTB 233-101c, 1999; Succop et al., 2004). For the purposes of this analysis, OSHA elected to use the unmodified LOD concentration value in

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[46] A "gravimetric" result is defined as a measurement of weight or mass (e.g., micrograms).

order to be as protective as possible.[47] This probably results in a slight overestimation of exposure levels; the true concentration is some unknown level between zero and the LOD.

For example, in exposure profile mean, median, and low-range calculations, OSHA assigns the value 12 μg/m^3 to a result that is less than an LOD of 12 μg/m^3. Furthermore, a value of 16 μg/m^3 is assigned for a smaller air volume sample with a result less than an LOD of 16 μg/m^3. If no LOD was provided for the results and sufficient supporting information was available, OSHA estimated the LOD. When discussing individual airborne concentration results for worker breathing zone samples in which silica was not detected, OSHA typically includes a note (e.g., "LOD") indicating that the reported value (e.g., 12 μg/m^3) is based on a calculated concentration LOD.

By using full-shift results (defined for purposes of this analysis as having a duration of 360 minutes or greater) for general industry, OSHA minimizes the number of results that are less than the LOD. Specifically, the LOD is never greater than 16 μg/m^3 for general industry sample results included in the exposure profiles.

In the construction industry, where task-based sampling is sometimes the most practical option, OSHA has limited the use of short-term samples with results below the LOD when the LOD is unreasonably high (e.g., results were usually excluded when the LOD was above the proposed PEL of 50 μg/m^3), instead giving preference to data covering a greater part of the workers' shifts. As a result, the values assigned to results below the LOD have only a limited impact on the economic and technological feasibility decisions based on this analysis.

Methods to Assess Feasibility of Control Technology

Feasibility of Control Technology

This analysis is based on published literature; documents from sources such as NIOSH, trade and industry organizations, and state health departments; IMIS data for respirable crystalline silica from 1979 through mid-2002; OSHA SEP inspection reports for establishments in which silica samples had been obtained as part of the inspection; information from industry representatives on typical workplace processes, job categories, available controls, and exposure data; and site visits conducted by ERG.

The IMIS data was evaluated to identify industries in which crystalline silica had frequently been sampled during OSHA inspections and in which analytical results frequently showed detectable airborne silica in the workplace. Based on these results and information from the available literature, a preliminary list of industries to be included in the technological feasibility analysis was developed. The list was adjusted as information warranted, and a list of affected job categories with notable exposure to silica was developed for each industry.

Silica exposure data for each job category in each industry were identified in the retrieved literature and other information sources.[48] These results formed the basis for the initial exposure profiles, which were presented along with process descriptions and methods of exposure control in two contractor

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[47] For example consider a "none detected" silica sample result obtained over a 360-minute period, at an air flow rate of 1.7 liters per minute (lpm), and analyzed using a method with a 10 μg LOD. The laboratory will report the result as ND (i.e., below the LOD). OSHA would assign to that sample result the unmodified value of the concentration LOD, in this case 16 μg/m^3 (see text and Table IV.A-1). In contrast, Flanagan et al. (2006) assign non-detect samples a value of one-half of the concentration LOD and so would assign to this particular sample result a value of 8 μg/m^3. Both LOD values are well below 25 μg/m^3, and so the value assigned to the 360-minute sample will not affect the distribution of the results in the exposure profile and is unlikely to affect the median value.

reports: *Cost and Economic Impact Analysis of the Draft Crystalline Silica Standard for General Industry* (September 23, 2003, available in the silica docket as OSHA0H006A-2006-0800-0020) and *Technological Feasibility Study and Cost and Impact Analysis of the Draft Crystalline Silica Standard for Construction* (dated August 19, 2003, and available as OSHA-H006A-2006-0800-0002).

Subsequently, updated contractor documents were made available in 2008 (ERG-C, 2008; ERG-GI, 2008). These revised reports included minor adjustments of the technological feasibility analyses, considered additional possible PELs (e.g., 75 µg/m^3), expanded information on certain industries (engineered stone), and incorporated some more recent information on silica exposure control methods. The 2008 documents made little change to the exposure data presented in the 2003 documents.

For the present technological feasibility analysis, OSHA has relied on the contractor reports (ERG-C, 2008; ERG-GI, 2008) and has included the same industries and job categories addressed in those documents. OSHA conducted a literature search covering the period 1999 to 2009 to identify more recent materials. Where additional information is available, OSHA has incorporated it into the current analysis. The present exposure profiles contain additional data as indicated in the discussion of individual industry sectors. Industries included in this analysis are those identified as having substantial potential for respirable crystalline silica.

OSHA recognizes that the available data unequally represent facilities at which more samples were collected and seeks additional information to further define the distribution of worker exposure in these industries.

Sector Analysis for General Industry and Maritime

The technological feasibility analyses for general industry and maritime workplaces are grouped by industry sector. Within each industry sector, data are further divided into general job categories representing groups of workers with common trends in materials, work processes, equipment, and available exposure control methods. OSHA notes that these job categories are intended to represent job functions; actual job titles and responsibilities might differ depending on the facility. OSHA recognizes that many other job categories exist in these industries, but those job categories are not associated with substantial direct silica exposure and are not included in the analyses.

OSHA seeks additional information that will help identify other job categories that should be addressed in the final rule.

Activity Analysis for Construction Industry

OSHA has preliminarily determined that the best method for analyzing the construction industry is to group workers by construction activity (e.g., workers sawing, drilling, crushing rock). In other grouping strategies, construction workers are categorized either in jobs related to a construction phase or material (e.g., concrete workers, demolition workers) that often encompass many different dusty activities, or that are grouped under a broad title (e.g., “laborer”), which is insufficiently specific to permit meaningful evaluation for the purposes of this technological feasibility analysis. By discussing individual construction industry activities, OSHA can apply the exposure profile and exposure control methods for these activities to workers who perform these activities in any segment of the construction industry.

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[48] An underlying assumption is that available data represent exposures of workers across the nation, regardless of whether results come from a few facilities or facilities that were sampled multiple times (e.g., before and after modifications). Furthermore, results from before facility upgrades represent worker exposure levels under similar conditions at facilities that have not yet been upgraded to that extent.

OSHA would like to receive information that will help identify other construction activities that should be addressed in the final rule.

Data Handling for General Industry and Shipyard Employment

All results in the general industry and shipyard employment exposure profiles are 8-hour time-weighted average (TWA) PBZ samples collected over periods of 360 minutes or more (for the purposes of this analysis, defined as “full-shift”). To determine an 8-hour TWA, the exposure level for the period sampled is assumed to have continued over any unsampled portion of the shift. OSHA has preliminarily determined that this sample criterion is valid because workers in general industry are likely to work at the same general task or same repeating set of tasks over most of their shift; thus unsampled periods generally are likely to be similar to the sampled periods.

By setting a minimum sampling period criterion of 6 hours, ERG and OSHA ensured that every sample included in the analysis encompasses at least three-quarters of a typical 8-hour shift and probably captures most activities at which the worker spends a substantial amount of time (NIOSH-77-173, 1977). If activities differ during the initial and final portions of the shift, the activities are more likely to involve processes required for initial setup and shutting down, which should contribute less to workers’ silica exposure. OSHA believes the 6-hour (360-minute) minimum sampling requirement limits the extent of uncertainty about workers’ true exposure, as no more than 25 percent of an 8-hour shift would be unsampled.

The minimum sampling period also eliminates the ambiguity associated with the LOD for low air volume samples. As noted previously in the discussion of LODs, using a common sampling method for respirable silica (i.e., using a nylon cyclone operated at 1.7 lpm), an LOD less than 25 μg/m^3 will always be achieved if the sample was obtained for at least 360 minutes. This permits results that are reported in the original data source as below the LOD to be included without contributing substantial uncertainty regarding their relationship to the proposed PEL. This is particularly important for general industry samples, which on average have lower silica levels than typical results for many tasks in the construction industry. At silica concentrations found in many industrial work sites, the smaller air volume obtained using typical methods during a shorter sample period did not collect sufficient silica to result in a reading above the LOD. At the same time, the LOD for these shorter duration sample would be higher than it is for a 6-hour sample. Using an extreme example, a result of “none detected” for a 30-minute sample (obtained at 1.7 lpm) would have an LOD of 196 μg/m^3. The assigned LOD-based value for that sample would indicate only that the true value was somewhere between 0 and 196 μg/m^3, a range too large to be meaningful to OSHA’s analysis concerning a proposed PEL of 50 μg/m^3. By relying on 6-hour samples for the exposure profile, OSHA eliminates this ambiguity.

Data obtained in the shipyard employment industry have been handled in the same manner as data for general industry.

Data Handling for the Construction Industry

Construction workers perform variable combinations of tasks that generate silica dust. They also perform these tasks for varying amounts of time, depending on the job. Many workers only occasionally perform one of the construction industry tasks discussed in this technological feasibility analysis, or they perform the task daily, but for only a portion of the shift. Other workers spend the entire shift intermittently performing the same task or a mix of several of these dusty tasks. A few construction workers perform tasks that frequently continue uninterrupted over an entire work shift (e.g., heavy equipment operator). However, like most construction workers, these workers often spend a portion of the shift in transit between job sites, setting up or preparing to depart a site, or idle while waiting for another construction trade to complete an activity.

The data that OSHA incorporated into the exposure profiles reflect real construction site working conditions. The data set contains results from both shorter duration task-based samples (providing that the sample value was not based on a high LOD)[49] and extended period sampling, including results obtained over entire 8-hour work shifts. Furthermore, a portion of the sample results available to OSHA cover periods when the workers performed multiple activities, sometimes involving more than one of the tasks analyzed here by OSHA.[50]

Because the duration of the sampled exposure varies widely within this construction industry data set, OSHA has standardized the exposure levels to 8-hour TWA concentrations. In general, these 8-hour TWAs were calculated using an approach that assumes that the sampled period encompassed the majority of the workers' silica exposure, with no notable additional exposure during any unsampled portion of the shift.[51, 52] OSHA considers this approach the best of the available options for several reasons. The 8-hour TWAs calculated in this manner would most closely reflect the silica exposure of workers under the greatest range of the working conditions described above.

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[49] The vast majority of the task-based samples that OSHA used for the construction industry exposure profile have a duration of at least 2 hours. Shorter duration samples with limits of detection above the range of OSHA's interest were excluded from this analysis when no silica was detected in the sample. As discussed for a previous example, a result of "none detected" for a shorter 30-minute sample (obtained at 1.7 lpm) would have an LOD of 196 μg/m^3, too large to be meaningful to OSHA's analysis concerning a proposed PEL of 50 μg/m^3. A "none detected" result based on an LOD such as this would have been excluded from the construction industry analysis. However, because elevated silica exposure is prevalent in the construction industry, silica was detected in most of the available task-based exposure results available to OSHA.

[50] For the purposes of this analysis, any sample collected over a period when the worker performed multiple activities was assigned to the specific construction task judged likely to have had the greatest influence on the worker's silica exposure level.

[51] The alternative approach (used for general industry samples of at least 6 hours duration, as discussed previously) assumes that the exposure level during any unsampled period is the same as during the sampled period. That method is not appropriate for task-based samples, since the task in question generally is not continued for the entire shift.

[52] An exception to this approach was made in cases where information associated with an exposure result clearly stated that the same exposure continued for the entire shift (although only a portion of the shift was sampled). OSHA respected the judgment of the investigator who obtained the sample and calculated the 8-hour TWA assuming that exposure continued at the same concentration over any unsampled portion of the shift. Furthermore, when information provided with a sample indicated that the shift was greater than 8 hours, the 8-hour TWA was adjusted according to the notes of the investigator who collected the sample.

For example, when adjusted in this manner, the task-based samples (both of short and long duration) would accurately represent the exposure of workers who performed the task for a portion of their shift, with little or no additional silica exposure. Other samples that encompass most, or all, of a work shift represent the exposure of workers who perform the task (either constantly or intermittently) over the course of the whole shift. Because the sampling period covers most of the shift, the calculated 8-hour TWA is not substantially affected by the assumption that no exposure occurred during any unsampled portion of the work shift.

When workers performed multiple activities during the sampling period, the results provide the average silica level from all sources of exposure experienced by the worker during that period. The 8-hour TWAs for these multi-task samples are calculated using the same method used for individual task-based samples.

OSHA acknowledges that this approach is likely to result in some underestimates of exposure and requests comment on whether this approach or another one should be used.[53]

Respirable Dust Properties and Use in Evaluating Control Options

Respirable crystalline silica particles usually make up only a portion of the respirable dust in a worker’s breathing zone. The remainder of the respirable dust is typically composed of other minerals and other fine particles in the workplace air. Silica and all other components of respirable dust are typically separated from particles of other sizes based on aerodynamic properties. The use of size-selective samplers for respirable dust particles means that the collected particles all have similar aerodynamic properties: they behave similarly in an air stream. Based on this principle, OSHA preliminarily concludes that the results of ventilation control measures tested by evaluating capture of airborne respirable dust particles will be equally applicable to the respirable silica component of a respirable dust.

In addition, OSHA finds that there is considerable evidence that water spray droplet size is a primary factor in the efficiency of water sprays used to control dust. The most effective spray uses a droplet size similar to the size particles that the spray is intended to control (Spray Systems, no date). Therefore, OSHA preliminarily concludes that studies of wet dust control methods applied to respirable dust will be similarly applicable to the silica portion of respirable dust.[54]

Use of Surrogate Data

In some cases, when exposure information from a specific job category is not available, OSHA has based that portion of the exposure profile on surrogate data from one or more similar job categories in related industries. The “surrogate” data are selected based on strong similarities between raw materials (e.g., source of silica, percent silica, particle size), equipment, worker activities, and exposure duration in the job categories. Although other factors differentiate the industries, the individual job categories were determined to be sufficiently similar. When used, OSHA has clearly identified the surrogate data and the relationship between the industries or job categories.

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[53] As noted previously, other uncertainties, such as assigning the unmodified LOD to “none detected” results, contribute to an overestimation of exposure.

[54] This statement applies regardless of whether the water is applied as a spray or as a stream that generates a spray or mist through tool action, as is the case for water-fed abrasive saws (e.g., saws used in the stone products industry or as stationary masonry saws in the construction industry).

Use of Short-Term Sampling Results

The exposure profiles in this technological feasibility analysis do not include short-term exposure concentrations, for reasons described above. However, short-term samples can provide important information about the effectiveness of controls. Short-term samples also permit multiple trials of controlled and uncontrolled activities. In studies of this nature, investigators measure intensive periods of an activity (such as concrete sawing), without pauses in the process or supplemental activities that can complicate comparisons of airborne dust during controlled and uncontrolled conditions. Results of brief samples, even just a few minutes in duration, can provide useful comparative information, and OSHA considers these experimental results in the discussion of additional controls for specific groups of workers.

Disclaimer

References to specific commercial products or manufacturers in this technological feasibility analysis are included for reference or informational purposes only, and do not constitute endorsements by OSHA of such products or manufacturers.

Technological Feasibility Analyses

The remainder of this analysis addresses the technological feasibility of monitoring silica exposure levels, and the technological feasibility of controlling exposures to or below the proposed PEL in general industry, shipyard employment, and the construction industry.

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FEASIBILITY OF MEASURING RESPIRABLE CRYSTALLINE SILICA EXPOSURES AT THE PROPOSED PEL AND ACTION LEVEL (Revised March 27, 2013)

As part of OSHA's assessment of the technological feasibility of a new or revised chemical standard, the Agency must determine whether available methods for measuring worker exposures have sufficient sensitivity and precision to ensure that employers can reliably evaluate compliance with the standard and that workers have a reasonably accurate assessment of their exposure to hazardous chemicals. Over the years, respirable crystalline silica has been measured in a variety of ways, with early methods (i.e., pre-1970) based on counting concentrations of particles in the air and later methods relying on gravimetric analysis to measure the mass of total dust or respirable dust in the air. Both particle count and gravimetric dust measurements were combined with analysis of the crystalline silica content of bulk material, such as settled dust, to arrive at estimates of worker exposure to airborne respirable silica dust. Many of these early methods are described more completely in OSHA's review of the health effects literature since epidemiologic studies relied on exposure data obtained from these early techniques. These early strategies for assessing exposures are in fact reflected in the current OSHA permissible exposure limits (PELs) for quartz, adopted from the 1968 American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs), which are formulas that incorporate the concentration, either by mass or particle count, of respirable dust in the air with the percent silica content of the dust present in the workplace.

Since the late 1960s, exposures to respirable crystalline silica have been typically measured by using personal respirable dust samplers coupled with laboratory analysis of the crystalline silica content of the collected airborne dust. The laboratory analysis is usually performed using X-ray diffraction (XRD) or infrared spectroscopy (IR) analysis of the dust that was collected using a personal sampler, although a colorimetric method of analysis is used by a few laboratories. OSHA has successfully used XRD analysis since the early 1970s to enforce its PELs for crystalline silica, which, for general industry, are approximately equivalent to 100 micrograms per cubic meter ($\mu g/m^3$) for quartz and 50 $\mu g/m^3$ for cristobalite and tridymite.

OSHA is proposing to revise its current formula PELs for all covered forms of respirable crystalline silica to 50 $\mu g/m^3$. This represents essentially no change in the general industry exposure limits for cristobalite and tridymite, and reduces the current general industry PEL for quartz, the most prevalent form of crystalline silica, by about half. The proposed PEL is approximately one fifth of the current construction PEL. OSHA is also proposing an action level of 25 $\mu g/m^3$ to trigger additional exposure monitoring. In this section of OSHA's technological feasibility analysis, OSHA presents information on the capabilities of existing sampling and analytical methods to reliably measure occupational exposures to respirable crystalline silica at the proposed PEL and action level. Information on respirable dust sampling devices is presented first, followed by a discussion of the available analytical techniques, and then by a discussion of the sensitivity and precision of the available analytical techniques for detecting crystalline silica concentrations in the range of the proposed PEL and action level. Based on OSHA's analysis of this information, the Agency preliminarily concludes that it is feasible to measure respirable crystalline silica exposures at the proposed PEL of 50 µg/m^3 with a reasonable degree of accuracy and precision. Although the variability in measurements of exposures at the proposed action level of 25 µg/m^3 is higher than that for the proposed PEL, OSHA preliminarily concludes that measurement of exposures at the proposed action level is sufficiently precise to permit employers to adequately determine when additional exposure monitoring is necessary under the standard.

Background

The three types of crystalline silica covered under the proposed standard (i.e., quartz, cristobalite and tridymite) are members of the larger class of minerals known as silicates, which includes many different mineral species that are related to each other by their structure and chemistry. Together, the silicate minerals are among the most common minerals found in the Earth's crust. A silicate mineral is composed of the substance silica, an oxide of silicon, and one or more positively charged metal ions that are bonded to the silicon and oxygen atoms of silica. The silicon and oxygen atoms are arranged in a tetrahedral structure with one silicon atom bonded to four oxygen atoms. The oxygen atoms are bonded to the silicon atoms in adjacent tetrahedral groups resulting in a large-scale ratio of one atom of silicon to two atoms of oxygen; this structure is chemically expressed using the molecular formula SiO_2.

Silica exists in both non-crystalline and crystalline forms. The non-crystalline forms of silica are amorphous with unorganized, randomly arranged silica tetrahedra that are not bonded in a three-dimensional repeating pattern. The non-crystalline forms of silica include natural and manufactured glasses (quartz glass, vitreous silica, and fused silica), biogenic and abiogenic silica, and opals, the latter of which are amorphous silica hydrates.

The crystalline forms of silica include several polymorphs. The term *polymorphic* as applied to crystalline silica describes the different minerals formed when silica tetrahedra combine together to create different three-dimensional crystalline structures. The primary polymorphic forms of crystalline silica that historically have been the subject of occupational exposure standards are quartz, cristobalite, and tridymite. Naturally formed quartz is the most prevalent form of crystalline silica found in the workplace. Most rocks and soils contain at least trace amounts of quartz. Quartz is also present in sand, mortar, concrete, fluxes, abrasives, aggregate, porcelain, paints, and bricks. It is used to manufacture many products including glass and ceramics. It is also used as filler in paper, paints, epoxies, cosmetics, and pharmaceuticals. Cristobalite is found less frequently in the workplace than quartz. Diatomaceous Earth that has been flux-calcined (heated, usually in the presence of sodium carbonate) can contain a substantial amount of cristobalite. Quartz can be converted to cristobalite when subjected to prolonged high temperature such as happens to quartz in brick that is used to line ovens or furnaces. Volcanic eruptions can release cristobalite-containing dust into the air. Tridymite is rarely found in nature or in the workplace. There are other forms of crystalline silica that are extremely rare such as synthetic keatite, meteor-impact-related coesite and stishovite, and morganite.

The names and terms used when discussing crystalline silica are often used interchangeably and without reference, which might result in confusion when the context is unknown or unclear. The term *silica* applies to materials that are comprised of silicon atoms bonded to four oxygen atoms in such a way as to form tetrahedra. It applies to both crystalline and non-crystalline forms. However, it is often used to refer to quartz alone or any or all of the crystalline silica minerals collectively. The term *free silica* is most often used to refer to quartz, but might, in context, refer to any or all of the crystalline silica minerals. The term *crystalline silica* applies to any silica mineral that has a crystalline structure, meaning that the silica tetrahedra are arranged in a long-range regular array. These are known as *framework silicates*. While there are many different minerals in this group, for the purposes of this OSHA standard, the term *crystalline silica* refers collectively to quartz, cristobalite, and tridymite. Note that in general discussion and often in the literature, the terms *silica*, *free silica*, or *crystalline silica* are commonly used to refer only to quartz because quartz is the most common silica mineral in the workplace. It is important to understand the context wherever possible so as to avoid confusion or over-generalization. To reiterate, OSHA uses the term *crystalline silica* to refer to the regulated crystalline minerals, quartz, cristobalite, and tridymite.

Crystalline silica is often only one component of the airborne dust collected during exposure measurements taken in work environments. Samples of industrial air might contain other silicates that, because of the similarity of their molecular structure to that of regulated crystalline silica, become a potential source of interference when analyzing dust samples for the crystalline silica content. When analyzing respirable dust samples, the crystalline silica content of the dust must be determined to assess the severity of the health hazard. This requires sensitive and accurate sampling and analytical methods to detect and quantify crystalline silica in the presence of other types of dust.

Particle Size-Selective Sampling

Measurement of respirable dusts requires the separation of particles by size to assess exposures to the respirable fraction of airborne dusts. Respirable dust standards and sampling equipment have been developed on the basis of separating the larger particles from the smaller particles in a manner that simulates the size-selective characteristics of the human's upper airways. This allows for the collection of dust samples that only contain particles that are small enough to penetrate deep into the lung (Raabe and Stuart, 1999). Size-selective samplers do not actually model the deposition of respirable particles in the lung, but instead provide a measure of the particulate mass *available* for deposition to the deep lung during breathing (Raabe and Stuart, 1999).

For purposes of assessing exposures to respirable dust, the respirable fraction of airborne dust is defined based on the particle size collection efficiency model of the lung. A variety of different industrial hygiene sampling devices, such as cyclones and elutriators, have been developed to separate the respirable fraction of airborne dust from the non-respirable fraction. Cyclones are the most commonly used size-selective sampling devices, or "samplers," for collecting personal exposure measurements to respirable dusts, such as crystalline silica. The current OSHA (ID-142 revised December 1996), NIOSH (7500, 7601, 7602), and Mine Safety and Health Administration (MSHA) (P-2 and P-7) methods for crystalline silica all specify the use of cyclones (OSHA ID-142, 1996; NIOSH 03-127-7500, 2003; NIOSH 03-127-7601, 2003; NIOSH 03-127-7602, 2003; MSHA P-2, 1999; P-7, 1994).

Principle of Operation

Many commercially available cyclone samplers employ a vortical flow of air inside a cylindrical or conical chamber. They function according to the principle that the rapid circulation of air separates particles according to their aerodynamic diameter. As air enters a cyclone, the larger particles are centrifugally separated and fall into a grit pot, while the smaller particles pass into a sampling cassette, where they are captured by a filter membrane that can later be analyzed in a laboratory to determine the mass of respirable dust collected (Figure IV.B-1). More specifically, air enters an inlet near the top of the cyclone, creating a double vortex flow within the cyclone body. The flow spirals down the outer portion of the chamber and then reverses and spirals up the inner core to the exit tube (Blachman and Lippmann, 1974; Hering, 2001). Larger particles, which have higher inertia than do smaller particles, do not follow the air streamlines, and impact the cyclone walls and fall into the grit pot. With the proper airflow through the cyclone, virtually all particles having aerodynamic diameters greater than 10 µm (i.e., non-respirable particles) cannot stay within the vortex but contact the sides of the cyclone and fall out through the bottom. Conversely, virtually all particles less than 1 µm in diameter are able to follow the airstream and deposit on the filter. Particles with diameters between 1 and 10 µm will follow the airstream and be collected on the filter in decreasing proportion to their size. Thus, as the aerodynamic diameter of particles increases, the mass fraction of a given size of particles that can deposit on the filter decreases.

Another property of cyclones is that they are very sensitive to flow rate. As the flow rate is increased, a greater percentage of larger and higher-mass particles are removed from the airstream, and smaller particles are collected with greater efficiency, changing the particle collection characteristics of the sampler. Therefore, precise calibration of the sampling pump and maintenance of proper flow rate during the sampling period is an essential element of industrial hygiene sampling protocol.

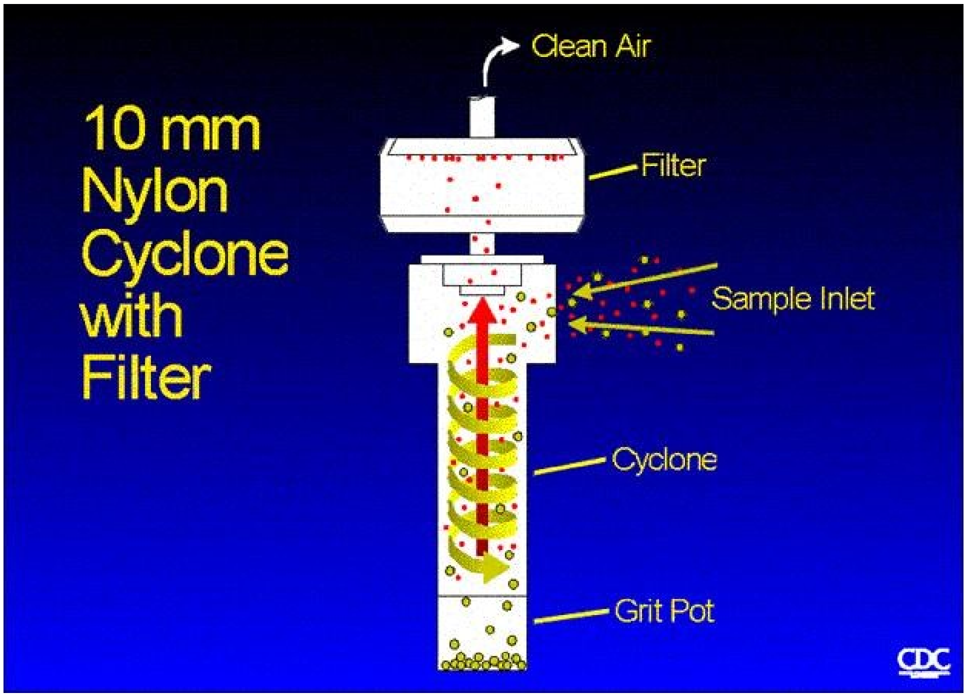

Figure IV.B-1: Schematic Cyclone Assembly

Cyclones are small enough in size to allow for the collection of breathing zone samples. During the sampling period, the cyclone-cassette assembly is attached as close to the worker's breathing zone as possible, normally to the worker's collar. A pump is attached to the cyclone with flexible connective tubing. The pump draws air into the cyclone and is typically clipped to the worker's belt. After the sampling period is over, the cassette is removed, sealed, and sent to a laboratory for analysis.

Particle Size Selection Criteria for Respirable Dust Samplers

Although respirable dust commonly refers to dust particles having an aerodynamic diameter of 10 µm or less, it is more precisely defined by the collection efficiency of the respiratory system as described by a collection efficiency model. These are often depicted by particle collection efficiency curves that describe, for each particle size range, the mass fraction of particles deposited in various parts of the respiratory system. The respirable fraction is that size range which can reach the gas-exchange portion of the lung. These curves describe the mass fraction of particles deposited as a function of particle size and serve as the "yardsticks" against which the performance of cyclone samplers should be compared (Vincent, 2007). Figure IV.B-2 below shows particle collection efficiency curves for two particle size selection criteria that are discussed at length below; these include the criteria specified in the 1968 ACGIH TLV for respirable dust, which is the basis for current OSHA dust standards, and an international specification given by the International Organization for Standardization (ISO) and the Comité Européen de Normalisation (CEN) known as the ISO/CEN model, which is the basis for the proposed definition of respirable crystalline silica. In addition to the curves, which cover the full range of particle sizes that comprise respirable dust, particle size collection criteria are also often described by their 50-percent respirable “cut size” or “cut point.” This is the aerodynamic diameter at which 50 percent of the particle mass is collected, i.e., the particle size that the sampler can collect with 50-percent efficiency. Particles smaller than the 50-percent cut point are collected with an efficiency greater than 50 percent, while larger particles are collected with an efficiency of less than 50 percent.

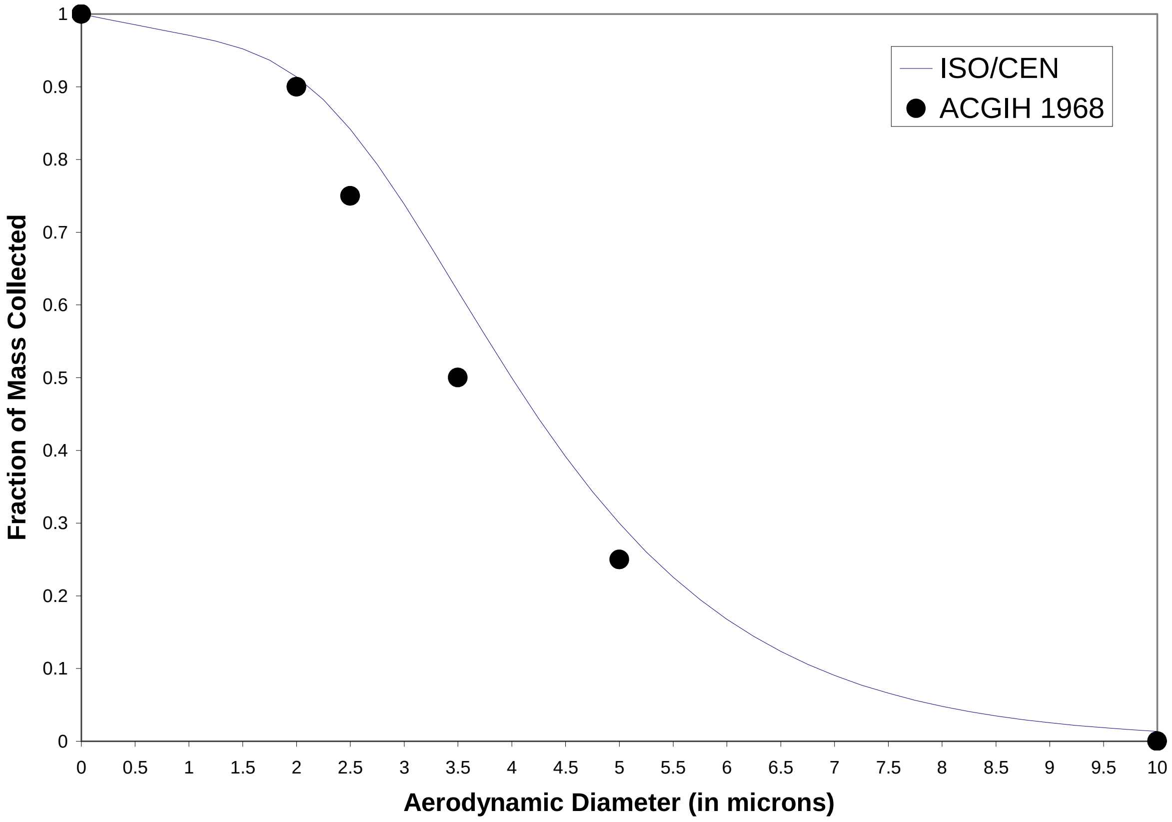

Figure IV.B-1: Comparison of the 1968 ACGIH and ISO/CEN Particle Size Collection Models

Several quantitative definitions for an aerodynamically defined respirable fraction of dust have been set forth since the 1950s (Vincent, 2007). An early definition of respirable dust came from the British Medical Research Council (BMRC) in 1952 and included a 50-percent respirable cut-point of 5 µm. The Atomic Energy Commission (AEC) established a definition for respirable dust in 1961 with a 50-percent cut-point at an aerodynamic diameter of 3.5 µm. (Lippmann, 2001).

In 1968, the ACGIH proposed a definition almost identical to that of the AEC, differing only for 2-µm-size particles, which allowed for a 90-percent efficiency for 2 µm particles rather than 100 percent (Lippmann, 2001). In 1971, OSHA adopted the ACGIH size-selective criteria for respirable dust in its Air

Contaminants Standard (29 CFR 1910.1000, Table Z-3). Thus, the current OSHA general industry PEL for crystalline silica is based on the 1968 ACGIH definition for respirable dust, as displayed in Table IV.B-1.

Table IV.B-1—ACGIH Definition for Respirable Dust 1968

Aerodynamic Diameter (Unit Density Sphere) (µm)	**Percentage of Mass Passing Selector**
2	90
2.5	75
3.5	50
5.0	25
10	0

In the early 1980s, ISO and ACGIH pioneered a new framework of thinking in aerosol science in which three aerosol fractions were identified and defined: the inhalable fraction, the thoracic fraction, and the respirable fraction (Vincent, 2007). The criteria for the respirable fraction continued to be shaped during the 1980s and 1990s. ACGIH quantitatively defined the respirable fraction according to the following collection efficiency equation (ACGIH, 2009):

$$RPM(dae) = IPM\ (dae)\ [1-F(x)],$$

Where: RPM = respirable particulate matter;

d_{ae} = aerodynamic diameter of particle in µm;

IPM = inhalable particulate matter = $0.5[1 + \exp(-0.06\ d_{ae})]$ for $0< d_{ae}100\mu m$;

F(x) = cumulative probability function of the standardized normal variable, x;

$x = \ln(d_{ae}/\Gamma)/\ln(\Sigma)$;

ln = natural logarithm;

$\Gamma = 4.25\ \mu m$ (median aerodynamic diameter for respirable fraction); and

Σ = 1.5 (standard deviation for respirable fraction).

The criteria stated in the above equation are consistent with those of CEN and ISO, enabling a degree of international harmonization (Vincent, 2007). These criteria for respirable dust are typically referred to as the ISO/CEN model.

To remain consistent with the idea of international harmonization, OSHA is proposing to adopt the ISO/CEN model for respirable dust in its proposed change to the existing PEL for crystalline silica. More specifically, OSHA is proposing the following definition for respirable crystalline silica:

> *Respirable crystalline silica means airborne particles that contain quartz, cristobalite, and/or tridymite and whose measurement is determined by a sampling device designed to meet the characteristics for respirable-particle-size-selective samplers specified in International Organization for Standardization (ISO) 7708:1995: Air Quality – Particle Size Fraction Definitions for Health-Related Sampling*.

One distinction between the criteria for respirable dust used in OSHA's existing PEL for crystalline silica and that used in OSHA's proposed change to the PEL for crystalline silica is that the former has a 50-percent respirable cut-size of 3.5 µm, while the latter has a 50-percent respirable cut-size of 4.0 µm. Additional differences between the two definitions include (Soderholm, 1991):

The ISO/CEN model specifies a higher sampler collection efficiency at most particle sizes and a slightly lower collection efficiency for particles with an aerodynamic diameter smaller than 2 µm.

For most workplace conditions, the proposed change in the criteria for respirable dust would increase the mass of respirable dust collected over that measured under the current criteria by an amount that depends on the size distribution of airborne particles in the workplace.

The fractional increase in the measured respirable mass concentration would tend to be larger for particle size distributions having larger mass median aerodynamic diameters (MMAD) and smaller geometric standard deviations (GSD).

Soderholm (1991) examined these differences based on 31 aerosol size distributions measured in various industrial workplaces (e.g., coal mine, lead smelter, brass foundry, bakery, Shielded Metal Arc [SMA] welding, spray painting, pistol range) and determined the percentage increase in the mass of respirable dust that would be collected under the ISO/CEN model over that which would be collected under the 1968 ACGIH criteria. Soderholm (1991) obtained the size distribution data from a study by Hinds and Bellin (1988), who in turn collected their data from a compilation of published studies reporting aerosol size distributions. Soderholm (1991) concluded that, for all but three of the 31 size distributions that were evaluated, the increased respirable dust mass that would be collected using the ISO/CEN model for respirable dust instead of the 1968 ACGIH criteria would be less than 30 percent, with most size distributions (25 out of the 31 examined, or 80 percent) resulting in a difference of between 0 and 20 percent. In addition, for most particle size distributions having a median diameter of less than 2 µm, there would be less respirable dust mass collected under the ISO/CEN model as compared with the 1968 ACGIH model. It should be noted that two of the three outlier distributions consisted almost exclusively of particles outside the respirable size range (i.e., MMAD of > 30 µm and GSD of about 2.4). Soderholm suggested that for particle size distributions most often seen in the workplace, the change to the ISO/CEN model had the same effect as reducing the respirable dust TLV by only 25 percent or less. OSHA believes that the magnitude of this effect does not outweigh the advantages of updating the respirable silica PEL by adopting the ISO/CEN model. In particular, as discussed below, incorporating the ISO/CEN model in the definition of respirable crystalline silica will permit employers to use any sampling device that can be operated to conform to the ISO/CEN model.

Performance of Personal Cyclones Against the ISO/CEN Model

There are a variety of cyclone samplers on the market, such as the Dorr-Oliver, Higgins-Dewell (HD), GK, SIMPEDS, and SKC. Each cyclone has different operating specifications and performance criteria. The sampling flow rate can be adjusted to yield the desired performance. For example, as the airflow rate through a cyclone increases, the 50-percent cut point decreases, and the collection efficiency for larger particles decreases; conversely, lower flow rates will permit more efficient collection of particles at the larger end of the respirable dust size range. Because of the differences between various respirable dust definitions, manufacturers of cyclone samplers specify the flow rates that are necessary to conform to various particle size collection criteria such as the ISO/CEN model.

The current OSHA sampling method for crystalline silica (ID-142 revised December 1996), as well as the MSHA Method P-2 for metal/non-metal mines, specify that a respirable sample should be collected by drawing air at 1.7 ± 0.2 liters/minute (L/min) through a Dorr-Oliver 10 millimeter (mm) nylon cyclone attached to a cassette containing a 5-µm pore-size, 37-mm diameter polyvinyl chloride (PVC) filter (OSHA ID-142, 1996). Currently, OSHA allows the use of an alternative selector design to the Dorr-Oliver 10-mm nylon cyclone for compliance purposes, if it has been verified to achieve comparable selectivity at all five aerodynamic diameters listed in its Air Contaminants Standard (29 CFR 1910.1000, Table Z-3).

NIOSH has three sampling and analysis methods for crystalline silica: 1) Method 7500 (by XRD), 2) Method 7602 (by infrared absorption spectrophotometry), and 3) Method 7601 (by visual absorption spectrophotometry) (NIOSH 03-127-7500, 2003; NIOSH 03-127-7601, 2003; NIOSH 03-127-7602, 2003). All three NIOSH methods have adopted the ISO/CEN model with flow rate specifications of 1.7 ± 5 percent L/min for the Dorr-Oliver 10-mm nylon cyclone and 2.2 ± 5 percent L/min for the HD cyclone. Method 7500 also allows for the use of an aluminum cyclone at 2.5 ± 5 percent L/min. Like OSHA Method ID-142 (revised December 1996), the three NIOSH methods employ a 5-µm pore size, 37-mm diameter PVC filter, and Method 7601 also allows for a 0.8-µm pore size, 37-mm diameter mixed cellulose ester (MCE) filter.

Many cyclones have been evaluated for their compliance with the ISO/CEN criteria for respirable dust. Although there is currently no cyclone that matches the ISO/CEN criteria exactly, available research indicates that many existing cyclones can achieve good agreement with the ISO/CEN criteria for respirable dust when operated at a flow rate that is optimized to minimize bias against the ISO/CEN criteria (Bartley et al., 1994; Chen et al., 1999; Gautam and Sreenath, 1997; Gorner et al., 2001; Kar and Gautam, 1995; Kenny and Gussman, 1997; Liden, 1993; Liden and Kenny, 1993; Soderholm, 1991). Many commercially available sampling devices tend to yield particle collection efficiency curves that are steeper than that of the ISO/CEN curve; that is, the devices will be less efficient (i.e., will collect less mass than predicted by the ISO/CEN model) in capturing larger particles and more efficient in capturing smaller particles than the ISO/CEN model.

Although it would be ideal to know the size distribution of the aerosol that will be sampled to choose the optimum flow rate, this is normally not practical given the wide range of particle size distributions encountered in workplace environments. Instead, researchers determine an optimum flow rate that gives the best outcome over a range of particle size distributions (Liden and Kenny, 1993). This means that bias against the ISO/CEN model will change with different size distributions of particles in the air. Bias against the ISO/CEN model can be either positive (i.e., the device will collect more mass than predicted by the ISO/CEN model) or negative (i.e., less mass will be collected compared with the ISO/CEN model). In general, for most of the commercial cyclones studied, bias against the ISO/CEN model will increase as the particle size distribution in the workplace becomes increasingly monodisperse or as the MMAD of the particle size distribution increases. The discussion that follows briefly summarizes studies that have investigated the optimum flow rates for cyclones to minimize bias against the ISO/CEN model. The general design of these studies was to test the device in a wind chamber with a polydisperse test aerosol to characterize the particle size collection efficiency curve of each device tested. The bias exhibited by each device against the ISO/CEN model can then be determined for a range of particle size distributions (defined by the MMAD and GSD of the distribution) by mathematical simulation.

Bartley et al. (1994) applied polydisperse test aerosols in a wind tunnel to analyze sampling efficiencies for the Dorr-Oliver 10-mm nylon cyclone and the conductive HD cyclone using an aerodynamic particle sizer. Data were collected at various sampling flow rates from 1.5 to 3.0 L/min. Bartley et al. (1994) reported that the Dorr-Oliver 10-mm nylon cyclone matched the ISO/CEN model for respirable dust with minimum bias at an optimized flow rate of 1.7 L/min and the HD cyclone at a flow rate of 2.2 L/min. According to Bartley et al., use of the 1.7 L/min flow rate for the Dorr-Oliver resulted in a 50 percent cut point of about 4.5 µm, which compensates for the under-sampling of larger particles and thus minimizes bias. The biases of the Dorr-Oliver 10-mm cyclone and the HD cyclone were found to be nearly identical, with a magnitude of ±10 percent or less over a wide range of size distributions.

Using a wind tunnel, polydisperse anthracite coal particles, and an aerodynamic particle sizer, Kar and Gautam (1995) evaluated the effect of inlet orientation (0° , 90°, 180°) to the wind direction on the sampling efficiency of the Dorr Oliver 10-mm nylon cyclone at three different flow rates (1.2, 1.7, and 2.0 L/min). They found that a sampling flow rate of 1.7 L/min provided the closest agreement to the

ISO/CEN model with a mean bias of 4.63 percent. The bias was greatest for the 0° orientation and decreased for the 90° and 180° orientations.

Liden and Kenny (1993) also reported an optimized flow rate of 1.7 L/min for the Dorr-Oliver 10-mm nylon cyclone and 2.1 L/min for the SIMPEDS cyclone, with a residual mean bias after optimization of less than 0.5 percent overall across a wide range of particle size distributions. Depending on the specific particle size distribution, bias was predominately in the range of -20 to +10 percent. Chen et al. (1999) reported that, although Liden and Kenny's (1993) recommended flow rates were based on minimum inaccuracy over the whole curve rather than examination of one point at a cutoff size of 4 µm, a sampling flow rate of 1.5 L/min for the Dorr-Oliver 10-mm nylon cyclone was found in their study to be best for the requirements on the 50-percent cut point of 4 µm. Chen et al. (1999) also evaluated two foam samplers that showed a very good fit to the ISO/CEN model with a 1 to 6 percent bias. They tested the samplers using polydisperse particles and an aerodynamic particle sizer under controlled laboratory conditions.

Gautam and Sreenath (1997) used polydisperse test aerosols and an aerodynamic particle sizer to test the Dorr-Oliver 10-mm nylon cyclone in a wind tunnel. They evaluated sampling flow rates of 1.5, 1.7, and 2.0 L/min and found the cyclone to be in good agreement with the ISO/CEN model at the slightly lower flow rate of 1.5 L/min, with a mass bias of +7.5 percent. By comparison, the higher flow rate of 1.7 L/min resulted in a mean bias of -20 percent with respect to the ISO/CEN model. In addition, Gautam and Sreenath (1997) sampled a newer multi-inlet cyclone and found that it matched the ISO/CEN model with a mean bias of only +1 percent at an optimized flow rate of 2.5 L/min. This multi-inlet cyclone is now commercially available from SKC as the GS-3 cyclone (Vincent, 2007).

Gorner et al. (2001) used polydisperse coal dust and an aerodynamic particle sizer method to measure the sampling efficiency of 15 samplers, including several cyclones, in a wind tunnel and found that most were suitable for sampling according to the ISO/CEN model for respirable dust with a modification in flow rate. They reported the following optimized flow rates: 1) 1.5 L/min for the Dorr-Oliver 10-mm nylon cyclone, 2) 1.9 L/min for the plastic SKC cyclone, and 3) 2.2 L/min for the aluminum SKC cyclone. Bias against the ISO/CEN model was calculated for particle size distributions having a MMAD ranging from 1 to 25 µm (in 1 µm steps) and a GSD ranging from 2.0 to 3.5 (in steps of 0.25), for 175 different distributions evaluated. For the Dorr-Oliver and aluminum SKC devices, bias was ±10 percent or less for 84 and 86 percent, respectively, of the particle size distributions examined. Biases greater than 10 percent were predicted to occur more frequently with the plastic SKC device, with a bias of ±10 percent or less predicted for 58 percent of particle size distributions examined. Liden (1993) also reported that an early generation of the aluminum SKC cyclone offers a good fit to the ISO/CEN model for respirable dust at an approximate optimized flow rate of 2.2 L/min, with a bias usually within ±5 percent.

Of special interest, Kenny and Gussman (1997) employed an aerodynamic particle sizer-based testing method and found that the GK2.69 cyclone by BGI Inc. had good agreement with the ISO/CEN model at a higher flow rate of 4.2 L/min. At this flow rate, the cut point for this sampler was about 4.2 µm and exhibited a collection efficiency curve that was steeper than the ISO/CEN model, with lower efficiency in collecting larger particles and higher efficiency in collecting smaller particles. For particle size distributions up to an MMAD of 25 µm and GSD of 1.5 to 3.5, bias against the ISO/CEN model was generally between +5 and -10 percent, and up to -20 percent for particle size distributions with MMAD above 10 µm and low GSDs. Use of a higher flow rate increases the mass of respirable crystalline silica that is collected over a given sampling duration, thus enabling the collection of a quantifiable sample mass during tasks of short duration or of low dustiness (NIOSH 2003-154, 2003).

The literature reviewed above shows that measured sampling efficiencies and optimized flow rates of commercially available cyclones relative to the ISO/CEN model differ somewhat between studies. In particular, for the Dorr-Oliver nylon cyclone, some authors reported an optimized flow rate of 1.7 L/min while others reported a flow rate of 1.5 L/min. According to Gorner et al. (2001), these reported differences reflect that sampler efficiency measurement is a rather complicated experimental exercise with many sources of uncertainty arising from the experimental setup, the experimental aerosol, the flow rate control, and the method of particle size analysis. Also, there appears to be insufficient standardization in the methods of aerosol generation and measurement for evaluating respirable dust sampling devices, which could lead to greater variability in findings between laboratories. In addition, lower flow rates are more difficult to optimize, given that the changes in flow rates required for optimization are small (less than 0.1 L/min) and there is a greater need for flow-rate stability at lower flow rates in order to optimize the flow rate (Gorner et al., 2001). OSHA invites the public to submit additional information on this topic. In particular, studies on or experience with the GK2.69 and multi-inlet cyclone samplers would be of interest.

Despite these small reported discrepancies, OSHA preliminarily concludes that several commercially available personal sampling cyclones exist, including the Dorr-Oliver cyclone currently used by OSHA, that can be operated at flow rates that permit the devices to conform to the ISO/CEN particle size selection criteria with an acceptable level of bias. Other devices include the SKC aluminum cyclone (at a flow rate of 2.2 L/min), the HD cyclone (2.2 L/min), the BGI GK 2.69 (4.2 L/min), and the SKC GS-3 multi-inlet cyclone. For most particle size distributions encountered in the workplace, bias against the ISO/CEN criteria will fall within ±20 percent and often is within ±10 percent

Ability of Personal Cyclones to Collect Sufficient Crystalline Silica for Analysis

The devices discussed above, when used at the appropriate flow rates, are capable of collecting a quantity of respirable crystalline silica that exceeds the quantitative detection limit for quartz of 10 µg for OSHA's XRD method (OSHA ID-142 revised December 1996). For several scenarios based on using various devices and sampling times (8-hour, 4-hour, and 1-hour samples), OSHA calculated the amount of respirable quartz that would be collected at quartz concentrations equal to the current general industry PEL, the proposed PEL, and the proposed action level (Table IV.B-2). Two flow rates were considered for the Dorr-Oliver, since two optimized flow rates have been reported for the Dorr-Oliver in the literature (Bartley et al., 1994; Gautam and Sreenath, 1997; Gorner et al., 2001; Kar and Gautam, 1995; Liden and Kenny, 1993). As seen in Table IV.B-2, computations suggest that the 10-mm nylon Dorr-Oliver operated at an optimized flow rate of 1.5 or 1.7 L/min, the HD cyclone operated at an optimized flow rate of 2.2 L/min, and the GK2.69 operated at an optimized flow rate of 4.2 L/min will all collect enough quartz during an 8-hour full-shift sample to exceed the 10 µg quartz limit of quantification for OSHA Method ID-142 (revised December 1996). In addition, all of the cyclones operated at their optimized flow rates will collect 10 µg or more of respirable quartz during a 4-hour sampling period, with the exception of the Dorr-Oliver operated at 1.5 L/min, at the proposed action level. Therefore, OSHA preliminarily concludes that each of the commercially available cyclones is capable of allowing a sufficient quantity of quartz to be collected from atmospheric concentrations as low as the proposed action level to exceed the limit of quantification for the analytical method, provided that at least 4-hour air samples are taken.

Table IV.B-2—Amount of Quartz Collected by Various Personal Cyclones by Respirable Quartz Concentration and Sampling Time

Cyclone Sampler	25 µg/m^3 (proposed action level)			50 µg/m^3 (proposed PEL)			100 µg/m^3 (current PEL)		
	1 hr	4 hr	8 hr	1 hr	4 hr	8 hr	1 hr	4 hr	8 hr
Dorr Oliver 10 mm nylon (at 1.5 L/min)	2	9	18*	4.5	18	36	9	36	72
Dorr Oliver 10 mm nylon (at 1.7 L/min)	3	10	20	5	20	41	10	41	82
Aluminum SKC (at 2.2 L/min)	3	13	26	7	26	53	13	53	106
HD (at 2.2 L/min)	3	13	26	7	26	53	13	53	106
Multi-inlet sampler (at 2.5 L/min)	4	15	30	8	30	60	15	60	120
GK2.69 (at 4.2 L/min)	6	25	50	13	50	101	25	101	202

* Shaded boxes represent scenarios that will allow for the collection of enough quartz to meet or exceed the 10 µg limit of quantification for OSHA Method ID-142 (revised December 1996).

For cristobalite, OSHA currently achieves a "Limit of Quantification" (LOQ) of 20 µg with Method ID-142 (OSHA SLTC, 2010). With the exception of the Dorr-Oliver operated with a flow rate of 1.5 L/min, the devices listed in Table IV.B-3 will collect a sufficient quantity of cristobalite for a full-shift sample taken at the proposed PEL and action level. In addition, the GK2.69, with its higher flow rate, can collect an amount of cristobalite exceeding OSHA's LOQ with a 4-hour sample taken at the proposed PEL and action level. Therefore, OSHA believes that these devices are also capable of collecting more than the minimum amount of cristobalite at the proposed PEL and action level necessary for quantification with OSHA's Method ID-142 (revised December 1996).

These limits of quantification, 10 µg for quartz and 20 µg for cristobalite, are determined using NIST certified standard materials which are free of interferences. Compliance samples which are collected in some workplace environments may have increased limits of quantification due to the potential for interference from particulates other than crystalline silica that could be collected on the filter.

Analytical Methods

This section evaluates the feasibility of reliably measuring quantities of crystalline silica collected from the sampling devices discussed in Section IV.B.2 – Particle Size-Selective Sampling to evaluate worker exposures at the proposed PEL and action level. OSHA's preliminary feasibility analysis begins with a description of national recognized analytical methods. This is followed by an assessment of the limits of detection and quantification of the methods, and of the precision achievable in the range of the proposed PEL and action level. Finally, OSHA presents its analysis of total laboratory variability and factors that contribute to inter-laboratory variability in analyzing crystalline silica. After considering the information and analysis presented here, OSHA preliminarily concludes that nationally recognized analytical methods are capable of reliably measuring crystalline silica at filter loadings obtained from sampling devices currently used to assess worker exposures at the proposed PEL of 50 µg/m^3 and action level of 25 µg/m^3.

Reliable analysis of crystalline silica presents several challenges that have been described in the published literature. (Madsen 1995, Hearl 1997, Eller 1999) Non-crystalline (amorphous) silica and other types of minerals that are often mixed with crystalline silica in airborne dust samples have the potential to interfere with the laboratory analysis. Special handling procedures are required during the collection, preparation, and analysis of samples to avoid or to correct for interferences that can result in either an overestimation or underestimation of the quantity of crystalline silica present on the sample filter. (Key-Schwartz, 1994). Factors such as sample loading and particle size can also affect the accuracy of the analysis. The standard reference materials used for the preparation of calibration curves is also critical, particularly for quantification near the analytical limit of detection. Thus, the analysis of crystalline silica requires a high level of laboratory proficiency to reliably measure airborne concentrations at the proposed PEL and action level.

The three most commonly used analytical techniques for the quantitative determination of crystalline silica are XRD, IR, and colorimetric spectrophotometry. The advantages and disadvantages of these techniques, and nationally recognized analytical methods for each technique, are summarized in Table IV.B-3.

Table IV.B-3—Analytical Techniques for Determination of Crystalline Silica

Analytical Technique	Advantages	Disadvantages
XRD • OSHA ID-142 • NIOSH 7500 • MSHA P-2	Non-destructive; samples can be reanalyzed if necessary. Specificity for different polymorphs of crystalline silica. Least prone to interferences.	Equipment is expensive and requires skilled operator.
IR • NIOSH 7602 • NIOSH 7603 • MSHA P-7	Non-destructive; samples can be reanalyzed if necessary. Can be efficient for routine analysis of samples with well characterized matrix.	Difficult to distinguish between polymorphs of crystalline silica. More prone to interferences than XRD.
Colorimetric (Vis) • NIOSH 7601	Requires least amount of equipment and expense.	Most prone to interferences. Labor intensive. Sample is destroyed during analysis. Cannot distinguish between polymorphs of crystalline silica.

A major difference among these analytical techniques relates to their ability to remove or adjust for interferences. Interference in the analysis of crystalline silica occurs because of the structural resemblance of various forms of crystalline silica, its amorphous non-crystalline forms, and the ubiquitous occurrence of the silica tetrahedron in other silicates.

X-Ray Diffraction

The three-dimensional orientation and composition of atoms, molecules, or ions of a crystalline material create a unique pattern that are characteristic to a crystal's structure. When a thin layer of randomly oriented sample is presented to the X-ray beam, X-rays diffract from these crystal planes at specific angles where they are detected by a sensor and recorded as a diffraction peak (Smith 1998). Unique X-ray diffraction patterns are created when the diffraction peaks are plotted against the angles at which they occur. The intensity of the diffracted X-ray beams depends on the amount of crystalline silica present in the sample, which can be quantified based on the height and area of the diffraction peaks.

Analysts are able to identify the crystalline materials in a sample by comparing the sample's diffraction pattern to databases of known patterns. Using XRD, the amount of crystalline silica in an unknown sample can be quantified by comparing the areas of the diffraction peaks obtained from scanning the sample with those obtained from scanning a series of calibration standards prepared with known quantities of an appropriate reference material. Comparing multiple diffraction peaks obtained from the sample with those obtained from the calibration standards permits both quantitative and qualitative confirmation of the amount and type of crystalline silica present in the sample.

Ideally, sample deposits presented for XRD analyses should be composed of a thin layer of particles. When sample loading is too high, crystallites might mask each other. X-rays reflected from the bottom layer of crystalline silica in the sample might also be reabsorbed in the upper sample layers. Sample loadings of up to 2 to 3 milligrams (mg) of respirable dust typically permit deposition of a single layer of sample. XRD analytical methods compensate for heavy sample loadings either by limiting sample weight, removing excess mineral material by an acid wash, or applying correction factors.

The size of the silica crystallites collected for analysis affects each of the analytical techniques used for crystalline silica analyses differently. In the case of XRD analyses, smaller crystallites yield broader diffraction peaks with reduced peak height compared with larger crystallites. Performing the analysis using area integrations of the diffraction peaks rather than peak height alone helps to diminish this particle-size effect. In addition, standard reference materials used for instrument calibrations are prepared in the respirable size range to match the sizes of dust particles collected by particle-size-selective sampling devices (described above in Section IV.B.2 – Particle Size-Selective Sampling), thus minimizing particle size differences between the sample and the reference standards used in the analysis.

A major advantage of XRD compared with the other techniques used to measure crystalline silica is that X-ray diffraction is specific for crystalline materials. Neither non-crystalline silica nor the amorphous silica layer that forms on crystalline silica particles affects the analysis. The technique is also non-destructive, so samples can be reanalyzed if necessary. The ability of this technique to quantitatively discriminate between different forms of crystalline silica and other crystalline or non-crystalline materials present in the sample makes this method least prone to interferences.

The OSHA Technical Manual lists the following substances as potential interferences for the analysis of crystalline silica using XRD: aluminum phosphate, feldspars (microcline, orthoclase, plagioclase), graphite, iron carbide, lead sulfate, micas (biotite, muscovite), montmorillonite, potash, sillimanite, silver chloride, talc, and zircon. The interference from other minerals usually can be recognized by scanning multiple diffraction peaks quantitatively. Diffraction peak-profiling techniques can resolve and discriminate closely spaced peaks that might interfere with each other. Sometimes interferences cannot be directly resolved using these techniques. Many interfering materials can be chemically washed away in acids that do not dissolve the crystalline silica in the sample. Properly performed, these acid washes can dissolve and remove these interferences without losing substantial amounts of crystalline silica.

XRD instrumentation is more expensive than the equipment used for IR or colorimetric crystalline silica analyses and analysts need to have a high degree of scientific training to properly interpret XRD data.

The nationally recognized analytical methods using XRD include NIOSH 7500, OSHA ID-142 (revised December 1996), and MSHA P-2 (Table IV.B-4). All are based on the XRD of a redeposited thin layered sample with comparison to standards of known concentrations. The methods differ on the techniques used to compensate for high sample loading. MSHA and NIOSH methods use correction factors to compensate for high sample loading, whereas the OSHA method specifies that highly loaded samples be split into fractions small enough not to need correction. These methods also differ on diffraction peak confirmation strategies. The OSHA and MSHA methods require at least three diffraction peaks to be scanned. The NIOSH method only requires that multiple peaks be qualitatively scanned on representative bulk samples to determine the presence of crystalline silica and possible interferences, and quantitative analysis of air samples is based on a single diffraction peak for each crystalline silica polymorph analyzed. The diffraction peak(s) used for quantification in this method must be shown to be interference-free in the bulk sample. There are some drawbacks for relying solely on the bulk sample for identification of polymorphic forms of crystalline silica and the presence of interferences. For example, if the air sample contains a material that interferes with the primary peak and the bulk sample does not, the result will be artificially high. Both the OSHA Method ID-142 (revised December 1996) and MSHA Method P-2 XRD have provisions for acid washing samples to remove interferences when needed.

Table IV.B-4 lists the specifications for these analytical methods for silica utilizing XRD. Methods for Determination of Hazardous Substances (MDHS) 101 is a method used in the U.K., and is included for comparison; it is fundamentally different from U.S. methods in that for MDHS 101, XRD is performed directly on sample filters and not redeposited on silver membrane filters prior to analysis.

Table IV.B-4—X-ray Diffraction Sampling and Analytical Methods for Crystalline Silica

	NMAM 7500	**OSHA ID-142**	**MSHA P-2**	**MDHS 101**
Silica Polymorph	Quartz cristobalite tridymite	Quartz cristobalite	Quartz cristobalite	Quartz cristobalite

Table IV.B-4—X-ray Diffraction Sampling and Analytical Methods for Crystalline Silica

	NMAM 7500	**OSHA ID-142**	**MSHA P-2**	**MDHS 101**
Sampler	10-mm nylon cyclone, 1.7 L/min Higgins-Dewell cyclone, 2.2 L/min	10-mm nylon Dorr-Oliver cyclone, 1.7 L/min	10-mm nylon Dorr-Oliver cyclone, 1.7 L/min	Higgins-Dewell cyclone, 1.9 L/min
Filter	37-mm 5-µm PVC membrane	37-mm 5-µm PVC membrane	37-mm 5-µm PVC membrane	25-mm 5-µm PVC membrane
Volume	400–1000 L total dust <2 mg	408–816 L total dust <3 mg	400–1000 L total dust <3 mg	≥456 L total dust <2 mg
Filter Preparation	RF plasma asher, muffle furnace, or dissolve filter in THF	Dissolve filter in THF	RF plasma asher	None
Redeposition	On 0.45-µm silver membrane filter	On 0.45-µm silver membrane filter	On 0.45-µm silver membrane filter	None
Drift Correction	Silver internal standard	Silver internal standard	Silver internal standard	External standard (eg., aluminum plate)
X-Ray Source	Cu Kα 40 kV, 35 mA	Cu Kα 40 kV, 40 mA	Cu Kα 55 kV, 40 mA	Cu Kα 45 kV, 45 mA

Table IV.B-4—X-ray Diffraction Sampling and Analytical Methods for Crystalline Silica

	NMAM 7500	**OSHA ID-142**	**MSHA P-2**	**MDHS 101**
Calibration	Suspensions of SiO_2 in 2-propanol (deposited on silver membrane filter)	Suspensions of SiO_2 in 2-propanol (deposited on silver membrane filter)	Suspensions of SiO_2 in 2-propanol (deposited on silver membrane filter)	Sampling from a generated atmosphere of standard quartz dust
Proficiency Testing	PAT	PAT	PAT	WASP
Range (µg quartz)	20–2000	50–160 (validation range)	20–500	50–2000
LOD (µg quartz)	5 (estimated)	Qualitative: 5 Quantitative: 10	5	Qualitative: 3 Quantitative: 10
Precision	CV pooled = 0.08 @ 50–200 µg	CV pooled = 0.106 @ 50–160 µg	CV = 10 % @ 20–500 µg	Not reported

NMAM—NIOSH Manual of Analytical Methods; OSHA—Occupational Safety and Health Administration; MSHA—Mine Safety and Health Administration; MDHS—Methods for Determination of Hazardous Substances; PVC—polyvinyl chloride; RF—radio frequency; THF—tetrahydrofuran; Cu—copper; kV—kilovolts; mA—milliamps; PAT—proficiency analytical testing; WASP—workplace analysis scheme for proficiency; LOD—limit of detection; CV—coefficient of variation; RSD—relative standard deviation.

Source: Adapted from NIOSH 2002-129, 2002; United Kingdom-Health and Safety Executive, 2005.

Infrared Spectroscopy

Infrared spectroscopy is based on the principle that molecules of a material will absorb specific wavelengths of infrared electromagnetic energy that match the resonance frequencies of the vibrations and rotations of the electron bonds between the atoms making up the material. IR techniques for the quantification of crystalline silica are based on the absorption of infrared energy in resonance with the vibrations and rotations of the silicon-oxygen electron bonds in the silica tetrahedron. The absorption of IR radiation of the sample is compared with the IR absorption of calibration standards of known concentration to determine the amount of crystalline silica in the sample. Using IR can be efficient for routine analysis of samples that are well characterized, and the technique is non-destructive allowing samples to be reanalyzed if necessary.

Compared with XRD instrumentation, standard IR instruments are relatively inexpensive. Fourier-Transform (FT-IR) instruments, used by most modern laboratories, are more expensive than standard IR instruments, but still less expensive than XRD instruments. FT-IR instruments have greater sensitivities than standard IR instruments and can eliminate some of the analytical interferences inherent to this technique. This instrumentation also has the ability to rapidly perform multiple scans that can be averaged together, which minimizes random noise and increasing the signal to noise ratio of the absorbance spectrum (Ainsworth et al., 1989).

Interferences from silicates and other minerals can affect the accuracy of IR results. The electromagnetic radiation absorbed by silica in the infrared wavelengths consists of broad bands. In theory, no two compounds have the same absorption bands; however, in actuality, the IR spectra of silicate minerals contain silica tetrahedra and have absorption bands that will overlap. This can be a serious limitation because 90 percent of the minerals in the Earth's crust contain silica tetrahedra that will interfere with the analyses of crystalline silica. These interfering bands can be additive, enhancing the absorption band measured for crystalline silica. If interferences enhance the baseline measurement and are not taken into account, they can have a negative effect that might underestimate the amount of silica in the sample. Compared with XRD, the ability to compensate for these interferences is limited. If the interfering material has an interference-free absorption band at another wavelength, its contribution to the silica band can be subtracted based on the intensity of the non-interfering band. The MSHA and NIOSH methods for analyzing quartz in respirable coal dust samples by IR use this approach to correct for the interfering absorption of kaolinite, a hydrated aluminum silicate commonly found in coal. Other techniques employed include acid washing and high- or low-temperature ashing to reduce or eliminate interferences (Madsen et al., 1995).

It is difficult to distinguish among the different polymorphic forms of crystalline silica by IR because the primary IR band for both quartz and cristobalite occurs at the same wavelength. When quantitative determination for quartz in the presence of cristobalite is needed, the contribution of the cristobalite primary band needs to be subtracted from the quartz primary band. Determining the amount of cristobalite in the sample requires that the secondary cristobalite band be analyzed and found to be free of interferences.

Dark-colored samples might cause attenuation of the quartz bands by as much as 75 percent. Such dark materials should be removed during sample preparation. For example, the coal in coal dust samples to be analyzed for crystalline silica is eliminated with an ashing technique used by NIOSH and MSHA to prepare samples for analysis. If dark material persists in the sample, FT-IR or IR instruments that can compensate for the interference must be used to overcome this problem (United Kingdom-Health and Safety Executive, 2005).

Amorphous silica is a positive interference for IR analyses of quartz and cristobalite. As the particle size decreases below a nominal physical size of 1.5 µm (which equates to an aerodynamic diameter of 4 µm) the amorphous layer surrounding silica particles starts contributing substantially to the mass of the particle.

Because of the potential for interferences with IR spectroscopy, OSHA believes IR techniques should only be used to evaluate workers' exposures when the matrix of the sample is characterized sufficiently, such as with coal dust, and shown to be free of uncorrectable interferences.

The principle IR analytical methods for crystalline silica analyses are NIOSH 7602, NIOSH 7603, and MSHA P-7, the specifications of which are listed in Table IV.B-5. NIOSH Method 7603 and MSHA P-7 are both optimized for the analysis of quartz in respirable coal dust. The IR method used in the U.K. for crystalline silica is also described in MDHS 101 and is summarized in Table IV.B-5 for comparison with the U.S. methods.

Table IV.B-5—Infrared Sampling and Analytical Methods for Crystalline Silica

	NMAM 7602	**NMAM 7603**	**MSHA P-7**	**MDHS 101**
Matrix		Coal mine dust	Coal mine dust	
Sampler	10-mm nylon cyclone, 1.7 L/min Higgins-Dewell cyclone, 2.2 L/min	10-mm nylon cyclone, 1.7 L/min Higgins-Dewell cyclone, 2.2 L/min	10-mm nylon Dorr-Oliver cyclone, 2.0 L/min	Higgins-Dewell cyclone, 1.9 L/min
Filter	37-mm 5-µm PVC or MCE membrane	37-mm 5-µm PVC membrane	37-mm 5-µm PVC membrane,	25-mm 5-µm PVC membrane

Table IV.B-5—Infrared Sampling and Analytical Methods for Crystalline Silica

	NMAM 7602	**NMAM 7603**	**MSHA P-7**	**MDHS 101**
			pre-weighed	
Volume	400–800 L total dust <2mg	300–1000 L total dust <2mg	Not stated	≥456 L total dust <1mg
Filter Preparation	RF plasma asher muffle furnace	RF plasma asher muffle furnace	RF plasma asher	None
Analytical Sample Prep	Mix residue with KBr, press 13 mm pellet	Redeposit on 0.45-µm acrylic copolymer filter	Redeposit on 0.45-µm acrylic copolymer filter	None
Standard	Polystyrene film	Polystyrene film	Polystyrene film	Polystyrene film
Calibration	Quartz diluted in KBr	Standard suspension of quartz in 2-propanol	Standard suspension of quartz in 2-propanol	Sampling from a generated atmosphere of standard quartz dust
Proficiency Testing	PAT	PAT	PAT	WASP
Range (µg quartz)	10–160	30–250	25–250	10–1000
LOD (µg quartz)	5 (estimated)	10 (estimated)	10	Qualitative: 5 Quantitative: 10

Table IV.B-5—Infrared Sampling and Analytical Methods for Crystalline Silica

	NMAM 7602	NMAM 7603	MSHA P-7	MDHS 101
Precision	CV pooled <0.15 @ 30µg	CV pooled = 0.098 @ 100 - 500 µg	CV = 7–10 % (corrected 2006) @ 100–500 µg	Not Reported

NMAM—NIOSH Manual of Analytical Methods; MSHA—Mine Safety and Health Administration; MDHS—Methods for Determination of Hazardous Substances; PVC—polyvinyl chloride; MCE—methyl cellulose ester; RF—radio frequency; KBr—potassium bromide; PAT—proficiency analytical testing; WASP—workplace analysis scheme for proficiency; LOD—limit of detection; RSD— relative standard deviation (equivalent to coefficient of variation); CV—coefficient of variation (equivalent to relative standard deviation).

Source: Adapted from NIOSH 2002-129, 2002; United Kingdom-Health and Safety Executive, 2005.

Colorimetric Spectrophotometry

Colorimetric spectrophotometry techniques take advantage of the insolubility of crystalline silica in most mineral acids and its solubility in hydrofluoric acid. Using this technique, the sample is subjected to a phosphoric acid wash to remove silicate and other silica-containing materials present in the sample. After a timed heating with phosphoric acid, the sample is rinsed in hydrochloric and boric acids to remove the dissolved silicates. The remaining material is dissolved in hydrofluoric acid creating silicon fluoride in solution. A reagent that forms a color with silicon is added and the intensity of the color is measured using a spectrophotometer that operates at visible wavelengths. Sample response from the spectrophotometer is compared with calibration standards of known concentration to determine the amount of silicon present in the sample. The silicon present in the sample is then reported as crystalline silica (Talvite, 1951).

Colorimetric spectrophotometry techniques have numerous possible analytical interferences. In highly loaded samples, interfering materials might not be completely dissolved and eliminated, whereas crystalline silica might be lost during acid washing of samples with low loadings. Silicon-containing substance resistance to phosphoric acid will interfere. Variation in particle size might have either a positive or negative impact on the analysis because of the differences in solubility. The different polymorphic forms of crystalline silica cannot be distinguished, and cristobalite might be lost because it is slightly more soluble in phosphoric acid than quartz. False positive results in samples and blanks are also common.

Colorimetric spectrophotometry analytical methods can be performed by personnel with a minimal amount of scientific training using relatively inexpensive equipment. However, it is a labor-intensive procedure, requiring use of highly hazardous hydrofluoric acid, and the technique destroys the sample eliminating the possibility of re-analysis.

Poor inter-laboratory agreement and lack of specificity render colorimetric spectrophotometry inferior to XRD or IR techniques (Eller et al., 1999a; 1999b). NIOSH has published a colorimetric method for crystalline silica, but NIOSH recognizes the limitations of the method and reports that other methods based on XRD and IR have better "laboratory to laboratory agreement." Thus, NIOSH recommends the method be used for "research use only." Given these considerations, OSHA is proposing not to permit employers to rely on exposure monitoring results based on analytical methods that use colorimetric, and is not considering this technique further in the feasibility analysis.

Sensitivity and Precision of Analytical Methods

Sensitivity

The sensitivity of an analytical method or instrument refers to the smallest quantity of a substance that can be measured with a specified level of accuracy, and is expressed as either the "Limit of Detection" (LOD) or the "Limit of Quantification" (LOQ). These two terms have different meanings. The LOD is the smallest amount of an analyte that can be detected with acceptable confidence that the instrument response is due to the presence of the analyte. The LOQ is the lowest amount of analyte that can be reliably measured in a sample with acceptable analytical precision and recovery. The LOQ is usually about three times greater than the LOD. These values can vary from laboratory to laboratory as well as within a given laboratory between batches of samples because of variation in instrumentation, sample preparation techniques, and the sample matrix, and must be confirmed periodically by laboratories.

For an analytical method to have acceptable sensitivity for determining exposures at the proposed PEL of 50 μg/m^3 and action level of 25 μg/m^3, the LOQ must be below the amount of analyte that would be collected in an air sample taken where the concentration of analyte is equivalent to the proposed PEL or action level. At a concentration of 50 μg/m^3, the mass of crystalline silica collected on a full-shift (480 minute) air sample at a flow rate of 1.7 L/min for a total of 816 L is approximately 41 μg. At a concentration of 25 μg/m^3, the mass collected is about 20 μg. The LOQ for quartz for OSHA's XRD method is 10 μg (OSHA ID-142, 1996), which is below the amount of quartz that would be collected from full-shift samples at the proposed PEL and action level. Similarly, the reported LODs for quartz for the NIOSH and MSHA XRD and IR methods (see Tables IV.B-4 and IV.B-5) are lower than that which would be collected from full-shift samples taken at the proposed PEL and action level.

A survey of analytical laboratories that participated in proficiency analytical testing (PAT) round 133 was conducted to identify factors that influence performance based on the PAT results (Eller, 1999).

Completed questionnaires were received from 80 of the 82 laboratories (98 percent). The responses to questions on laboratory practices and measurement parameters were analyzed. The reported LODs for crystalline silica ranged from 5 to 50 µg, and an LOD of 10 µg was commonly reported (Eller et al., 1999). OSHA believes that the higher LODs reported by some laboratories do not reflect an inability of the method to detect crystalline silica at lower filter loads, but instead reflect laboratory practices with respect to instrument calibration and quality control practices. Therefore, OSHA believes that the XRD and IR methods of analysis are both sufficiently sensitive to quantify levels of quartz that would be collected on air samples taken from concentrations at the proposed PEL and action level.

The proposed 50 µg/m^3 PEL for crystalline silica includes quartz, cristobalite, and tridymite in any combination. For cristobalite, the current general industry formula PEL is approximately 50 µg/m^3, so the proposed change in the PEL for crystalline silica does not represent a substantive change in the PEL for cristobalite when quartz is not present. OSHA Method ID-142 (revised December 1996) lists a 30-µg LOQ for cristobalite; however, the current LOQ for cristobalite for OSHA's XRD method as implemented by the Salt Lake Technical Center (SLTC) is about 20 µg (OSHA SLTC, 2010). OSHA believes that its XRD method is sufficiently sensitive to quantitatively determine cristobalite at filter loadings obtained by full-shift sampling at the proposed PEL and action level.   Tridymite is rarely encountered, thus OSHA has very limited experience with the laboratory analysis of tridymite, for which standard reference materials are not readily available.

Precision

All analytical methods have some measurement error. Measurement errors can be either random or systematic. The term precision refers to the amount of random error or variation in replicate measurements of the same sample, and is often expressed as a standard deviation about the mean of the measurements (denoted as S_T). When random errors are normally distributed, a 95-percent confidence interval can be calculated, $\overline{X} \pm (1.96 \times SD)$, where $\overline{X}$ is the mean and SD is the standard deviation. The relative standard deviation (RSD), calculated by dividing the standard deviation by the mean for a data set, is often used to estimate error for analytical methods. The RSD is also known as the coefficient of variation (CV). Systematic error, or bias, is the difference between the mean of a set observed values and a known reference value. Systematic errors can be identified through replicate analyses of samples spiked with a standard containing a known quantity of a reference material.

The Overall Analytical Error cited in OSHA Method ID-142 (revised December 1996) is a function of both the CV and the bias for the analytical method determined from the analysis of 300 internally prepared quality control samples during 1986–1988. It was calculated by adding the absolute value of the bias to 2 × CV, (i.e., 0.052 + (2 × 0.106)). For OSHA's Method ID-142 (revised December 1996), the overall error of the analytical method was estimated to be ±26 percent over the range of 50–160 µg/sample.

OSHA also uses a statistic called the Sampling and Analytical Error (SAE) to estimate the precision of air sampling and analytical methods to assist compliance safety and health officers (CSHOs) in determining compliance with an exposure limit. The estimate of the SAE is unique for each analyte and analytical method, and must be determined by each laboratory based on its own quality control practices. At SLTC, the SAE is based on statistical analysis of results of internally prepared quality control samples. Specifically, OSHA calculates the standard deviation of the analytical recoveries (defined as measured quantity divided by theoretical quantity) of the previous *n* number of quality control sample results ($18 \leq n \leq 99$). Sampling and analytical components are assessed separately, where CV_1 reflects analytical error that is estimated from the analysis of quality control samples, and CV_2 is the sampling error, assumed to be 5 percent due to variability in sampling pump flow rates that can affect sample air volume. Analytical error is combined with sampling pump error, and the SAE is calculated as a one-sided 95 percent confidence limit with the following formula:

$$\mathrm{SAE} = 1.645 \times \sqrt{\mathrm{CV}_1^2 + \mathrm{CV}_2^2}$$

The current SLTC SAE for crystalline silica is 0.231 ($CV_1 = 0.131$) as of July 2010. The average SLTC SAE for the time period February 2007 to present and over the range of 50 to 300 µg/sample is 0.227 ($CV_1 = 0.129$). The estimated error in the range of lower sample loadings is 0.252 ($CV_1 = 0.144$), based on a subset of samples analyzed from March 2007 to present and having filter loadings of 50–60 µg/sample. These CV_1s are higher, but still similar to the CV_1 of 0.106 cited in OSHA Method ID-142 (revised December 1996).

OSHA's SLTC conducted a more recent evaluation of the accuracy and precision for the analysis of crystalline silica using XRD at filter loadings of 20 and 40 µg corresponding to the amounts of crystalline silica that would be collected from full-shift sampling at the proposed action level and PEL, respectively (i.e., 816-L samples) (SLTC, Personal Communication, March 2013). For quartz, two sets of 10 replicate filters were prepared with loadings of 21.0 and 40.6 µg using NIST standard quartz reference material SRM 1878a. For cristobalite, filter loadings of 20.0 and 40.0 were prepared using NIST SRM 1879a. The spiked filters were prepared and analyzed at SLTC using a Rigaku ultraX 18-kilowatt (kW) rotating-anode X-ray diffractometer. The mass of crystalline silica detected on the filter was quantified based on the area of the primary peak (i.e., the most sensitive peak) as compared with a standard calibration curve. The results for this test are shown in Table IV.B-6. The RSD (CV_1) of the data for both levels of quartz is 0.080 and for cristobalite it is 0.082. These are lower than the CV_1 of 0.144, that was determined from the analysis of quartz quality control samples loaded with 50–60 µg/filter at SLTC. These results also show that, although the RSD increases at the lower filter loadings, accuracy and precision of the method remain acceptable at filter loadings down to 20 µg.

Table IV.B-6—Accuracy and Precision at the Proposed PEL and Action Level

Nominal	Filter							
Air concn	Loading	n	Mean	SD	RSD	SEE	Accuracy	Precision

($\mu g/m^3$)	(μg)		(μg)	(μg)			(%)	(%)
Quartz								
25	21.0	10	18.7	1.6	0.086	0.099	89	19
50	40.6	10	38.2	2.8	0.073	0.088	94	17
Cristobalite								
25	20.0	10	20.0	1.6	0.082	0.096	100	19
50	40.0	10	38.9	3.2	0.082	0.096	97	19
n =	Number of replicate filters analyzed							
Mean =	Average mass detected on filter							
SD =	Standard deviation of mass detected							
RSD =	Relative standard deviation (or CV_1)							
SEE =	Standard error of estimate (includes $CV_2 = 0.05$ for pump error)							
Precision =	Precision at 95% confidence level							
Accuracy =	Recovery, amount detected divided by amount added to filter							

Standard Error of Estimate (SEE) and precision at the 95 percent confidence level were calculated by the following formulas:

$$\mathrm{SEE} = \sqrt{\mathrm{CV}_1^2 + \mathrm{CV}_2^2} \qquad \mathrm{Precision} = 1.96 \times \mathrm{SEE}$$

NIOSH Method 7500 for XRD analysis of crystalline silica reports an analytical precision (CV_1) of 0.08 determined for filter loadings in the range of 50 to 200 µg per sample, which is lower than that reported in OSHA Method ID-142 (revised December 1996). The overall accuracy of the NIOSH method is reported to be ±18 percent over this range of filter loadings. The analytical precision (CV_1) achieved for the infrared methods NIOSH Method 7603 and MSHA Method P-7 are similar, 0.098 (100–500 µg/filter) and 0.05–0.10 (25–250 µg/filter), respectively.

Analysis of Total Variability Using Round Robin Test Data

The sources of random and systematic error described above reflect the variation in sample measurement experienced by a single laboratory; this is termed intra-laboratory variability. Another source of error that affects the reliability of results obtained from sampling and analytical methods is inter-laboratory variability, which describes the extent to which laboratories would obtain disparate results from analyzing the same sample. Inter-laboratory variability can be characterized by using data from round robin testing, where laboratories analyze similarly prepared samples and their results are compared. In practice, however, it is difficult to separate intra- and inter-laboratory variability because each laboratory participating in a round robin test provides analytical results that reflect their own degree of intra-laboratory variability. Thus, use of round robin test data to compare performance of laboratories in implementing an analytical method is really a measure of total laboratory variability. In this section, OSHA evaluates round robin test data to characterize the total variability that has been seen from different laboratories with respect to crystalline silica analysis.

American Industrial Hygiene Association Proficiency Analytical Testing Program

The best available source of data for characterizing total variability (which includes an inter-laboratory variability component) of crystalline silica analytical methods is the American Industrial Hygiene Association (AIHA) PAT program. The AIHA PAT Program is a comprehensive round robin testing program that provides an opportunity for laboratories to demonstrate competence in their ability to accurately analyze air samples through comparisons with other labs. The PAT program is designed to help consumers identify laboratories that are proficient.

Crystalline silica (using quartz only) is one of the analytes included in the proficiency testing program. The AIHA PAT program evaluates the total variability among participating laboratories based on round robin testing of specially prepared silica samples. The AIHA contracts the preparation of their crystalline silica PAT samples to an independent laboratory that prepares four spiked PAT samples and one blank sample for each participating laboratory per round. Each set of PAT samples with the same sample number is prepared with as close to the same mass of crystalline silica deposited on the filter as possible. However, some variability occurs within each numbered PAT sample set because of small amounts of random error during sample preparation. Before the contract laboratory distributes the round, it analyzes a representative lot of each numbered set of samples to ensure that they meet established criteria. The samples are distributed to the participating laboratories on a quarterly basis.

The PAT program does not specify the particular analytical method to be used. However, the laboratory is expected to analyze the PAT samples using the methods and procedures it would use for normal operations. A review of the current list of AIHA-accredited laboratories currently posted on the AIHA Web site found 28 laboratories accredited for analysis of crystalline silica by XRD and 23 laboratories that are accredited for analysis of crystalline silica by IR (Table IV.B-7).

Table IV.B-7—Number of AIHA Accredited Laboratories by Method

Analytical Method	Total Labs	Commercial Labs
XRD	28	17
IR	23	15
Both	12	8

The results of the PAT sample analysis are reported to the AIHA by the participating laboratories. For each PAT round, AIHA compiles the results and establishes upper and lower performance limits for each of the four sample results based on the mean and RSD of the sample results. For each of the four samples, a reference value is defined as the mean value from either 1) results from all participating laboratories or 2) results from a selected set of reference laboratories. The RSD for each of the four samples is used to establish the upper and lower performance limits, which are set at three times the RSD. A participating laboratory receives a passing score if at least three out of the four sample results reported are within the specified performance limits of the respective samples. Two or more results reported by a lab in a given round that are outside the limits results in the lab receiving an unsatisfactory rating. An unsatisfactory rating in 2 of the last 3 rounds results in revocation for that lab of the AIHA accreditation for the analysis of crystalline silica. Participation in the PAT program is a prerequisite for accreditation through the AIHA Industrial Hygiene Laboratory Accreditation Program (IHLAP).

Inter-Laboratory Performance In the Proficiency Analytical Testing Program

An evaluation of inter-laboratory variability was performed using the data for AIHA PAT Rounds 156 through 165 that were obtained from AIHA in August 2006 and encompassing the time period of April 2004 through June 2006. There were 60 to 65 laboratories that participated in various rounds during this time frame. Each PAT round (e.g., round 156) for each participating laboratory consists of four samples and one blank. Except for PAT Round 165, reference values were obtained by determining the mean of the sample results from all participating laboratories. Starting with PAT Round 165, AIHA started calculating the reference value from the mean of reported results submitted by certain reference laboratories.

There were two substantial changes in the implementation of the PAT program between Rounds 156 and 165. First, the method for preparing samples changed from aerosol deposition (Rounds 156–160) to direct deposition from a liquid suspension (Rounds 161–165), which was intended to reduce variation in crystalline silica loading of samples. Second, prior to PAT round 159, AIHA based its performance limits for each sample in the round (i.e., ±3 times the calculated RSD) on the actual RSDs calculated from the results. Beginning with Round 159, AIHA decided to limit the maximum RSD to 20 percent, which effectively capped the performance limits.

A summary of the results obtained by OSHA for PAT Rounds 156–165 (AIHI PAT 156-165, 2006) appears in Table IV.B-8 and shows the effect of these program changes. Overall, data for all of the PAT rounds (156 to 165) show a total laboratory RSD (pooled) of 19.5 percent for the analytical range of 49 to 165 µg, and the RSD from the reported results exceeded 20 percent for about half of the 40 samples prepared for these rounds. Data from earlier PAT rounds (156 to 160) when samples were prepared by aerosol deposition show a total laboratory RSD (pooled) of 21.5 percent for the analytical range of 54 to 136 µg, and for 16 of the 20 samples prepared for these rounds, the RSD of reported results exceeded 20 percent. Beginning with Round 161, after the AIHA's contract laboratory changed from using aerosol deposition to direct liquid deposition for preparing the samples, the total laboratory RSD (pooled) declined to 17.2 percent with only three of the 20 sample sets having an RSD above 20 percent. Most likely, the decline in sample RDSs reflect improved consistency in the preparation of the PAT samples. However, it is important to note that these data still reflect errors associated with the preparation of the PAT samples using liquid suspensions.

For Rounds 156 through 158, when the AIHA based its performance limits on the calculated RSDs, the pooled RSD for these rounds was 23.2 percent, and the RDS exceeded 20 percent for eight out of the 12 samples prepared for these rounds. After round 158, when AIHA decided to limit the maximum RSD to 20 percent, total laboratory variability seemed to improve. The RSD for rounds 161 to 165 only exceeded 20 percent for three out of 20 samples prepared for those rounds, compared with 16 out of 20 for the previous rounds (156 to 160).

Table IV.B-8—Total Laboratory Variability of Crystalline Silica PAT Data

	Rounds 156 to 158	**Rounds 156 to 160**	**Rounds 161 to 165**	**Rounds 156 to 165**
Program change	**Rounds Prior to Rounding SD and RSD to 20%**	**PAT Samples Prepared Using Aerosol Generation**	**PAT Samples Prepared Using Liquid Suspensions**	**Summary of All Rounds**
Median Mass (µg)	85	89	107	98
Average Mass (µg)	88	91	106	98
Mass Range (µg)	57 to 133	54 to 136	49 to 165	49 to 165
Air Concentration Range (µg/m^3)	70 to 163	66 to 166	60 to 202	60 to 202

Table IV.B-8—Total Laboratory Variability of Crystalline Silica PAT Data				
	Rounds 156 to 158	**Rounds 156 to 160**	**Rounds 161 to 165**	**Rounds 156 to 165**
Based on 816 L				
Average Standard Deviation (µg)	19	19	18	19
Average Relative Standard Deviation (pooled) (%)	23.2	21.5	17.2	19.5
Number of Rounds	3	5	5	10
Number of PAT Numbered Sample Sets	12	20	20	40
Numbered Sample Sets in Which RSD Exceeded 20%	8	16	3	19

OSHA used the PAT data to evaluate the frequency with which laboratories achieve reasonably good agreement in their analytical results, defined for this purpose as having a sample result that is ±25 percent of the reference value. Table IV.B-9 shows the percentage of labs participating in rounds 156 to 165 that reported sample results that were within ±25 percent of the reference value for each sample prepared for these rounds. Across all PAT samples, an average of 80 percent of labs reported a result that was within ±25 percent of the reference value. At the low end of the range of filter loading (≤ 70 µg, 11 samples), the percentage of labs that reported results within ±25 percent of the group mean ranged from 56 to 90 percent, with an average of 81 percent. These observations suggest that the majority of laboratories achieve reasonably good agreement in their sample results, even at the lower range of filter loadings.

Table IV.B-9—The Percentage of Laboratories Reporting Values

Within Plus or Minus 25% of Mean by PAT Round and Sample Number

Round Number	Sample Number	Number of Labs	Mean (mg)	RSD	Percent of Labs Within 25% of Ref Value
156	1	62	0.0566	0.2389	66%
156	2	62	0.1200	0.1812	81%

156	3	62	0.0678	0.2139	71%
156	4	62	0.1145	0.2333	73%
157	1	64	0.0906	0.2661	66%
157	2	64	0.0854	0.2725	53%
157	3	64	0.0700	0.1923	72%
157	4	63	0.0671	0.2100	75%
158	1	62	0.0700	0.2346	69%
158	2	62	0.1330	0.2027	74%
158	3	62	0.1005	0.1959	84%
158	4	62	0.0624	0.2545	71%
159	1	63	0.1077	0.1779	68%
159	2	63	0.1141	0.1999	81%
159	3	63	0.1058	0.1999	73%
159	4	63	0.0792	0.1997	76%
160	1	62	0.0879	0.2000	69%
160	2	62	0.0541	0.1999	56%
160	3	62	0.1361	0.2000	60%
160	4	62	0.1006	0.1999	53%
161	1	60	0.0952	0.1365	87%
161	2	60	0.1380	0.1792	73%
161	3	60	0.1293	0.2000	73%
161	4	60	0.0604	0.1793	83%
162	1	61	0.1551	0.1596	85%
162	2	61	0.0606	0.1316	90%
162	3	61	0.1227	0.1496	85%
162	4	61	0.0709	0.1630	79%
163	1	63	0.1118	0.2000	84%
163	2	63	0.1651	0.1541	87%

163	3	63	0.0508	0.1827	75%
163	4	63	0.0866	0.1684	75%
164	1	61	0.1020	0.1855	77%
164	2	61	0.1237	0.1817	82%
164	3	61	0.1609	0.1294	87%
164	4	61	0.0759	0.1956	79%
165	1	62	0.0837	0.2000	66%
165	2	62	0.0490	0.1577	79%
165	3	62	0.1149	0.1572	84%
165	4	62	0.1573	0.1989	77%
Average			0.1057	0.1705	80%

Although PAT data are useful for characterizing inter-laboratory performance in the analysis of crystalline silica, the results cannot be used for method validation or to characterize intra-laboratory variability. For method validation, the mass of material on the samples must be known with a high degree of certainty. Although substantial improvements have recently been made, it has been historically difficult to prepare crystalline silica PAT samples with a high degree of precision. Thus, PAT sample preparation errors contribute to the total analytical variability as characterized by the RSDs of the sample results reported to AIHA. In addition, laboratory results are compared with a reference value, which is the mean of a group of sample results reported by participating laboratories, not to the known or “true” quantity used to spike the samples. The reference mean can be affected by a variety of factors. For example, the analytical equipment and methods vary between labs. For PAT Round 165, there were 38 (61 percent) laboratories that reported using XRD methods, 22 (36 percent) laboratories that reported using IR methods, and two (3 percent) laboratories that reported using colorimetric methods. IR analyses might bias the sample high because the amorphous silica fraction present in the PAT samples contributes to the result if left uncorrected. The laboratories that analyze crystalline silica using colorimetric techniques, although small in number, also contribute to apparent inter-laboratory variability because of the relatively greater imprecision inherent to that methodology.

The analytical standard reference material used by laboratories in these analyses might also be different in homogeneity and quality from the National Institute of Standards and Technology (NIST, formerly the National Bureau of Standards) standard reference material (SRM) 1878a. Furthermore, the reference mean has been determined in a variety of ways over the years. Sometimes the mean of the results from all the laboratories reporting PAT sample results were used as the reference value. Other times only the results from laboratories that meet the criteria of being a “reference laboratory” were used to calculate the mean that is used as the reference value. For these reasons, the results obtained from the PAT data (i.e., measures of RSDs and recoveries obtained from results reported by the laboratories) will usually be higher than a particular laboratory's internal estimated CV_1, and cannot be used to estimate the precision that can be achieved by a laboratory implementing one of the analytical methods.

To evaluate whether there has been any change in overall laboratory performance since the period covered by the PAT data described above, OSHA obtained the aggregate results of PAT samples for rounds 160 to 180 (21 rounds) conducted between June 2005 and February 2010. However, OSHA believes that, because of AIHA's change in practice to cap the RSD at 20 percent for the purpose of establishing performance limits, the later data are too limited to adequately characterize trends in total variability experienced by participating laboratories.

OSHA's Experience With the Proficiency Analytical Testing Program

OSHA's own experience with the PAT program illustrates that results obtained from PAT samples are not suitable measures of analytical accuracy and precision. Recent PAT data from OSHA's SLTC were obtained for PAT Rounds 160-180 covering a period from June 2005 through February 2010 (OSHA SLTC, 2010). A total of 88 PAT samples from the 22 rounds were analyzed by XRD for crystalline silica using OSHA Method ID-142 (revised December 1996). Percent recovery was calculated by dividing the total micrograms of crystalline silica reported by the SLTC laboratory by the reference values determined by the reference laboratories that participated in the same PAT rounds.

The percent recovery is plotted over a range of reference values in Figure IV.B-3. The mean recovery was 99 percent, and the RSD for this set of samples was 19 percent, with a range of 55 to 165 percent. A total of 71 samples (81 percent) were in the range of ±25 percent of the reference mean, indicating that a large proportion of samples was in reasonable agreement with the reference values. Two of the samples in one set (Round 173) were outside the accuracy limits of plus or minus three standard deviations (i.e. z-score greater than 3) from the reference mean, and so a second set of samples was analyzed for the proficiency test.

Figure IV.B-3.

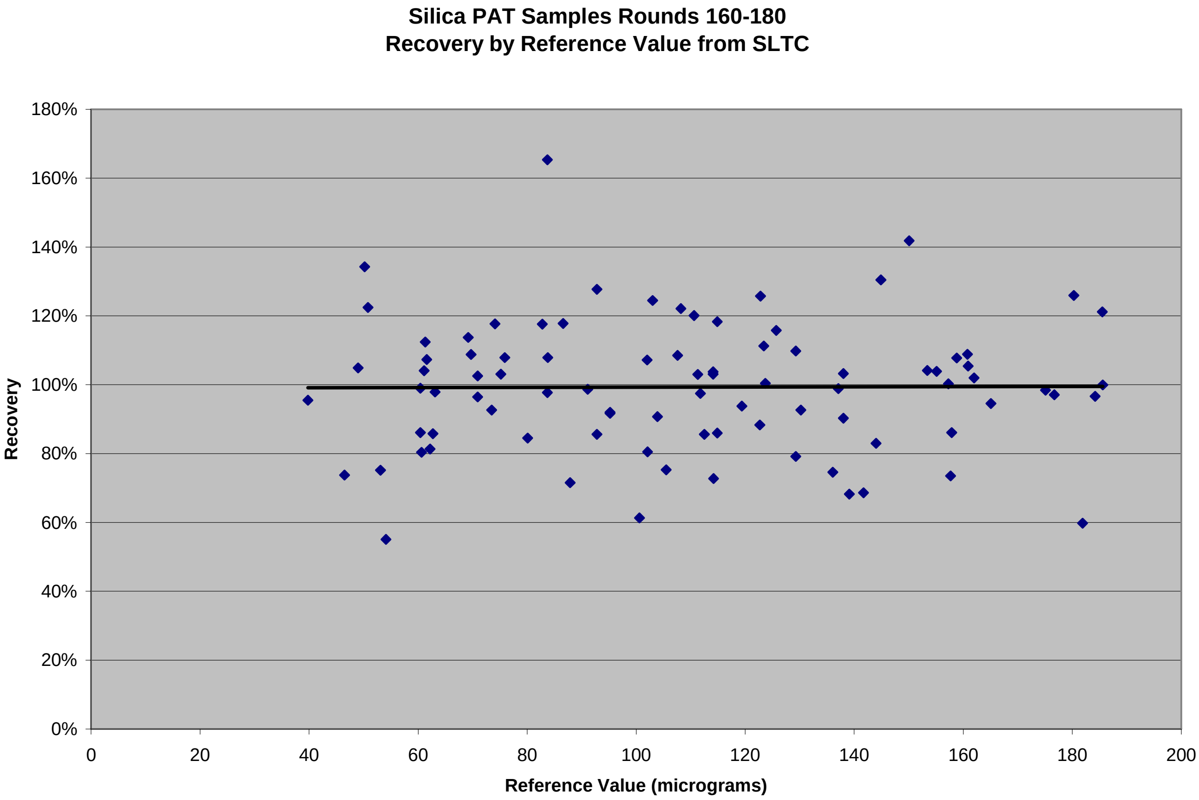

Figure IV.B-3. Recovery vs. Reference Value for Analysis of AIHA PAT Crystalline Silica Samples by SLTC for Rounds 160–180

The overall RSD of 19 percent for this set of samples is substantially greater than the CV_1 of 10.6 percent cited in OSHA Method ID-142 (revised December 1996), and it is higher than the various CV_1s that were obtained from the analysis of quality control samples analyzed at SLTC. Based on OSHA's experience, estimates of the RSD from the PAT data are consistently higher than the precision that is achievable by individual laboratories and cannot be used to estimate analytical precision.

Recommendations for Improved Inter-Laboratory Precision

The total variability seen among laboratories participating in the PAT program for crystalline silica is larger than that seen for metals or solvents. The RSD for metals and solvents ranges from 4 to 6 percent, whereas the RSD for crystalline silica ranges from 14 to greater than 20 percent. One study evaluated laboratory practices in an effort to identify factors contributing to the higher variability seen among labs analyzing crystalline silica (Eller, 1999b). Questionnaires were sent to labs that participated in PAT Round 133, and were completed by 80 of the 82 labs, a 98-percent response rate. The responses to the questionnaires among eight labs whose analysis of the PAT samples were outside the "normal" range, identified by statistical analysis as "outliers," were compared with the practices reported by laboratories whose results were within ±40 percent of the group mean.

Poor accuracy and precision were attributed to five factors: 1) six different reference materials were used, 2) four of the labs calibrated equipment annually or even less frequently, 3) three of the labs reported an LOD >30 µg, 4) three labs did not use a standard less than 15 µg for calibration, and 5) two labs used only three or fewer calibration standards. Based on the response from laboratories that achieved the highest level of accuracy and precision, Eller (1999b) made the following recommendations:

> Use only NIST SRM 1979 for reference material and correct for purity. (Note: Presently, quartz is NIST SRM 1878a, and cristobalite is SRM 1879a. Use a certified SRM for tridymite when and if it becomes available.)
>
> Check calibration each day that samples are analyzed.
>
> Use five or more standards to prepare calibration curve.
>
> Use additional low level standards (as low as 10 µg/sample).
>
> Optimize methods and instruments to obtain an LOD <15 µg.

OSHA believes that such varying practice and less rigorous quality control procedures as documented by Eller (1999b) contribute to the higher total variability seen for crystalline silica as compared with other common analytes. The proposed OSHA standard requires employers to use laboratories that engage in certain practices such as those recommended by Eller (1999b) (see Section X of the preamble to the proposed rule, Summary and Explanation). OSHA believes that these proposed requirements will further reduce total variability in the analysis of crystalline silica by XRD and IR. OSHA is inviting comment on the experiences of laboratories that adhere to these or other practices designed to improve analytical precision.

Preliminary Conclusions

OSHA preliminarily concludes that it is technologically feasible to reliably measure exposures of workers at the proposed PEL of 50 µg/m^3 and action level of 25 µg/m^3. OSHA bases this preliminary conclusion on available information describing the performance of respirable dust sampling devices (e.g., personal cyclone samplers) and on the documented precision of nationally recognized XRD and IR methods to analyze respirable dust samples for crystalline silica content.

OSHA notes that, in certain circumstances, its existing general industry PELs already limit worker exposures to the proposed PEL of 50 µg/m^3 for respirable crystalline silica. The current general industry PEL is calculated using the formula: 10 / (2 + % quartz). Thus, the exposure limit is dependent on the silica content of the dust. The existing PEL is equivalent to (or less than) the proposed PEL when the quartz content of respirable dust is 2 percent or less. For example, the existing PEL for respirable dust containing 2 percent quartz is 2.5 mg/m^3, which corresponds to a concentration of respirable quartz of 0.05 mg/m^3, or 50 µg/m^3 (i.e., 2 percent of 2.5 mg/m^3). Thus, the proposed PEL of 50 µg/m^3 is at the low end of the range of exposures allowed under the current formula standard. Furthermore, the current general industry PEL for cristobalite is half that of quartz, or 50 µg/m^3 for dusts containing 100 percent cristobalite. Thus, in these limited circumstances, OSHA has successfully enforced its existing standards.

With regards to the accuracy of sampling respirable dust, there are several personal cyclone sampling devices commercially available that conform closely to the ISO/CEN particle size selection criteria; these include the Dorr-Oliver 10 mm nylon cyclone, currently specified by OSHA's Method ID-142, MSHA's Method P-2, and NIOSH's Method NMAM 7500 for crystalline silica; the Higgens-Dewell aluminum cyclone specified in the NIOSH Method NMAM 7500; the SKC aluminum cyclone; and the BGI GK 2.69 cyclone. For most particle size distributions encountered in the work environment, the variation of respirable particles collected by these devices will be within ±20 percent, and often within ±10 percent, of that specified by the ISO/CEN model. OSHA believes that this degree of bias against the ISO/CEN model is within a reasonable error to adequately assess worker exposures to respirable dust.

OSHA's XRD method has an LOQ of 10 µg for quartz and 20 µg for cristobalite. Therefore, sampling devices must be able to collect at least this much material over a full work shift to evaluate worker exposures against the proposed PEL and action level. Flow rates for the Dorr-Oliver, Dewell-Higgens, and SKC cyclones are 1.7, 2.2, and 2.2 L/min, respectively, to conform to the ISO/CEN model. As such, all of these devices are capable of collecting at least 10 µg of quartz with a four-hour air sample at concentrations equal to the proposed PEL and action level. A higher flow rate device, the BGI GK 2.69, has a recommended flow rate of 4.2 L/min, and can collect more than 10 µg quartz with a 1-hour sample at the proposed PEL. For cristobalite, all of these samplers can collect at least 20 µg in a full-shift sample, and the BGI GK 2.69 can collect a sufficient amount of cristobalite in a 4-hour sample at the proposed PEL and action level to exceed OSHA's LOQ. Therefore, OSHA preliminarily concludes that personal sampling devices are commercially available that permit collecting a sufficient sample of crystalline silica for analysis over a work shift at concentrations equal to the proposed PEL and action level.

OSHA also preliminarily concludes that available analytical methods are capable of measuring crystalline silica with sufficient precision to provide reliable results when full-shift air samples are taken in concentrations equal to the proposed PEL and action level. For the OSHA XRD Method ID-142 (revised December 1996), precision ($\pm 1.96 \times \sqrt{0.106^2 + 0.05^2}$) is ±23 percent at a working range of 50 to 160 µg crystalline silica. The NIOSH and MSHA XRD and IR methods report a similar degree of precision. A full-shift 8-hour sample (480 minutes) taken using a Dorr-Oliver cyclone operated at 1.7 L/min will result in 816 L of air being sampled, which, at the proposed PEL of 50 µg/m^3, will collect 41 µg of crystalline silica. This amount is just below the low end of the validation range for OSHA's method. Studies by OSHA's SLTC to evaluate the precision of ID-142 (revised December 1996) at lower filter loadings have shown an acceptable level of precision is achieved at filter loadings of approximately 40 and 20 µg corresponding to the amounts collected from full-shift sampling at the proposed PEL and action level, respectively. This analysis showed the precision of the OSHA method for quartz at filter loadings of 40 µg was 17 percent and at filter loadings of 20 µg was 19 percent. For cristobalite, the precision was 19 percent at filter loadings of both 40 and 20 µg. OSHA believes that these results demonstrate that the

OSHA XRD method is capable of achieving acceptable precision to evaluate exposures at the proposed PEL and action level.

Analysis of AIHA PAT data to evaluate inter-laboratory variability in sample analysis for crystalline silica indicates that the majority of laboratories obtain analytical results that are within reasonable agreement; for each sample distributed over 10 PAT rounds conducted between April 2004 and June 2006, an average of 80 percent of laboratories reported sample results that were within ±25 percent of the mean reference value for filter loadings ranging from 49 to 165 µg. There was a similar degree of agreement between labs at the lower end of the range (≤ 70 µg). OSHA believes that the PAT data show that an acceptable level of variability is achieved by most laboratories most of the time. OSHA is proposing requirements for employers to use laboratories that engage in certain quality control practices that the Agency believes will further reduce variability in sample results between labs. In addition, the change from the existing formula PEL to the proposed PEL will allow for the direct comparison of a sample result with the PEL, which simplifies the assessment of compliance by eliminating the need to calculate the PEL based on the percent silica content and eliminates the sampling and analytical error associated with the determination of the mass of respirable dust levels in addition to the calculation of the percent silica content. Therefore, OSHA preliminarily concludes that it is technologically feasible to obtain reliable analytical results from XRD or IR analysis at filter loadings that equate to full-shift sampling of respirable crystalline silica at the proposed PEL and action level.

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CONTROLLING SILICA EXPOSURE

Asphalt Paving Products

Description

Silica-containing materials are commonly used as aggregate to add bulk and durability to asphalt mixtures and blocks (unit pavers) used for pavement construction, rehabilitation, and/or maintenance. Common aggregates for asphalt paving products include sand, gravel, crushed stone, and reclaimed asphalt pavement (RAP) and account for about 95 percent of the total mixture by weight. Additionally, virgin portland cement is sometimes added as a stabilizer (ERG-GI, 2008). For the purposes of this discussion, manufacturing is regarded as the production of asphalt paving products at stationary central mix asphalt plants (versus mixed-in-place asphalt paving mixtures at construction sites). Asphalt paving product manufacturing facilities are classified in the six-digit North American Industry Classification System (NAICS) code 324121, Asphalt Paving Mixture and Block Manufacturing.

There are two types of central mix plants broadly classified as batch mix plants and drum mix (continuous) plants, depending on the process by which the raw materials are mixed. There are also two commonly used types of asphalt paving mixtures that are produced at mix plants: hot mix and cold mix.[55]

Hot mix asphalt is a hot mixture of asphalt binder (cement) and well-graded, high quality aggregate. When producing hot mixes in batch plants, the aggregate is dried and heated first, then transported to a screening unit which separates the aggregate by size and deposits the graded aggregate into heated storage bins. Transporting, drying, and screening of aggregate are significant sources of silica dust. Aggregate and mineral filler (another source of silica) are then weighed and transferred to a mixer called a pug mill, where they are mixed with heated asphalt cement to produce asphalt concrete. In hot mix drum plants, a rotary dryer dries a measured amount of aggregate and mixes it with heated asphalt cement that is introduced directly into the dryer chamber (ERG-GI, 2008). Both batch and rotary drum hot mix plants have similar potential to emit silica dust.

Cold mix asphalt is an unheated mixture of aggregate and emulsified (or cutback) asphalt binder. Cold mixes can be mixed in place, made in a standard hot mix plant without any heating, or made by a purpose-designed stationary or portable cold mix plant. Because cold mixes do not require dryers or screens, this equipment is eliminated as a source of silica exposure at plants producing cold mix asphalt (ERG-GI, 2008). Silica dust can still be released during aggregate transfer, conveying, and mixing processes.

Asphalt concrete blocks are unit pavers made from asphalt cement, crushed-stone aggregate, and inorganic dust or filler. Facilities that manufacture these pavers feed the raw materials into a block molding machine where the mixture is rammed, pressed, or vibrated into its final form. The finished

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[55] A new “warm mix” technology, widely used in Europe, has also become popular in the United States over the past decade. Although similar to hot mix asphalt, warm mix technologies differ in that they allow asphalt mixes to be produced and placed at lower temperatures than hot mixes. Warm mix asphalt may be produced in hot mix plants with some plant modifications. The Federal Highway Administration (FHWA) reports that the benefit is a reduction in energy consumption required by burning fuels to heat traditional hot mix asphalt. The lower production temperature also allows reduced emissions from burning fuels and decreased fumes and odors generated at the plant and the paving site (FHWA, 2008). Although many asphalt plants have begun using warm mix asphalt technologies as an alternative to hot mixes, this trend does not affect workers’ exposure to silica.

pavers are then stacked and allowed to cure. Asphalt-block pavers are available in many sizes, shapes, colors, and finish textures, and are a paving alternative with applications including roads, plazas, parks, playgrounds, piers, driveways, sidewalks, and industrial flooring (ERG-GI, 2008).

Asphalt paving product workers can be exposed to silica-containing dusts when handling loose, dry aggregate; during crushing and screening activities; and when mixing aggregate with asphalt cement (ERG-GI, 2008). The job categories with potential for exposure to silica include facility operator, front-end loader operator, and maintenance worker. Table IV.C-1 summarizes the major activities and sources of exposure in this industry.

There is potential for further exposure in facilities with recycling activities that include crushing and screening of recovered concrete and/or RAP. These workers have job titles such as crusher operator and tender (belt picker, laborer), and their activities might involve the use of mobile rubble crushing plants, lump breakers, and screeners. For a discussion of crusher operators and tenders refer to Section IV.C.31 – Rock-Crushing Machine Operators and Tenders.

Table IV.C-1

Job Categories, Major Activities, and Sources of Exposure of Workers

in the Asphalt Paving Products Industry (NAICS 324121)

Job Category*	Major Activities and Sources of Exposure

Table IV.C-1

Job Categories, Major Activities, and Sources of Exposure of Workers

in the Asphalt Paving Products Industry (NAICS 324121)

Facility Operator	Controls and monitors production of asphalt paving products with an automated computer-controlled process. Operates conveyors, elevators, dryers, and mixing equipment, and dispenses product into trucks or storage silos from a control room/booth. Most control rooms are fully enclosed and ventilated with little potential for exposure to silica-containing dusts. • Dust from "manually" operating production operations (when necessary). • Dust from material handling activities and the plant yard/haul road (when control rooms are not fully enclosed).
Front-End Loader Operator	Transports raw materials using a front-end loader. Might oversee receipt of raw materials via truck or rail car. • Dust from manually transporting sacks of specialty materials (when necessary). • Dust from material handling activities (when the front-end loader is not equipped with a fully enclosed and ventilated cab). • Dust from the plant yard/haul road.
Maintenance Worker	Inspects, services, repairs, and adjusts equipment. Cleans up around the facility. • Dust from the plant yard/haul road, raw material storage piles, conveyors, weight scales, and process equipment (such as dust collectors).

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the facility.

Source: ERG-GI, 2008.

Baseline Conditions and Exposure Profile

The following sections describe baseline conditions and the exposure profile for each affected job category based on two OSHA Special Emphasis Program (SEP) inspection reports, previously described in ERG-GI (2008).[56] After reviewing the information presented above, OSHA concludes that cold mix plants are no dustier than hot mix plants (and might be somewhat less dusty as they lack dryers and screens). Furthermore, some plants equipped to produce hot mix also produce cold mixes. Therefore, in the absence of information specific to cold mix plants, OSHA preliminarily concludes that the available exposure data apply to both hot and cold mix production, but might overestimate the exposure of some workers when the plant is making a product using cold mix techniques.

The exposure data available to OSHA for this industry include one sample greater than 6 hours duration (53 micrograms per cubic meter [μg/m^3]) and four samples between 4 and 5 hours duration (all below the limits of detection [LOD] of 19 to 21 μg/m^3).[57] Had the sample durations been longer, all four samples would have resulted in lower volume-adjusted non-detectable concentrations.[58] Although limited, these sources represent the best data available to OSHA for workers in the asphalt paving products industry. Table IV.C-2 summarizes the exposure information for the affected job categories.

Baseline Conditions for Facility Operators

The only information available for facility operators is one personal breathing zone (PBZ) respirable quartz exposure result at the LOD, which in this case is less than or equal to 21 μg/m^3 (290-minute sample). This value was obtained for an operator working in an air-conditioned room at a continuous feed asphalt plant where visible dust had been greatly reduced by maintenance and adjustments to an existing ventilation system on the blending equipment and water spray in the

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[56] As noted in Section IV.A – Methodology, OSHA's exposure profiles give preference to samples that are 6 hours or longer. However, due to the extremely limited exposure data available for the asphalt paving industry, here OSHA has also considered data from four samples greater than 4 hours duration. In this case all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) derived from samples of 4-hours or longer, assuming the exposure concentration during any unsampled portion of the shift was the same as the concentration during the period sampled. Unless explicitly stated otherwise, all results discussed in the additional controls section meet the same criteria. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

[57] Results reported as "none detected" are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

[58] Assuming that these workers' exposures remain negligible or very low, an increased sampling time and subsequent increase in collected volume would result in a lower nondetectable concentration (i.e., the quantity of silica would remain consistent, but the volume would increase). Note that where full-shift results are available for a job category, OSHA has relied primarily on those better-supported data.

sand/aggregate drier exhaust system (OSHA SEP Inspection Report 300576204). In the absence of additional information, OSHA preliminarily concludes that this is

Table IV.C-2
Respirable Crystalline Silica Exposure Range and Profile for Workers in the Asphalt Paving Products Industry (NAICS 324121)

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean (μg/m^3)**	**Median (μg/m^3)**	**Min (μg/m^3)**	**Max (μg/m^3)**		**<25 (μg/m^3)**	**≥25 and ≤50 (μg/m^3)**	**>50 and ≤100 (μg/m^3)**	**>100 and ≤250 (μg/m^3)**	**>250 (μg/m^3)**
Facility Operator	1	21	21	21	21		1 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Front-End Loader Operator	2	37	37	20	53		1 (50%)	0 (0%)	1 (50%)	0 (0%)	0 (0%)
Maintenance Worker	2	20	20	20	20		2 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Totals	**5**	**27**	**20**	**20**	**53**		**4** **(80%)**	**0** **(0%)**	**1** **(20%)**	**0** **(0%)**	**0** **(0%)**

Notes: All samples are personal breathing zone (PBZ) results for durations of 272 minutes or more and represent 8-hour time-weighted average exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Source: ERG-GI, 2008.

the baseline working condition for facility operators and that the baseline exposure level for these workers is 21 μg/m^3.

Because of the limited data available, OSHA also reviewed the exposure results for batch operators in the ready-mixed concrete sector (addressed elsewhere in this analysis). Batch operators at ready-mixed concrete plants perform tasks similar to those performed by plant operators at asphalt plants (both hot and cold mix). The three PBZ exposure results available for batch operators are all less than the LOD (ERG-GI, 2008). Although these data are for a different industry sector, they lend additional support to the exposure result for facility operators in the asphalt paving products manufacturing industry.

Baseline Conditions for Front-End Loader Operators

Based on a review of two silica results obtained during two OSHA inspections at asphalt plants (ERG-GI, 2008), OSHA found that for front-end loader operators both the median and mean exposure levels are 37 μg/m^3 and that results range from the LOD (in this case 20 μg/m^3, for a 290-minute sample) to 53 μg/m^3 (435-minute sample). At both of the plants, the front-end loader operators scooped sand, aggregate, and other filler materials and dumped them into hoppers (OSHA SEP Inspection Report 2116507 and 300576204). At one of the plants, previous maintenance work on existing dust controls had substantially reduced visible dust on the sampling date. OSHA concludes that the working conditions for these front-end loader operators are typical of baseline conditions.

Just as it did for the previous job category, OSHA also reviewed the exposure results for front-end loader operators in the ready-mixed concrete sector. These workers are referred to as raw material handlers in the ready-mixed concrete sector discussion. The eight full-shift PBZ samples for raw material handlers have a median of 13 μg/m^3, a mean of 23 μg/m^3, and a range from 10 μg/m^3 to 57 μg/m^3. Although the ready-mixed concrete exposure data are for a different (but similar) industry sector, they lend support to the preliminary finding that the true median exposure for front-end loader operators in the asphalt paving products industry is similar to, or possibly somewhat less than, the median of 37 μg/m^3 in Table IV.C-2.

Based on the best available information, OSHA preliminarily concludes that at least half (50 percent) of front-end loader operators are currently exposed to silica levels of 37 μg/m^3 (the median level presented in Table IV.C-2) or less, and that most exposures are expected to be below the proposed 50 μg/m^3 PEL.

Baseline Conditions for Maintenance Workers (Laborers)

OSHA reviewed two PBZ samples obtained during the OSHA inspection at the same asphalt plant previously described (where maintenance recently performed on existing controls had reduced visible dust). These laborers serviced machinery, picked trash from the belt carrying aggregate to the blender, and assisted with trucks (OSHA SEP Inspection Report 300576204). OSHA preliminarily concludes that these are baseline conditions for maintenance workers. As summarized in Table IV.C-2, the mean and median PBZ respirable quartz exposure level for these maintenance worker results is 20 μg/m^3 (LOD) (ERG-GI, 2008). This value is based on two PBZ samples (sample durations of 282 and 297 minutes).

OSHA also reviewed exposure data for maintenance workers in the ready-mixed concrete industry (ERG-GI, 2008). The five full-shift PBZ samples for these workers have a median of 11 μg/m^3 and a mean of 27 μg/m^3. These results ranged from 11 μg/m^3 to 58 μg/m^3. The findings in the ready-mixed concrete industry (an industry that is similar to asphalt paving product manufacturing) suggest that typical exposures for maintenance workers might be less than 50 μg/m^3 and so support the available results for workers in this job category in the asphalt paving industry.

Based on the best available exposure data, OSHA preliminarily concludes that the results summarized in Table IV.C-2 represent baseline conditions for this job category. Thus, the preliminary baseline exposure level is estimated to be 20 μg/m^3.

Additional Controls

Additional Controls for Facility Operators

OSHA does not anticipate that the routine activities of facility operators will generate silica concentrations in excess of 50 μg/m^3 because the facility operator's work station is typically isolated from production operations. Therefore, additional exposure controls are not required for this job category. In those instances where elevated exposure might occur, silica levels can be reduced through the use of fully enclosed and ventilated operator control rooms and/or by controlling adjacent sources of silica-containing dust through local exhaust ventilation (LEV) and dust suppression methods.

Although few data are available regarding exposure reduction through LEV or dust suppression methods, these methods are generally effective in controlling silica dust. In a 272-minute sample, OSHA measured a PBZ concentration less than the LOD (21 μg/m^3 in this case) for a facility operator who worked in an air-conditioned booth at the previously discussed hot-mix asphalt plant where maintenance and adjustments to existing local exhaust ventilation (on the blender) and wet scrubber (aggregate drier exhaust) had greatly reduced visible dust (OSHA SEP Inspection Report 300576204).

Related studies with the use of dust suppressants suggest that a significant reduction in silica exposure can be achieved with the proper use of dust suppressants to control fugitive dust emissions associated with haul roads, and aggregate storage and handling. For example, a university study compared the performance of four dust suppressants (lignosulfonate, calcium chloride, magnesium chloride, and no treatment) on an unpaved roadway over 4 1/2 months. The dust suppressants reduced fugitive dust emissions by 50 to 70 percent when compared with the untreated section (Addo and Sanders, 1995).

Additional Controls for Front-End Loader Operators

Based on summary information from Table IV.C-2 and from the ready-mix concrete industry, OSHA finds that the exposures of at least half (50 percent) of front-end loader operators is already less than 50 µg/m^3. In those instances where elevated exposure still occurs, the silica exposure of front-end loader operators will be reduced through improved maintenance of existing dust control systems. Furthermore, silica levels can be reduced through the use of fully enclosed, sealed, ventilated, and maintained operator cabs and/or by controlling adjacent sources of silica-containing dust through LEV and wet or other dust suppression methods.

Dust suppression methods are particularly beneficial for work with sand and aggregates, such as those that are manipulated by front-end loader operators. Simple foams provide dust control benefits similar to water spray, but offer increased dust control capacity compared with the same volume of water (Midwest-Edwards, 2009). For this reason a simple foam applied at the hopper can be an appropriate dust suppression method for aggregates that will eventually pass through a drier (where energy is required to remove moisture). The foam will provide dust suppression benefits for the front-end loader operator and downstream workers (such as belt pickers and maintenance workers), and compared with plain water the foam will contribute less moisture that must be removed later in the drier. OSHA notes that it is important to consider the ultimate use of the aggregate and the compatibility of dust suppressant substances to that use (Midwest-Edwards, 2009).

For facilities where elevated exposures persist, well-sealed, air-conditioned cabs maintained under positive pressure with filtered air provide an additional control option for loader operators. While cabs are available, the cabs are not consistently used as a dust control measure. Operators frequently open the windows and cab interiors can contain a notable amount of silica-containing dust. Additionally, NIOSH and the Mine Safety Health Administration (MSHA) report that, in general, heavy equipment cabs are poorly sealed and that original-equipment ventilation design does not necessarily provide positive pressure or appropriately filter air (NIOSH 2009-123, 2009; NIOSH Mobile Cab Web site, no date; MSHA 2000a, 2000b, 2000c). To effectively reduce the silica exposure of loader operators, cabs will need to be modified.

Although data documenting the effectiveness of such enclosures (i.e., equipment cabs) at asphalt paving product facilities are not available, data from other sources suggest a 94 to 99.5 percent reduction in respirable dust (inside compared with outside the cab) with well-sealed, air-conditioned, and filtered cabs (ERG-GI, 2008). The precise reduction depends on dust size and the ventilation system. Operators working in heavy equipment cabs designed to meet the American Society of Agricultural Engineers' (ASAE) standard should experience exposure reductions in this general range. Although these cabs require regular maintenance to function properly and concerns regarding the construction standards of new heavy equipment exist, OSHA estimates that appropriately fitted and maintained cabs would offer a similar reduction in silica exposure for front-end loader operators in the asphalt paving products industry (ERG-GI, 2008).

Additional Controls for Maintenance Workers (Laborers)

Based on the exposure profile (Table IV.C-2), OSHA estimates that the current exposure level for most maintenance workers (laborers) is less than 25 µg/m^3. In those instances where elevated exposure occurs, silica levels can be reduced by: 1) controlling adjacent sources of silica-containing dust (e.g., yard dust and dust associated with aggregate storage and handling activities) through wet or other dust suppression methods (discussed above), 2) installing enclosures and exhaust ventilation, and/or 3) using wet cleaning methods and high-efficiency particulate air (HEPA)-filtered vacuuming. For some maintenance and repair activities engineering controls might not be feasible (e.g., servicing the inside of a dust collector/bag house). In these cases respiratory protection might be necessary to control worker exposure to silica.

The use of effective exhaust ventilation in controlling worker exposures to silica is illustrated by a Canadian study of a rock crushing plant that installed an LEV system with a wet dust collector (Grenier, 1987). To evaluate the system, researchers collected area samples for silica at five locations inside the facility before and after the original general exhaust ventilation system was replaced with the LEV system. Operation of the LEV system was associated with reductions of silica levels ranging from 20 percent to 79 percent.

In another study, the U.S. Bureau of Mines designed and evaluated a total mill ventilation system (TMVS) for a clay processing facility that performed crushing and screening operations (Cecala et al., 1996). Use of the system was associated with an average respirable dust reduction of 40 percent throughout the facility. Although personal samples were not collected and silica exposures were not determined, OSHA anticipates that similar reductions in respirable dust levels in asphalt paving products facilities would result in reduced exposures for maintenance workers.

NIOSH repeatedly recommends vacuuming with an approved HEPA-filtered vacuum or the use of wet cleaning methods to minimize worker exposure to hazardous air contaminants such as asbestos, silica, and heavy metals during housekeeping activities (ERG-GI, 2008). Additionally, OSHA general industry standards for asbestos and cadmium specify that work surfaces are to be cleaned wherever possible by vacuuming and that HEPA-filtered vacuuming equipment must be used for vacuuming.

Feasibility Finding

Feasibility Finding for Facility Operators

OSHA estimates that most facility operators experience exposure levels less than 25 µg/m^3. This finding is based on one sample result and analogous exposure data from the ready-mixed concrete industry. OSHA finds that most facility operators are not likely to have silica exposures in excess of 50 µg/m^3 because they are usually isolated from production operations in a control room or booth. Additional exposure controls are not anticipated for this job category. In instances where elevated exposures might occur, OSHA estimates that silica levels can be reduced to 50 µg/m^3 or less through the use of fully enclosed and ventilated operator control rooms and/or by controlling adjacent sources of silica-containing dust through LEV.

Feasibility Finding for Front-End Loader Operators

OSHA estimates the preliminary baseline exposure level for front-end loader operators to be less than 50 µg/m^3. This finding is based on two sample results and analogous exposure data from the ready-mixed concrete industry. Additional exposure controls are not anticipated for this job category; however, should elevated exposure occur, OSHA estimates silica levels can be reduced to 50 µg/m^3 or less through the use of fully enclosed, sealed, ventilated, and maintained operator cabs and/or by controlling adjacent sources of silica-containing dust through LEV or dust suppression methods.

Feasibility Finding for Maintenance Workers (Laborers)

OSHA estimates the preliminary baseline exposure level for all maintenance workers to be less than 25 µg/m^3. This finding is based on two sample results (both under 25 µg/m^3) and relevant exposure data from the ready-mixed concrete industry. While a need for additional controls is not anticipated, in instances where elevated exposures might occur OSHA estimates silica levels can be reduced to 50 µg/m^3 or less by: 1) utilizing wet or other dust suppression methods, 2) installing engineering controls such as enclosures and LEV, and 3) using wet cleaning methods and HEPA-filtered vacuuming.

Overall Feasibility Finding for Asphalt Paving Facilities

In summary, OSHA preliminarily concludes that, by implementing additional controls for some workers, asphalt roofing facilities can achieve exposure levels of 50 µg/m^3 or less for most of their workers most of the time.

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[OSHA SEP Inspection Report 300576204] OSHA Special Emphasis Program Inspection Report 300576204.

Asphalt Roofing Materials

Description

Manufacturers of asphalt roofing materials produce roofing products that can be classified in three broad categories: shingles, surfaced and smooth roll roofing, and asphalt-saturated felt rolls. Shingles and roll roofing are outer roof coverings, and saturated felts are inner roof coverings used as underlayment protection for the exposed roofing materials. Shingles and roll roofing consist of three basic components: 1) a base material of organic felt or fiberglass mat, 2) an asphalt coating, and 3) a surfacing of mineral granules. Saturated felts consist of dry felt saturated with asphalt (ERG-GI, 2008). These manufacturers are classified in the six-digit North American Industry Classification System (NAICS) 324122, Asphalt Shingle and Coating Materials Manufacturing.

The production of asphalt roofing materials is a continuous process performed on a roofing machine that begins with a roll of base material at one end and concludes with the finished product at the other end (ERG-GI, 2008). In simple terms, the principal steps in the manufacturing process include unwinding a roll of base material and saturating it with asphalt by passing this continuous sheet of material through a series of hot asphalt tanks, ending with a coater unit that applies a final layer of mineral-stabilized asphalt (ERG-GI, 2008). After leaving the coater unit, the base material for either shingles or roll roofing passes through a mineral applicator where minerals are pressed into the hot, coated surface on both sides.[59] The mineral stabilizers increase the coating's resistance to weathering and fire. After application of the mineral surfacing, the coated sheet is rapidly cooled and air dried. A strip of adhesive is applied to the dry material, which is then cut and packaged (ERG-GI, 2008).

Although this process is highly automated, employees ensure the flow of raw materials and monitor the machinery. Mineral stabilizer material is delivered by truck, conveyed to storage bins, heated, and then mixed with the coating asphalt. Granules and back surfacing materials are brought by rail or truck and mechanically or pneumatically conveyed to storage bins and hoppers (ERG-GI, 2008). Each step in the operation has a worker assigned to it, and exposures are primarily from the materials that are added at that step. For the purposes of this discussion, workers with potential silica exposure have been identified as production operators and (mineral) material handlers. Their job descriptions are described in Table IV.C-3.

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[59] Typical mineral stabilizers include finely ground slate (5 to 15 percent silica content), limestone (up to 67 percent), dolomite (0 to 3 percent), and trap rock (up to 12 percent). Other materials also may be used (ERG-GI, 2008). Backing minerals include talc (up to 5 percent silica content), sand (75 to 98 percent), or mica (up to 10 percent), while the front side can also receive ceramic granules (ERG-GI, 2008).

Table IV.C-3

Job Categories, Major Activities, and Sources of Exposure of Workers in the Asphalt Roofing Materials Industry (NAICS 324122)

Job Category*	**Major Activities and Sources of Exposure**
Production Operator (coater, press, cooling section, and relief operator)	Monitoring production line operations. • Dust from drying and preheating mineral stabilizer. • Dust from mineral surfacing (pressing minerals such as mica or talc into both sides of the base material). • Dust from mineral storage hoppers and bins in close proximity to the coater.
Material Handler (slate assistant, granule assistant)	Handling and monitoring the use of granules and other minerals and loading the materials into hoppers. • Dust from manually loading materials into hoppers. • Dust from the mineral transfer system. • Dust from mixing silica-containing minerals with coating asphalt.

*Job categories are intended to represent job functions; actual job titles may differ and responsibilities may be allocated differently, depending on the facility.

Source: ERG-GI, 2008.

Baseline Conditions and Exposure Profile

The only available personal breathing zone (PBZ) respirable quartz monitoring data for the asphalt roofing industry are 12 samples from five NIOSH health hazard evaluations (HHE) conducted in the late 1970s at five different facilities (ERG-GI, 2008).[60] These results are summarized in Table IV.C-4. In the absence of other exposure data, these reports provide the most complete information available on silica exposures and represent the best available data.

Because the NIOSH HHEs were all conducted in the 1970s, OSHA reviewed more recent silica exposure data from 1983 through 2001 from OSHA's Integrated Management Information System (IMIS).[61] These data are difficult to interpret because information regarding worker activities, workplace conditions, engineering controls, personal protective equipment, non-detectable sample concentrations,

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[60] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) derived from samples of 6-hours or longer, assuming the exposure concentration during any unsampled portion of the shift was the same as the concentration during the period sampled. Unless explicitly stated otherwise, all results discussed in the additional controls section meet the same criteria. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

and sample duration is not available. However, the IMIS data represent the only other source of more current information to date for this analysis and supplement the NIOSH evaluations.

Asphalt shingles and rolled roofing products are manufactured on high-speed, continuously operating machines. Worker exposure to dust and other particulate matter associated with mineral handling and storage operations is typically controlled through the use of process enclosures and local exhaust ventilation (LEV) hoods. During mineral surfacing, the application of granules and mineral-backing or parting agents generates dust in the mineral application and cooling process areas of the plant. All manufacturers reportedly use LEV and bag-type dust collectors. General dilution ventilation in the cooling sections of the manufacturing line also contributes to lower contaminant exposures, although its effectiveness may vary within the industry (NIOSH 2001-127).

Baseline Conditions for Production Operators

The exposure profile for production operators is based on five PBZ silica samples obtained by NIOSH at four different asphalt roofing manufacturing facilities. The samples have a median exposure of 29 micrograms per cubic meter (µg/m^3), a mean of 56 µg/m^3, and a range from less than 28 µg/m^3 (below sample limit of detection [LOD]) to 131 µg/m^3.[62]

To provide additional insight into the exposure profile for this job category, OSHA examined the IMIS database for relevant exposure information in Standard Industrial Classification (SIC) group 2952. The database contains 17 entries (between August 1983 and July 2001) for workers with job descriptions matching those in the production operator exposure profile. Ten (59 percent) of these samples had detectable silica with a median of 57 µg/m^3, a mean of 120 µg/m^3, and a range from 2 µg/m^3 to 739 µg/m^3. Only positive IMIS results are included in this descriptive analysis because the volume-adjusted reporting limit concentrations for the non-detectable samples are not available. The true median is likely to be lower because seven samples (41 percent) of the IMIS entries representative of roofing machine production line equipment operators are non-detectable.

OSHA has determined that the exposure profile derived from the NIOSH HHE reports is the best characterization of these workers' baseline exposure level. As indicated in Table IV.C-4, for production operators this HHE data has a median of 29 µg/m^3, indicating that even in the 1970s the exposure level of most production operators was less than 50 µg/m^3.

Asphalt roofing industry information for other air contaminants suggests that more recent silica exposure values could be lower. The asphalt roofing products manufacturing industry summarized exposure data collected during 1980 to 1997 at 53 plants of four companies. The data collected was composed of total particulate samples and benzene- or cyclohexane-soluble samples. A review of the data indicates that the average exposures, expressed as total particulates or as solubles, declined after 1990. Silica exposures are also likely to have declined since the successfully implemented engineering controls would also be effective for silica. This reduction is attributed to the following circumstances: 1) the

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[61] OSHA reviewed the IMIS data for this industry to supplement the NIOSH data, which, obtained in the 1970s, are considerably older than results available for other industries evaluated for this analysis. For each applicable silica result presented in IMIS as Exposure-Type "T" (time-weighted average), the silica concentration was calculated based on the reported 8-hour TWA PEL and the reported respirable dust exposure level.

[62] Results reported as "none detected" are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

elimination of the initial saturating process due to the introduction of fiberglass mats, which do not require this step; 2) the improvement of capture efficiency of exhaust hoods; 3) the conversion to process enclosures; and 4) the reduction of fugitive emissions associated with the requirements of the Clean Air Act Amendment of 1990 (NIOSH, 2001).

Table IV.C-4
Respirable Crystalline Silica Exposure Range and Profile for Workers in the Asphalt Roofing Materials Industry (NAICS 324122)

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean (μg/m³)**	**Median (μg/m³)**	**Min (μg/m³)**	**Max (μg/m³)**		**<25 (μg/m³)**	**≥25 and ≤50 (μg/m³)**	**>50 and ≤100 (μg/m³)**	**>100 and ≤250 (μg/m³)**	**>250 (μg/m³)**
Production Operators	5	56	29	28	131		0 (0%)	3 (60%)	1 (20%)	1 (20%)	0 (0%)
Material Handlers	7	83	67	29	188		0 (0%)	2 (29%)	3 (43%)	2 (29%)	0 (0%)
Totals	**12**	**71**	**59**	**28**	**188**		**0 (0%)**	**5 (42%)**	**4 (33%)**	**3 (25%)**	**0 (0%)**

Notes: All samples are personal breathing zone (PBZ) results for durations of 360 minutes or more and represent 8-hour time-weighted average exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Source: ERG-GI, 2008.

Internationally, the comparable German asphalt roofing felt and bitumen webs manufacturing industry saw a marked decline in worker quartz exposure over the decades between 1983 and 2004. The Institute fur Arbeitsschultz der Deutschen Gesetzlichen Unfallversicherung (BGIA, 2006) reported that the mean respirable quartz exposure level fell from 150 µg/m^3 (average of more than 225 results from 22 plants for the years 1983 to 1988) to 40 µg/m^3 (average of 22 results from 10 plants between 1995 and 2004). Over the same periods, the median silica result was reduced from 40 µg/m^3 to 10 µg/m^3, and the 90th percentile value (representing the higher individual exposures) was cut by 62 percent to 100 µg/m^3 in the German asphalt roofing industry. Although reductions in the percent quartz in air samples accounted for much of the decline, over the decades the biggest change was in the measured concentration of respirable dust, indicating that improvements in equipment, materials, control technology, and work practices have effectively reduced exposure levels for even the dustiest jobs in this industry.

Similarly, Anttila et al. (2009) examined concentrations of respirable quartz dust from data collected at roofing membrane surfacing plants in Finland from 1975 to 2005. They estimated the mean to be 980 µg/m^3 (n=34) for the years 1975 to 1979. For the years 2000 to 2005, however, the mean for production workers was 380 µg/m^3 (n=27).[63] The authors credit improvements in dust control and work methods implemented in the mid-1980s for reducing average exposures. Although approximately one-third of the data are from personal measurements and two-thirds are from area measurements, the data still demonstrate a greater than two-fold reduction in silica concentrations over a 30-year period.

OSHA believes that, given the implementation of more efficient technology and updated work practices since the NIOSH evaluations in the late 1970s, the U.S. trends and international experience are strong indications that silica exposures in the U.S. have also been reduced in the asphalt roofing materials manufacturing industry. As a result, OSHA estimates that current silica exposure levels are lower by half than those reported in the NIOSH HHE reports of the 1970s.

Baseline Conditions for Material Handlers

The exposure profile for material handlers is based on seven PBZ silica samples collected by NIOSH investigators during HHEs at five different roofing manufacturing facilities. As shown in Table IV.C-4, the exposure profile for these workers has a median of 67 µg/m^3, a mean of 83 µg/m^3, and a range from less than 29 µg/m^3 (below sample limit of detection) to 188 µg/m^3.

Just as it did with the previous job category, OSHA examined the IMIS database for relevant exposure information in SIC group 2952. The database contains 22 entries (December 1979 to July 2001) for workers with job descriptions most representative of material handlers in the roofing materials manufacturing industry. Twelve (55 percent) of the sample entries are positive for silica and have a median of 60 µg/m^3, a mean of 105 µg/m^3, and a range from 21 µg/m^3 to 462 µg/m^3. As indicated previously, only positive IMIS results are included in this descriptive analysis because the volume-adjusted reporting limit concentrations for the non-detectable samples are not available. The true median for this job category is likely to be lower than 60 µg/m^3 because 45 percent (10 samples) of the sample entries are non-detectable.

OSHA has determined that the exposure profile derived from the HHE reports is the best characterization of material handlers' baseline exposure level. The median for this group of workers is 67 µg/m^3 (the exposure profile median level). Based on the same information from NIOSH (2001-127) and BGIA (2006) presented in the discussion of production operators, OSHA finds that the results for material

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[63] The liquid sedimentation technique used in Finland produces respirable quartz concentrations that are 2-fold greater than the commonly used cyclone separation method.

handlers generated from the NIOSH data might overestimate the baseline exposure level for this job category by greater than half.

Additional Controls

Additional Controls for Production Operators

OSHA estimates that 60 percent of production operators currently experience exposure levels of 29 μg/m^3 or lower. This finding is based on five sample results from HHEs, a review of relevant exposure information in the IMIS database, and international trends for this industry. Based on the available data, additional exposure controls will be required for 20 to 40 percent of production operators. In those instances where elevated exposures occur (e.g., at the coater, cooling, and press areas), appropriate control options to reduce silica levels to 50 μg/m^3 or less include adequate LEV and process enclosures, and less dusty housekeeping methods (e.g., high-efficiency particulate air [HEPA]-filtered vacuums). In addition, the use of washed sand can reduce exposure. In an analysis of respirable quartz exposures obtained at two Finnish roofing membrane plants from 1975 to 2005, worker exposure was significantly lower when washed quartz sand was used compared with unwashed quartz sand (Anttila et al., 2009).

Ventilation and Process Enclosures

During two HHEs at asphalt roofing products manufacturing facilities, NIOSH investigators recorded PBZ silica exposures of 131 μg/m^3 and 61 μg/m^3 (non-detectable/sample limit of detection) for one coater operator and one press operator, respectively. In both cases, NIOSH recommended that LEV be provided over the coater and press areas to reduce operator exposures (ERG-GI, 2008). At other roofing products facilities, NIOSH investigators recommended that process enclosures and ventilation systems be serviced/repaired to eliminate fugitive emissions associated with enclosure leaks and less-than-optimal hood capture (ERG-GI, 2008).

At present, the best way to remove process emissions at the coater is through adequate general and local exhaust ventilation in conjunction with full enclosure of the coating process or canopy hoods (over the process). Canopy hoods also can be extended from the coater to the press area to control emissions associated with mineral surfacing/granule application (NIOSH 2001-127).

OSHA does not have data specifically measuring the exposure reductions achieved with adequate ventilation and enclosures in the asphalt roofing products manufacturing industry; however, evidence from similar processes in other industries suggests the size of the reduction that may be achievable. The use of effective exhaust ventilation in controlling worker exposures to silica is illustrated by a Canadian study of a rock-crushing plant (Grenier, 1987). Area samples collected before and after installation of an LEV system with a wet dust collector demonstrated that operation of the system was associated with silica reductions ranging from 20 percent to 79 percent.

Additionally, silica levels below 50 μg/m^3 are reported for a pottery product manufacturing facility with properly enclosed and ventilated process equipment. OSHA reported an exposure level of 29 μg/m^3 for a worker who operated LEV-equipped mixers to which raw materials were transferred from bins by ventilated, automated conveyance equipment (OSHA SEP Inspection Report 300384435). OSHA also obtained a similar result (23 μg/m^3) for a worker who charged mixers, primarily using enclosed automated equipment (OSHA SEP Inspection Report 300180916).

Housekeeping

NIOSH and OSHA both recommend vacuuming with an approved HEPA-filtered vacuum (or the use of wet cleaning methods) as a method to minimize worker exposure to silica in the workplace. During five HHEs at asphalt roofing products manufacturing facilities, NIOSH recommended vacuuming as opposed to compressed air for cleaning fine dust out of process equipment (ERG-GI, 2008). Additionally, OSHA general industry standards for hazardous substances (such as asbestos and cadmium) specify that work surfaces are to be cleaned whenever possible by vacuuming and that HEPA-filtered vacuuming equipment must be used for vacuuming.

Implementing vacuuming as a cleaning method will contribute to lower worker exposure levels. A study of Finnish construction workers compared the silica exposure levels for workers dry sweeping and using alternate cleaning methods. Compared with dry sweeping, estimated worker exposures were approximately three times lower when the workers used squeegees to sweep surfaces, and approximately five times lower when workers used vacuums (Riala, 1988).

Additional Controls for Material Handlers

Based on the exposure profile (Table IV.C-4), OSHA estimates that the current exposure level for at least 29 percent of mineral material handlers is less than 50 μg/m^3. This finding is based on seven sample results from NIOSH HHEs and a review of relevant exposure data from the OSHA IMIS database. Additional controls are required to reduce exposures to 50 μg/m^3 or less for the remaining material handlers (up to 71 percent, but likely many fewer). These control options include local exhaust ventilation, preventive maintenance, and the use of less dusty housekeeping methods such as HEPA-filtered vacuuming.

Local Exhaust Ventilation

Adequate exhaust ventilation and process enclosures for the manufacture of asphalt roofing products have been described previously for the production operator job category and are equally applicable to mineral handling systems. NIOSH reports that LEV is generally installed at slate and dust drums, granule and backdust applicators, and transfer rolls to reduce dust exposure associated with mineral surfacing/handling activities (NIOSH 2001-127). Additionally, during four out of five HHEs conducted at asphalt roofing products manufacturing facilities, NIOSH investigators noted that mineral hoppers for talc, mica, and sand were ventilated (ERG-GI, 2008). In one case, the capture efficiency was less than optimal and in need of improvement.

During HHEs at the five asphalt roofing products manufacturing facilities (ERG-GI, 2008), NIOSH recommended the following engineering controls:

- Providing LEV at all mineral transfer points (five facilities).
- Repairing leaks in the mineral transfer system (four facilities).
- Providing all hoppers into which mineral products (such as sand and talc) are dumped with LEV (one facility) or increased LEV (one facility).

The highest exposures in the exposure profile (78 μg/m^3, 120 μg/m^3, and 188 μg/m^3) are associated with two facilities that did not have LEV at slate transfer points in the slate rooms (ERG-GI, 2008). The exposure of 120 μg/m^3 also was associated with a slate transfer system that leaked and required repairs.

OSHA does not have data specifically illustrating the exposure reductions achieved with adequate ventilation and enclosures in the asphalt roofing products manufacturing industry. However, the effectiveness of these engineering controls in reducing exposure levels below 50 µg/m^3 in other industries has been discussed in Section 1.3.1.1 (OSHA SEP Inspection Report 300384435, OSHA SEP Inspection Report 300180916).

Preventive Maintenance

Properly maintained mineral handling systems are necessary to ensure low exposures to silica-containing dusts during material transfer and other process-related operations. NIOSH investigators noted process leaks in and around enclosures and less-than-optimal LEV in one nonmetallic mineral processing facility manufacturing roofing granules (NIOSH HETA 91-0091-2418). NIOSH recommendations included: 1) implementing a preventive maintenance program, 2) designing and testing LEV systems according to recognized guidelines, and 3) replacing process enclosures that are removed for inspection or maintenance purposes as soon as the work is completed (NIOSH HETA 91-0091-2418).

Similarly, recommendations regarding specific operating and maintenance procedures were made by an engineering firm that completed ventilation improvements at a pottery clay manufacturer that mixed and packaged dry and de-aired moist clay products (OSHA SEP Inspection Report 116178096). The recommendations included: 1) sealing all holes in the elevators, pug mills, and other vessels holding or transporting product; and 2) performing routine preventive maintenance on equipment, including changing LEV filters.

Housekeeping

The effectiveness that low dust-producing cleaning methods (such as HEPA-filtered vacuuming) may have in reducing worker exposure to silica has been discussed earlier in this section.

Feasibility Finding

Feasibility Finding for Production Operators

Based on the best available information, OSHA estimates that the current exposure level for most production operators is 50 µg/m^3 or less. This finding is based on information presented in Table IV.C-4 indicating that 60 percent (or more) of these workers already have exposure levels of 50 µg/m^3 or below. In those instances where elevated exposure might occur, silica levels can be reduced to 50 µg/m^3 or less through the use of adequate LEV, process enclosures, and the use of low dust-producing cleaning methods such as HEPA-filtered vacuuming. OSHA obtained results of 23 µg/m^3 and 29 µg/m^3 at two facilities that used enclosed and ventilated process equipment in another industry (pottery products) where workers oversee equipment that uses silica-containing mineral powders (OSHA SEP Inspection Reports 300384435 and 300180916).

Feasibility Finding for Material Handlers

OSHA estimates that more than 70 percent of material handlers require additional controls. This finding is based on seven sample results, presented in Table IV.C-4, and a review of the sample entries in the OSHA IMIS database (1979 to 2001) that are most representative of material handlers in the asphalt roofing products manufacturing industry. Where elevated exposures occur, additional controls will be required to reduce exposures to 50 µg/m^3 or less for material handlers. Control options include properly enclosed, ventilated, and maintained mineral handling systems and the use of low dust-producing cleaning methods such as HEPA-filtered vacuuming. Though OSHA does not have data demonstrating the effectiveness of engineering controls in asphalt roofing industry, their success in reducing exposure levels below 50 µg/m^3 in other industries has been previously discussed in the section on ventilation and process enclosures. Likewise, though OSHA does not have data documenting the effectiveness of preventive maintenance, both NIOSH and OSHA inspectors recommended preventative measures at asphalt roofing facilities (NIOSH HETA 91-0091-2418, OSHA SEP Inspection Report 116178096).

Overall Feasibility Finding for Asphalt Roofing Product Manufacturers

In summary, OSHA preliminarily concludes that by implementing additional controls for some workers, asphalt roofing facilities can achieve exposure levels of 50 µg/m^3 or less for most of their workers most of the time.

Information published by BGIA (2006) suggests that exposure levels in the equivalent German industry have decreased by more than half since the early 1980s. OSHA believes that in the United States current exposure levels in this industry have also declined since the 1970s (when data used in the exposure profile was obtained by NIOSH). Thus, the exposure profile likely overestimates current exposures in the asphalt roofing industry. Additional information on full-shift PBZ silica results is needed for asphalt roofing industry employees to better characterize exposure for these workers in the United States.

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Concrete Products

Description

Silica-containing materials are the main ingredients in the manufacture of concrete products, such as blocks, bricks, tanks, pipes, and dry mixes. Facilities manufacturing concrete products are classified in six-digit North American Industry Classification System (NAICS) codes 327331, Concrete Block and Brick Manufacturing; 327332, Concrete Pipe Manufacturing; 327390, Other Concrete Product Manufacturing; and 327999, All Other Miscellaneous Nonmetallic Mineral Product Manufacturing. OSHA has grouped together facilities in these industries based on the similarity of raw materials, processes, and worker activities associated with potential silica exposure. Another similar industry, NAICS 327320 – Ready-Mix Concrete Manufacturing, differs from those addressed here in many of the processes and job categories associated with silica exposure, and thus OSHA has created a separate section for it (see IV.C.17 – Ready-Mix Concrete).

Concrete products are typically made by mixing cement (usually Portland cement), sand, and aggregate materials (such as gravel or crushed stone) with water in varying proportions depending on the final product. The mixed concrete is poured into forms or molding machines. The formed products are then allowed to harden (cure), and the forms are removed.[64] Certain products are finished by sawing, grinding, drilling, or abrasive blasting. Dry-mixed concrete is normally produced by drying the raw materials (cement, sand, and aggregate), mixing the dried materials, and then packaging the dry mixture (ERG-GI, 2008).

Based on the available literature and exposure monitoring data presented in NIOSH documents and OSHA Special Emphasis Program (SEP) reports, OSHA preliminarily concludes that workers in all phases of the production of concrete products have the potential for silica exposure. The primary job categories with potential for exposure are: material handler, mixer operator, forming operator, finishing operator, and packaging operator. Certain workers regularly perform tasks associated with multiple job categories. Table IV.C-5 presents a summary of the primary activities associated with silica exposure of workers in each job category. For detailed process descriptions, see ERG-GI (2008).

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[64] "Curing" is the term for the chemical reaction that causes hardening of cement-based materials, such as concrete. Within hours of casting, most concrete products becomes firm enough to handle without the mold, but it can take days or weeks for the concrete to reach its full strength. "Uncured" concrete has recently become firm, but has not yet completed the hardening process.

Table IV.C-5

Job Categories, Major Activities, and Sources of Exposure of Workers in the Concrete Products Industry (NAICS 327331, 327332, 327390, 327999)

Job Category*	Major Activities and Sources of Exposure
Material Handler	Transferring silica-containing raw materials from storage silos to weigh hoppers via front-end loader; transferring product via fork lift or travel lift; manually stacking and palletizing product. • Dust generated during transfer and dumping of raw material. • Dust resuspended by heavy equipment operations. • Dust from adjacent operations.
Mixer Operator	Weighing and transferring silica-containing raw materials into mixing machines; operating and cleaning mixing machines. • Dust generated during manual weighing and ingredient transfer. • Dust generated during manual cleaning of mixers, especially dried concrete deposits.
Forming Operator	Transferring concrete into forms or molding machines manually or automatically; removing formed products; preparing and cleaning forms. • Dust generated while removing forms from cast product and during cleaning of forms, especially dried concrete deposits. • Dust from adjacent operations.
Abrasive Blasting Operator	Abrasive blasting on cured products. • Dust from silica abrasive blasting media and concrete surface being abrasively blasted.
Finishing Operator	Grinding, chipping, coring, sawing, patching, or sanding on formed products. • Dust generated during finishing activities on cured products.
Packaging Operator	Packaging dry, powdered concrete mixture. • Dust released at bag nozzle. • Dust in air displaced during filling or expelled when the bag is released from filling nozzle and drops to conveyer. • Dust from low-quality bags breaking.

*Job categories are intended to represent job functions; actual job titles might differ and responsibilities might be allocated differently, depending on the facility.

Source: ERG-GI, 2008

Baseline Conditions and Exposure Profile

To evaluate silica exposures of workers in concrete product manufacturing facilities, OSHA reviewed exposure monitoring data from 17 OSHA SEP inspection reports, five NIOSH case studies of concrete manufacturing, one contractor site visit, and one article in the published literature.[65] These data have been previously described in ERG-GI (2008).[66, 67] OSHA also identified one additional article that contributes to the exposure profile (Heitbrink, 2007). The facilities covered by these inspections, case studies, and articles produced a wide variety of concrete products ranging from precast concrete wall cladding and decorative concrete architectural elements, to water pipes and sacks of dry concrete and mortar mixes. Because of the richness of these data, OSHA restricted its analysis to observations obtained for workers performing single, well-defined tasks during the sampling period, thereby permitting a better characterization of the exposures associated with each job category. These exposure data are supplemented with qualitative process information from industry contacts and published literature.

OSHA identified three additional sources of information**—**NIOSH EPHB 282-11a (2003), Meijer et al. (2001), and BGIA (2008)**—**that are not described in the ERG-GI (2008) analysis and that do not contribute data to the exposure profile but provide relevant supporting information. Specifically, in NIOSH EPHB 282-11a (2003), though exposure data from a NIOSH investigation of a small business that fabricates concrete counter tops were not sufficiently documented (sample durations were not provided), the report indicates that three workers performing mixing and forming operations had trace 8-hour time weighted average (TWA) exposures (between the limit of detection [LOD] and the limit of quantification), and two workers performing patching and sanding operations in a room with general extraction and dilution ventilation and a ceiling mounted fan had a trace exposure and an exposure below the LOD.[68] This information demonstrates that establishments manufacturing concrete products can achieve low exposures for their workers.

Providing an international perspective, Meijer et al. (2001) reviewed silica exposure monitoring data from 96 workers at two Dutch concrete materials-producing factories and reported a mean of 59

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[65] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) derived from samples of 6-hours or longer, assuming the exposure concentration during any unsampled portion of the shift was the same as the concentration during the period sampled. Unless explicitly stated otherwise, all results discussed in the additional controls section meet the same criteria. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

[66] One NIOSH report (NIOSH ECTB 233-101c, 1999), described in ERG-GI (2008) and included in the ERG-GI (2008) exposure profile, has now been excluded from data for this industry. Instead, the data from this NIOSH report are deemed more applicable to the exposure profile for the ready-mixed concrete industry and have been included in the technological feasibility analysis for the section covering that industry.

[67] Results from Fairfax (1998) (the article in the published literature) are described in ERG-GI (2008) but are not considered as part of the exposure profile due to a lack of sampling details (e.g., sample duration). The results are similarly excluded from this exposure profile.

[68] 8-hour TWA exposures are as reported by the investigator.

micrograms per cubic meter ($\mu g/m^3$) and a range from 0.3 $\mu g/m^3$ to 186 $\mu g/m^3$ for samples averaging 8 hours in duration.[69] Other international information, from the Institute for Occupational Safety and Health of the German Social Accident Insurance, indicates that silica exposure levels have been decreasing in German concrete products manufacturing facilities over recent decades.[70] Based on more than 400 recent and historic samples, the mean silica result for German facilities manufacturing concrete products and precast components was 50 $\mu g/m^3$ during the decade ending in 2004, down from an average of 80 $\mu g/m^3$ for a similar period ending in 1984 (BGIA, 2008). BGIA (2008) attributed decreased exposure levels in this industry to improved (low-dust) production methods and increased use of enclosures, local exhaust ventilation (LEV), and wet methods to control dust.

Baseline Conditions and Exposure Profile for Material Handlers

As shown in Table IV.C-6, the median, full-shift personal breathing zone (PBZ) respirable quartz exposure reading for material handlers is 30 $\mu g/m^3$ with a range of 11 $\mu g/m^3$ to 620 $\mu g/m^3$ and a mean of 80 $\mu g/m^3$. These values represent the combined total of 31 readings reported for material handlers (ERG-GI, 2008). Eleven of the 31 exposure readings (35 percent) exceed 50 $\mu g/m^3$, and five (16 percent) exceed 100 $\mu g/m^3$.

All of the exposure readings for material handlers exceeding 50 $\mu g/m^3$ were obtained in facilities where the majority of exposure readings for workers in all job categories also exceeded 50 $\mu g/m^3$, suggesting poor dust control throughout these facilities. For example, OSHA obtained a result of 116 $\mu g/m^3$ for a material handler who operated a forklift to transport cast concrete products between various surface finishing stations at a facility that manufactured precast concrete siding. The report indicated that dust generated by various other processes in the facility was a contributing factor (OSHA SEP Inspection Report 300997012). This conclusion was supported by the fact that 9 of the 10 samples collected for workers in four job categories at the facility also exceeded 100 $\mu g/m^3$. These circumstances suggest that material handlers at some facilities experience elevated silica exposure simply from passing through or working in areas where other workers' activities generate high concentrations of silica. If dust from these activities is permitted to accumulate, silica particles resuspended by passing forklifts can exacerbate the situation. The results for this industry also suggest that when dust is controlled for all job categories, material handler exposure levels are also reduced. In fact, most of the concrete products industry material handler exposure readings below 50 $\mu g/m^3$ were obtained in facilities where the majority of exposure values for workers in all job categories also were less than 50 $\mu g/m^3$.

At another concrete products facility, four samples for two material handlers evaluated on two consecutive days resulted in values of 48 $\mu g/m^3$, 54 $\mu g/m^3$, 57 $\mu g/m^3$, and 73 $\mu g/m^3$ while the workers inspected and prepared to palletize concrete blocks exiting an automated de-hacking machine used to unload blocks from a curing kiln (NIOSH ECTB 233-112c, 1999) and also performed a variety of other tasks, including dry sweeping. NIOSH noted that "most of the facility has 1/8-inch dust on the floor." The investigators concluded that the dry sweeping might have had a notable effect on worker exposure and that as an alternative the facility could eliminate dry sweeping by switching to either a centralized or portable HEPA-filtered vacuum system.

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[69] The low reading of 0.3 $\mu g/m^3$ is as reported by the investigators. Samples for silica analysis were collected on cellulose acetate filters using Casella cyclones with airflow of 1.9 liters per minute (Meijer et al. 2001).

[70] At the time, Germany's Institute for Occupational Safety and Health of the German Social Accident Insurance was known as BGIA, but this organization is now called by the German acronym IFA.

Table IV.C-6
Respirable Crystalline Silica Exposure Range and Profile for Workers in the Concrete Products Industry (NAICS 327331, 327332, 327390, 327999)

	Exposure Summary			Exposure Range			Exposure Profile				
Job Category	**Number of Samples**	**Mean (µg/m^3)**	**Median (µg/m^3)**	**Min (µg/m^3)**	**Max (µg/m^3)**		**<25 (µg/m^3)**	**≥25 and ≤50 (µg/m^3)**	**>50 and ≤100 (µg/m^3)**	**>100 and ≤250 (µg/m^3)**	**>250 (µg/m^3)**
Material Handlers[A]	31	80	30	11	620		13 41.9%	7 22.6%	6 19.4%	3 9.7%	2 6.5%
Mixer Operators[B]	13	69	25	10	281		6 46.2%	2 15.4%	0 0.0%	4 30.8%	1 7.7%
Forming Operators	42	22	14	11	107		35 83.3%	3 7.1%	3 7.1%	1 2.4%	0 0.0%
Abrasive Blasting Operators[C]	15	2,484	126	10	26,826		2 13.3%	1 6.7%	3 20.0%	4 26.7%	5 33.3%
Finishing Operators	37	82	29	11	347		17 45.9%	6 16.2%	4 10.8%	6 16.2%	4 10.8%
Packaging Operators	6	117	84	11	370		2 33.3%	0 0.0%	2 33.3%	1 16.7%	1 16.7%
Totals	**144**	**315**	**24**	**10**	**26826**		**75** **52.1%**	**19** **13.2%**	**18** **12.5%**	**19** **13.2%**	**13** **9.0%**

Notes: All samples are personal breathing zone (PBZ) results for durations of 360 minutes or more and represent 8-hour time-weighted average exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

[A] Four results for material handlers (no yard maintenance) from NIOSH ECTB 233-101c (1999), previously described in ERG-GI (2008), were excluded from this exposure profile because they are more appropriately categorized in Section IV.C.17 – Ready-Mix Concrete of this feasibility analysis.
[B] Two results for mixer operator from NIOSH ECTB 233-101c (1999), previously described in ERG-GI (2008), were excluded from this exposure profile because they are more appropriately categorized in Section IV.C.17 – Ready-Mix Concrete of this feasibility analysis.
[C.] Three results for workers performing abrasive blasting (one result from ERG-concrete-fac-C [2002] and two results from OSHA SEP 300236882), previously described in the ERG-GI (2008) exposure profile, were excluded from this exposure profile due to short sample durations (less than 360 minutes).

Sources: ERG-GI, 2008; Heitbrink, 2007.

Although the exposure of many material handlers appears to have been influenced by the activities of other job categories, in a few cases material handlers were performing tasks that generated substantial dust. The two highest results available to OSHA for this job category, 610 µg/m^3 and 620 µg/m^3, were obtained in a packaging area with ineffective ventilation where one material handler palletized sacks of dry concrete mix and the other used a front-end loader to transfer sand to a hopper feeding the dry mix blending equipment (OSHA SEP Inspection Report 108738295). Results of 60 µg/m^3 (palletizing job) and 193 µg/m^3 (loader operator moving sand and gravel) had been obtained in the same part of the plant the previous year (the report provides no explanation for the difference in exposure levels from one year to the next). OSHA did note that forced-air jets, intended to slightly levitate 80-pound sacks of dry mix concrete as the worker slid the sacks off the conveyer, blew dust (emitted from the bags during the transfer) into the workers' breathing zone. These results comprise three of the four values above 100 µg/m^3 (among a total of 31 results for this job category), indicating that most material handlers at other concrete product facilities work under less extreme conditions. In this facility, however, both material handlers and packaging operators contributed to the substantial airborne silica in the area, where the material handlers were usually the most highly exposed workers.[71]

For material handlers operating in outdoor work areas and product storage yards, thirteen results (42 percent) are associated with some variety of yard maintenance to control dust (not necessarily effectively), including the use of water spray, dust suppressants, crushed aggregate ground cover, or regular power-sweeping of paved surface. These results range from 11 µg/m^3 to 110 µg/m^3 and have a median of 24 µg/m^3 and a mean of 34 µg/m^3. The highest of these outdoor readings, 110 µg/m^3, is associated with a yard that had been previously watered but let dry. Other watered yards (presumably not dried) and yards using a dust suppressant are associated with very low exposure readings, including five readings at or below the LOD and one reading of 21 µg/m^3.[72]

OSHA has preliminarily determined that the baseline conditions are best represented by the range of working conditions associated with the results summarized in Table IV.C-6. Therefore, the median value for all material handlers (30 µg/m^3), shown in Table IV.C-6, is also the median baseline value.

Baseline Conditions and Exposure Profile for Mixer Operators

As shown in Table IV.C-6, the median, full-shift PBZ respirable quartz exposure reading for mixer operators is 25 µg/m^3 with a range of 10 µg/m^3 to 281 µg/m^3 and a mean of 69 µg/m^3. These values are based on 13 readings for mixer operators (ERG-GI, 2008). Of the 13 mixer operator exposure samples, five results (38 percent) exceed 100 µg/m^3, and the remaining eight results are 25 µg/m^3 or less.

Two of the highest readings, 281 µg/m^3 and 122 µg/m^3, were obtained for mixer operators who cleaned the interior of a concrete mixer using handheld jackhammers to chip dried concrete residue. Other elevated readings—134 µg/m^3, 108 µg/m^3, and 107 µg/m^3—were obtained for operators manually dumping bags of silica-containing materials at hoppers equipped with ineffective LEV systems (ERG-GI, 2008).

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[71] The packaging operator working in the same area also had elevated exposures (370 µg/m^3 and 142 µg/m^3 in the two respective years) (OSHA SEP Inspection Report 108738295).

[72] Results reported as "none detected" are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

Several low exposure readings include operators controlling enclosed mixers from ventilated control rooms. One low exposure result, 24 µg/m^3, is for an operator who used a pneumatic chipping hammer and a compressed air wand to remove dried concrete from the interior of the mixer. This result, along with the two high exposure results described in the previous paragraph, indicates a wide variability in exposure for operators removing concrete from mixing drums, possibly due to variations in work practices, the amount of concrete being removed, and the amount of time spent on the task (a function of how frequently cleaning is performed).

Information from industry contacts suggests that common controls for mixer operators include enclosed mixers, automated weighing and charging of raw materials, and wet methods to clean mixing equipment. Facilities in this industry commonly use at least one of these controls, but no single control is consistently used throughout the industry (i.e., the baseline condition includes use of any one of several controls) (ERG-GI, 2008). Examples of results associated with these conditions include 12 µg/m^3, 24 µg/m^3, and 25 µg/m^3. Mixer operators at some facilities, however, continue to manually charge mixers and clean mixing equipment using dry methods and experience higher exposure levels (ERG-GI, 2008).

OSHA has preliminarily determined that the baseline conditions for this job category are best represented by the range of situations under which results summarized in Table IV.C-6 were obtained. Thus, the median value for mixer operators in the Table IV.C-6 exposure profile (25 µg/m^3) also represents the median value for this job category under baseline conditions.

Baseline Conditions and Exposure Profile for Forming Operators

As shown in Table IV.C-6, the median, full-shift PBZ respirable quartz exposure reading for forming operators is 14 µg/m^3 with a range of 11 µg/m^3 to 107 µg/m^3 and a mean of 22 µg/m^3. These values are based on 42 readings for forming operators obtained from six OSHA SEP inspection reports and four NIOSH case studies (ERG-GI, 2008). Just four of the 42 full-shift PBZ respirable quartz readings for forming operators (10 percent) exceed 50 µg/m^3, and only one reading (2 percent) exceeds 100 µg/m^3. Thirty-five (83 percent) of the readings are 25 µg/m^3 or lower.

The highest reading, 107 µg/m^3, was associated with a forming operator removing concrete siding from forms and palletizing it at an unventilated workstation. At this facility, 9 of 10 full-shift PBZ respirable quartz readings for workers in four job categories exceeded 100 µg/m^3, indicating poor control of silica throughout (OSHA Inspection Report 300997012). OSHA notes that secondary exposure from activities of other workers might have contributed to the silica exposure of this forming operator.

Other exposures between 50 µg/m^3 and 100 µg/m^3 are associated with similar, widespread dust control problems (ERG-GI, 2008). Two such results were obtained at a facility for a worker controlling a concrete block-making machine. The worker stood 10 feet from the machine, which generated dust, and a dry sweeping activity. Additionally, this worker was 20 feet from a mixing machine, which emitted dust during hopper loading (NIOSH ECTB 233-112c, 1999).

Among the lowest results are six readings, ranging from less than or equal to 12 µg/m^3 (LOD) to less than or equal to 14 µg/m^3 (LOD), which were obtained for four operators at a facility visited by NIOSH. Three of the operators formed concrete products using computer-controlled molding machines. The operators used water spray, shovels, and mold vibrators to evenly distribute the wet concrete in the molds. The fourth operator manually assembled forms and then cleaned them by brushing and grinding (ERG-GI, 2008).

Based on OSHA SEP and NIOSH reports and discussions with concrete product manufacturers, OSHA finds that current or baseline conditions for forming operators involve the same range of working conditions represented by the results for this job category summarized in Table IV.C-6. Thus, the overall median for that group is also the median baseline level for forming operators.

Baseline Conditions and Exposure Profile for Abrasive Blasting Operators

As shown in Table IV.C-6, the median, full-shift PBZ respirable quartz exposure reading for abrasive blasting operators is 126 μg/m^3 with a range of 10 μg/m^3 to 26,826 μg/m^3, with a mean of 2,484 μg/m^3. These values, generally higher than other job categories, are based on 15 results for abrasive blasting operators reported by OSHA, NIOSH, and ERG (described in ERG-GI, 2008), and an article from the Center to Protect Workers' Rights (Heitbrink, 2007). Eighty percent of the abrasive blaster results exceed 50 μg/m^3.

The three highest exposure readings (26,826 μg/m^3, 6,482 μg/m^3, and 2,303 μg/m^3) were obtained at two facilities, where operators performed abrasive blasting of concrete panels in unenclosed, outdoor workstations.[73] The operators at both facilities used silica sand blast media containing 87 percent to 99.9 percent quartz, according to the media manufacturer material safety data sheets (ERG-GI, 2008). Among the workers performing abrasive blasting, some of the lowest results were associated with outdoor blasting on concrete panels using coal slag blast media[74] (20 μg/m^3, 30 μg/m^3, and 54 μg/m^3), although values as high as 473 μg/m^3 were also reported. Results of 10 μg/m^3 and 154 μg/m^3 were obtained at a facility using silica sand blasting media with a dust suppressant additive (ERG-GI, 2008). A study described by Heitbrink (2007) used silica sand media with less than 3 percent fines[75] by weight (screened with 100-mesh) in conjunction with a water induction nozzle using water at a rate of 13 pounds per minute (approximately 1.5 gallons per minute). The wet abrasive blasting was performed outdoors and exposed the underlying aggregate of precast concrete building panels. Under these working conditions, the investigator obtained two full-shift silica exposures of 75 μg/m^3 and 124 μg/m^3.

Manual abrasive blasting of concrete products is most often conducted outdoors as a dry process; however, as indicated previously, some concrete product manufacturers are attempting alternate methods. Therefore, OSHA has preliminarily determined that together the various working conditions represented by data summarized for abrasive blasting operators in Table IV.C-6 best describe the baseline conditions for all abrasive blasting operators in this industry. Thus the median value for this job category shown in Table IV.C-6 also represents the median baseline silica exposure level for abrasive blasting operators.

Baseline Conditions and Exposure Profile for Finishing Operators

As shown in Table IV.C-6, the median, full-shift PBZ respirable quartz exposure reading for 37 finishing operators is 29 μg/m^3 with a range of 11 μg/m^3 to 347 μg/m^3 and a mean of 82 μg/m^3. Thirty-

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[73] OSHA presumes that these workers were wearing the OSHA-required abrasive blasting airline helmet-style respirators (required under 29 CFR 1910.94 – ventilation).

[74] A low-silica abrasive blasting media.

[75] "Fines" is a general term referring to very small particles in a mixture of varying sizes. A 100-mesh screen is defined as having 100 openings per linear inch, meaning that the screen openings are 149 microns in size and will separate out particles of smaller size.

eight percent of the hand tool worker results exceed 50 ug/m^3. The values for finishing operators were reported by OSHA and NIOSH as described in ERG-GI (2008).

Elevated exposures for workers performing finishing activities other than abrasive blasting are associated with workers using an inadequately ventilated surfacing machine[76] (210 µg/m^3, 240 µg/m^3, 281 µg/m^3, and 318 µg/m^3), a punch press operator located in a facility with widespread dust control problems (96 µg/m^3), and workers using handheld power tools to grind concrete panels (308 µg/m^3 and 69 µg/m^3) (ERG-GI, 2008). An exposure level of 347 µg/m^3 was recorded for another finishing operator performing patching of finished panels in the sandblasting area at the same facility. Some of the lowest exposures for hand tool workers include two exposure readings of less than or equal to 12 µg/m^3 (LOD) for finishing operators who cut or scored uncured precast concrete products. This cutting was performed using non-powered hand tools while the "zero-slump" concrete was still wet, thus eliminating the need for power tools, which are required after the concrete has dried (ERG-GI, 2008). Zero slump concrete lacks any fluidity and retains its shape prior to curing, thus enabling finishing operations to be performed on still-damp concrete. At this site, none of the 17 results for three of the other job categories exceeded 21 µg/m^3, indicating that dust was well controlled throughout the facility.

Activities and associated conditions vary greatly for finishing operators. Based on a review of OSHA SEP and NIOSH reports, ERG-GI (2008) noted that baseline conditions for manual finishing operations involve outdoor, dry work performed on cured concrete, while automated finishing operations typically are conducted indoors with some form of control (one-third use wet methods, two-thirds use LEV). Nevertheless, OSHA has preliminarily determined that together the various working conditions represented by data summarized for finishing operators in Table IV.C-6 best describe the baseline conditions for all finishing operators in this industry. Thus the median value for this job category shown in Table IV.C-6 also represents the median baseline silica exposure level for finishing operators.

Baseline Conditions and Exposure Profile for Packaging Operators

As shown in Table IV.C-6, the median, full-shift PBZ respirable quartz exposure reading for packaging operators is 84 µg/m^3 with a range of 11 µg/m^3 to 370 µg/m^3 and a mean of 117 µg/m^3. These results are based on six readings for packaging operators obtained from four OSHA SEP inspection reports for facilities where workers used bag-packing machines to fill sacks with dry concrete mix (ERG-GI, 2008). Four of the six full-shift PBZ respirable quartz readings for packaging operators (67 percent) exceed 50 µg/m^3, and two (33 percent) exceed 100 µg/m^3.

The two highest exposure readings were obtained for packaging operators at a facility inspected by OSHA. OSHA obtained a reading of 142 µg/m^3 for a worker who used a bag-filling machine to load 80-pound bags of dry-mix concrete, with general exhaust ventilation fans located near the workstation. After the inspection, the facility installed an LEV system for the packaging operation, but an industrial hygiene consultant later obtained a reading of 370 µg/m^3 for the packaging operator even with the new ventilation system in place. The consultant found that the system did not effectively remove dust generated by the packaging operation but offered no explanation (ERG-GI, 2008).[77] These results

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[76] The surfacing machine action is not specified but presumably involves automated grinding to level the surface or modify texture.

[77] The inspection report associates the exposures readings with cement packaging. OSHA, however, described the facility as a concrete packaging plant, and the percentage of quartz (6 percent) found in the sample suggest that the reading is associated with concrete packaging.

demonstrate the value of conducting followup sampling to confirm that installed engineering controls have produced the desired effect.

The lowest reading for this job category, less than or equal to 11 μg/m^3 (the reported LOD), was obtained for a packaging operator at a facility that had upgraded its dust controls following an OSHA SEP inspection. The facility had improved the LEV system for the packaging operation by relocating hoods closer to the operator's position while filling bags. The facility also had rebuilt the LEV system to generate greater airflow and installed a new filter bag. In addition, daily housekeeping for the workstation had been implemented after the inspection (OSHA SEP Inspection Report 300114378). Unfortunately, no exposure information is available to OSHA regarding exposure levels prior to the implementation of these controls.

Based on the available reports, ERG-GI (2008) found that typical conditions for packaging operators include manual insertion of empty bags into bag-filling machines equipped with LEV; however, the exhaust ventilation systems often are poorly maintained or function inefficiently. Dust is generated when filled bags expel product as they are released from bag-filling machines and when filled bags covered with spilled product are dropped onto conveyors (ERG-GI, 2008). ERG considered this scenario to also be a baseline condition for most packaging operators (ERG-GI, 2008). However, OSHA disagrees and preliminarily finds that the results summarized in Table IV.C-6 provide a better description of conditions for this job category. These data were collected under a range of situations and serve as a representation of current conditions in the industry. As a result, the median for packaging operators represents the median baseline value for this group of workers.

Additional Controls

Additional Controls for Material Handlers

Table IV.C-6's exposure profile indicates that additional controls are required for 35 percent of material handlers. Appropriate control measures include adding or improving LEV at raw material receiving hoppers (particularly in the dry bagged concrete mixing area), making changes to the area where material handlers transfer finished sacks from conveyers onto pallets, suppressing dust in storage yards, and using equipment cabs where exposures continue to be elevated. Other adjacent operations also need to be controlled in order to reduce most material handler exposures. Specifically, changes described later under additional controls for packaging operators (e.g., improved LEV for bag-filling machines and switching to bags designed to emit less dust) will also help reduce the exposure of material handlers who work in the area or eventually handle the same bags.

Local Exhaust Ventilation

Ineffective LEV contributed to the exposures of a front-end loader operator transferring sand and aggregate into a hopper feeding a concrete dry-mix blender at a concrete products facility. A good description of how this activity releases silica dust appears in Section IV.C.15 – Pottery in this technological feasibility analysis and is reproduced here. A pottery industry source document, NIOSH HETA-84-066-1883 (1988), indicates that samples were obtained on two consecutive days for a worker operating an unenclosed front-end loader to scoop dry flint, ball clay, and feldspar (other silica-containing mineral powders) into enclosed, ventilated weigh hoppers feeding an open system that conveyed raw materials to mixing equipment. The report suggests that housekeeping was poor, based on a comment that settled dust was disturbed by the loader activity. Additionally, the NIOSH investigator noted that the LEV at the hoppers (with air flow velocity of 155 feet per minute across the enclosure) was "overwhelmed" by the amount of dust released during the material transfer. Based on descriptions of exhausted enclosures for material transport recommended by the American Conference of Governmental Industrial Hygienists

(ACGIH, 2010), OSHA preliminarily determined that, in this case, the LEV system was not designed and used to the best advantage; the LEV system could be upgraded to increase dust capture, and work practices could be improved to transfer raw materials in a manner that reduces airborne dust.

ACGIH (2010, Chapter 13.50) provides design recommendations for ventilated hoppers receiving dusty materials. This document recommends a minimum air flow of 150 feet per minute (fpm) across bin and hopper openings for manual loading operations. However, for other loading methods that cause material enters the hopper in a manner different than manual loading (e.g., using a front-end loader, or during high-speed automated loading operations), ACGIH recommends an air velocity of one-and-a-half to two times that air flow rate. The recommended velocity depends on the material flow rate (a front-end loader adds materials at a much greater material flow rate than manual transfers), dustiness (the material at this site was apparently very dusty), and the height the material falls (influenced by either hopper design or by material handler work practices). Furthermore, ACGIH recommends that the enclosure be “large enough to accommodate the ‘splash’ effect” that occurs when a load is dumped into the hopper.

OSHA has preliminarily determined that concrete product loader operator exposures can be reduced by using a redesigned hopper enclosure of adequate size to accommodate the loader scoop and resulting “splash” effect. Air must be exhausted from the enclosure at a rate commensurate with the material flow rate and dustiness (potentially up to two times the minimum recommended rate of 150 fpm, equal to a rate of 300 fpm across the enclosure opening). Again drawing on information from the pottery industry, OSHA notes that although some pottery facility material handler results remain above the proposed permissible exposure limit (PEL) of 50 µg/m^3, when workers have access to LEV described as functional, the results are markedly lower (median exposure level 27 µg/m^3) than when workers use material transfer stations where LEV is clearly inadequate or missing (median exposure level 530 µg/m^3). Based on the similarity of hoppers, conveyers, and mixing equipment used to blend the similar mineral powders used by both industries, OSHA has preliminarily determined that LEV at material transfer stations is just as effective in the concrete product industry as in the pottery industry.

Yard Dust Management

Exposure observations at facilities that implemented yard dust management controls show that levels at or below 50 µg/m^3 are achieved in almost all cases (85 percent of the readings). These observations include four readings of less than 21 µg/m^3 for facilities using dust suppressants, two readings of less than 19 µg/m^3 for those that consistently wetted yard dust, a reading of less than 40 µg/m^3 for a facility using an aggregate bed, and four readings of less than 57 µg/m^3 for facilities using power sweeping of a paved yard (NIOSH ECTB 233-112c, NIOSH ECTB 233-125c). In contrast, and as previously noted, a reading of 110 µg/m^3 was obtained at a facility where wetted yards were allowed to dry (ERG-GI, 2008). Additional support for the application of dust suppressants includes a study by Addo and Sanders (1995) that examined three chemical dust suppressants (lignosulfate, calcium chloride, and magnesium chloride) applied to an unpaved roadway for four and a half months. The study found that compared to an untreated roadway, the suppressants reduced fugitive dust emissions by 50 to 70 percent.

Wet dust suppression methods also may be used to minimize exposure during raw materials transfer. One industry contact reported use of dampened aggregate to minimize dust release as materials are dumped into hoppers (ERG-GI, 2008). Although the effectiveness of this control has not been quantified, wetting the material effectively prevents fine particles mixed with the aggregate from becoming airborne.

Control of yard dust offers the best results when used in conjunction with other efforts to control silica dust. One facility, for example, controlled exposures through the use of worker training and regularly applied dust suppressants, enclosed equipment, wet methods, and rigorous housekeeping as elements of a comprehensive dust control program. The three exposure readings for the material handlers at this facility were all less than 13 μg/m^3 (LOD) (ERG-GI, 2008).

Improved Housekeeping

Poor housekeeping contributes substantially to worker exposure levels in material handling areas, and a thorough, professional-level cleaning in association with improved housekeeping procedures (to maintain cleanliness) can reduce exposures where dust has been allowed to accumulate. Exposure levels ranged from 48 to 73 for concrete product facility material handlers who performed dry sweeping during their shifts where "most of the facility has 1/8-inch of dust on the floor" (NIOSH ECTB-233-112, 1999).

In the structural clay industry, another industry with similar material handling requirements, professional cleaning of a brick manufacturing facility dramatically reduced exposure levels (by 90 percent or more in some cases) for workers in areas where raw materials were transported or handled (raw material storage, near grinding equipment and conveyers, during bag dumping, and at raw material hoppers) (see Section IV.C.21 – Structural Clay in this technological feasibility analysis). In these areas, most worker exposures were reduced to less than 50 μg/m^3 without other abatement efforts (ERG-GI, 2008).

Enclosed Operator Cabs

Enclosed operator cabs offer another option for reducing the exposure of material handlers. OSHA estimates that only a quarter of concrete product manufacturing facilities use well-enclosed cabs equipped with air filtration and air conditioning to effectively control exposures of material handlers operating mobile equipment in dusty areas (ERG-GI, 2008). A reading of 21 μg/m^3 was obtained at a precast concrete facility for a material handler who used a front-end loader with an air-conditioned cab enclosure to transport raw materials across a water and dust suppressant-treated yard (NIOSH ECTB 233-127c).

NIOSH recommends several cab design features and emphasizes the importance of maintenance and cleanliness (NIOSH 2009-123, 2009). Cabs employing several of these recommendations regularly achieve exposure reductions (inside versus outside the cab) exceeding 90 percent (Cecala et al., 2005; NIOSH 528, 2007).

Multiple silica exposure control strategies (e.g., enclosed cab, plus dust suppressant on the ground as described in the example above) can be used simultaneously if a single method is inadequate to reduce the exposure levels.

Additional Controls for Mixer Operators

Although the exposure data suggest that most (62 percent) mixer operators have silica exposure less than or equal to 50 μg/m^3, Table IV.C-6 shows that additional controls are required for the remaining 38 percent of mixer operators with exposures above 100 μg/m^3. Operators in the group requiring additional controls experience elevated exposure while performing two activities: chipping residual concrete from mixing barrels and emptying bags of raw materials into the mixer during manual mixer charging. Additional controls for these two activities are discussed in more detail in the following sections.

In the concrete products industry, the chipping activity is usually performed once daily (and at least weekly), typically for brief periods, during which the airborne silica levels in operators' breathing zones are substantial and warrant control. Controls include wet methods for cleaning mixing equipment before residual concrete has dried, as well as use of wet methods and LEV when chipping is required.

Other control measures are necessary when mixer operators are exposed to elevated levels of silica during manual mixer charging and raw material mixing. Use of ventilated bag dumping stations or automated mixer charging, and operator isolation in a control room or booth, also can reduce mixer operators' silica exposures to levels below 50 μg/m^3. These control options are discussed in more detail in the following paragraphs.

Controls for Chipping Operations

Chipping activity to clean hardened concrete from in-plant mixing drums is essentially the same task that workers perform to remove hardened concrete from ready-mixed concrete truck drums. Work on truck drums, however, represents the worst-case scenario. That activity occurs in a more challenging (more enclosed) environment, takes longer (several hours compared to several minutes), and usually involves a notably heavier concrete buildup on the mixer drum walls because, according to the National Ready Mixed Concrete Association (NRMCA, 2009), truck drums are typically only cleaned twice per year compared with the daily or weekly cleaning schedule for in-plant mixer barrels. Based on the similarities between the two processes, OSHA has preliminarily determined that exposure controls for ready-mixed concrete truck drum cleaning (the worst-case condition) will be at least as effective for cleaning in-plant mixer barrels. Options for controlling worker exposure during ready-mix truck drum cleaning are discussed in detail in Section IV.C.17 – Ready-Mix Concrete in this technological feasibility analysis and in ERG-GI (2008). For convenience, the control methods discussed there are summarized briefly in the following paragraphs.

After reviewing the information presented in Section IV.C.17 – Ready-Mix Concrete in this technological feasibility analysis and in ERG-GI (2008), OSHA has preliminarily determined that LEV, wet methods, and more careful and frequent rinsing of the barrel will reduce mixer operator silica exposure in the concrete products industry as well.

Investigators have found that the following control methods used for ready-mixed concrete truck drum cleaning offer exposure reductions of at least 70 percent compared with uncontrolled levels (typically up to approximately 1,000 μg/m^3).[78]

- *LEV-equipped chipping tool plus general exhaust ventilation:* Silica levels reduced to 220 μg/m^3 (NIOSH EPHB-247-19, 2001).
- *Water misting device and push/pull ventilation system:* Silica levels reduced to 128 μg/m^3 (Strelec, 2008).
- *Periodic spraying of the interior surface of the drum and directing continuous water spray at the chisel point during chipping:* Silica levels reduced to "less than the PEL" (100 μg/m^3 or somewhat less, calculated using OSHA's general industry standard for respirable dust containing silica) (Williams and Sam, 1999).

OSHA notes that for the concrete products industry, information included in the discussion of the mixer operator exposure profile indicated that the highest result available to OSHA for this job category is 281 μg/m^3. The second highest result associated with mixer barrel cleaning is 122 μg/m^3 and all other

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[78] The exposure levels shown in the bulleted list are for workers who spent at least half of the sampling period (and usually the entire period) chipping concrete from inside truck mixing drums (the worst-case scenario).

results are lower. A 70-percent reduction would lower the second highest result to a level of 37 µg/m^{3}and reduce to levels less than 37 µg/m^3 all the other results included in the mixer operator exposure profile summarized in Table IV.C-6, except the highest value of 281 µg/m^3.

Controls for Mixer Charging

Manual mixer charging is potentially another source of mixer operator exposure for mixer operators in non-automated plants. Control options include ventilated bag dumping stations, automatic mixer charging systems, and operator control booths. The following paragraphs describe these options.

Bag Dumping Stations

Bag-dumping stations can potentially control dust generated by bag emptying and disposal. While data from concrete product facilities using ventilated bag dumping stations are not available, a bag dumping station with fully functioning LEV was found to reduce silica exposure by at least 95 percent in a paint manufacturing facility where workers emptied 50-pound bags of silica-containing materials (ERG-paint-fac-A, 1999). The stations consist of hoppers topped with grates enclosed by LEV hoods. After each bag is emptied, the worker releases it and suction automatically pulls the bag into the ventilation system and transfers it to an enclosed storage area. Because ventilation system performance is the ultimate test of effectiveness, OSHA anticipates that other styles of ventilated bag dumping and disposal units would also be as effective as the one just described. Ventilated bag dumping and disposal stations are readily available from commercial sources (Carolina Conveying, 2010; Chicago Conveyor, 2004; Flexicon, 2009; Vac-U-Max, 2006a; Whirl-air, 2003).

Automatic Mixer Charging

Automatic mixer charging equipment reduces operator exposure by allowing the worker to stand at a distance from the mixer while controlling the flow of raw materials into the mixer. Automated systems are widely used in many industries and are readily available from commercial sources. A result of less than or equal to 12 µg/m^3 (the LOD) was reported for a mixer operator using an automated charging system at a precast concrete architectural panel facility (ERG-concrete-fac-C, 2002). In a related industry, an 86-percent reduction in respirable quartz exposure readings occurred at a structural clay product facility after a manual bag dumping station was replaced with an enclosed, automated sand transfer system (OSHA SEP Inspection Report 300523396). Like mixer operators in the concrete products industry, workers in the structural clay industry handle silica-containing dry ingredients (clay, sand, and other ground minerals), which they mix with water to create wet clay to form into products. Because the structural clay industry workers use a wider range of silica-containing materials, potentially milled to smaller particle sizes, OSHA has preliminarily determined that control measures that are effective in the structural clay industry will be at least as effective in the concrete products industry.

Operator Control Booths

When exposures continue to be elevated during automated mixer charging, the charging system controls can be placed in an enclosed operator booth. To effectively control silica exposure, the operator booth must be maintained to exclude dust through tight seals at doors and windows and must provide clean air that keeps the booth under slight positive pressure to help exclude dust. At a structural clay facility visited twice by OSHA, an area sample collected inside a poorly sealed ventilated control room resulted in an average silica concentration of 111 µg/m^3 (OSHA SEP Inspection Report 300523396). Before OSHA's next visit, the facility sealed gaps around the main entrance door to the control room. This modification reduced airborne silica levels inside the room to 11 µg/m^3, a 90-percent reduction compared to the earlier sample. The reduced level likely represented an even greater percent reduction compared to the dusty grinding equipment area outside the control room. OSHA notes that low silica levels inside the control room suggest that the room provides a substantial level of protection for any worker inside. At the same facility, OSHA obtained a reading of 23 μg/m^3 for a worker who operated a computer-controlled mixer operation and charging equipment from an enclosed booth (OSHA SEP Inspection Report 300523396).

Additional Controls for Forming Operators

The data summarized in Table IV.C-6 show that 83 percent of forming operators' exposures are 25 μg/m^3 or less, and 90 percent have exposures of 50 μg/m^3 or less. OSHA does not anticipate that routine activities of forming operators generate silica concentrations that exceed 50 μg/m^3 and notes that controlling adjacent sources of silica dust (e.g., chipping in mixer barrels, finishing processes that are performed near the forming area) will reduce the exposure levels of those few forming operators (10 percent) that have elevated exposures. As noted previously, the highest result (107 μg/m^3) was associated with a worker who emptied and palletized forms at a facility where 9 out of 10 quartz results in four job categories exceeded 100 μg/m^3.

In the event that additional controls are needed after adjacent sources of exposure have been controlled, concrete product facilities can improve housekeeping and add LEV to work stations, particularly those stations associated with automated processes. Two of the results between 50 μg/m^3 and 100 μg/m^3 were associated with both adjacent sources of exposure and a block-forming machine that emitted dust (NIOSH ECTB 233-112c, 1999).

Forming operators can also use cleaning techniques that limit dust released when they clean forms and work areas. HEPA-filtered vacuums used in place of dry brushing or sweeping will minimize worker exposure to silica during these activities. Thorough professional-level cleaning will help reduce exposure from settled dust that might have accumulated in the work area. Disturbed dust is another likely contributor to the silica exposure for all three of the workers with results above 50 μg/m^3 discussed in the previous paragraphs.

Additional Controls for Abrasive Blasting Operators

As indicated in Table IV.C-6 80 percent of abrasive blasting operators currently experience silica exposures in excess of 50 μg/m^3. One alternative to abrasive blasting, surface retarding, can eliminate exposure to silica, while exposing aggregate on concrete surfaces (a primary objective of some abrasive blasting tasks). Other exposure control methods do not reduce silica exposure to the same extent but do provide some benefit. Wet abrasive blasting can suppress dust considerably, provided sufficient water is added to the abrasive media. Additionally, compared to abrasive blasting with silica sand, use of low-silica abrasive blasting media that are less toxic than quartz sand also reduces worker silica exposure. The concrete surfaces that workers abrasively blast contribute to the silica dust released during abrasive blasting, however, so some exposure can occur even if the media contains no silica. These methods are reviewed in the following paragraphs. For a more in-depth discussion of alternatives to abrasive blasting, see Section IV.C.22 – Abrasive Blasters in this technological feasibility analysis, which covers abrasive blasting in the construction industry.

Alternatives to Abrasive Blasting – Surface Retarding

Operators creating certain product finishes can use a surface retarder to inhibit curing and allow an outer layer of concrete to be washed or brushed away as an alternative to abrasive blasting. The chemical retarder applied to the mold for concrete panels allowed finishing operators to remove the outer layer of concrete by pressure-washing the surface with water. Use of the retarder reduces the need for abrasive blasting by as much as 40 percent (NIOSH ECTB 233-127c]. An industry representative indicated that use of retarders is rapidly becoming the preferred method of finishing concrete (Concrete Product Industry Representative A, 2000). A wide range of finishes can be achieved using different surface retarder and acid wash products, ranging from the look of exposed aggregate to the appearance of a smooth sand-blasted surface (ERG-GI, 2008).

Wet Methods

Wet abrasive blasting and hydro-blasting are effective controls. During outdoor abrasive blasting of a parking garage to remove the outer layer of cured concrete (e.g., to expose the aggregate), workers using a mix of 80 percent dry sand and 20 percent water had a geometric mean silica exposure of 200 μg/m^3 (Mazzuckelli et al., 2004). Another facility that produced precast concrete used a water induction nozzle to control silica exposure (Heitbrink, 2007). The nozzle combines water with the abrasive-media-and-air mixture so that atomized liquid droplets are added to the abrasive blasting stream. Operators performed three different activities outdoors: light blasting of wall units to even the color, light blasting of fire stairs to roughen the texture, and heavier blasting of building panels to expose the aggregate. The geometric mean personal silica exposure for 10 samples was 62 μg/m^3, with a range of 20 μg/m^3 to 130 μg/m^3 (Heitbrink, 2007). OSHA notes that in addition to the water nozzle, this facility also used pre-screened silica sand media from which most of the fines had been removed (rendering the new abrasive media less dusty). The beneficial effect of the pre-screened media cannot be separated from the effect of the water induction nozzle (both likely reduced silica exposure). Although many exposures reported in Mazzuckelli et al. (2004) and Heitbrink (2007) still exceed the proposed PEL of 50 μg/m^3, they are much lower than the highest exposures reported in the exposure profile for uncontrolled, outdoor abrasive blasting with sand in this industry (e.g., 26,826 μg/m^3, 6,482 μg/m^3, and 2,303 μg/m^3).

ERG-concrete-fac-C (2002) evaluated wet abrasive blasting at the precast concrete architectural panel manufacturing facility that also used coal slag abrasive blasting media. Results are provided in the paragraphs that follow in the discussion on alternate abrasive blast media. Water flow rate measurements showed that the rate of water application was a fraction of the amount recommended by the water-fed abrasive blasting nozzle manufacturer.[79] The application rate, approximately one-half fluid ounce per minute (a steady rapid drip), was less than 2 percent of the 0.75 quart (24 ounces) to 6 quarts (192 ounces) per minute range recommended by the nozzle manufacturer (ERG-concrete-fac-C, 2002). Split-shift results (two hours of dry abrasive blasting and subsequent hours wet abrasive blasting) showed that this low-moisture wet method did not consistently provide lower silica exposure results compared to the same worker performing dry abrasive blasting with the same media.

Another alternative is hydroblasting, which uses high-pressure water without added abrasive. After reviewing other published and unpublished work, Lahiri et al. (2005) estimated that silica exposure associated with sand blasting can be eliminated by using hydroblasting, even when the surface being hydroblasted contains silica, such as with concrete. OSHA recognizes, however, that this method cannot replace abrasive media blasting under all circumstances.

Alternate Abrasive Blast Media

Using alternate types of abrasives that are low in silica or silica-free will reduce abrasive blasting operator silica exposure levels but not eliminate exposure when blasting is performed on silica-containing substrates, such as concrete. Outdoor abrasive blasting at two concrete product facilities using silica sand

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[79] The nozzle is fitted with a water hose that provides low pressure tap water. The compressed air and media stream creates negative pressure at the nozzle, which causes water from the hose to be sucked into and distributed through the blast media stream (ERG-concrete-fac-C, 2002).

media was associated with exposure readings of 26,826 µg/m^3, 6,482 µg/m^3, 2,303 µg/m^3, 371 µg/m^3, and 56 µg/m^3. By contrast, outdoor abrasive blasting at a concrete product facility using coal slag (low-silica) blast grit (mixed with a small amount of water) was associated with exposure readings of 54 µg/m^3 and 30 µg/m^3 (OSHA SEP Inspection Report 116200940). Outdoor abrasive blasting with coal slag media in a strong wind at another facility was associated with a reading of 20 µg/m^3 (OSHA SEP Inspection Report 300096930).

At a third facility that produced concrete architectural panels, silica levels of 133 µg/m^3 (a less-than full-shift sample of 319 minutes), 149 µg/m^3 and 473 µg/m^3 were measured during a combination of wet and dry abrasive blasting using coal slag blasting media. Company exposure data indicated that prior to switching to coal slag media, silica exposure levels during dry abrasive blasting ranged from 430 µg/m^3 to 5,400 µg/m^3 with three of four quartz results above 2,000 µg/m^3 (ERG-concrete-fac-C, 2002).[80]

Use of a ventilated booth for abrasive blasting of granite monuments (another silica-containing substrate) using alternate low-silica media was associated with a median exposure reading of 51 µg/m^3 (ERG-GI, 2008). Employers will need to consider the possible hazards of abrasive media substitutes, however, if switching from silica. For example, depending on the abrasive, alternative media can result in elevated levels of other hazardous air contaminants such as metals (KTA-Tator-Phase-2, 1998). For further discussion on abrasive blasting in the construction industry, see Section IV.C.22 – Abrasive Blasters in this technological feasibility analysis.

Enclosure and Local Exhaust Ventilation

Complete isolation of the operator from the blasting operation (i.e., use of a glove box-type ventilated blasting cabinet) can reduce silica exposure during abrasive blasting of smaller pieces. For example, ventilated blasting cabinets used by three operators in Georgia granite sheds (using either silica sand or an alternate media) generated exposure results of 15 µg/m^3 to 77 µg/m^3 with a mean of 41 µg/m^3 (Wickman and Middendorf, 2002). OSHA estimates that exposure levels associated with blasting cabinets can be reduced to levels consistently below 50 µg/m^3 by using silica-free blast media that is less toxic than sand and a combination of other engineering and work practice controls. These controls include enclosed and ventilated media recycling systems, interlocks to prevent operators from opening doors before the cabinet has been exhausted, and use of HEPA-filtered vacuums instead of dry sweeping or compressed air to clean in and around the cabinet. Ventilated abrasive blasting enclosures (booths) also are effective in limiting the exposure of adjacent workers where blasting must be performed.

Large, glove box-style cabinets for abrasive blasting oversize or awkward shape objects are available commercially (Media Blast, 2009). For example, one manufacturer produces ventilated cabinets that have reportedly been used for abrasive blasting of granite tombstones (Pauli, 2001a; Pauli, 2001b). This size box is interlocked, to prevent operation unless the unit is sealed, and ventilated at 840 cubic feet per minute (cfm). In addition, the boxes are fitted with a dust collector (99.9 percent filter efficiency for 0.3 micron particles available for some models) and a completely enclosed, ventilated media reclamation system. A larger ventilation system is required when two or more of these cabinets are linked together to provide a larger internal workspace (Pauli, 2001b).

Large items that cannot fit in a blast cabinet might be better controlled by another commercially available option: a gauntlet glove panel and window that can be inserted into the wall of a walk-in sized sealed and ventilated abrasive blast booth (Pauli, 2009).

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[80] The less-than-full-shift and company-reported results are not included in the exposure profile.

Combination of Controls

As noted previously, workers used a combination of wet and dry abrasive blasting methods outdoors with coal slag abrasive blasting media at a facility that produced precast concrete architectural panels. The wet methods, however, used a fraction of the water flow rate recommended by the wet abrasive blasting nozzle manufacturer. Under these conditions, silica levels of 133 µg/m^3 (less-than full-shift sample of 319 minutes), 149 µg/m^3, and 473 µg/m^3 were measured during a combination of wet and dry abrasive blasting using coal slag blasting media (ERG-concrete-fac-C, 2002). Based on results reported by Heitbrink (2007), described in the discussion of the exposure profile, OSHA anticipates that using a greater flow rate would have resulted in somewhat lower silica levels.

German concrete products and precast component manufacturing plants have reduced abrasive blasting operator exposures through a combination of abrasive blasting in enclosed, recirculating systems with dust collection and using conditioned abrasive blasting media. Exposure levels are approximately 100 µg/m^3 using these methods (BGIA, 2008).

Additional Controls for Finishing Operators

Table IV.C-6 indicates that 62 percent of finishing operators currently have exposure levels of 50 µg/m^3 or less; however, additional controls are required to reduce the remaining exposures. As described in the following paragraphs, available controls include the use of wet finishing methods, LEV, non-silica blast media, and changes in work practices to perform more finishing operations on uncured concrete. Workers can use a combination of control measures for most activities.

Wet Methods

A number of finishing tools use wet methods to help control dust. These tools include water-fed drilling, grinding, cutting, and chipping equipment and automated wet process finishing equipment. ERG-GI (2008) describes several types of water-fed tools used for concrete finishing. For example, at a facility that manufactured precast concrete structural and utility products, workers used a horizontal coring machine (for holes 2 to 31 inches in diameter) with a water-fed bit. The measured silica exposures of these workers were less than or equal to 12 µg/m^3 (LOD) and 31 µg/m^3 (NIOSH ECTB 233-127c).

OSHA has also located additional studies on wet dust control methods for the construction industry, in which workers use similar (and often identical) equipment to finish concrete at construction sites. Because concrete product manufacturers work at fixed locations, typically with unlimited water supplies, and can modify the work area to control runoff, OSHA believes that there are no limitations to using dust control methods available for construction work and that these methods should be at least as effective at concrete product facilities as on construction sites.

In one experiment at an indoor field laboratory, the use of a wet grinder (a water hose attached to the grinder providing water at 3 liters per minute [L/min]) reduced the geometric mean silica exposure by 98.2 percent during brief periods of intensive concrete surface grinding compared to uncontrolled grinding (Akbar-Khanzadeh et al., 2007). During this test, however, the mean silica exposure during wet grinding was still extremely high: 896 µg/m^3. An additional study examined the exposures associated with the use of a handheld abrasive cutter to make cuts through concrete blocks (NIOSH EPHB 282-13, 2007). The use of a water spray attachment (providing water at 1.4 L/min) reduced silica exposures by an average of 90 percent compared to uncontrolled cutting. Again, however, quartz exposures were still extremely high, ranging from 1,100 µg/m^3 to 2,400 µg/m^3. In both of these studies, test periods were extremely brief (5 to 10 minutes), during which intensive grinding took place without the normal frequent pauses to change the work angle, change concrete blocks, take measurements, or reposition materials. The conditions in this environment are much different from those during typical grinding operations. Samples collected during these conditions typically produce higher results. They are valuable for evaluating control methods, but do not represent 8-hour TWA exposure levels.

Lahiri et al. (2005) described unpublished data reporting reductions of 81 and 82 percent during chipping and sawing concrete using wet methods. Further details on the type of intervention and data collected are not available, however. OSHA notes that many electric grinder housings might not be sufficiently sealed to permit safe use in wet environments. To minimize the hazard of electric shock, the stone and stone products industry uses pneumatic hand-held grinding tools to grind high-silica stone such as granite (Simcox et al., 1999).

When considering the use of wet methods, it is important to note that wet grinding can create safety hazards, such as slippage and electrocution, and might be unsuitable for indoor or freezing environments. In addition, wet methods can cause aesthetic problems (e.g., water marks) if appearance is an important component of the final product (e.g., architectural elements).

Local Exhaust Ventilation

LEV or ventilated enclosures might be required for facilities finishing architectural concrete products and where wet methods are infeasible for surface finishing. Handheld grinders equipped with LEV are widely available and can help control operator and bystander exposures. No data are available quantifying the effectiveness of LEV or ventilated enclosures for reducing exposures associated with finishing operations in the concrete products industry. Studies of concrete finishers in the construction industry, however, provide substantial data on analogous activities. The use of vacuum dust collection systems for concrete grinders reduced workers' silica exposures by 74 to 93 percent (ERG-GI, 2008). Another comparative study evaluating an abrasive cutter (on concrete) found an average reduction in silica of 95 percent with an LEV shroud and vacuum cleaner (NIOSH EPHB 282-13, 2007). Finally, the use of four different hood-vacuum combinations on a hammer-drill being used to drill concrete reduced silica concentrations from 308 μg/m^3 (no LEV) to between 6 μg/m^3 and 28 μg/m^3 (overall reduction of 94 percent) (Shepherd et al., 2009).

Even when substantial exposure reductions are reported with LEV shrouds and vacuum attachments, however, worker exposure levels often still exceed 100 μg/m^3 and are sometimes several times higher (Akbar-Khanzadeh et al., 2007; Flynn and Susi, 2003; Echt and Sieber, 2002; NIOSH EPHB 282-13, 2007). These levels can result from inadequate air flow rates. Although investigators in the cited studies considered vacuum capacity when matching suction equipment to grinding shrouds, based on information presented in the following paragraph, OSHA estimates that actual vacuum cleaner air flows were likely less than the published, nominal air flows (specified with zero static pressure at the air inlet) due to pressure losses attributed to the hood, hose, bends in the hose, vacuum cleaner body, vacuum cleaner filters, and debris accumulation on filters. Echt and Sieber (2002) reported that 36 pounds of debris were collected in a vacuum cleaner during one shift of concrete grinding.

In addition, the vacuum cleaners used for dust control during concrete grinding and cutting might have been undersized. In Akbar-Khanzadeh et al. (2007), the grinder used with LEV had a diameter of 6 inches. Based on criteria in the ACGIH ventilation manual (25 cfm/inch of blade diameter), an air flow of 150 cfm is recommended (ACGIH, 2010). The vacuum cleaner models used in Akbar-Khanzadeh et al. (2007) had a free air flow rating of only 106 cfm.[81] Considering system pressure losses, the actual air flow was likely substantially lower for the reasons discussed previously. To optimize performance, a vacuum

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[81] "Free air flow" is air flow without accounting for various pressure losses including debris accumulation on the filters, resistance in the vacuum hose, and static pressure losses throughout the vacuum.

system should include cyclonic pre-separation, large (2-inch) diameter hoses, a gauge indicating filter pressure, a high-efficiency filter with a large surface area, and a powerful motor (sufficient to move the required air flow even as filter loading begins to occur) (Collingwood and Heitbrink, 2007; Heitbrink and Santalla-Elias, 2009). For additional discussion of issues surrounding air flow rates and vacuums, refer to Section IV.C.32 – Tuckpointers and Grinders in this technological feasibility analysis.

Finishing Uncured Concrete

Silica exposures can be reduced if operators perform finishing operations on uncured concrete. Some facilities in the concrete products industry currently use two such methods, as summarized in ERG-GI (2008). For example, workers cutting, scoring, and adjusting the finish on uncured concrete products eliminated the need for power-grinding and air-hammering (which typically produce large quantities of dust). This work on uncured concrete was associated with silica readings of less than or equal to 12 µg/m^3 (LOD) (NIOSH ECTB 233-125c, 2000).

Combination of Controls

Finishing operators' respirable dust and silica exposure levels have decreased in German concrete products and precast component manufacturing plants as the facilities have implemented targeted controls, often in combination (BGIA, 2008). Examples include:

- Abrasive blasting in enclosed, recirculating systems with dust collection and conditioned abrasive blasting media (exposure levels around 100 µg/m3).
- Wet grinding.
- Dry grinding with dust collection (exposure levels around 50 µg/m3).
- Sawing wet or dry with LEV (which reduces exposure levels by at least 50 percent below wet sawing alone).
- Using clean water for wet sawing to minimize silica aerosols generated by dust-bearing recirculated water.

Although these German facilities encounter some results above 150 µg/m^3 during certain tasks, the median silica value obtained during finishing and treating of concrete products was 20 µg/m^3 (BGIA, 2008).

Additional Controls for Packaging Operators

As shown in Table IV.C-6, additional controls are required to reduce the silica exposure of two-thirds (66 percent) of packaging operators. Dust is generated during several parts of the packaging process: when bags are filled, when filled bags drop from the filling equipment onto the conveyor, and when workers use compressed air for cleaning (ERG-GI, 2008). Control options include installing or adding effective ventilation systems, improving existing ventilation equipment, and using alternate bag and bag valve designs to minimize dust release.

Local Exhaust Ventilation

OSHA SEP inspection report results illustrate the effectiveness of well-designed LEV for concrete packaging tasks. At one facility, installing a more powerful fan motor and new filter bag for the bag-filling machine LEV and moving the hoods closer to the packaging operator's position reduced respirable dust exposure by 92 percent.[82] After these improvements, a concrete packaging operator had a full-shift silica exposure below the LOD (in this case, 11 µg/m^3). OSHA obtained a similar result (12 µg/m^3, the LOD) at another facility that also had installed dust collection equipment on the concrete bagging equipment (OSHA SEP Inspection Report 116007451). Another type of ventilation for bag-filling operations, an overhead air supply island system (OASIS) (described in ERG-GI, 2008), has been shown to reduce respirable dust exposure by 98 percent and 82 percent for packaging operators at two mineral processing facilities. OSHA believes that OASIS would be similarly effective at reducing silica exposures of packaging operators in the concrete products industry because dry concrete is a form of mineral dust.

A dual concentric nozzle system for bag-filling machines also can reduce exposures for packaging operators. This system consists of an inner-fill nozzle (to load the bag with material) surrounded by an outer nozzle (to depressurize the filled bag and remove dust from bag valve, thereby preventing dust release). A study conducted by Cecala et al. (2000) at a mineral processing facility (described in more detail in ERG-GI, 2008) found that this type of system reduced respirable dust levels by 83 percent compared to unvented nozzles.

Bag Design and Quality

The use of bags with valves that seal effectively and prevent product leakage from filled bags is another way to control exposure. In addition to studying nozzles, Cecala et al. (2000) found that the use of 6-inch extended polyethylene valves reduced respirable dust exposures by more than 60 percent compared with standard paper valves, and the use of 4-inch foam valves reduced exposures by more than 45 percent. Because the concrete products industry, like the mineral processing industry, packs mineral powders, OSHA believes that a dual-nozzle system and effective bag valves will be as effective in the concrete products industry as these studies have shown it is in the mineral processing industry.

Alternate bag designs that minimize spillage and leaks reduce levels of airborne silica in the workplace. Bags that break during filling can be a notable source of silica dust and can contribute to operator exposures of two to three times the current PEL (Concrete Product Industry Associate, 2001). On a busy production line, improperly handled or low-quality bags might break frequently, up to 10 to 20 times an hour, releasing dust in the air as the contents spill and while workers clean up spilled material (ERG-GI, 2008). In addition, leakage from bags that do not fully contain the product during filling also can be a major source of exposure. Workers should be trained on proper techniques for filling and handling bags and should be provided with high-quality bags, filling equipment, and subsequent handling requirements that together minimize dust release (ERG-GI, 2008). One dry concrete bagging facility reduced worker respirable dust and silica exposure levels by changing product packaging from a three-ply bag perforated throughout, to a two-ply bag perforated only on the inner layer. This change alone reduced respirable dust by 83 percent and caused silica levels to fall from 180 µg/m^3 to 83 µg/m^3 (Klein, 2009, 2010).[83] A subsequent adjustment to the ventilation system (temporarily repositioning the ductwork

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[82] Respirable dust was reduced by 92 percent from an initial level of 15,500 µg/m^3 (15.50 mg/m^3) to 1,150 µg/m^3 (1.15 mg/m^3) after these modifications (OSHA SEP Inspection Report 300114378). Silica was only evaluated after the modifications were made, however, at which point the worker exposure level was 11 µg/m^3.

[83] Dusty displaced air from the filling process was released from points all over the sack through the perforations in the three-ply bags. In contrast, only the inner layer of the two-ply bags was perforated and displaced air passed inside the solid outer layer to a single relief point at the sack opening (i.e., nozzle entry point). Dusty air exiting from between layers at the relief point was captured by LEV associated with the filling nozzle.

directly over the filling area) further reduced respirable dust by an additional 48 percent. A somewhat less effective variation of the ventilation system was later made permanent.[84] Worker silica exposures associated with the last two changes ranged from 10 µg/m^3 to 23 µg/m^3, representing an 87- to 94-percent reduction compared to the original silica level of 180 µg/m^3. The samples for which durations are available were obtained over 4-hour periods (morning, afternoon) before and after modifications (midday) and so are not of sufficient duration to include in the exposure profile.

If the exposures of all packaging operators with currently elevated exposures were reduced by 83 percent (achieved by changing the type of bag being filled), then the percentage of packaging operators with results above 50 µg/m^3 in Table IV.C-6 would be reduced from 66 percent to 17 percent. If the highest result for a packaging operator from Table IV.C-6 (370 µg/m^3) were reduced by 87 to 94 percent by modifying bags and improving LEV, this worker's silica exposure level would be reduced to a value between 22 µg/m^3 and 48 µg/m^3.

Feasibility Finding

Feasibility Finding for Material Handlers

Exposure data collected by OSHA and NIOSH, presented in Table IV.C-6, shows that 65 percent of the material handlers in this industry currently experience silica exposures of 50 µg/m^3 or less. Because these levels have already been achieved for the majority of material handlers, OSHA preliminarily concludes that levels of 50 µg/m^3 or less can also be achieved for most of the remaining 35 percent of workers in this job category by using appropriately designed, well-maintained ventilation systems; implementing more consistent housekeeping and yard dust management programs; and reducing the exposures of workers in other job categories to levels of 50 µg/m^3 or less. All of these control measures will be required for the most highly exposed workers.

Among the data available to OSHA for this job category, the five results above 100 µg/m^3 (summarized in Table IV.C-6) were associated with material handlers for whom adjacent operations contributed to worker exposure. Additionally, three of the same four results were also dramatically affected by ineffective LEV. Although information from the concrete products industry is insufficient to confirm the benefit of LEV for this job category, information for material handlers in the pottery industry indicates that when workers have access to functional LEV, the results are markedly lower (median exposure level 27 µg/m^3) than when workers use material transfer stations where LEV is clearly inadequate or missing (median exposure level 530 µg/m^3). Based on the similarity of front-end loaders, hoppers, and mixing equipment used to blend mineral powders used by both industries, OSHA has preliminarily determined that LEV at material transfer stations will be just as effective in the concrete product industry as in the pottery industry. OSHA preliminarily concludes that installing or upgrading

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[84] With each additional exposure control, the consultant also documented a progressively lower percent of silica in respirable dust samples (all of which were confirmed to be associated with concrete dry mix packaging). Although no explanation was given for this phenomenon, OSHA notes that using sand consisting of larger particles or cleaned sand from which much of the fines have been removed could achieve this result. Thus, the change in respirable dust likely provides the most accurate assessment of control method effectiveness. Hood position and capture velocity at the nozzle turned out to be more critical than anticipated, however. After temporary ductwork was formalized as a permanent, flanged hood, the extra 48 percent reduction in respirable dust level was no longer observed (perhaps due to a decrease in capture velocity with the wider hood). Nevertheless, because the silica percentage was reduced concurrently, silica declined with each modification and ultimately reached a level "less than 40 percent of the ACGIH threshold limit value (TLV)" (Klein, 2009). Forty percent of the TLV of 25 µg/m^3 equals 10 µg/m^3.

LEV to meet ACGIH (2010) recommendations, particularly at blender hoppers charged by material handlers operating front-end loaders, will reduce even the highest results reported for material handlers in the concrete products industry to levels in the range of 100 µg/m^3.[85] OSHA also notes that controlling adjacent operations to levels of 50 µg/m^3, in addition to upgrading the LEV, could reduce exposure levels to even lower levels (e.g., the median of 27 µg/m^3 calculated for the pottery industry), providing that yards and floors do not contribute airborne silica.

In order to achieve levels of 50 µg/m^3 or less for all material handlers, silica emissions from yard dust and poor housekeeping practices (e.g., dry sweeping and disturbing dust settled in the plant) also need to be controlled. Exposures at facilities that implemented yard dust management controls include four readings of less than 21 µg/m^3 for facilities using dust suppressants, and two readings of less than 19 µg/m^3 for those that consistently wetted yard dust (NIOSH ECTB 233-112c, NIOSH ECTB 233-125c). In contrast, a material handler result of 110 µg/m^3 was associated with a yard that had been previously watered, but let dry. Furthermore, material handler exposure levels ranged from 48 to 73 for material handlers who performed dry sweeping during their shifts where "most of the facility has 1/8-inch of dust on the floor" (NIOSH ECTB-233-112, 1999). In the structural clay industry, another industry with similar material handling requirements, professional cleaning of a brick manufacturing facility dramatically reduced exposure levels (by 90 percent or more in some cases). In material handling areas where the professional cleaning was performed, most worker exposures were reduced to less than 50 µg/m^3 without other abatement efforts (ERG-GI, 2008). Where dust does accumulate, facilities can switch from brooms to HEPA-filtered vacuums to eliminate dry sweeping as a source of exposure.

In the event that some material handlers continue to experience elevated exposure, other control options are also available, such as enclosed, sealed, filtered and air-conditioned cabs, which can reduce the driver's exposure level by more than 90 percent. When this control is combined with the benefits of LEV, dust-suppressing yard maintenance, and reduced exposures associated with other job categories, OSHA preliminarily concludes that an exposure level of 50 µg/m^3 could be achieved for most material handlers most of the time. For example, NIOSH obtained an exposure of 21 µg/m^3 for an operator who used a front-end loader with an air-conditioned cab to transport raw materials across a water and dust suppressant-treated yard (NIOSH ECTB 233-127c).

Feasibility Finding for Mixer Operators

Based on Table IV.C-6, OSHA preliminarily concludes that 62 percent of all mixer operators currently have exposures of 50 µg/m^3 or less (46 percent have exposures less than 25 µg/m^3). To achieve that level, the remaining 38 percent of operators require additional controls during mixer drum chipping and manual bag dumping. Appropriate controls include frequent and conscientious rinsing of mixing equipment before residual concrete hardens on the barrel and using wet methods with chipping equipment when it becomes necessary to remove hardened concrete. During mixing activity, exposures can be controlled through ventilated bag dumping stations or automated mixer charging. In the event that results remain elevated, ventilated control rooms or booths can offer additional protection. The effectiveness of these controls is discussed in the following paragraphs.

Based on information presented earlier in the discussion of additional controls for mixer operators, OSHA preliminarily concludes that for truck drum cleaning, LEV-equipped chipping tools, water misting devices used with push-pull ventilation, or wetting the barrel interior and directing continuous water spray to the chipping point offer exposure reductions of *at least* 70 percent compared

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[85] This conclusion is based on the apparent prevalence of secondary exposure for this job category noted above (improved ventilation will reduce exposure levels, but will continue to be elevated until adjacent sources of exposure are also controlled).

with uncontrolled levels typically up to approximately 1,000 µg/m^3. OSHA preliminarily concludes that a 70-percent reduction in silica exposure would lower the second highest result available to OSHA for this job category (as identified in the discussion of the exposure profile for mixer operators performing barrel chipping in this industry) from 122 µg/m^3 to a level of 37 µg/m^3 and reduce to levels less than 37 µg/m^3 all the other results included in the mixer operator exposure profile summarized in Table IV.C-6, except the highest value of 281 µg/m^3.

For those mixer operators who experience elevated exposure while manually charging mixers, OSHA preliminarily concludes that ventilated bag dumping stations will reduce even the highest exposures associated with manual mixer charging to levels of 50 µg/m^3 or less. While data from concrete product facilities using ventilated bag dumping stations are unavailable, workers at a paint manufacturer, which also charged mixers with high-silica powdered mineral products, utilizing a bag dumping station with fully functioning LEV experienced a reduction in silica exposure of at least 95 percent (ERG-paint-fac-A, 1999).

Additionally, automated mixer charging reduces mixer operator exposure levels. An exposure of less than or equal to 12 µg/m^3 (LOD) was reported for a mixer operator using an automated charging system at a precast concrete panel facility (ERG-concrete-fac-C, 2002). OSHA reiterates that nearly half (46 percent) of mixer operators currently have exposure levels of 25 µg/m^3 or less; most of these values are associated with automatic mixer charging.

In the event that mixer operator exposure continues to occur during automated mixer charging, ventilated control rooms are also effective in maintaining a low exposure. OSHA obtained a reading of 23 µg/m^3 for a worker who operated a computer-controlled mixer operation and charging equipment from an enclosed booth (OSHA SEP Inspection Report 300523396).

Because the evidence indicates that such controls will individually bring exposures well below 50 µg/m^3, not all controls will be needed at all plants.

Feasibility Finding for Forming Operators

Table IV.C-6 indicates the vast majority (90 percent) of results for forming operators are 50 µg/m^3 or less, leading OSHA to preliminarily conclude that facilities can achieve exposures of 50 µg/m^3 or less for all forming operators. This goal can be accomplished primarily by controlling the exposure levels of adjacent workers. OSHA bases this conclusion on information indicating that among the data available to OSHA for this job category, the forming operators associated with silica values exceeding 50 µg/m^3 or 100 µg/m^3 were subject to silica dust from adjacent sources and from the activities of other workers that had exposure levels above 100 µg/m^3 (NIOSH ECTB 233-112c, 1999). The highest result summarized in Table IV.C-6 for this job category (107 µg/m^3) was obtained under these conditions at a facility where 9 of 10 results exceeded 100 µg/m^3 (OSHA SEP Inspection Report 300997012).

In the event that additional controls are required for forming operators (after the exposures of other job categories are controlled to levels of 50 µg/m^3 or less), available measures include adding LEV to forming operator workstations, particularly those with automated processes, and improving housekeeping, starting with a professional level cleaning to remove accumulated dust and continuing with the benefit of HEPA-filtered vacuums to clean forms and the facility. OSHA preliminarily concludes that these control measure could benefit workers in this job category because a forming operator with results exceeding 50 µg/m^3 on two consecutive days controlled a concrete block-forming machine that emitted dust. That forming operator’s location was near the mixing area, from which dust was emitted during mixer charging. Another worker performed dry sweeping nearby (CITE). OSHA preliminarily concludes that controlling these sources of exposure will reduce forming operators’ overall exposure.

Feasibility Finding for Abrasive Blasting Operators

OSHA preliminarily concludes that just 20 percent of abrasive blasting operator silica exposures are already 50 µg/m^3 or less, as indicated in Table IV.C-6. More than half of the workers in this job category (60 percent) experience exposure levels that exceed 100 µg/m^3, and many results are extremely high. Among the results available to OSHA, the maximum exposure level for an abrasive blasting operator in this industry is 26,826 µg/m^3. Although abrasive blasting has historically been associated with very high silica levels, OSHA has preliminarily determined that these exposure levels can be reduced (although not eliminated) by using alternative abrasive blasting media that is less toxic than silica or by switching to wet abrasive blasting (or a combination of both).

The primary method for reducing the exposure of those abrasive blasters with the highest exposures is using retarders and water spray to wash away incompletely cured concrete and expose aggregate. Where abrasive blasting must be performed, wet methods used outdoors or in a ventilated environment will substantially reduce silica exposure levels. However, the use of appropriate respiratory protection and proper ventilation, especially within enclosures, will still be needed to protect workers from hazardous levels of contaminants that can be generated during abrasive blasting, from either the abrasive or the substrate, or both. To ensure protection, ventilation and respiratory protection must meet the requirements of 29 Code of Federal Regulations (CFR) 1910.94 and 1910.134, respectively (29 CFR 1910.94 and 1910.134).

As an alternative exposure reduction method, low-silica abrasive blast media that is less toxic than silica sand can also reduce exposure levels for abrasive blasting operators in this industry. Although concrete surfaces remain a source of silica dust during abrasive blasting even when low- or non-silica media are used, these levels are often notably lower than silica concentrations measured during abrasive blasting with quartz sand. For example, three readings, 54 µg/m^3, 30 µg/m^3, and 20 µg/m^3, were obtained from two facilities at which finishing operators performed abrasive blasting of concrete products outdoors with coal slag media (OSHA SEP Inspection Report 116200940, OSHA SEP Inspection Report 300096930). Employers must consider the possible hazards of substitutes if switching from silica sand, however. For example, depending on the abrasive, alternative media can result in elevated levels of other hazardous air contaminants such as heavy metals (KTA-Tator-Phase-1, 1998; KTA-Tator-Phase-2, 1998; KTA-Tator-Phase-3, 1999). Furthermore, total and respirable dust levels will continue to be a concern even with alternate abrasive blasting media.

OSHA has reviewed the information contained in the discussion of additional controls for abrasive blasting operators in this industry and in the related section of this technological feasibility analysis covering abrasive blasting in the construction industry (Section IV.C.22 – Abrasive Blasters). Based on this information, OSHA preliminarily concludes that by using wet methods or alternative abrasive blasting media, the exposure of abrasive blasting operators working outdoors can be reduced to levels consistently below 500 µg/m^3.

Feasibility Finding for Finishing Operators

Based on Table IV.C-6, OSHA preliminarily concludes that 62 percent of finishing operators have exposure levels at or below 50 µg/m^3. By using water-fed equipment, LEV, and modified work practices (e.g., finishing of uncured products), the exposure levels of most finishing operators can be brought below 50 µg/m^3 most of the time. This finding is based on four exposure readings, ranging from less than or equal to 12 µg/m^3 (LOD) to 31 µg/m^3, obtained for finishing operators at two concrete product facilities using these additional controls. Two of the readings, obtained for finishing operators who used hand and power tools to work on uncured concrete products, were both less than or equal to 12 µg/m^3 (LOD) (NIOSH ECTB 233-125c). Two other readings, less than or equal to 12 µg/m^3 (LOD) and

31 µg/m^3, were obtained for a finishing operator who used a water-fed coring machine to drill concrete products (NIOSH ECTB 233-127c).

Feasibility Finding for Packaging Operators

OSHA preliminarily concludes that 33 percent of packaging operator exposure levels are already 50 µg/m^3 or less, as indicated in Table IV.C-6. Exposures of the remaining 67 percent of packaging operators can be controlled to 50 µg/m^3 or less by switching to package (bag) designs that release less dust and by improving or adding adequate workstation ventilation. Exposure readings of less than or equal to 12 µg/m^3 (LOD) and less than or equal to 11 µg/m^3 (LOD) were obtained at two facilities for packaging operators who loaded bags of dry-mixed concrete using bag-filling machines equipped with effective LEV systems (OSHA SEP Inspection Report 300114378, OSHA SEP Inspection Report 116007451). A third concrete products facility reduced silica exposure levels from 180 µg/m^3 to 10 µg/m^3 and 23 µg/m^3 by changing the bag design (to reduce dust emissions) and improving LEV to capture residual dust (Klein, 2009, 2010).

Overall Feasibility Finding

OSHA preliminarily concludes that by implementing the controls described in this section, silica exposure levels of 50 µg/m^3 or less can be achieved most of the time for most workers in all job categories in this industry, except the abrasive blasting operator job category. Workers performing abrasive blasting will continue to require respiratory protection under 29 CFR 1910.94.

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Cut Stone

Description

Slabs of silica-containing dimension stones are cut, shaped, and often polished to form a diverse range of products including floor tile, countertops, roofing slates, building cladding, and funeral monuments. The most commonly used dimension stones with the highest percentage of free quartz are granite (up to 45 percent quartz), sandstone (42 to 95 percent quartz), high-silica limestone (9 to 67 percent quartz), and slate (31 to 45 percent quartz) (ERG-GI, 2008). In 2003, the U.S. Geological Survey reported that granite comprised 41 percent of the dimension stone used in the United States; sandstone contributed another 9 percent; and slate comprised 6 percent (ERG-GI, 2008). Although many other stones contain silica, most have less desirable physical characteristics and are not cut for commercial purposes. Two of the other most commonly used dimension stones, marble and low-silica limestone, occasionally contain low levels of silica as impurities, but do not contribute significantly to worker exposure (ERG-GI, 2008).

Fabricating facilities that produce cut stone and stone products are classified in the six-digit North American Industry Classification System (NAICS) 327991, Cut Stone and Stone Products Manufacturing. In contrast, the manufacture of man-made stone is classified separately as NAICS 327999, All Other Miscellaneous Nonmetallic Mineral Product Manufacturing, and is discussed in Section IV.C.7 – Engineered Stone Products in this technological feasibility analysis. Once manufactured, however, these engineered stones are cut to shape and finished by the stone and stone products industry.

The essential steps used in the fabrication of stone products vary little across the industry. Natural stone is delivered as blocks that workers cut into slabs or, more frequently, stone is delivered as slabs precut to the approximate thickness of the ultimate product. Sawyers cut slabs to appropriate dimensions for the product. Fabricators change the contours and finish and assemble the pieces. Additional specialized steps can include manual chipping or splitting; mechanical trimming or milling; and abrasive blasting. Table IV.C-7 identifies and describes the five job categories with sources of exposure for workers in the stone and stone products industry.

Baseline Conditions and Exposure Profile

Stone industry workers can be exposed to silica when they saw large blocks and slabs of stone; grind or chip the stone; finish the pieces by smoothing, polishing, or abrasive blasting the surface; and handle or transport stone. There is significant potential for worker and bystander exposure to silica at each step in the process; however, the actual exposure varies enormously with the silica content of the stone, the work practices, and the equipment used.

Table IV.C-7

Job Categories, Major Activities, and Sources of Exposure of Workers

in the Cut Stone Industry (NAICS 327991)

Job Category*	**Major Activities and Sources of Exposure**
Sawyer	Operates large water-fed stationary bridge or gantry-type saws. • Dust from wet-sawing stone. • Dust disturbed from stone and work surfaces. • Dust from adjacent activities.
Fabricator	Produces finished stone products from slabs. • Dust from dry grinding, edging, milling, contouring, and polishing stone. • Dust disturbed from stone and work surfaces. • Dust from adjacent activities.
Splitter/Chipper (Splitter, Stone Cutter, Sculptor)	Uses hand-held equipment to change the shape of the stone. • Dust from dry chipping, splitting, and cleaving stone using hammer and chisel. • Dust generated while operating power tools for drilling and chipping. • Dust disturbed from stone and work surfaces. • Dust from adjacent activities.
Machine Operator (Trimmer, Gouger, Puncher, Planer)	Operates trimming, punching, gauging, or planing machines. • Dust emitted from unventilated, unenclosed trimming, punching, gauging, or planning machines. • Dust disturbed from stone and work surfaces. • Dust from adjacent activities.
Abrasive Blasting Operator	Operates blasting equipment. • Dust generated during blasting with silica sand or alternative media on silica-containing stone. • Dust from using compressed air for cleaning stone. • Dust disturbed from stone and work surfaces.

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the facility.

Source: ERG-GI, 2008.

Yassin et al. (2005) analyzed OSHA's Integrated Management Information System (IMIS) data for the period 1988–2003 and found a downward trend in exposure levels for cut stone and stone products workers compared with earlier IMIS data. This industry had geometric mean silica exposure levels 9.8 times higher in 1979–1987 than in 1988–2003 (619 micrograms per cubic meter [μg/m^3] to 63 μg/m^3), suggesting modern equipment and work practices are having a beneficial effect on worker exposures. This finding is in contrast to the experience of stone workers in Germany, who as an industry experienced very little reduction in silica exposure over the past four decades. The Institute for Occupational Safety and Health of the German Social Accident Insurance[86] (BGIA, 2008) attributed these intractable silica exposure levels to the increased popularity of granite (rather than the previously popular and virtually silica-free marble) as a decorative building material in Europe over this same time period. Increased demand for the higher silica granite offset improvements in local exhaust ventilation (LEV) and water-fed stone working equipment at stone product fabricating plants. Attfield and Costello (2004) evaluated older data for Vermont granite workers and found average measured personal and area silica levels were lower after 1950 compared with earlier years for several job categories applicable to the stone and stone products industry. This could have been due to either improved dust control (including increased automation) or increased use of lower silica stone (e.g., marble).

The following sections describe baseline conditions and the exposure data for each affected job category based on more than one dozen OSHA Special Emphasis Program (SEP) inspection reports and several NIOSH reports, previously described in ERG-GI (2008). Table IV.C-8 summarizes the exposure information for the affected job categories.[87]

Baseline Conditions and Exposure Profile for Sawyers

Sawyers typically operate large, powerful stationary bridge or gantry-type saws, with single or multiple heads. All of the results included in the exposure profile are associated with water-fed saws of these general varieties. OSHA reviewed 23 exposure results for sawyers from 10 OSHA SEP Inspection reports and one NIOSH report (ERG-GI, 2008). The results have a full-shift median exposure of 54 μg/m^3, a mean of 62 μg/m^3, and a range of 15 μg/m^3 to 134 μg/m^3. Thirteen results (57 percent) exceed 50 μg/m^3, and four results (17 percent) exceed 100 μg/m^3.

OSHA inspection reports indicate that sawyers generally cut stone from 30 minutes to 4 hours per day, but might work at the task up to 8 hours per day. A typical shop will employ approximately 25 percent of the production work force as saw operators, although the percentage might be higher in mass production shops, such as floor tile or slate roof manufacturing facilities (ERG-GI, 2008).

An extremely high-pressure water jet, often containing abrasives, can also be used to cut stone. A small but growing number of facilities are using water jet equipment to cut specialty shapes (e.g., sink openings in countertops) in smaller pieces of stone. The operator programs the automated equipment and

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[86] In 2008 Germany's Institute for Occupational Safety and Health of the German Social Accident Insurance was known as BGIA, but this organization is now called by the German acronym IFA.

[87] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) derived from samples of 6-hours or longer, assuming the exposure concentration during any unsampled portion of the shift was the same as the concentration during the period sampled. Unless explicitly stated otherwise, all results discussed in the additional controls section meet the same criteria. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

positions the stone inside an enclosed space, and a fine, high-pressure water spray (computer controlled) is directed along the cutting line (ERG-GI, 2008).

Baseline Conditions and Exposure Profile for Fabricators

Fabricators produce finished stone products from the sawn slabs or shapes. Fabricators use both electric and pneumatic tools, including hand-held dry circular saws and angle-grinders, hand-held or hand-guided grinders and routers, and higher speed polishing tools. OSHA reviewed 24 full-shift respirable quartz monitoring results for fabricators from eight OSHA SEP inspection reports and two NIOSH reports (ERG-GI, 2008). The results have a median of 49 μg/m^3, a mean of 126 μg/m^3, and a range of 12 μg/m^3 (limit of detection [LOD]) to 460 μg/m^3.[88] Twelve results (50 percent) exceed 50 μg/m^3, and 10 (42 percent) exceed 100 μg/m^3.

Although both grinding and polishing might be performed as wet processes, the typical shop uses primarily dry methods. A study conducted in the state of Washington found that fabricators in one-third of the facilities evaluated were primarily using wet methods at the time of the initial visit (Simcox, 1999). Sixty to 100 percent of production workers in typical custom architectural component (e.g., kitchen countertop) manufacturing facilities are classified as fabricators. Workers typically grind stone 20 minutes to 4 hours per day, and spend the balance of the day polishing, filling defects, waxing, inspecting work, performing housekeeping activities, and helping other workers (ERG-GI, 2008).

Baseline Conditions and Exposure Profile for Splitters/Chippers

Splitters/chippers typically use hand-held hammers and chisels, working within arm's length of their breathing zones, to change the shape of stone. OSHA reviewed 29 full-shift personal breathing zone (PBZ) results for chippers from eight OSHA SEP inspection reports and two NIOSH reports (ERG-GI, 2008). The results have a range of less than or equal to 13 μg/m^3 (LOD) to 208 μg/m^3, with a median of 98 μg/m^3 and a mean of 90 μg/m^3. Twenty results (69 percent) exceed 50 μg/m^3, and 14 (48 percent) exceed 100 μg/m^3. Four of the highest results, ranging from 134 μg/m^3 to 181 μg/m^3, are associated with dry splitting of slate (a high silica stone, therefore a worst case condition). These scenarios, which involve inadequately implemented controls or no attempt to control exposure, are typical of the slate-splitting work areas described by OSHA. Splitters/chippers typically work at this task for the full shift but might rotate to other tasks if the need arises. Typical slate tile manufacturing facilities employ approximately 30 percent of their production force as splitters (ERG-GI, 2008).

Baseline Conditions and Exposure Profile for Machine Operators

Machine operators are typically employed in facilities that mass produce large quantities of identical stone products (e.g., tiles). For the purposes of this discussion, machine operators are considered to operate stationary equipment. The stone is conveyed through the machine, processed, and conveyed out the back or side of the machine to be manually or automatically stacked on a pallet (ERG-GI, 2008). Typical machine functions include trimming, gouging, punching, and planning.

OSHA reviewed 17 full-shift PBZ results for machine operators from seven OSHA SEP inspection reports and one NIOSH report (ERG-GI, 2008). The results have a range of less than or equal to 13 μg/m^3 (LOD) to 314 μg/m^3, with a median of 69 μg/m^3 and a mean of 125 μg/m^3. Twelve results

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[88] Results reported as "none detected" are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

(71 percent) exceed 50 µg/m^3, and eight (47 percent) exceed 100 µg/m^3. Three of the highest results were collected from two slate trimming machine operators and a punching machine operator where controls (e.g., ventilation) were absent or ineffective or equipment was malfunctioning. These higher results (and the associated controls) are representative of those typically seen in facilities prior to abatement efforts instigated by an OSHA inspection (ERG-GI, 2008). The processes are performed dry and, at the time of OSHA's initial visits, were typically unventilated. In these facilities, machine operators make up 20 to 30 percent of the production workforce and work at their tasks approximately 8 hours per day (ERG-GI, 2008).

Baseline Conditions and Exposure Profile for Abrasive Blasting Operators

Abrasive blasting operators in this industry typically use traditional dry abrasive blasting methods to etch patterns, such as lettering or decorations, into stone. OSHA reviewed seven full-shift PBZ respirable quartz monitoring results for abrasive blasting operators from one OSHA SEP Inspection Report and three NIOSH reports (ERG-GI, 2008). The results have a range of 22 µg/m^3 to 309 µg/m^3, with a median of 55 µg/m^3 and a mean of 137 µg/m^3 (ERG-GI, 2008). Four results (57 percent) exceed 50 µg/m^3, and three (43 percent) exceed 100 µg/m^3.

At all six facilities considered in the exposure profile, the abrasive blasting media consisted of various grit sizes of aluminum oxide or bauxite. Aluminum oxide contains little or no silica, and bauxite can contain 2 to 9 percent quartz. Some operators also use silica sand to finish or "whiten" the blasted surface (ERG-GI, 2008).

Abrasive blasting operators might spend 1 to 7 hours per 8-hour shift operating blasting equipment. In addition to blasting, operators spend substantial amounts of time applying masking materials to protect portions of the stone from the effects of blasting. Operators' other activities include cleaning dust from stone, usually with compressed air, and removing spent media and stone dust from the blasting area using shovels and brooms. In memorial production facilities, 10 to 30 percent of production workers are abrasive blasting operators (ERG-GI, 2008).

NIOSH evaluated blasting booths at two of the three establishments they visited and found that the ventilation rate measured less than half the rate recommended by the American Conference of Industrial Hygienists (ACGIH) (2001): 100 cubic feet per minute per square foot (cfm/ft^2). OSHA also reviewed four less than full-shift PBZ results collected by NIOSH for abrasive blasting operators at a stone monument manufacturer. Although these data are less than full shift and thus are not included in Table IV.C-8, they provide additional insight into the ventilation controls experienced by these workers. The sample times range from 4 to nearly 6 hours, and all results are below 50 µg/m^3 for the periods (mean of 29 µg/m^3) sampled. Three of the operators performed automated blasting in ventilated abrasive blasting booths, and one used both the ventilated blasting booth and a manual blasting cabinet contained within an enclosure with a rubber curtain that acted as a barrier for dust. Although the type of media used was not reported, the percent of silica in total respirable dust for these samples ranged from 14 percent to 33 percent. The measured face velocity at the screen was 160 feet per minute (fpm) for the automated blasting operation, and 100 fpm at the curtain for the manual blasting operation (NIOSH EPHB 247-22, 2003).

Table IV.C-8
Respirable Crystalline Silica Exposure Range and Profile for Workers in the Cut Stone Industry (NAICS 327991)

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean (μg/m^3)**	**Median (μg/m^3)**	**Min (μg/m^3)**	**Max (μg/m^3)**		**<25 (μg/m^3)**	**≥25 and ≤50 (μg/m^3)**	**>50 and ≤100 (μg/m^3)**	**>100 and ≤250 (μg/m^3)**	**>250 (μg/m^3)**
Sawyer	23	62	54	15	134		4 17%	6 26%	9 39%	4 17%	0 0%
Fabricator	24	126	49	12	460		4 17%	8 33%	2 8%	6 25%	4 17%
Splitter/Chipper	29	90	98	13	208		5 17%	4 14%	6 21%	14 48%	0 0%
Machine Operator	17	125	69	13	314		2 12%	3 18%	4 24%	6 35%	2 12%
Abrasive Blaster	7	137	55	22	309		1 14%	2 29%	1 14%	1 14%	2 29%
Totals	**100**	**101**	**67**	**12**	**460**		**16** **16%**	**23** **23%**	**22** **22%**	**31** **31%**	**8** **8%**

Notes: All samples are personal breathing zone (PBZ) results for durations of 360 minutes or more and represent 8-hour time-weighted average exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Source: ERG-GI, 2008.

Additional Controls

Additional Controls for Sawyers

Additional controls are required for the 57 percent of sawyers whose exposures exceed 50 µg/m^3. These controls include LEV, and thorough housekeeping to prevent the accumulation of dried slurry and other dust that can be re-suspended. Increased water flow to the saw and saw enclosures might be required in some facilities.

OSHA SEP inspection reports suggest that a combination of housekeeping and other measures can reduce silica levels. For example, the median full-shift PBZ silica exposure level was 30 µg/m^3 for eight sawyers at four facilities that implemented housekeeping in combination with other control measures, such as enclosing the saw in a booth with a fan, pre-washing stone, managing slurry, increasing water flow for wet processes, and controlling dust from adjacent processes (ERG-GI, 2008). This level is more than 40 percent lower than the median result for all sawyers reported in the exposure profile (54 µg/m$^{3)}$. It is also lower than the median of 100 µg/m^3 for sawyers in three facilities using some form of additional controls, but where rigorous housekeeping was not reported (ERG-GI, 2008).

Housekeeping activities at the four low-exposure facilities included steps that minimized dust accumulation on surfaces and kept floors damp. In the event that recirculating water for saws is becoming laden with stone dust (as occurs with brick dust during masonry cutting in the construction industry), changing the water more frequently could also reduce the amount of silica in mist and dried slurry. OSHA was unable to obtain information identifying the specific benefits of housekeeping because most facilities improve housekeeping at the same time that they implement other control methods.

The value of combining LEV with whole-shop exposure control efforts is illustrated by exposure monitoring data obtained by OSHA at a facility where efforts to augment housekeeping, enclose the saw, and control other sources of silica dust in the shop had already reduced the sawyers' median exposure from 84 µg/m^3 to 49 µg/m^3 (ERG-GI, 2008). After management modified the ventilation to exhaust directly from the top of the saw, the silica median exposure for sawyers was further reduced to 22 µg/m^3.

Stand-alone fan-powered dust collectors are a feasible method to lower dust levels in small dimension stone processing shops, especially during times when windows cannot be opened. Air cleaning units, however, must be properly sized to clean dust loads and keep acceptable dust levels low.[89]

Additional Controls for Fabricators

The 50 percent of fabricators whose exposure level exceeds 50 µg/m^3 will require additional controls. The primary controls for fabricators include wet methods when polishing and grinding stone and rigorous housekeeping throughout the facility.

The exposure level for fabricators can be reduced substantially by converting to water-fed equipment and switching to wet methods. According to Simcox et al. (1999), exposures of fabricators at granite handling facilities were reduced from a mean of 490 µg/m^3 to 60 µg/m^3 (88 percent) when all dry grinding tools used on granite were either replaced or modified to be water fed. The same study reported

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[89] Chekan, et al. (2008) demonstrate that a 2.24 kilowatt (kW) motor cleaning unit cleaned 19 percent more air and captured 32 percent more respirable dust than the 0.56 kW unit. The study also discussed cost-effective retrofit options. Although dust collectors are practical means to reduce respirable dust, reliable data do not exist to determine their effectiveness.

similar reductions in exposure at other fabricating facilities when wet grinding, polishing, and cutting methods were adopted.

Results obtained from NIOSH and OSHA SEP inspection reports also show a substantial reduction in fabricator exposure levels associated with wet methods. All seven full-shift PBZ silica results for fabricators using water-fed equipment exclusively are 51 µg/m^3 or less (ERG-GI, 2008). In six of these instances of wet-method use, the fabricator was polishing granite; in one case, the fabricator was working with marble in a facility that also handled granite.

Rigorous control of water from wet processes prevents dust left by evaporated water from being disturbed and becoming airborne. The following methods, combined with water-fed equipment, are associated with reduced exposure levels for fabricators: frequent replacement or filtration of recirculated water for milling machines, adequate collection of used water from hand-held equipment, and frequent washing of floors and surfaces where dust-laden water might evaporate or dust might accumulate.

OSHA also considered grinding equipment fitted with shrouds attached to vacuums as a means of reducing exposure. This type of equipment has been shown to reduce exposure levels of concrete finishers by 75 to 93 percent (Akbar-Khanzadeh and Brillhart, 2002; Croteau et al., 2002; NIOSH ECTB 247-21c, 2002; NIOSH-construction-site-16, 1998); however, shrouds work best on flat surfaces and are less effective when workers use these tools on edges and corners, which constitute most of a granite fabricator’s work with hand-held tools.

Stand-alone fan-powered dust collectors, discussed previously as an additional control for sawyers, also are a feasible method to lower dust levels in small-dimension stone processing shops.

Additional Controls for Splitters/Chippers

Additional controls are needed to reduce exposures for the 69 percent of splitters/chippers whose exposures exceed 50 µg/m^3. Available controls include LEV at workstations, rigorous housekeeping, and wet methods. Based on the similarity of tools and exposures, OHSA anticipates that splitters and chippers benefit similarly from the controls discussed in this section.

OSHA does not possess data that quantifies the benefits of LEV or water fed tool attachments, as individual controls or in combination, in the stone products industry. However, there is evidence that demonstrates that a combination of LEV, wet methods, and other efforts can be very effective in reducing exposures. For example, at a facility visited by OSHA, workers also used a combination of housekeeping, LEV, and wet methods to control splitter/chipper exposure. In this case, workers washed stone with a constant stream of water (rather than a spray). The single full-shift PBZ splitter/chipper exposure result was 31 µg/m^3. Previous silica results for chippers/splitters at the facility had been 132 µg/m^3, 124 µg/m^3, and less than 13 µg/m^3 (no quartz detected in the 13 µg/m^3 sample) (ERG-GI, 2008). Both these facilities also found that individual exposure reduction efforts alone failed to maintain exposures below 100 µg/m^3, but were successful when jointly employed.

At another facility OSHA visited, the workers wet stone with a hose before and between each operation, washed floors daily with a fire hose and kept them damp at all times, and controlled dust from the saws by modifying ventilation to exhaust directly from the top of the saws. Additionally, the facility retrofitted splitting stations with LEV. Under these conditions, the full-shift respirable quartz exposures for splitters were reduced from 104 µg/m^3, 109 µg/m^3, and 137 µg/m^3 (a mean of 117 µg/m^3) to levels of 17 and 19 µg/m^3 (a mean of 18 µg/m^3) (ERG-GI, 2008).

Other dust control options for power chipping tools include LEV fitted directly to the chipping bit and water feeds that spray mist at the chipping point. Although neither control is commercially available, shop-made versions have been assembled from materials available at hardware stores (NIOSH ECTB 247-19c, 2001; Sam, 2000). In short-duration tests, both LEV and water-fed attachments reduced the silica exposure of workers removing hardened concrete from the interior of concrete-mixer drums. For example, NIOSH reported a 69 percent reduction in worker exposure levels when the suction fitting was used with jack hammers. During controlled, short-duration tests, the geometric mean PBZ silica concentration was 300 µg/m^3 with the LEV, compared with 970 µg/m^3 when no controls were used (NIOSH ECTB 247-19c, 2001). Silica levels decreased further when general exhaust ventilation was used in addition to LEV. The combined controls provided a net reduction of 78 percent (from 970 µg/m^3 to 213 µg/m^3).

Wet methods also can reduce the exposure levels associated with hand-held power chipping equipment. The automatic water spray attachment for pneumatic chippers described by Williams and Sam (1999), used in combination with general exhaust ventilation, reduced worker respirable dust exposures by 70 percent compared with uncontrolled chipping in concrete-mixer drums.

Stand-alone fan-powered dust collectors, discussed previously as an additional control for sawyers, also are a feasible method to lower dust levels in small dimension stone processing shops.

Additional Controls for Machine Operators

As indicated in the exposure profile, more than half (71 percent) of the full-shift PBZ results for this job category exceed 50 µg/m^3. Thus, OSHA finds that additional controls are required for workers in this job category. Appropriate controls include enclosing machines, adding exhaust ventilation close to the point where dust is generated, converting to water-fed equipment, employing rigorous housekeeping, and frequently washing stone and floors.

Facilities that use a combination of these controls can reduce machine operator exposure substantially. For example, a slate-working establishment exhausted the machine at the point where dust was generated, pre-wet the stone, installed spray mister nozzles to keep the stone wet, and took steps to reduce dust released from the adjacent saws. Under these conditions, the operator exposure level dropped from 220 µg/m^3 to 26 µg/m^3 (ERG-GI, 2008). At another facility, OSHA reported two full-shift PBZ silica results of 44 µg/m^3 and 314 µg/m^3 around the time of the initial compliance inspection. The facility implemented procedures to pre-wash stone, controlled dust from other operations, and enclosed trimmers in exhausted plastic housing. After the modifications, full-shift silica results for operators were more consistent, at 60 µg/m^3 and 69 µg/m^3 (ERG-GI, 2008). Although these results are more consistent and have a much lower average (65 µg/m^3 vs. 179 µg/m^3) than those collected before the modifications, they are still above 50 µg/m^3.

The respirable quartz exposures of machine operators can be reduced significantly by the use of wet process rather than dry process machines and by manufacturer-designed, adequately exhausted machine housing. Stone Working Equipment Distributor A (2000) indicated that most new machines sold to high-volume production facilities come with LEV dust collectors and/or enclosures as standard equipment. New water-fed machines and machines using ultra-high pressure water or laser instead of abrasive action also are increasingly available. New equipment has the added advantage of increased automation, allowing the operator to work at a greater distance from the dust source.

Machine operators with exposures currently greater than 100 µg/m^3 will require the entire range of controls described above to be increase the likelihood of maintaining exposure values below this level. Although there is one example of a machine operator whose exposure dropped from 220 µg/m^3 to 26 µg/m^3 with a combination of controls, data are not sufficient to demonstrate that all exposures can be reduced below 100 µg/m^3 with any subset of the controls.

Additional Controls for Abrasive Blasting Operators

Full-shift PBZ silica exposure results for more than half (57 percent) of abrasive blasting operators exceed 50 µg/m^3. Additional controls are required for this job category, including improved maintenance of blasting cabinets, adequate ventilation, and alternative low-silica or silica-free blasting media that is less toxic than silica sand.

Complete isolation of the operator from the blasting operation (i.e., use of a glove box-type ventilated blasting cabinet) can reduce silica exposure during abrasive blasting. Also, ventilated blasting cabinets used by three operators in Georgia granite sheds (using either silica sand or an alternate media) generated exposure results of 15 µg/m^3 to 77 µg/m^3 with a mean of 41 µg/m^3 (Wickman and Middendorf, 2002). OSHA estimates that exposure levels associated with blasting cabinets can be reduced to levels consistently below 50 µg/m^3 by using silica-free blast media and a combination of other engineering and work practice controls. These controls include enclosed and ventilated media recycling systems, interlocks to prevent operators from opening doors before the cabinet has been exhausted, and use of high-efficiency particulate air (HEPA)-filtered vacuums instead of dry sweeping or compressed air to clean in and around the cabinet. A well-sealed blast cabinet (a type of containment) isolates a worker from the dust generated inside and the interlock and ventilation systems ensures that the cabinet is free of airborne dust before the operator opens it. When well constructed, maintained, and used as intended, evidence from the pharmaceutical industry indicates that containment devices that operate on this principle can maintain worker exposures to pharmaceutical chemicals at levels below pharmaceutical potent active ingredient (API) occupational exposure limits of 10 µg/m^3 or less (Axon et al. (2008).

Large, glove box-style cabinets for abrasive blasting oversize or awkward shape objects are available commercially (Media Blast, 2009). For example, one manufacturer produces ventilated cabinets that have reportedly been used for abrasive blasting of granite tombstones (Pauli, 2001a; Pauli, 2001b). This size box is interlocked, to prevent operation unless the unit is sealed, and ventilated at 840 cfm. In addition, the boxes are fitted with a dust collector (99.9 percent filter efficiency for 0.3 micron particles available for some models) and a completely enclosed, ventilated media reclamation system. A larger ventilation system is required when two or more of these cabinets are linked together to provide a larger internal workspace (Pauli, 2001b).

For large items that cannot fit in a blast cabinet, improving ventilation to at least the ACGIH-recommended air flow rate of 100 cfm per square foot of face area (equivalent to 5,000 cfm for a 7-by-7-foot booth) is likely to decrease the exposure of blasting operators. Alternatively, using an abrasive blasting booth that includes an incompletely sealed partition to separate the operator from the blasting activity (for example roll-up doors with an access slot and window) may provide an additional level of protection, if negative pressure is maintained in the blasting enclosures. For example, ventilated blasting booths used by three operators at a stone monument manufacturer resulted in exposures of less than 50 µg/m^3 (mean of 29 µg/m^3) for all three workers. Silica content ranged from 14 percent to 20 percent. Although the 4- to 6-hour sample times for these exposures are less than full shift, these durations are typical of the industry (NIOSH EPHB 247-22, 2003).

In addition, this type of equipment (abrasive blasting booth that includes an incompletely sealed partition) was used by two of the three granite working facilities in which NIOSH conducted control technology assessments (NIOSH ECTB 233-106c, 1999; NIOSH ECTB 233-131c, 2000; Ruemelin, 2000). Exposure monitoring data associated with these partitions at one of the sites, however, showed mixed results, with full-shift PBZ exposures of 22 µg/m^3 and 252 µg/m^3 (NIOSH ECTB 233-106c, 1999).

Although investigators indicated that the ventilation system was not operating for part of the sampling period, the available documentation is inadequate to correlate worker exposure and properly operating equipment.[90] The partitions were not evaluated at the other site. Air pressure and turbulence introduced during blasting might limit the reliability of this control option. The intermittent elevated exposure evident with this style of enclosure (access slot in door) might be better controlled by another commercially available option: a gauntlet glove panel and window that can be inserted into the wall of a walk-in size sealed and ventilated abrasive blast booth (Pauli, 2009).

More extensive use of silica-free blast media also might reduce operator exposures. Bauxite can contain up to 9 percent silica and might contribute to worker exposure (ERG-GI, 2008). Aluminum oxide and steel shot, which also are used as blast media, contain little to no silica.

As noted previously, the use of stand-alone fan-powered dust collectors also is a feasible method for lowering dust levels in small-dimension stone processing shops.

Wet abrasive blasting methods are widely available and work well on all structural and most decorative concrete surfaces. OSHA preliminarily concludes that these methods may be similarly effective on stone (stone aggregate is a major component of concrete). Abrasive blasters in this industry can use wet methods as an alternative to ventilated process enclosures that separate workers from the abrasive blasting area.

Although the silica exposure levels for abrasive blasting operators performing open blasting can exceed OSHA's permissible exposure limit (PEL), OSHA already requires that employers provide these workers with respiratory protection and, when the work is in an abrasive blasting booth, ensure that they have the benefit of exhaust ventilation. For more information on these requirements, see 29 CFR 1910.94–Ventilation and 1910.134–Respiratory Protection.

Feasibility Finding

Feasibility Finding for Sawyers

Based on the information reviewed above, OSHA preliminarily concludes that the respirable quartz exposures of most sawyers can be controlled to levels of 50 μg/m^3 or less by implementing a combination of engineering and work practice controls. For example, the median full-shift PBZ silica exposure level for sawyers was 30 μg/m^3 at facilities that implemented housekeeping as well as other control measures (enclosing the saw, pre-washing stone, managing slurry, and controlling dust from adjacent processes) (ERG-GI, 2008). Although these examples are from slate product manufacturers, OSHA concludes that the same controls would be similarly effective in facilities that process granite and other stone.

Feasibility Finding for Fabricators

Based on information summarized in Table IV.C-8, OSHA preliminarily concludes that the exposure of fabricators can be reduced below 50 μg/m^3 through the use of wet processes and rigorous housekeeping. All seven full-shift PBZ silica results for fabricators using water fed-equipment exclusively are 51 μg/m^3 or less (ERG-GI, 2008). Additionally, Simcox reported a mean silica worker exposure of 60 μg/m^3 after wet method controls were implemented. Note that all the data are results of applying wet methods (other controls not implemented). OSHA anticipates that improved housekeeping

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[90] The NIOSH ECTB 233-106c (1999) report does not indicate which sampling period is associated with the functioning ventilation system.

will reduce exposures similar to these to levels below 50 μg/m^3 since resettled dust contributes significantly to worker exposures in this industry. Additionally the most successful exposure reductions have all originated from efforts to complement engineering controls with housekeeping measures. Controlling water from wet processes prevents dust left by evaporated water from being disturbed and becoming airborne. Managing dust from adjacent operations also should help maintain exposures of fabricators below 50 μg/m^3.

Feasibility Finding for Splitters/Chippers

Based on the available information, OSHA preliminarily concludes that the silica exposure of most splitters/chippers can be controlled to levels below 50 μg/m^3 by implementing a combination of engineering and work practice controls similar to those used for sawyers. The combination of rigorous housekeeping, daily floor washing, wetting of the stone before and between operations, and controlling dust from adjacent operations has been shown to be effective for splitters (note the full shift mean respirable quartz reduction from 117 μg/m^3 to 18μg/m^3 at a facility visited by OSHA reported in ERG-GI, 2008)

More rigorous controls will also be necessary for some workers, including the 48 percent of splitters/chippers who are currently exposed at levels exceeding 100 μg/m^3. These workers are typically employed at slate facilities and some facilities manufacturing memorials, which will need to install LEV at splitter/chipper stations. A facility using a combination of housekeeping, LEV, and wet methods (constant water flow) to control splitter/chipper exposures reduced the splitter/chipper exposure level to 31 μg/m^3 (ERG-GI, 2008). Facilities also might need to improve drainage to allow frequent washing of stone and floors.

Exposure results for splitters/chippers suggest that memorial manufacturers might require supplemental exhaust trunks to ensure that LEV is readily accessible to all points around large three-dimensional products. Furthermore, those establishments where chipper/splitters use power tools (e.g., pneumatic chipping equipment) will need to implement task-specific controls. Options include tool-mounted water-fed or tool-mounted LEV devices as described by NIOSH (NIOSH ECTB 247-19c, 2001) and Williams and Sam (1999). These controls are discussed in more detail in Section IV.C.26 – Jackhammer and Impact Drillers in this technological feasibility analysis.

Feasibility Finding for Machine Operators

Based on information presented in this section, OSHA preliminarily concludes that stone product facilities can achieve silica exposure levels of 50 μg/m^3 or less for all machine operators in this industry. Thirty percent of machine operators already experience exposures below this level. OSHA finds that by using a combination of controls the exposures for the remaining workers in this job category can also be reduced to 50 μg/m^3 or less. Appropriate controls include enclosing machines, adding exhaust ventilation close to the point where dust is generated, converting to water-fed equipment, and rigorous housekeeping, as well as frequently washing stone and floors.

To consistently achieve levels of 50 μg/m^3 or less, OSHA anticipates that facility may have to employ the full extent of available controls. For example, a facility visited by OSHA implemented procedures to pre-wash stone, controlled dust from other operations, and enclosed trimmers in exhausted plastic housing. After the modifications, exposures were reduced from a mean of 179 μg/m^3 to 65 μg/m^3. The facility did not modify the equipment to include a water delivery system, and the Agency estimates that exposures could have been further reduced if dust originating from the machine was suppressed by water. This determination is based the exposure reduction obtained at a slate-working establishment, which exhausted the machine at the point where dust was generated, pre-wet the stone, installed spray mister nozzles to keep the stone wet, and took steps to reduce dust released from the adjacent saws. Under these conditions, the operator exposure level dropped from 220 µg/m^3 to 26 µg/m^3.

Incremental improvements will reduce exposures sufficiently for some workers; however, for the most highly exposed machine operators (e.g., the 47 percent who experience exposures in excess of 100 µg/m^3 per Table IV.C-8), a more extensive range of controls will be necessary to achieve operator exposures of 50 µg/m^3 or less. OSHA preliminarily concludes that wet dust suppression methods or LEV (or both) will usually be required. Machine operators' exposure levels dropped from 179 µg/m^3 to 65 µg/m^3 after one facility began pre-washing stone, controlled dust from other operations, and enclosed trimmers (ERG-GI, 2008). Although the facility achieved a marked decrease in silica exposure, additional controls, such as applying water at the point of operation or adding exhaust ventilation to the machine enclosure, would be needed to reduce silica concentrations to levels of 50 µg/m^3 or lower.

Another slate-working establishment used both LEV and wet methods to control machine operator exposures. This facility applied exhaust ventilation to the machine at the point where dust was generated, pre-wet the stone, installed spray mister nozzles to keep the stone wet, and took steps to reduce dust released from the adjacent saws. Under these conditions, the operator exposure level was reduced from 220 µg/m^3 to 26 µg/m^3. Employers in the stone products industry will also need to put programs in place to ensure that controls for machine operators are functioning optimally (ERG-GI, 2008).

Feasibility Finding for Abrasive Blasting Operators

Based on information contained in this analysis, OSHA preliminarily concludes that the exposure of most abrasive blasting operators can be controlled to levels of 50 µg/m^3 or less through the use of HEPA-filtered vacuum cleaning and sealed, ventilated, and interlocked blasting cabinets. These controls are appropriate for small to medium-size stone objects, including all modest memorials. Properly maintained blast cabinets can offer complete isolation from exposures and are commonly used for this purpose. Ventilated blasting cabinets used by three operators in Georgia granite sheds (using either silica sand or an alternate media) generated a mean exposure result of 41 µg/m^3 (Wickman and Middendorf, 2002). Although a high result of 77 µg/m^3 was recorded by these investigators, OSHA estimates that exposure levels associated with blasting cabinets can be reduced to levels consistently below 50 µg/m^3 by using silica-free blast media that is less toxic than silica sand or a combination of other engineering and work practice controls. These controls include enclosed and ventilated media recycling systems, interlocks to prevent operators from opening doors before the cabinet has been exhausted once blasting is complete, and use of HEPA-filtered vacuums instead of dry sweeping or compressed air to clean in and around the cabinet.

For larger stone objects, OSHA believes that ventilated blasting booths might be used to control exposures to levels of 50 µg/m^3 and below. For example, ventilated blasting booths used by three operators at a stone monument manufacturer resulted in exposures of less than 50 µg/m^3 (mean of 29 µg/m^3) for all three workers. Although the 4- to 6-hour sample times for these exposures are less than full shift, these durations are typical of the time spent performing abrasive blasting in this industry (NIOSH EPHB 247-22, 2003).

Overall Feasibility Finding for Cut Stone Products Manufacturers

In summary, using the controls described in this section (LEV, wet methods – including water delivery systems at the point of operation, and rigorous housekeeping), OSHA preliminarily concludes that cut stone product manufacturers can achieve exposure levels of 50 µg/m^3 or less for most of their workers most of the time.

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Dental Equipment and Supplies

Description

Certain establishments that manufacture dental equipment and supplies produce silica-containing filling materials, for dentists to use in teeth, and investment materials, for dental laboratories to create the mold into which metal is poured during metal casting.[91] Some dental supply manufacturers also operate small sand-casting foundries to produce dental metal alloys (ERG-GI, 2008). Producers of supplies and equipment for dental offices and laboratories are classified in the six-digit North American Industry Classification System (NAICS) code 339114, Dental Equipment and Supplies Manufacturing.

Workers at dental equipment and supply manufacturers (production operators) process silica-containing materials when they blend batches of restorative materials, porcelains, plasters, and refractory investment materials. Both quartz and cristobalite are found in these materials, which can contain up to 100 percent silica. The same or different workers package the resulting dry powdered products. Other workers, in facilities that produce metal alloys for the dental industry, might encounter silica if they use sand molds to cast ingots as part of a small foundry operation; however, the extent of foundry work in the dental equipment and supply industry is unknown (ERG-GI, 2008).

Production operators (blenders, compounders, and packaging operators) oversee all phases of silica handling, including receiving raw ingredients, product blending, and packaging. Dry, powdered quartz and/or cristobalite are typically received in sacks (e.g., 50-pound bags) or larger containers, such as tanker trucks. The silica ingredients arrive at the facility in a ready-to-use form and typically do not require additional processing to reduce particle size. Large-scale operations use automated processes (e.g., pneumatic material handling equipment) to transfer silica-containing material between tankers, storage tanks, and hoppers, while workers involved in low-volume operations manually empty sacks of materials into hoppers or use a hand-held scoop to transfer materials from bags to weighing equipment (ERG-GI, 2008). From hoppers or weighing equipment, production operators add silica-containing ingredients and other dry, viscous, or liquid ingredients to mixing tanks where the products are blended.

In some facilities, production operators also control automated or semi-automated equipment that fills sacks, barrels, boxes, buckets, or small single-use envelopes (containing a few ounces of product) with dry, powdered product for distribution to customers (ERG-GI, 2008). Some operators monitor mostly-enclosed, automated machinery; others manually place buckets under spouts or put bags on filling nozzles within arms-length of the packaging equipment (ERG-GI, 2008).

Table IV.C-9 summarizes the major activities and primary sources of silica exposure for this industry.

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[91] "Investment material" is a ceramic-type, heat-resistant (refractory) material used to enclose a three-dimensional pattern during investment casting (lost-wax casting is an example of investment casting) (ILO, 1983). These refractory materials can contain up to 70 percent crystalline silica (ERG-dental-lab-A, 2000).

Table IV.C-9

Job Categories, Major Activities, and Sources of Exposure of Workers in the Dental Equipment and Supplies Manufacturing Industry (NAICS 339114)

Job Category*	Major Activities and Sources of Exposure
Production Operator (blender, compounder, packaging operator)	Preparing and packaging batches of silica-containing restorative materials, porcelains, plasters, and refractory investment materials. • Dust released during transfer of raw materials from delivery vehicles to storage areas and from storage to mixing areas. • Dust released during weighing or metering raw materials into mixers (from hoppers, by dumping bags, or pouring by hand). Operating mixing and filling equipment, including manual placement of containers on filling equipment. • Dust escaping from mixing/blending equipment. • Dust escaping from packaging equipment used to fill product containers (envelopes, bags, barrels). • Dust disturbed during use of vibrating equipment used to compact powdered product in containers. Housekeeping • Dry sweeping and vacuuming silica-containing materials.

* Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the facility.

Source: ERG-GI, 2008.

Baseline Conditions and Exposure Profile

The exposure information for production operators is limited to only three personal breathing zone (PBZ) samples: two obtained from an OSHA Special Emphasis Program (SEP) inspection report of a dental alloy supplier, and one from a manufacturer of silica-containing dental restorative material (OSHA SEP Inspection Report 122252281; Dental Equipment and Supplies Manufacturer A, 2000).[92]

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[92] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) derived from samples of 6-hours or longer, assuming the exposure concentration during any unsampled portion of the shift was the same as the concentration during the period sampled. Unless explicitly stated otherwise, all results discussed in the additional controls section meet the same

Data from another facility, though informative, was not specific enough to include in the exposure profile (Dental Equipment and Supplies Manufacturer B, 2000).

Although 11 exposure results were recorded from four inspections of the dental alloy supplier conducted over several months (October 1995 to March 1996), only two of the 11 samples were collected over a full shift. OSHA excluded the other nine results from the exposure profile because of their short duration (less than 360 minutes) and because worker rotation was used to control exposure. After the initial two full-shift samples were collected, the employer initiated an administrative control by limiting worker exposures to no more than 4 hours in the investment production area—the primary area where silica dust occurred (OSHA SEP Inspection Report 122252281). Although limited, these data represent the best data available to OSHA for workers in this industry and provide information on engineering controls the facility implemented to control dust from the refractory blending and packaging operation.

The exposure profile for the dental equipment and supplies industry is shown in Table IV.C-10. Sample results range from 10 micrograms per cubic meter (μg/m^3) to 214 μg/m^3, with a median of 90 μg/m^3 and a mean of 105 μg/m^3. Thirty-three percent of the results are less than the proposed permissible exposure limit (PEL) of 50 μg/m^3.

Local exhaust ventilation (LEV) was available on mixing and packaging equipment at all three facilities for which ERG obtained information (ERG-GI, 2008). Baseline conditions at the dental alloy supplier, however, included excessively sharp or 90 degree bends in the ventilation hoses; inefficient fans; poorly designed, inappropriately positioned, or missing hoods; and generally low exhaust rates. Additionally, work practices were poor (e.g., LEV was positioned so the worker was between the LEV and dust generated by mixer charging), and workers reportedly routinely spilled material. The respirable quartz levels associated with these conditions are 90 μg/m^3 and 214 μg/m^3 (OSHA SEP Inspection Report 122252281).

At the second manufacturing facility, an elevated exposure (200 μg/m^3) was also attributed to poor work practices, such as a worker leaning into the mixer to monitor the process (Dental Equipment and Supplies Manufacturer B, 2000). Information provided was not specific enough to include this result in the exposure profile (e.g., the sample duration was not provided), but the value is offered as supporting material.

Additional Controls

The exposure profile indicates that silica exposure levels for one-third of all production operators are already 50 μg/m^3 or less. To achieve this level for the remainder of the production operators, dental supply manufacturers will need to use a combination of improvements or upgrades in existing LEV systems and modified work practices to reduce the amount of dust that becomes airborne.

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criteria. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

Table IV.C-10
Respirable Crystalline Silica Exposure Range and Profile for Workers in the Dental Equipment and Supplies Industry (NAICS 339114)

	Exposure Summary			Exposure Range			Exposure Profile				
Job Category	**Number of Samples**	**Mean (μg/m^3)**	**Median (μg/m^3)**	**Min (μg/m^3)**	**Max (μg/m^3)**		**<25 (μg/m^3)**	**≥25 and ≤50 (μg/m^3)**	**>50 and ≤100 (μg/m^3)**	**>100 and ≤250 (μg/m^3)**	**>250 (μg/m^3)**
Production Operator	3	105	90	10	214		1 (33%)	0 (0%)	1 (33%)	1 (33%)	0 (0%)

Notes: All samples are personal breathing zone (PBZ) results for durations of 360 minutes or more and represent 8-hour time-weighted average exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Source: ERG-GI, 2008.

From 1994 to 1996, OSHA compliance and consultation officers tracked a facility that achieved substantial exposure reduction through a combination of efforts (OSHA SEP Inspection Report 122252281). Extensive real-time airborne dust monitoring indicated that both mixing (including bag dumping and charging) and packaging activities generated substantial amounts of airborne dust. Peak periods of dust release occurred when workers broke bags or spilled material, loaded and operated the mixer, dropped empty bags (from a height, releasing visible dust), and used vibrating equipment to compact product in containers. Short-term PBZ monitoring showed that worker exposures dropped dramatically when the facility implemented the following improvements:

1. Improved LEV systems, including enhanced hood designs and realigned ventilation exhaust points to provide better capture at the bag dumping station, mixer charging area, and packaging area. Added a high-efficiency particulate air (HEPA)-filtered exhaust system to a bag dumping station and upgraded the bag houses. Improved duct angles and upgraded fans to increase air flow through the ventilation systems (reportedly achieving a five-fold increase on one system).
2. Reduced leaks in the mixer and packaging systems and enclosed a portion of the packaging operation.
3. Added a partially enclosed and ventilated sleeve at the mixer charging port (to guide ingredients during mixer charging).
4. Changed workstation designs to limit the drop distance for empty raw material bags (a source of dust) and product overflow from packaging activities.
5. Encouraged work practices that minimized spilled material and maintained the LEV between the workers' breathing zone and the point where dust was released.
6. Improved housekeeping and used a sweeping compound to reduce dust during all clean-up activities.

After the facility implemented this combination of controls, OSHA obtained five short-term silica results below the limit of detection (LOD) (24 µg/m^3, 26 µg/m^3, 29 µg/m^3, 32 µg/m^3, and 40 µg/m^3) and one short-term result of 66 µg/m^3 during two visits to the facility.[93] The median for these six results is 31 µg/m^3. Prior to the improvement, OSHA obtained three short-term results of 885 µg/m^3, 430 µg/m^3, and 372 µg/m^3. Although all of these data represent samples collected over less than four hours, OSHA believes that these data demonstrate the success of the engineering controls.

A full-shift exposure level of 10 µg/m^3 was reported at Manufacturer A, a facility that blends a silica-containing powder with other ingredients to form a paste product. At this facility, worker exposures are controlled by a combination of careful work practices, LEV at the weighing station, and a sealing (air-tight) cover on the mixer (Dental Equipment and Supplies Manufacturer A, 2000). In addition, the worker who hand-scoops material to a weigh bucket is required to position an 8-inch exhaust trunk with a conical hood as close as feasible to the raw material bag opening before hand-scooping. The bag, bucket, and scale are under a hood/enclosure (ventilated by the 8-inch duct). A company representative quoted reports

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[93] Results reported as "none detected" are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

of annual air sampling results going back more than five years that indicate consistently low silica exposures.

Comparable information regarding the effectiveness of properly designed and maintained equipment for controlling dust generated during bag dumping and disposal exists for other industries that handle similar materials. For example, ERG obtained respirable quartz exposure monitoring data for workers at a paint manufacturing facility who use bag-dumping stations with automated bag disposal features to empty 50-pound bags of a silica-containing material (ERG-paint-fac-A, 1999). The stations consist of hoppers topped with grates enclosed by LEV hoods. After each bag is emptied, the worker releases it and suction automatically pulls the bag into the ventilation system and transfers it to an enclosed storage area. Results of five full-shift PBZ exposure readings were less than or equal to 12 µg/m^3 (LOD) for five workers who emptied bags at these stations. By contrast, a full-shift PBZ exposure reading of 263 µg/m^3 was obtained for a worker who used a bag-dumping station at which the LEV system failed to operate for approximately two hours. While the LEV system was inoperative, the worker was required to manually stack and compress empty bags adjacent to the station, which generated visible dust (ERG-paint-fac-A, 1999).

A NIOSH report (NIOSH CT-144-19a, 1983) also describes an effective bag-dumping station. This system is equipped with an enclosure; empty bag compactor; bag disposal chute; and LEV system consisting of a fan, baghouse, and plenum. The LEV system ventilates both the enclosure and compactor. NIOSH evaluated the unit by measuring PBZ respirable dust levels with real-time aerosol monitors before and while workers emptied bags of crushed limestone and found no statistically significant elevation of PBZ respirable dust over background levels. Ventilated bag-dumping stations that include a ventilated bag compactor are readily available from commercial sources (Whirl-air, 2003).

Feasibility Finding

Based on the available information, OSHA preliminarily concludes that manufacturers of silica-containing dental products can limit the silica exposure of most workers to 50 µg/m^3 or less most of the time by implementing a combination of controls that reduce the amount of dust that becomes airborne and using LEV to capture dust that is released. Such controls include replacing or improving existing ventilation systems (at bag dumping stations, weighing and mixing equipment, and packaging machinery) and designing workstations to minimize opportunities for silica materials to spill, fall, or drop (e.g., adding a sleeve to guide raw materials into an open mixer). Additionally, it will be necessary for facilities to ensure that workers properly use the LEV systems and encourage work practices that minimize spills and release of airborne silica dust. For a facility implementing these controls, OSHA obtained a median of 31 µg/m^3 for six short-term (less than four hours) silica results (24 µg/m^3, 26 µg/m^3, 29 µg/m^3, 32 µg/m^3, 40 µg/m^3, and 66 µg/m^3). Prior to the improvements, OSHA obtained three short-term (less than four hours) results of 885 µg/m^3, 430 µg/m^3, and 372 µg/m^3 (OSHA SEP Inspection Report 122252281).

References

Dental Equipment and Supplies Manufacturer A, 2000. Personal communication between a representative of Dental Equipment and Supplies Manufacturer A and Eastern Research Group, Inc. June 13.

Dental Equipment and Supplies Manufacturer B, 2000. Personal communication between a representative of Dental Equipment and Supplies Manufacturer B and Eastern Research Group, Inc. August 3.

[ERG-dental-lab-A] Eastern Research Group, Inc., 2000. Site visit to Dental Laboratory A. August 3.

[ERG-GI] Eastern Research Group, Inc., 2008. Technological Feasibility Study of Regulatory Alternatives for a Proposed Crystalline Silica Standard for General Industry, Volume 1 and 2.

[ERG-paint-fac-A] Eastern Research Group, Inc., 1999. Site Visit to Paint Facility A. July 6.

[ILO] International Labour Office, 1983. Entry for foundries, in Encyclopedia of Occupational Health and Safety, volume 1. Pages 916-917.

[NIOSH CT-144-19a] National Institute for Occupational Safety and Health, 1983. An evaluation of control technology for bag opening, emptying and disposal – the self contained filter/bag dump station, The Young Industries, Inc., Muncy, Pennsylvania.

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Dental Laboratories

Description

Dental laboratories use silica-containing materials both as a component of dental appliances (crowns, bridges, orthodontic appliances, and dental prostheses) and as an abrasive material for finishing these products. Dental laboratories are classified in the six-digit North American Industry Classification System (NAICS) 339116, Dental Laboratories. Dental technicians produce custom dental appliances, first by constructing plaster models of dental impressions, and then using the models as templates to make metal, plastic, or ceramic castings. The four steps in dental product manufacture that can involve silica include plaster model and mold production, investment casting,[94] finishing of metal castings, and coating dental appliances with porcelain enamel.

Depending on the size and configuration of the facility, a single dental technician may perform all of the activities described above, or a technician may perform one activity repeatedly, such as abrasive finishing. Table IV.C-11 summarizes the major activities and primary sources of silica exposure in this industry.

Baseline Conditions and Exposure Profile

Using the best available data, OSHA evaluated 31 full-shift personal breathing zone (PBZ) silica results for dental technicians obtained by ERG from one dental lab and by the New Jersey Department of Health and Senior Services (NJDHSS) from 13 dental labs (ERG-dental-lab-A, 2000; NJDHHS, 2006).[95] The data from these two sources, previously described by ERG (2008-GI), form the basis of the exposure profile for dental technicians and are summarized in Table IV.C-12. ERG's prior analysis included review of the available published silica exposure monitoring data described here and several reports of elevated exposure levels for dental technicians thought to represent dated, and poorly controlled conditions in dental laboratories. The reports indicate the potential for elevated exposure and suggest that past silica exposures were significantly higher in some dental laboratories.

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[94] Investment casting is a form of metal casting that involves enclosing a three-dimensional pattern in a heat-resistant ceramic mold called investment material. Lost-wax casting is an example of a type of investment casting commonly used in the dental laboratory industry (ERG-dental-lab-A, 2000).

[95] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) derived from samples of 6-hours or longer, assuming the exposure concentration during any unsampled portion of the shift was the same as the concentration during the period sampled. Unless explicitly stated otherwise, all results discussed in the additional controls section meet the same criteria. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

Table IV.C-11

Job Categories, Major Activities, and Sources of Exposure of Workers in Dental Laboratories (NAICS 339116)

Job Category*	**Major Activities and Sources of Exposure**
Dental Technician	Constructing plaster models of dental impressions. • Manual mixing of plasters, some of which can contain silica (e.g., 30% quartz). • Molding and grinding of dry plaster models. • Casting of dental products using plaster models. • Dry sweeping or using compressed air to clean work areas Using investment casting techniques to produce metal dental appliances. • Manual mixing of powdered investment material containing up to 70% silica as quartz and cristobalite. • Breaking investment materials to release metal castings. Finishing cast metal appliances. • Grinding metal castings to remove adhered investment material. • Abrasive blasting of castings to remove embedded investment material (typically in a ventilated glove box). Applying and finishing porcelain coatings on dental appliances. • Grinding and polishing porcelain coatings. • Abrasive blasting of porcelain coatings (typically in a ventilated glove box).

*Job categories are intended to represent job functions; actual job titles may differ and responsibilities may be allocated differently, depending on the facility.

Source: ERG, 2008-GI.

As shown in Table IV.C-12, the 31 sample results range from less than or equal to 5 micrograms per cubic meter (μg/m^3) (the limit of detection [LOD]) to 58 μg/m^3, with a median of 8 μg/m^3 and a mean of 13 μg/m^3.[96] Ninety-seven percent of the sample results are less than the proposed permissible exposure

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[96] Results reported as “none detected” are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional

limit (PEL) of 50 µg/m^3, with 17 (55%) below the LOD. The single result that exceeded 50 µg/m^3 (58 µg/m^3) was obtained for a dental technician trainee divesting castings, working with wax, and performing abrasive blasting. The next highest result, 40 µg/m^3, represents the exposure of a dental technician at a different laboratory performing investing, casting, sandblasting, grinding, and polishing. The other results for dental technicians performing various combinations of similar activities range from 5 µg/m^3 to 32 µg/m^3. Silica was detected in at least one sample from 10 of the 14 total laboratories evaluated (71 percent) and 14 of the 31 total full-shift PBZ samples (45 percent). These data suggest that silica continues to be present in dental laboratories; however, the work practices and controls currently used by these technicians produce exposures less than 50 µg/m^3 the vast majority of the time. Additionally, the generally low silica exposures of dental technicians may result from the small quantities of silica-containing materials in use and the brief duration of exposure. For example, during ERG's visit to a dental laboratory, a technician performed abrasive blasting for less than 5 minutes during the 8-hour work shift (ERG-dental-lab-A, 2000).

Based on descriptions of dental technician's activities discussed in the ERG report (ERG-dental-lab-A, 2000), OSHA finds that baseline conditions for this group of workers typically include the use of ventilated work benches; enclosed, ventilated equipment for blasting; and ventilated or water-fed grinders. These conditions, in conjunction with the small amounts of silica-containing materials handled and the short duration of use, are associated with a median exposure level of 8 µg/m^3. This finding is supported by a Korean study by Kim et al. (2002) that showed sample means less than 25 µg/m^3 for two groups of dental technicians working in dental laboratories equipped with local exhaust ventilation (LEV) systems.

The Korean investigators obtained 41 full-shift PBZ silica samples for dental technicians categorized as either polishing workers (model making, wax-up, investing, burn-out, casting, divesting, abrasive blasting, and polishing) or porcelain workers (metal trimming, porcelain buildup, porcelain firing, and porcelain grinding). Twenty-two samples collected on polishing workers ranged from 3 µg/m^3 to 51 µg/m^3, with a mean of 15 µg/m^3; and 19 samples collected on porcelain workers ranged from 1 µg/m^3 to 19 µg/m^3, with a mean of 7 µg/m^3.[97] Combined, the 41 samples ranged from 1 µg/m^3 to 51 µg/m^3, with a mean of approximately 11 µg/m^3. These results are in line with the dental workers' exposure summary shown in Table IV.C-12.

Based on the available information, OSHA preliminarily concludes that most dental laboratory technicians are currently exposed to silica at levels well below 50 µg/m^3.

Additional Controls

Several publications reviewed by ERG (ERG-GI, 2008) indicate the potential for dental technicians to be exposed to elevated levels of silica at least occasionally. Monitoring data summarized in Table IV.C-12 show that one out of 31 dental technicians (3 percent) was exposed full-shift at a level greater than 50 µg/m^3. For these 3 percent of workers, improved engineering controls and work practices will be necessary to reduce exposure. Options for additional controls include the following:

- Substitution of silica sand with alternative low-silica or silica-free blast media (e.g., glass beads or various grades of aluminum oxide) (ERG-dental-lab-A, 2000). In some cases it also

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information on LODs.

[97] Low sample results are the values reported by the investigator.

may be possible to substitute non-silica or low silica plaster and investment materials for casting.

- Improved LEV/enclosures (e.g., use of a properly designed abrasive blasting cabinet, installation of properly designed and operating laboratory hoods, improved filtration of air exhausted from hoods and blasting cabinets [if not exhausted outdoors]) (ERG-dental-lab-A, 2000).

Table IV.C-12
Respirable Crystalline Silica Exposure Range and Profile for Workers in Dental Laboratories (NAICS 339116)

	Exposure Summary			Exposure Range			Exposure Profile				
Job Category	**Number of Samples**	**Mean (µg/m^3)**	**Median (µg/m^3)**	**Min (µg/m^3)**	**Max (µg/m^3)**		**<25 (µg/m^3)**	**≥25 and ≤50 (µg/m^3)**	**>50 and ≤100 (µg/m^3)**	**>100 and ≤250 (µg/m^3)**	**>250 (µg/m^3)**
Dental Technicians	31	13	8	≤ 5	58		26 (84%)	4 (13%)	1 (3%)	0 (0%)	0 (0%)

Notes: All samples are personal breathing zone (PBZ) results for durations of 360 minutes or more and represent 8-hour time-weighted average exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Source: ERG-GI, 2008.

- Wet methods (e.g., breaking molds under a water stream or mist, wet grinding using a ventilated grinder) (ERG-dental-lab-A, 2000).
- Elimination of dry sweeping and compressed air for cleaning.
- Use of clean blast media for each session (to avoid recycling media contaminated with refractory material unless it can be cleaned).
- Improved work practices (e.g., allowing the blasting cabinet ventilation to clear the equipment of dust before opening the cabinet).
- Improved housekeeping (e.g., use of high-efficiency particulate air (HEPA) filter-equipped vacuums, daily where necessary).

Although there is no available information quantifying the effectiveness of each additional control in reducing silica exposures, the dental laboratory surveyed by ERG used several of these controls including LEV for mixing, abrasive blasting, and finishing operations, and enclosures and ventilation for mixing dry ingredients. The results of all five exposure samples were below the limit of detection (12 μg/m^3) (ERG-dental-lab-A, 2000). This dental lab used several modeling plasters, one of which contained 30 percent quartz. The lab also cast dental appliances using investment material containing up to 70 percent silica. Although workers frequently used silica-containing materials, the equipment and work practices effectively controlled silica exposures.

OSHA also notes that these controls have proven successful in other sectors, where contact with silica is much more frequent and the volumes of silica-containing materials encountered are much greater than in this sector (see Sections IV.C.8 – Foundries and IV.C.22 – Abrasive Blasters).

Feasibility Finding

Based on the available information, OSHA preliminarily concludes that using currently available technology, dental laboratories can limit the silica exposure of most workers to 50 μg/m^3 or less. Most dental technicians are currently exposed to silica at levels less than 50 μg/m^3. OSHA estimates that facilities will need to add or improve controls at the workstations of 3 percent of dental technicians. Where exposures exceed 50 μg/m^3, facilities have several options for reducing exposure, including improved housekeeping and work practices, enhanced LEV, further worker isolation, and the use of wet methods. In a dental laboratory surveyed by ERG that used several of these controls, all five exposure measurements were below 12 μg/m^3 (ERG-dental-lab-A, 2000). The dental laboratory used alternate methods for cleaning (other than compressed air) and alternate materials for blasting (other than silica-containing).

These techniques have proven successful in controlling exposures in other sectors with much higher exposures and larger volume silica use. Additionally, substitutes for silica are gaining acceptance and may be used to reduce or eliminate silica exposure in some dental laboratories.

References

[ERG-dental-lab-A] Eastern Research Group, Inc., 2000. Site visit to Dental Laboratory A. August 3.

[ERG-GI] Eastern Research Group, Inc., 2008. Technological Feasibility Study of Regulatory Alternatives for a Proposed Crystalline Silica Standard for General Industry, Volume 1 and 2.

Kim, T.S., H.A. Kim, Y. Heo, Y. Park, C.Y. Park, and Y.M. Roh, 2002. Levels of silica in the respirable dust inhaled by dental technicians with demonstration of respirable symptoms. Industrial Health 40:260-265.

[NJDHSS] State of New Jersey Department of Health and Senior Services, 2006. Results of air monitoring for airborne respirable crystalline silica dust (in 13 dental studios 2003-2005). Facsimile transmitting summary data sheets from NJDHSS to the U.S. Occupational Safety and Health Administration. February 9.

Engineered Stone Products

Description

Engineered stone (also called compound stone) is made by compacting a stone mix using a combination of vibration and compression, while holding the mix under a vacuum (ERG-GI, 2008). The stone mix typically consists of natural stone aggregates, fine mineral particles, and bonding agents. The engineered stone products produced in the United States are made of 93 percent ground quartz and 7 percent resin and pigments. The resulting engineered stone slabs are used as an alternative to granite in applications such as custom countertops (ERG-GI, 2008). In the United States, this industry is made up of a single manufacturer with a total of approximately 60 workers who might experience silica exposure at one time or another.[98]

The engineered stone production process involves receiving bulk raw materials, primarily as a high-quartz ground mineral product, mixing bonding resin and mineral components to form a dry blend, molding the blended materials by compressing them under vacuum pressure, then grinding and polishing the surface to achieve the desired finish. The finished engineered stone slabs are shipped to fabrication facilities (covered under the Stone and Stone Products industry addressed elsewhere in this technological feasibility analysis) where they are cut and shaped (ERG-GI, 2008).

Workers who might be exposed to silica during the slab production process include production workers who operate automated equipment and perform related activities to support production (e.g., moving bulk materials, collecting samples, cleaning the work area) (ERG-GI, 2008). The primary job category, major activities, and sources of exposure are summarized in Table IV.C-13.

Engineered stone product manufacturing is classified under the six-digit North American Industry Classification System (NAICS) code 327999, All Other Miscellaneous Nonmetallic Mineral Product Manufacturing. In addition to engineered stone, there are other products made in the United States in this and other industries using a combination of plastic resin and minerals. Cultured stone is one example of such a product. ERG (ERG-GI, 2008) investigated these industries and found no evidence of silica exposure because these industries use low- or non-silica-containing mineral fillers such as calcium carbonate.

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[98] Engineered stone is produced more frequently in other countries, which distribute it as a functional substitute for granite in flooring, shower and tub enclosures, fireplace surrounds, wet bars, furniture, and internal and external cladding for buildings. The United States imports more engineered stone than it makes.

Table IV.C-13

Job Categories, Major Activities, and Sources of Exposure of Workers in the Engineered Stone Products Industry (NAICS 327999)

Job Category*	**Major Activities and Sources of Exposure**
Production Worker (operators, inspectors, quality control, maintenance, housekeeping)	Performing intermittent manual production and maintenance tasks (e.g., receiving and storing raw materials, performing housekeeping and maintenance). • Dust from manually opening sacks of ground quartz and moving bulk raw materials. • Dust from cleaning and scraping the mixer. • Dust from cleaning baghouses or using compressed air for cleaning. Monitoring automated processes (weighing, dispensing, mixing raw materials, slab finishing). • Dust from raw material hoppers. • Dust associated with raw material conveyance ductwork and dust collection systems (difficult to maintain because of the abrasive nature of concentrated silica powder).

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the facility.

Source: ERG-GI, 2008.

Baseline Conditions and Exposure Profile

OSHA conducted a compliance inspection of a slab plant in April 2007 and observed that, as a baseline condition, the slab production process is highly automated and many potential exposure points are fully enclosed (ERG-GI, 2008).

OSHA also reviewed the company’s silica exposure database; however, the individual results were not available to ERG for analysis (ERG-GI, 2008). ERG also reviewed the OSHA Integrated Management Information System (IMIS) database for observations of silica exposure pertaining to Standard Industrial Classification (SIC) 3299, Nonmetallic Mineral Products, Not Elsewhere Classified, and found no exposure results that pertain to this industry. The summary information available is deemed insufficient to generate an exposure profile.

Because of the extremely limited nature of the industry (comprising just one facility) the following descriptive information is considered adequate for this analysis.

In the absence of individual exposure results, OSHA relied on the available information from individuals familiar with exposure levels at the facility visited by OSHA (a U.S. company that manufactured quartz slabs) and described in ERG-GI (2008). OSHA conducted a compliance inspection of one of this company's plants in April 2007 (OSHA SEP Inspection Report 311079172), reviewed the company's recent silica exposure data, and interviewed personnel. The historic total number of samples in the company database was not made available; however, the OSHA inspector described the dataset for recent years as extensive. The 8-hour time-weighted average (TWA) exposure levels for all production workers were most typically slightly below the calculated permissible exposure limit (PEL). However, during some intermittent tasks (maintenance, housekeeping, and other manual processes performed by the production workers), exposures were occasionally elevated, and the facility required workers to wear respiratory protection for these activities (ERG-GI, 2008).

Based on this information and the percentage of quartz in the product (93 percent), ERG used OSHA's general industry PEL equation to estimate the PEL for respirable dust containing silica in this facility (105 $\mu g/m^3$ as respirable dust). As noted above, exposure levels are typically slightly below this PEL; therefore, ERG multiplied the estimated respirable dust level (105 $\mu g/m^3$) by the percent silica in the dust (93 percent) to derive a typical respirable quartz level of 98 $\mu g/m^3$ (ERG-GI, 2008).[99]

This generalization, based on the best information currently available to OSHA, might underestimate or overestimate silica exposures in this industry.

Additional Controls

Additional Controls for Engineered Stone Workers

The engineered quartz slab manufacturing plant evaluated by OSHA was a new purpose-built plant (constructed around the turn of the millennium) with many existing engineering controls to minimize exposure to silica. Nevertheless, as noted previously, worker exposures reportedly are just below the current OSHA PEL along the entire production line, and elevated exposures levels are associated with cleaning, housekeeping, and maintenance activities performed intermittently by production workers. Control technology exists for some sources of exposure, as evidenced by a new second production line that incorporates (undisclosed) improvements in the design of the line. The new mixing area in particular reportedly should further control silica exposures during production operations and mixer maintenance; however, supporting exposure data are not available to OSHA (ERG-GI, 2008).

Additional controls to reduce exposures on the original production line are reportedly feasible. Worker exposures can be reduced through increased inspection and maintenance of pneumatic conveying systems (including the exhaust ventilation system). Silica particles abrade ductwork and eventually damage duct integrity, allowing the system to leak. Specific concepts evaluated as improvements to the existing production line include installing new baghouses, replacing ductwork with ceramic piping for pneumatically conveyed raw materials, enhancing housekeeping, and using high-efficiency particulate air (HEPA)-filtered vacuums (ERG-GI, 2008). In the weighing and mixing areas, an additional exposure

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[99] The OSHA PEL for silica (quartz) respirable dust is calculated using the following formula: PEL = 10 $mg/m^3/(\% \text{ quartz} + 2)$. The company's engineered quartz contains 93 percent quartz; therefore the silica respirable dust PEL is estimated to be 10 $mg/m^3/95$, which is equal to 0.105 mg/m^3 or 105 $\mu g/m^3$. If the respirable dust contains 93 percent quartz, the silica level is approximately 98 $\mu g/m^3$ (0.93 x 105 $\mu g/m^3$).

control option could include an interlock system that automatically activates local exhaust ventilation when the raw material hoppers are used.

Among the issues identified by ERG as problematic for this industry is the use of compressed air for cleaning. The facility visited by OSHA described raw material storage and baghouse areas as locations where HEPA-filtered vacuums might be an option for cleaning (ERG-GI, 2008). Cleaning with compressed air (and dry sweeping) can result in significant worker exposure to hazardous air contaminants (ERG-GI, 2008). To the extent that elevated silica exposures in the raw material storage/baghouse areas are primarily associated with cleaning using compressed air, increasing reliance on HEPA-filtered vacuums will substantially reduce exposure levels.

Feasibility Finding

Based on the information presented above, OSHA estimates that production workers in this industry may currently experience exposures of approximately 98 μg/m^3, with occasional excursions to higher levels. OSHA preliminarily concludes that with improved housekeeping and more rigorous use and maintenance of existing ventilation systems, the estimated silica exposure levels of 98 μg/m^3 or less can be achieved more reliably in this industry for workers involved with routine production processes, but levels of 50 μg/m^3 might not be achievable all the time without completely replacing the existing decade-old production line with a new line (e.g., equivalent to that recently installed by the facility evaluated by OSHA). Even then, an increased level of inspection and maintenance will be necessary to ensure that raw material conveyance ducts and dust collection systems work efficiently.

Once these changes are made, OSHA preliminarily concludes that exposure levels of 50 μg/m^3 or less can be achieved for most workers in this industry most of the time. However, because of the high silica content of the raw materials (93 percent quartz), some workers will continue to experience elevated intermittent exposures during maintenance and housekeeping tasks, particularly in baghouses and raw material storage areas. Respirator use will continue to be necessary during these tasks.

References

[ERG-GI] Eastern Research Group, Inc., 2008. Technological Feasibility Study of Regulatory Alternatives for a Proposed Crystalline Silica Standard for General Industry, Volume 1 and 2.

Foundries (Metal Casting)

Foundries melt and cast metal in molds to produce precisely formed metal castings, which workers then trim and clean to create finished products. Major end-use markets for these metal castings are manufacturers of automotive parts, pipe, industrial machinery, transportation equipment, and aerospace equipment (U.S. DOE, 1995). Depending on the casting processes used, workers in as many as a dozen foundry job categories work directly with materials that contain silica, including sand used to create molds, refractory mold release agents, furnace linings, and residual sand mold material adhered to castings and scrap metal.

The foundry industry can be divided into four subsectors, based primarily on the types of metal and processes employed:

- Ferrous sand casting foundries.
- Nonferrous sand casting foundries.
- Non-sand casting foundries (ferrous and nonferrous).
- Captive foundries.

Captive foundries include establishments with foundry processes incidental to the primary products being manufactured.

Ferrous sand casting foundries employ a major share of foundry workers potentially exposed to silica and are covered extensively earlier in this section. Separate discussions are then presented for the other foundry sectors. Table IV.C-14 shows the four foundry sectors and the associated North American Industry Classification System (NAICS) industries.

Sand casting is the most common method of producing metal castings,[100] and the silica exposure hazards of casting using silica sand molds are far greater than those of casting methods not involving sand, such as permanent casting and die casting (NIOSH-79-114, 1978). Therefore, the discussion in this report focuses on job categories with potential for silica exposure applicable primarily to sand casting foundries. Furthermore, among sand casting foundry workers, the workers of iron and steel foundries typically have higher silica exposures than workers in other metal casting facilities, primarily because the higher temperatures required for melting ferrous metals, such as iron and steel, result in sand molds that are hotter, drier, and hence dustier than in other metal casting facilities (O’Brien, 1998). Although data from all types of ferrous sand casting foundries (NAICS 331511 and 331513)[101] are included in this OSHA’s analysis of ferrous sand casting foundries, silica exposures of workers in gray and ductile iron foundries (NAICS 331511) serve as the primary basis for discussion, since these foundries are the most numerous and the best studied with respect to worker exposure to silica. Workers in these foundries serve

as a basis of comparison for the three other major foundry groups addressed later in this foundry industry analysis.

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[100] Sand casting is used to produce an estimated 60 percent of all cast metal products, both ferrous and nonferrous (U.S. DOE, 1998).

[101] NAICS 331511 and 331513 generally correspond to Standard Industrial Classification (SIC) 3321, 3322, and 3325.

IV.C-14
Foundry Sectors

Foundry Sector	NAICS Industries	Comment
Ferrous Sand Casting Foundries	331511, Iron Foundries 331513, Steel Foundries (except Investment)	Foundries in these NAICS industries perform sand casting.
Nonferrous Sand Casting Foundries	331524, Aluminum Foundries, (except Die-Casting)—Part* 331525, Copper Foundries (except Die-Casting)—Part 331528, Other Nonferrous Foundries (except Die-Casting)—Part	Foundries in these NAICS industries perform sand casting.
Non-Sand Casting Foundries	331524, Aluminum Foundries, (except Die-Casting)—Part 331525, Copper Foundries (except Die-Casting)—Part 331528, Other Nonferrous Foundries (except Die-Casting)—Part 331512 Steel Investment Foundries	Foundries in these industries do not perform sand casting.
Captive Foundries	Various manufacturing industries	Foundries in this sector perform metal casting as part of a parent company's operations.

* "Part" included in the notation means that only part of this NAICS group is included in the indicated foundry sector, while the remainder of the group is included in another foundry sector. For example, part of the aluminum foundries in NAICS 331525 perform sand casting (placed in the non-ferrous sand casting foundry sector) and the remainder perform non-sand casting (in the non-sand casting foundry sector).

Ferrous Sand Casting Foundries—Description

The metal casting industry is diverse, employing many different casting processes for a wide variety of applications. The production of castings using sand molds includes the following basic processes: 1) preparing a mold, and often a central core; 2) melting and pouring the molten metal into the mold; and 3) cleaning the cooled metal casting to remove molding and core material and extraneous metal (NIOSH-85-116/86-116-1730, 1986). The sand molds are formed using moist sand created by mixing sand and clay. This malleable mixture is termed “green” sand.

The volume, size, and type of castings produced vary widely from one foundry to another, ranging from a few large specialized castings to thousands of small castings per shift. Depending on the size of the foundry, operators might be responsible for a single task or several tasks. In high-production foundries, workers are likely to be responsible for a single task (e.g., molder, coremaker, shakeout operator), whereas in small shops a single worker might be assigned to several operations, such as combined responsibilities for furnace operation, hot metal transfer, and pouring (NIOSH-79-114, 1978).

Table IV.C-15 presents a summary of the job categories, major activities, and primary sources of silica exposure of workers in sand-casting foundries. For detailed descriptions of jobs, please see ERG-GI (2008). In addition to the categories listed in Table IV.C-15, foundries typically conduct the following operations: pattern-making, welding, arc-air gouging, heat treating, annealing, X-ray inspection of castings, machining, and buffing. OSHA assumes that these operations are not associated with substantial direct silica exposure; therefore, they are not discussed in detail in this report.

Table IV.C-15
Job Categories, Major Activities, and Sources of Exposure of Workers
in Ferrous Sand Casting Foundries

Job Category*	**Major Activities and Sources of Exposure**
Sand Systems Operator	Controlling processing and mixing of new sand, recycled sand, and mold or core additives in mixer (muller) or sand reclamation equipment. Sand is typically fed via hoppers. Might be batch or continuous. • Dust released during loading of hoppers. • Dust released during sand transport. • Dust raised by using compressed air for cleaning.
Molder	Monitoring molding machine operation. Might apply mold parting/coating compound. • Dust generated by handling dry cores and refractory mold coatings (washes). • Dust raised by using compressed air for cleaning mold surfaces. • Dust released by adjacent operations.
Coremaker	Overseeing transfer of mixed sand and additives to automated coremaking equipment. Cleaning and finishing cores. Applying core coatings. • Dust created by grinding, filing, and sanding cores. • Dust raised by using compressed air for cleaning. • Dust released by adjacent operations.
Furnace Operator	Controlling and monitoring furnaces used to produce molten metal. In small operations, might hand-load metal into furnaces. • Dust generated as furnace emissions. • Dust from molding sand adhered to scrap metal for remelt. • Dust from adding sand to molten metal (e.g., stainless steel). • Dust released by adjacent operations.
Pouring Operator	Transferring molten metal into ladle or holding furnace, then into molds, typically via a crane or monorail configuration. • Dust released by adjacent operations.
Shakeout Operator	Overseeing operation. Contact with equipment and castings depends on the degree of automation. • Dust generated by agitating, breaking, and separating molds from castings.
Knockout Operator	Removing sprues, gates, and risers from castings. • Dust generated by the use of hammers and saws to remove excess metal

Table IV.C-15
Job Categories, Major Activities, and Sources of Exposure of Workers in Ferrous Sand Casting Foundries

Job Category*	Major Activities and Sources of Exposure
	from the castings. • Dust released from adjacent operations.
Abrasive Blasting Operator	Cleaning residual mold or core material from castings typically operating an abrasive blasting cabinet. • Dust generated by performing shotblasting on open floor or blasting booth, if the casting is large. • Dust raised by using compressed air for cleaning surfaces. • Dust released from poorly maintained abrasive blasting cabinet. • Dust released form adjacent operations.
Cleaning/Finishing Operator	Removing remaining molding sand from castings. • Dust generated by using portable or bench tools such as chippers, grinders, and polishers. • Dust raised by using compressed air for cleaning surfaces.
Material Handler	Transporting sand, castings, or other materials using a front-end loader, forklift, or other material moving equipment. • Dust generated when adding or removing materials from the sand system. • Dust raised by manually sweeping or shoveling dry sand. • Dust raised by using compressed air for cleaning surfaces. • Dust released from adjacent operations.
Maintenance Operator	Repairing and maintaining foundry and sand-handling equipment. Might perform repair and maintenance of refractory furnace linings. • Dust released during repair and maintenance of equipment. • Dust generated during removal of old refractory linings using hammers, pneumatic chisels, and jackhammers. • Dust released from adjacent operations.
Housekeeping Worker	Removing spilled sand and debris from floors, conveyor discharges, abrasive machines, and dust collectors. • Dust raised during dry sweeping, vacuuming, shoveling, or front-end loader operations.

*Job categories are intended to represent job functions; actual job titles may differ and responsibilities may be allocated differently, depending on the facility.

Table IV.C-15
Job Categories, Major Activities, and Sources of Exposure of Workers in Ferrous Sand Casting Foundries

Job Category*	Major Activities and Sources of Exposure

Source: ERG-GI, 2008.

Ferrous Sand Casting Foundries—Baseline Conditions and Exposure Profile

To develop the exposure profiles for these job categories, OSHA compiled the best available data from all identified industrial hygiene literature that included sample information, and from exposure monitoring conducted at selected site visits.[102] OSHA relied primarily on OSHA Special Emphasis Program (SEP) inspection reports, NIOSH reports, and reports from States that performed workplace evaluations (ERG-GI, 2008). OSHA elected to use information from 1990 to the present, except in cases where older sources provide special insight into exposures or controls in a specific area not readily described by more recent sources.

Table IV.C-16 provides a summary of exposure data available to OSHA for ferrous sand casting foundries. A discussion by job category follows.

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[102] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) derived from samples of 6-hours or longer, assuming the exposure concentration during any unsampled portion of the shift was the same as the concentration during the period sampled. Unless explicitly stated otherwise, all results discussed in the additional controls section meet the same criteria. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

Table IV.C-16
Respirable Crystalline Silica Exposure Range and Profile for Ferrous Sand Casting Foundries (NAICS 331511, 331513)

	Exposure Summary			Exposure Range		Exposure Profile				
Job Category	**Number of Samples**	**Mean (µg/m³)***	**Median (µg/m³)**	**Min (µg/m³)**	**Max (µg/m³)**	**<25 (µg/m³)**	**≥25 and ≤50 (µg/m³)**	**>50 and ≤100 (µg/m³)**	**>100 and ≤250 (µg/m³)**	**>250 (µg/m³)**
Ferrous Sand Casting Sand Systems Operator	58	228	78	11	2,430	10 17.2%	9 15.5%	15 25.9%	16 27.6%	8 13.8%
Molder	152	74	50	6	1,417	40 26.3%	37 24.3%	44 28.9%	29 19.1%	2 1.3%
Coremaker	106	76	39	9	1,780	27 25.5%	34 32.1%	31 29.2%	10 9.4%	4 3.8%
Furnace Operator	8	109	34	13	281	3 37.5%	2 25.0%	0 0.0%	1 12.5%	2 25.0%
Pouring Operator	24	79	48	10	280	6 25.0%	6 25.0%	4 16.7%	7 29.2%	1 4.2%
Shakeout Operator	97	101	66	10	500	14 14.4%	25 25.8%	29 29.9%	17 17.5%	12 12.4%
Knockout Operator	37	111	78	13	540	4 10.8%	13 35.1%	7 18.9%	9 24.3%	4 10.8%
Abrasive Blasting Operator	61	155	90	13	1,002	4 6.6%	15 24.6%	17 27.9%	17 27.9%	8 13.1%
Cleaning/Finishing Operator	213	196	77	12	1,868	33 15.5%	46 21.6%	41 19.2%	45 21.1%	48 22.5%
Material Handler	32	80	56	11	231	9 28.1%	6 18.8%	10 31.3%	7 21.9%	0 0.0%
Maintenance Operator	24	376	72	13	5,851	4 16.7%	6 25.0%	5 20.8%	4 16.7%	5 20.8%
Housekeeping Worker	14	146	75	16	646	2 14.3%	2 14.3%	6 42.9%	2 14.3%	2 14.3%
Total Ferrous Sand Casting Foundries	**826**	**138**	**62**	**6**	**5,851**	**156** **18.9%**	**201** **24.3%**	**209** **25.3%**	**164** **19.9%**	**96** **11.6%**

*µg/m³ = micrograms per cubic meter

Notes: All samples are personal breathing zone (PBZ) results for durations of 360 minutes or more and represent 8-hour time-weighted average (TWA) exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Sources: Burmeister, 2001; ERG-GI, 2008; Lee, 2009a, 2009b; OSHA SEP Inspection Report 303207518.

Relatively Well-Controlled and Poorly Controlled Foundries

Among the foundries with exposure results included in the Table IV.C-16 exposure profile are two subsets of facilities selected to represent foundries where silica is relatively well controlled and foundries where it is poorly (or not yet) controlled (ERG-GI, 2008). ERG conducted an informal review of characteristics common among each group. To facilitate the review, ERG selected several foundries that have been relatively successful in reducing exposures and several that experienced widespread elevated exposures. ERG focused on foundries where OSHA, NIOSH, or a State agency had collected air samples for multiple job categories and provided at least some documentation of working conditions at the time. ERG then compared the exposure controls and work practices reported in the documentation for each.

Specifically, the group of relatively well-controlled foundries includes facilities selected by ERG (ERG-GI, 2008) because the vast majority of the full-shift results were less than or equal to 50 μg/m^3, although a few results occurred above that level (and, rarely, above 100 μg/m^3). These results indicate the level of silica exposure that workers can experience in foundries where their own activities generate little airborne silica and, at the same time, where other sources are also limited. The group of relatively well-controlled foundries includes four gray and ductile iron foundries evaluated in 1989, 1994, 1997, and 1999 (ERG # MI-1485; NIOSH ECTB 233-107c; OSHA SEP Inspection Reports 109198036 and 116156266).

The four poorly controlled foundries are three gray and ductile iron foundries and one stainless steel foundry that range in size from 55 to 340 production workers. Two of these facilities were evaluated in 1992, while the others were visited in 1996 and 1999 (NIOSH HETA 92-044-2265; NIOSH HETA 92-090-2296; OSHA SEP Inspection Reports 116201997 and 122043151).

The relatively robust data set available to OSHA for ferrous sand casting foundries (826 full shift silica results) permits this more detailed treatment; such data are not available for other industries.

The findings from this informal review are described with the overall feasibility finding for ferrous sand casting foundries.

Baseline Conditions and Exposure Profile for Sand Systems Operators

Based on information available from OSHA SEP, NIOSH, State, and industry association reports summarized by ERG-GI (2008), OSHA concludes that most sand systems operators use automated mixers to blend sand with clay, water, and additives. While most facilities have some form of local exhaust ventilation (LEV), the mixing equipment (mixers, screens, hoppers) typically is not fully enclosed or equipped with effective LEV (ERG-GI, 2008).

Mixer charging is usually an open unventilated process involving sand transfer from weigh hoppers or front-end loaders. Sand systems operators typically transfer dry, silica-containing additives to mixers by manually emptying bags. Additionally, they often work near sand transport equipment such as open conveyors, which also can contribute to workers' silica exposures.

As indicated in Table IV.C-16, the 58 results for sand systems operators ranged from 11 μg/m^3 to 2,430 μg/m^3, with a median of 78 μg/m^3. The results were obtained from 35 data sources.[103]

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[103] All but one result were evaluated in ERG-GI (2008); the additional result (identified by OSHA) of 159 μg/m^3 is for a sand systems operator using a muller (OSHA SEP Inspection Report 303207518).

The two highest results were obtained at two separate facilities and are associated with poor ventilation. No LEV was present in the area where the highest result (2,430 μg/m^3) was obtained, and the report notes that the doors of the mixer were left open, presumably allowing sand dust to escape (NIOSH HETA 88-240-2210, 1992). The second-highest result, 2,312 μg/m^3, is associated with a sand systems operator dumping sand into a mixer from an overhead bin (OSHA SEP Inspection Report 300219755). A small fan exhausted air through the wall near the mixer, but the sand delivery and mixing equipment were not ventilated. Although the upper range of exposure levels for this job category exceeds 2,000 μg/m^3, Table IV.C-16 shows that most results (86 percent) are considerably lower (less than 250 μg/m^3).

Some of the lowest results for this job category are associated with sand systems operators working in areas where sand transport systems were isolated (enclosed or pneumatic) and mullers were fitted with exhaust ventilation. For example, a limit of detection (LOD) reading of 11 μg/m^3 was obtained by OSHA for a sand systems operator controlling a muller that had both the muller belts and elevator fully enclosed (OSHA SEP Inspection Report 108772377).[104] Exposure levels of 13 μg/m^3 (LOD) and 30 μg/m^3 (two sampling days) were associated with pneumatic sand transport equipment and use of larger size (50-grain) washed lake sand (NIOSH ECTB 233-107c, 2000).

Because a wide variety of conditions exist in foundries, OSHA has preliminarily determined that the baseline condition is best represented by the median for all exposure levels for this job category, as summarized in Table IV.C-16. Thus, the exposure level associated with baseline conditions for sand system operators is 78 μg/m^3.

Baseline Conditions and Exposure Profile for Molders

Based on information summarized by ERG-GI (2008), OSHA finds that baseline conditions for molders include the use of various semi-automated molding machines designed to shape and compact silica sand. The processes used often require manual handling of the mold. Although general exhaust ventilation is often present (e.g., wall or ceiling exhaust fans), it is common for most molders to work without LEV (ERG-GI, 2008). Molders typically use green sand (Schleg and Kanicki, 2000) and use compressed air to clean molds.

ERG-GI (2008) summarized 149 sample results for molders in ferrous sand casting foundries. These data were extracted from 49 OSHA SEP, NIOSH, and State reports. As described in the following paragraphs, OSHA has identified three additional results in two reports: a report from Lee (2009a) and an OSHA SEP Inspection Report (303207518).

Lee (2009a, 2009b) obtained one silica result of 109 μg/m^3 for a molder during an inspection of a facility where heavy industrial castings were made. Lee noted that dust was visible suspended in the air and accumulated on surfaces during an initial walk-though of the facility. A subsequent measurement reported as 6 μg/m^3 was collected by a consultant after the company made changes to the LEV and made repairs to the sand system in the foundry (Lee, 2009a). In a separate report on a different foundry, OSHA obtained a silica result of 234 μg/m^3 for a molder operating an automated mold former (OSHA SEP Inspection Report 303207518).

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[104] Results reported as “none detected” are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

The data summarized in Table IV.C-16 present the exposure profile for molders and represent the best exposure data available to OSHA for these workers. The 152 results for molders ranged from 6 μg/m^3 to 1,417 μg/m^3 with a median of 50 μg/m^3.

Exposure levels for molders tend to be higher in facilities where silica dust is poorly controlled throughout the facility. As discussed in ERG-GI (2008), some of the highest results for molders are associated with facilities where the results for other job categories also exceed 100 μg/m^3: seven results between 159 μg/m^3 and 1,417 μg/m^3 were obtained at three facilities where multiple samples in all job categories evaluated exceed 100 μg/m^3 (ERG # OH-1470; NIOSH HETA 92-090-2296, 1993; OSHA SEP Inspection Report 121905079).

Some of the lowest results (two 13 μg/m^3 [LODs], one 20 μg/m^3, and one 23 μg/m^3) were obtained by NIOSH and OSHA for four molders working in two foundries where pneumatic or enclosed conveyers were used to transport sand (NIOSH ECTB 233-107c, 2000; OSHA SEP Inspection Report 122122534). NIOSH noted that one of these establishments made a particular effort to control dust throughout the facility, although workers occasionally used compressed air to clean molds.

Because a wide variety of conditions exist in foundries, OSHA has preliminarily determined that the baseline condition is best represented by the median for all exposure levels for this job category, as summarized in Table IV.C-16. Thus, the exposure level associated with baseline conditions for molders is 50 μg/m^3.

Baseline Conditions and Exposure Profile for Coremakers

Based on information contained in ERG-GI (2008), OSHA has preliminarily determined that most coremakers operate or work near automated equipment associated with sand processing for coremaking. Additionally, some coremakers manually handle cores to coat, clean, assemble, or position the cores. OSHA based this determination on information from OSHA SEP, NIOSH, State, and industry association reports summarized by ERG-GI (2008). The work is typically conducted without LEV, but general ventilation might be present, and OSHA has preliminarily determined that these are the baseline conditions.

ERG-GI (2008) summarized 103 representative coremaker results obtained from 24 OSHA SEP, NIOSH, State, and industry association reports on ferrous sand casting foundries. In addition, OSHA has identified three results in a report recently published by Lee (2009a), who reported exposure levels of 106 μg/m^3 and 147 μg/m^3 for two coremakers in a facility that made heavy industrial castings during an inspection completed under OSHA's Site Specific Targeting (SST) program. A third result of 8 μg/m^3 was reported by a consultant to the same foundry after repairs were made to the sand systems and changes were made to LEV (Lee, 2009a, 2009b). The total of 106 results represent the best exposure data available to OSHA for coremakers in ferrous sand casting foundries. As shown in Table IV.C-16, the results range from 9 μg/m^3 to 1,780 μg/m^3, with a median of 39 μg/m^3.

Coremakers are routinely exposed to silica dust generated by adjacent sand processing and transport equipment, use of compressed air, and dust migrating into the coremaking area from sources elsewhere in the foundry. The two highest results (380 μg/m^3 and 1,780 μg/m^3) were obtained in 1999 in a California foundry (Scholz and Hayes, 2000b). At the same time, a result of 90 μg/m^3 was obtained for a third coremaker at the same facility. Although no information is available on the specific activities of the coremakers, the report suggests that ventilation was "stagnant" in the core area and that air from the melting and charge preparation area entered the space where the coremakers worked. In contrast, eight of the lowest exposure levels, all μg/m^3 and less, were obtained for coremakers working in two foundries that employed pneumatic sand transport systems (NIOSH ECTB 233-107c, 2000; OSHA SEP Inspection Report 100494079).

Because a wide variety of conditions exist in foundries, OSHA has preliminarily determined that the baseline condition is best represented by the median for all exposure levels for this job category, as summarized in Table IV.C-16. Thus, the exposure level associated with baseline conditions for coremakers is 39 µg/m^3.

Baseline Conditions and Exposure Profile for Furnace Operators

Based on the information provided in ERG-GI (2008), OSHA concludes that the primary sources of exposure for most furnace operators include the silica dust generated from poorly controlled adjacent operations, such as emissions released from hot, dry sand molds at shakeout (NIOSH-79-114, 1978; NIOSH-85-116/86-116-1730, 1986) and dust released when operators add silica sand to the furnace to correct slag acidity (AFS, 2001). However, no information was available to indicate exposure levels specifically associated with these practices.

Limited general data are available to characterize the exposures of furnace operators. ERG-GI (2008) summarized eight samples from five reports on ferrous sand casting foundries. Table IV.C-16 summarizes these results, which range from less than the LOD (13 µg/m^3) to 281 µg/m^3, with a median of 34 µg/m^3. Nearly two-thirds (62 percent) of the results are 50 µg/m^3 or less.

The highest reading (281 µg/m^3) was obtained in 1995 for a furnace operator who repaired the furnace lining (with refractory materials) every day (OSHA SEP Inspection Report 114154263).[105] Similarly, readings of 198 µg/m^3 and 280 µg/m^3 were obtained for furnace operators in a foundry where the respirable quartz levels were largely uncontrolled, according to NIOSH, and the sources of exposure included not only furnace emissions but also adjacent operations (NIOSH HETA 90-0249-2381, 1994). The report does not indicate whether these furnace operators participated in maintenance of refractory furnace linings.

Three of the lowest readings for furnace operators (29 µg/m^3 and two less than or equal to 13 µg/m^3) were measured at a single facility where operators worked in a control booth or on a ventilated melt deck (OSHA SEP Inspection Report 121977870). At another facility, a result of 20 µg/m^3 was obtained for a furnace operator tending a furnace with slotted hoods above and a retractable enclosing hood for ductile iron inoculations (Scholz and Hayes, 2000b).

No results for furnace operators are available among the data from the group of poorly controlled foundries. In the absence of other information, OSHA has preliminarily determined that seven of the eight results presented in the exposure profile represent some aspect of baseline conditions.

Because a wide variety of conditions exist in foundries, OSHA has preliminarily determined that the baseline condition is best represented by the median for all exposure levels for this job category, as summarized in Table IV.C-16. Thus, the exposure level associated with baseline conditions for furnace operators is 34 µg/m^3.

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[105] See the foundry “maintenance operator” job category for information on other foundry workers whose primary silica exposure is from work with refractory materials.

Baseline Conditions and Exposure Profile for Pouring Operators

The pouring operation itself is unlikely to release silica or be a source of silica exposure for pouring operators (O'Brien, 2000). However, data suggest that pouring operators are subject to silica exposure from adjacent operations. Based on available reports, OSHA has determined that pouring operators commonly perform manual manipulation of ladles or operating cranes and might use automated equipment in an open pouring area with no engineering controls or dust-suppressing work practices. Furthermore, pouring operations are generally located in the same area as furnace and shakeout operations, which can release considerable silica dust.

LEV is not a standard feature of pouring areas in ferrous foundries. Where LEV was reportedly associated with a pouring task, the ventilation system was noted to be in poor condition (ERG-GI, 2008; ERG # OH-1470).

ERG-GI (2008) summarized 24 samples ranging from the LOD (in this 10 µg/m^3) to 280 µg/m^3, with a median of 48 µg/m^3.[106] These data were obtained from 13 reports on ferrous sand casting foundries. Three of the four highest readings (150 µg/m^3, 150 µg/m^3, and 280 µg/m^3) for pouring operators were from a single foundry visited by the Industrial Commission of Ohio in 1987 (ERG # OH-1466). Respirable quartz levels throughout this foundry were poorly controlled. Another elevated level, 157 µg/m^3 (full shift), was obtained for a worker operating a pouring crane at a foundry visited by NIOSH in 1992 (NIOSH HETA 92-090-2296, 1993). At this foundry, half of the results from four job categories exceeded 100 µg/m^3, indicating airborne respirable quartz was released in or spread to most areas in the facility. According to the NIOSH report, the pouring crane operators at this facility were exposed to respirable quartz primarily from shakeout operations (NIOSH HETA 92-090-2296, 1993).

Because a wide variety of conditions exist in foundries, OSHA has preliminarily determined that the baseline condition is best represented by the median for all exposure levels for this job category, as summarized in Table IV.C-16. Thus, the exposure level associated with baseline conditions for pouring operators is 48 µg/m^3.

Baseline Conditions and Exposure Profile for Shakeout Operators

Shakeout operators monitor equipment that separates castings from mold materials by mechanically vibrating or tumbling the casting, a procedure that is generally termed "shakeout." In addition to causing elevated silica exposures for shakeout operators, dust generated from shakeout activities is frequently cited as a source of silica exposure for other workers in the foundry.

Shakeout conditions vary dramatically depending on the age and condition of the equipment or facility. A review of OSHA SEP, NIOSH, and State reports suggests that foundries frequently have installed LEV in the shakeout area. However, enclosures and ventilation are not uniformly effective as used, particularly on older equipment. New and modern shakeout equipment is generally associated with LEV designed to help manage dust from this process (ERG-GI, 2008; Kinergy Corporation, 2000; South Cast Equipment, 2000).

ERG-GI (2008) summarized 93 results from 31 reports representing shakeout operators. Additionally, OSHA identified four results in two reports from Lee and an SEP inspection report. Lee (2009a, 2009b) obtained two results of 107 µg/m^3, and 161 µg/m^3 for shakeout operators during an

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[106] Silica results for workers who primarily repaired refractory lining during the sampling period (including workers repairing ladle linings) were placed in the "maintenance operator" job category, regardless of their position/title at the foundry.

inspection of a facility where heavy industrial castings were made. A subsequent measurement of 32 µg/m^3 was collected by a consultant after the company made changes to the LEV and made repairs to the sand system in the foundry (Lee, 2009a, 2009b). In the SEP report, OSHA provided a result of 328 µg/m^3 for a shakeout operator dumping molds (OSHA SEP Inspection Report 303207518).

Table IV.C-16 presents the exposure profile for shakeout operators. This table summarizes the best exposure data available to OSHA for these workers. The 97 total shakeout operator results were collected during de-molding operations under a variety of working conditions and results ranged from 10 µg/m^3 to 500 µg/m^3, with a median of 66 µg/m^3.

Two of the lowest readings, both 13 µg/m^3 (LODs), were obtained for shakeout operators working with LEV at a foundry that reportedly made a concerted effort to control silica emissions throughout the facility (ERG # MI-1483). Results of 33 µg/m^3 and 41 µg/m^3 were associated with other shakeout operators at the same foundry. At another foundry, readings of 12 µg/m^3 (LOD), 21 µg/m^3, 22 µg/m^3, and 53 µg/m^3 were associated with shakeout area crane operators working in cabs supplied with fresh air (NIOSH ECTB 233-107c, 2000). At that facility, which also had an active silica management program, nine results obtained for manual shakeout operations were mixed, ranging from 22 µg/m^3 to 104 µg/m^3 (NIOSH ECTB 233-107c, 2000).

Four full-shift PBZ respirable quartz exposure results for shakeout operators at another foundry evaluated by NIOSH ranged from 37 to 214 µg/m^3, again indicating the potential for variability in respirable quartz exposures for a single job category at a single facility. Although not described, based on notes in the report these results are assumed to be associated with the use of an open shaker table and the use of a front-end loader to break large molds on the open floor (NIOSH HETA 92-044-2265, 1992).

Because a wide variety of conditions exist in foundries, OSHA has preliminarily determined that the baseline condition is best represented by the median for all exposure levels for this job category, as summarized in Table IV.C-16. Thus, the exposure level associated with baseline conditions for shakeout operators is 66 µg/m^3.

Baseline Conditions and Exposure Profile for Knockout Operators

Knockout operators are responsible for “knocking” any loosely adhered sand from castings and removing unwanted scrap metal left from the pouring process. These workers use hand and power tools or vibrating equipment on castings delivered from the shakeout process. Based on a review of OSHA SEP, NIOSH, and State reports on foundries, OSHA has determined that knockout procedures involve use of manual or semi-automated stationary workstations, typically with some form of LEV; however, these ventilation systems are not necessarily well maintained or operating efficiently (ERG-GI, 2008).

ERG-GI (2008) summarized 37 samples of knockout operator exposures obtained from 16 reports on ferrous sand casting foundries. These samples represent the best data available to OSHA, and are provided in Table IV.C-16. Exposures range from 13 µg/m^3 (LOD) to 540 µg/m^3, with a median of 78 µg/m^3.

Five of the highest readings for knockout operators (540 µg/m^3, 380 µg/m^3, 310 µg/m^3, 140 µg/m^3, and 90 µg/m^3) were collected at a single foundry where the workers used vibrating equipment to remove sand from casting interiors (NIOSH HETA 86-0284-1914, 1988). While knockout operators (along with sandblasters) had the highest exposure levels at this facility, NIOSH found elevated silica exposures in all foundry departments and recommended that the facility investigate the use of engineering controls such as local exhaust ventilation, downdraft molding platforms, and isolation of work areas to reduce worker exposure to silica, indicating that exposures at this facility were largely uncontrolled (NIOSH HETA 86-0284-1914, 1988).

At another foundry, levels of 95 µg/m^3 and 101 µg/m^3 are associated with inefficient LEV. However, this foundry made some improvements and several years later, after the LEV system had been upgraded, results less than 50 µg/m^3 were obtained for workers with the same job title (ERG # MI-1485).[107]

Among the data available to OSHA, lower results are associated with cleaner castings, ventilated workstations, and dust controls in the adjacent shakeout area. Three of the lowest results (13 µg/m^3, 24 µg/m^3, and 30 µg/m^3) and one somewhat higher reading (87 µg/m^3) were obtained on two sampling dates for two workers who used pneumatic chisels to open holes in castings (NIOSH ECTB 233-107c, 2000). On each of the two sampling dates, these knockout operators spent half the shift at ventilated workstations chiseling casting that had already passed from an enclosed two-stage shakeout area to an automated, enclosed abrasive grinder, and were carried to the knockout operator on a partially enclosed conveyer. Presumably the castings were relatively free of loose sand by this point. These operators spent the remainder of the shift transferring finished castings onto pallets.

Because a wide variety of conditions exist in foundries, OSHA has preliminarily determined that the baseline condition is best represented by the median for all exposure levels for this job category, as summarized in Table IV.C-16. Thus, the exposure level associated with baseline conditions for knockout operators is 78 µg/m^3.

Baseline Conditions and Exposure Profile for Abrasive Blasting Operators

Abrasive blasting operators use abrasive media to remove tightly adhered mold and core materials and prepare the surfaces of castings for further processing. Based on ERG-GI's (2008) review of OSHA, NIOSH, and State reports, OSHA preliminarily concludes that the vast majority of abrasive blasting operators (95 percent) in the foundry industry use automated or semi-automated blasting equipment (e.g., steel shot blast machines).[108] This equipment is typically designed to be fully (or nearly fully) enclosed and connected to an exhaust ventilation system with a dust collector; however, enclosures often leak and the associated ventilation is not necessarily effective (ERG-GI, 2008).

ERG-GI (2008) summarized 61 sample results for abrasive blasting operators. As shown in Table IV.C-16, these values range from 13 µg/m^3 to 1,002 µg/m^3, with a median of 90 µg/m^3. These results, which represent the best data available to OSHA, were obtained from 29 reports on ferrous sand casting foundries (ERG-GI, 2008).

Elevated exposures appear to be associated with poor work practices. Two of the highest results, 238 µg/m^3 and 1002 µg/m^3 (as well as a third result of 91 µg/m^3) were obtained in 1992 at a gray and

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[107] During the initial visit, additional results of 42 µg/m3 and 45 µg/m3 were obtained for a forklift driver in the knockout area and a worker who, based on the job title, is presumed to have been performing a knockout operation different from that of the other two workers.

[108] Most of the foundry industry abrasive blasting machines use steel shot as media. Therefore, the silica exposure to these abrasive blasting operators is predominantly from residual mold and core materials adhered to the casting, rather than originating in the abrasive blasting media. However, recycled abrasive blasting media that are poorly cleaned can carry residual mold and core materials.

ductile iron foundry. NIOSH noted that the workers used compressed air (presumably for cleaning) while they operated steel shot blasting machines equipped with LEV (NIOSH HETA 92-044-2265, 1993). At a different foundry visited by OSHA, a result of 909 µg/m^3 was reported for an abrasive blasting operator who monitored a continuous process steel shot blast machine as well as the dust-collection tote. This worker replaced the tote when it was full (OSHA SEP Inspection Report 116199589). This result suggests that the dust collection system performed poorly, that the act of monitoring and replacing the dust tote contributed to the silica exposure, or that both might have been factors.

Some of the lowest results for this job category are associated with control measures that isolate the operator from the process and control sources of dust surrounding the shot blasting machine. A result of 46 µg/m^3, approximately half the median for this job category, is associated with an abrasive blasting operator who operated an enclosed shot blasting machine from behind a transparent barrier. Automated manipulators positioned the parts. This gray iron foundry had implemented numerous exposure controls throughout the facility and results rarely exceeded 50 µg/m^3 in most job categories (NIOSH ECTB 233-107c, 2000). OSHA obtained two results of 34 µg/m^{3}and 47 µg/m^3 at a gray and ductile iron foundry that had enclosed and ventilated sand- and casting-handling equipment leading to and from the automated shot blasting machine (OSHA SEP Inspection Report 101548626). These abrasive blasting operators spent a couple hours sorting castings and the remainder of the shift operating the shot blasting equipment. Results obtained during earlier evaluations of this facility were substantially higher, as discussed in the review of additional controls for this job category.

Because a wide variety of conditions exist in foundries, OSHA has preliminarily determined that the baseline condition is best represented by the median for all exposure levels for this job category, as summarized in Table IV.C-16. Thus, the exposure level associated with baseline conditions for abrasive blasting operators is 90 µg/m^3.

Baseline Conditions and Exposure Profile for Cleaning/Finishing Operators

Based on NIOSH, OSHA SEP, and State reports summarized in ERG-GI (2008), OSHA concludes that most cleaning/finishing operators use hand-held grinding equipment, without LEV, for a substantial portion of the shift. While the same workers also might use stationary grinding equipment, OSHA finds that it is the hand-held equipment that is both most typical and the greater source of exposure.

ERG-GI (2008) summarized 209 sample results for cleaning/finishing operators from 53 OSHA, NIOSH, and State reports on ferrous sand casting foundries. OSHA subsequently identified four additional results in a report from Lee (2009a).

Lee (2009a, 2009b) obtained results of 161 µg/m^3, 181 µg/m^3, 216 µg/m^3, and 245 µg/m^3 for cleaning/finishing operators grinding on casings during an inspection of a facility. Although grinding stations were equipped with LEV, the LEV did not appear to be effective based on the amount of dust observed in the air and on the work surfaces (Lee, 2009a).

Table IV.C-16 summarizes the total of 213 exposure results for this job category. These results represent the best available exposure data for cleaning/finishing operators. The results range from 12 µg/m^3 to 1,868 µg/m^3, with a median of 77 µg/m^3. Twenty-three percent of the exposure values exceed 250 µg/m^3, and upon further examination of the data, OSHA notes that 23 of the 213 (11 percent) exceed 500 µg/m^3. These observations suggest that, along with maintenance operators, cleaning/finishing operators have many of the highest silica exposures in the foundry industry.

Some of the highest results (all greater than 500 µg/m^3) were associated with three facilities where most exposures for multiple job categories also were elevated (ERG # MI-1474; NIOSH HETA 92-0089-2368, 1993; Scholz and Hayes, 2000b). One of the highest respirable quartz readings, 1,120 µg/m^3, was obtained for a cleaning/finishing operator who performed hand grinding on large castings on the open floor (NIOSH HETA 92-090-2296, 1993). NIOSH recommended that the facility install a room for cleaning the castings, and recommended the use of ventilated tool hoods for hand grinders (NIOSH HETA 92-090-2296, 1993).

Worst-case exposures for grinders might be represented by a facility visited by NIOSH that performed only casting cleaning operations (NIOSH HETA 92-0089-2368, 1993). Castings at this facility were delivered on flatbed trucks; they were cleaned by workers operating 25 individual grinding stations separated by plywood partitions. Compressed air was used to remove excess sand from internal cavities. The 20 results for cleaning/finishing operators ranged from 300 µg/m^3 to 1,868 µg/m^3. Based on NIOSH recommendations for controlling exposures, OSHA assumes that these readings are associated with minimal or no controls.

Results for cleaning/finishing operators are not uniformly high, particularly where foundries have implemented controls. Two relatively low readings (both 30 µg/m^3) were reported for grinders at a foundry in Ohio. These results were associated with the use of separate booths for each grinder operator; the booths were equipped with benches serviced by local exhaust hoods, but were not further described (ERG # OH-1488). Most of the lowest results were associated with those facilities where exposures across all job categories were typically low (ERG-GI, 2008).

Because a wide variety of conditions exist in foundries, OSHA has preliminarily determined that the baseline condition is best represented by the median for all exposure levels for this job category, as summarized in Table IV.C-16. Thus, the exposure level associated with baseline conditions for cleaning/finishing operators is 77 µg/m^3.

Baseline Conditions and Exposure Profile for Material Handlers

Material handlers use mobile equipment to transport materials and castings throughout foundries and are subject to background silica dust associated with the conditions and controls found in those work areas. Information contained in OSHA SEP, NIOSH, and State reports suggests that enclosed cabs are not typically available or used to limit exposures. Material handlers routinely assist with cleaning tasks, typically involving dry sweeping or using compressed air.

ERG-GI (2008) summarized 32 results from 16 different reports presenting material handler silica exposure levels ranging from 11 µg/m^3 to 231 µg/m^3, with a median of 56 µg/m^3.

Some of the lowest exposure levels are associated with a facility that had made substantial and successful efforts to control silica dust across the entire facility. NIOSH obtained four results, all at or below the LOD (11 µg/m^3 to 13 µg/m^3), for two material handlers who operated powered equipment in a well-controlled facility (NIOSH ECTB 233-107c, 2000).

Because a wide variety of conditions exist in foundries, OSHA has preliminarily determined that the baseline condition is best represented by the median for all exposure levels for this job category, as summarized in Table IV.C-16. Thus, the exposure level associated with baseline conditions for material handlers is 56 µg/m^3.

Baseline Conditions and Exposure Profile for Maintenance Operators

Based on a review of OSHA SEP, NIOSH, and State reports, OSHA finds that most reported silica exposure for maintenance operators is due to work repairing (patching) or replacing refractory furnace and ladle lining materials. The related Section IV.C.19 – Refractory Repair addresses the similar (but more frequent and often large-scale) activities of contractors who travel from facility to facility offering refractory maintenance services. Those contractors are more likely to perform the periodic complete tear-out and replacement of refractory linings,[109] while the foundry maintenance operator is more likely to perform small-scale patch and repair jobs to maintain refractory linings between replacement cycles. The patch and repair tasks are typically performed weekly (OSHA SEP Inspection Report 122209679), but might be necessary more or less frequently depending on several factors such as the type of refractory material and how the furnace is used.

Maintenance operators most commonly perform these manual refractory repair processes in areas with general ventilation only. Furnace ventilation systems cannot be considered an effective control for those maintenance operators who maintain refractory furnaces. The ventilation systems associated with furnaces are designed to exhaust heat and rising fumes, but are inadequate to control silica dust generated during refractory maintenance activities (OSHA SEP Inspection Report 116201997).

ERG-GI (2008) summarized 23 exposure results obtained from 10 reports on ferrous sand casting foundries' maintenance operators. OSHA identified one additional exposure value in a report by Burmeister (2001), who presented a result of 215 µg/m^3 for a sample collected by OSHA while a maintenance operator relined a ladle. The operator "performed the pneumatic chipping and mixing of the refractory materials…" The foundry made several changes to the process, including initiating "a water control system" to reduce dust during chipping. Subsequent air sampling by a consultant indicated that exposure was reduced to a level slightly less than the calculated OSHA permissible exposure limit (PEL) for respirable dust containing silica (Burmeister, 2001).

Table IV.C-16 summarizes the 24 exposure results noted above, which represent the best exposure data available to OSHA for maintenance operators. The results range from 13 µg/m^3 to 5,851 µg/m^3, with a median of 72 µg/m^3.

Because a wide variety of conditions exist in foundries, OSHA has preliminarily determined that the baseline condition is best represented by the median for all exposure levels for this job category, as summarized in Table IV.C-16. Thus, the exposure level associated with baseline conditions for maintenance operators is 72 µg/m^3.

Maintenance operators also are subject to background levels of silica dust associated with the conditions and controls found in the work areas where they maintain equipment or make repairs during upset conditions. However, the results available to OSHA for maintenance operators are primarily associated with refractory repair activities.

Baseline Conditions and Exposure Profile for Housekeeping Workers

Based on a review of seven OSHA SEP, NIOSH, and State reports, OSHA concludes that housekeeping workers most frequently use manual methods to perform cleaning tasks. Exposures of housekeeping workers are closely related to the general exposure levels within the facility and to the specific area where they spend most of their time. Although reports contain few details regarding the

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[109] According to Refractory Products Supplier A (2010), 75 percent of establishments that use refractory furnaces also use a contract service to reline the furnaces.

specific activities of the available housekeeping worker results, data suggest that adjacent operations are the primary source of exposure for housekeeping workers, although their own work will likely contribute to their exposure when dry sand is involved.

ERG-GI (2008) summarized 14 results for housekeeping workers ranging from the LOD (less than or equal to 16 µg/m^3) to 646 µg/m^3, with a median of 75 µg/m^3. ERG obtained these results from seven OSHA, NIOSH, and State reports on ferrous sand casting foundries (ERG-GI, 2008). Although limited, these are the best data available to OSHA for foundry housekeeping workers.

Some of the lowest results for housekeepers include a value for a housekeeping worker shoveling and sweeping spilled mold sand. In this case the result was less than or equal to 16 µg/m^3, the LOD (OSHA SEP Inspection Report 122031487). At the same gray and ductile iron foundry, results for a maintenance operator and two knockout operators were also below 50 µg/m^3. The fact that these were the only workers OSHA elected to evaluate suggests that the foundry made a successful effort to control exposures throughout the facility.

Two other results, both 30 µg/m^3 (one was the LOD), were obtained at two ferrous metal sand casting foundries evaluated by the Michigan Department of Public Health in the early 1990s (ERG # MI-1473; ERG # MI-1483). One worker reportedly was responsible for cleaning an area where LEV was present. The other was classified as a “floor sweeper” (no further information available).

Higher housekeeper exposures were reported for a foundry visited by OSHA, where a result of 172 µg/m^3 was obtained for a “cleanup” worker whose duties included vacuuming sand (OSHA SEP Inspection Report 103471314). Other exposure values obtained on the same date at this facility included results of 87 µg/m^3 and 96 µg/m^3 for pouring operators (nearly twice the median level for that job category). The following month, two results of 276 µg/m^3 and 291 µg/m^3 were obtained for shakeout operators (four times greater than the median for this group), suggesting that the shakeout line might have been a contributing source of silica exposure for the other workers.

Because a wide variety of conditions exist in foundries, OSHA has preliminarily determined that the baseline condition is best represented by the median for all exposure levels for this job category, as summarized in Table IV.C-16. Thus, the exposure level associated with baseline conditions for housekeeping workers is 75 µg/m^3.

Ferrous Sand Casting Foundries—Additional Controls

Additional Controls for Sand Systems Operators

Table IV.C-16 includes the exposure profile for sand systems operators, which shows that one-third of the 58 results for this job category are below 50 µg/m^3. Additional controls will be required for the remaining two-thirds of these workers. Minimizing contact with dust generated by sand processing and transport can reduce exposures for sand-system operators. Foundries can accomplish this reduction through effective LEV and enclosures for sand mixing, processing, and transport equipment. Alternatively, substituting silica-free media that is less toxic than silica for the sand used in molds and cores can eliminate the silica exposures of sand systems operators.

Exposure monitoring data obtained by OSHA at a foundry showed an 83 percent reduction in sand systems operator silica levels (from 231 µg/m^3 to 40 µg/m^3) after the foundry installed LEV and repaired leaks in the mixer (OSHA SEP Inspection Report 122040488). Published standards for sand mixer and mullers, bins, hoppers, and screens specify that equipment be well enclosed and exhausted at a minimum rate of 150 cubic feet per minute (cfm) (200 cfm in the case of screens) per square foot of opening (ACGIH, 2010; AFS, 1985).[110]

Both OSHA and NIOSH showed that controlling dust from sand transport equipment as well as process equipment could reduce silica exposures. An exposure of 11 µg/m^3 (LOD) was obtained for a sand systems operator who was controlling a muller with both muller belts and sand elevator fully enclosed (OSHA SEP Inspection Report 108772377). NIOSH reported exposures less than 30 µg/m^3 at a facility where a sand systems operator monitored a pneumatic transport system that moved sand to the mixing equipment. In addition, this facility used specifically sized (A50-grain), pre-washed lake sand for casting, which likely helped reduce exposures (NIOSH ECTB 233-107c, 2000). Pre-washing sand can remove fine respirable-sized particles that might otherwise become airborne when workers use the sand.[111]

A steel foundry used the following combination of methods to reduce exposures: using fully enclosed mullers and hoppers, improving existing LEV, renovating the sand handling system across the entire facility, wetting hot sand reclaimed from the shakeout area, changing work practices, improving housekeeping, using pre-mixed additives, and controlling silica exposure sources throughout the facility. As a result, exposures decreased 82 percent from 159 µg/m^3 to 28 µg/m^3 (OSHA SEP Inspection Report 303207518).

Enclosed, ventilated, continuous process sand recycling and reclamation equipment is commercially available for foundries (South Cast Equipment, 2000). According to the manufacturer, this type of multifunctional equipment can be configured to accomplish most sand handling from shakeout and cast cleaning to screening and mixing as fresh molding sand. These systems can be used with a multitude of sand products for various castings (Didion, 2000b; Vulcan, 2005).

Substituting non-silica granular media (that is less toxic than silica) for silica sand used for molds and cores can virtually eliminate the silica exposures of all sand systems operators. Although the extent of exposure reduction from the use of substitution materials has not been quantified for sand systems operators in ferrous sand casting foundries, it has been documented in nonferrous sand casting foundries. A report from the Industrial Commission of Ohio shows that exposures dropped below the LOD for all workers when the foundry used olivine sand (ERG # OH-1460).[112] Another aluminum foundry reported

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[110] The American Conference of Governmental Industrial Hygienists (ACGIH) (ACGIH, 2010) recommends a higher air flow rate of 250 cfm per square foot of opening for toxic dusts, which might be more appropriate for silica-containing materials.

[111] Washed lake sands contain fewer very fine particles and the grains are more rounded than angular sand types. The sharp points on angular sands break as the sand is handled and the broken points contribute additional fine silica particles to the sand (Mohawk College, 2005). Fine particles detract from molding sand quality and contribute to airborne dust. For a variety of reasons, including reduction of fines, improved mold permeability, and reduced resin use, rounded or partially rounded sands provide better casting results for bonded sand casting methods. For some applications sand grain geometry is more important than size (Mohawk College, 2005; Naro, 2002).

[112] Olivine is a magnesium-iron ortho-silicate mineral, which contains little or no quartz and is commercially available as sand for foundries.

respirable dust levels of 300 to 1600 µ/m^3, but no exposure to silica when using olivine sand (Foundry Engineering Group Project – Case History H, 2000).[113] ERG-GI (2008) contains additional information on commercially available alternatives to silica sand as granular media for foundry applications.

Additional Controls for Molders

Table IV.C-16 shows that half of the molder exposure levels available to OSHA are 50 µg/m^3 or less. Additional controls will be required for the remainder of these workers. Minimizing molders' contact with dust released from dry sand and silica mold washes will reduce the exposures of molders. This might be accomplished by installing or upgrading LEV near molding equipment, improving housekeeping procedures to minimize the spread of sand, reducing use of compressed air and dry sweeping, and controlling dust from nearby processes (e.g., sand mixing, transport, recovery, shakeout). Alternatively, non-silica substitutes that are less toxic than silica can be used for washes and cores.

Exposures can be reduced by installing covered or enclosed systems for transporting sand through or near the molding area. NIOSH and OSHA evaluated pneumatic and enclosed systems to isolate the storage and transport of dry sand in two facilities. The four molder results from these foundries include two results of 13 µg/m^3 (LOD), 20 µg/m^3, and 23 µg/m^3 (NIOSH ECTB 233-107c, 2000; OSHA SEP Inspection Report 122122534). At another facility, OSHA reported a 65- to 70-percent reduction in exposures (from 140 µg/m^3 to 50 µg/m^3 and 42 µg/m^3) after the facility made improvements to sand delivery systems and exhaust ventilation systems throughout the facility (OSHA SEP Inspection Report 100494079).

Because work activities can vary throughout the day, a combination of engineering controls and housekeeping might be required to reduce exposures below 50 µg/m^3. A foundry evaluated by OSHA showed a 60-percent reduction in exposure (from 123 µg/m^3 to 49 µg/m^3) when the facility implemented a wide variety of controls (OSHA SEP Inspection Report 300530029). The controls included installing an efficient dust collector, enclosing a sand chute, adding a water spray to a sand feed belt, adding LEV to the return sand belt and bucket elevator, and improving housekeeping.

While the contribution to exposure reduction from housekeeping alone has not been quantified in ferrous sand casting foundries, poor housekeeping practices that disturb dust (dry sweeping and using compressed air) can diminish the effects of other controls (ERG-GI, 2008). However, data suggest that good housekeeping in combination with other controls will provide substantial exposure reduction. Irwin (2003) reported on a foundry that used a combination of LEV (enclosing and ventilating the mold dumping and sand return areas) and adding a rotary media tumbler to substantially reduce worker exposure levels. In addition, the foundry changed work practices and performed aggressive housekeeping. Altogether, implementing these controls reduced the exposure levels by at least 80 percent. The precise reduction could not be determined because no silica was detected in the sample; however, ERG estimated an 8-hour TWA exposure level of less than or equal to 40 µg/m^3.[114] Similar results were obtained on multiple sampling dates.

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[113] Samples were collected over 3- to 6-hour periods.

[114] Irwin (2003) did not report sample durations. This estimate is based on the respirable dust result (0.55 µg/m^3 after controls were in place) and the OSHA-calculated PEL (1.0 µg/m^3) provided for the initial uncontrolled sample and derived using the general industry equation for the PEL for respirable dust containing silica. ERG reversed the calculation to find the percentage silica in the initial respirable dust sample. Assuming the percent silica would be similar in the two samples, ERG estimated that the 8-hour TWA was less than or equal to 40 µg/m^3 (ERG-GI, 2008).

Vacuuming of molds offers an alternative to using compressed air for cleaning. NIOSH reported on a foundry that occasionally used vacuums, in addition to compressed air, for removing loose sand from molds and flasks (NIOSH ECTB 233-113c, 2000).

Additional Controls for Coremakers

The data summarized in Table IV.C-16 show that 58 percent of coremakers' exposures are already less than 50 µg/m^3. The remainder of the coremakers (42 percent) will require additional controls. Information summarized in ERG-GI (2008) indicates that the primary cause of exposures over 50 µg/m^3 is often dust from adjacent sand processing and transport equipment or other foundry processes. Therefore, controlling dust from adjacent sources will substantially reduce the exposures of most coremakers. Installing a pneumatic transport system has been shown to reduce exposures to below 21 µg/m^3 from levels ranging from 80 µg/m^3 to 360 µg/m^3 (OSHA SEP Inspection Report 100494079). NIOSH also reported low exposures (less than 36 µg/m^3) for coremakers working in an area with a pneumatic sand transport system (NIOSH ECTB 233-107c, 2000).

Area sample results from a foundry evaluated by OSHA further demonstrate the extent to which other foundry operations can affect background silica levels in the coremaking area. This foundry identified sand systems operations, molding, and shakeout areas as the primary sources of silica in the facility. Migrating dusts settled into other areas causing elevated exposures to adjacent workers. An initial area sample collected in the coremaking area showed an exposure of 200 µg/m^3. The foundry took steps to control the release of silica and improve the general ventilation and sand-handling systems, and clean accumulated dust in all production areas within the building. Additional samples showed exposures to coremakers dropped between 88 and 94 percent to 12 µg/m^3 and 24 µg/m^3 (OSHA SEP Inspection Report 303207518).

Additional Controls for Furnace Operators

The exposure profile indicates that more than nearly two-thirds (62 percent) of furnace operators already experience exposure levels less than 50 µg/m^3. The remaining one-third will require additional controls. Where adjacent operations release silica dust, control of these operations can reduce exposure levels of furnace operators.

Since furnace and pouring operations are often located in the same general area, OSHA has preliminarily determined that control strategies described for pouring operators (see below) also would benefit furnace operators to a notable extent. For example, in a highly automated foundry that made substantial efforts to control silica in all operations, NIOSH reported exposure readings of 27 µg/m^3 and 29 µg/m^3 for a worker performing tasks between the furnace and the pouring machine (NIOSH ECTB 233-107c, 2000). Although not specifically obtained for furnace operators, these values demonstrate how rigorous control of silica dust throughout a foundry can help minimize exposure levels in the area near the furnace.

Furnace operators handle sand or sand-contaminated scrap metal when they add these items to furnaces. In foundries where silica-contaminated foundry returns contribute to the exposure of furnace operators, the use of cleaner scrap and removal of sand from such returns prior to furnace charging will further reduce exposures. Metal scrap can be cleaned using rotary media mills (Didion, 2003). Facilities might need to alter work practices where furnace operators introduce silica sand as an additive to molten metal. For example, the operator might add sand at a point where existing ventilation will capture dust generated by the process. Other options include installing retractable enclosing hoods to add sand under controlled circumstances (Scholz and Hayes, 2000b).

Finally, ensuring that ventilation systems are installed and functioning properly as well as installing well-ventilated climate controlled monitoring booths (where feasible) will further reduce exposures. Use of a furnace operator control booth was associated with an exposure reading of 13 µg/m^3 (LOD), a 50-percent decrease compared the exposure result for one of two furnace operators working outside the control booth at the same facility (OSHA SEP Inspection Report 121977870). The other furnace operator that worked outside the booth had an exposure level of 13 µg/m^3 as well, making it difficult to confirm the benefit of this particular booth. The option of a booth for exposure control has proven effective in other industries; however, in foundries they are only effective for the more automated furnaces that require little hands-on tending.

Additional Controls for Pouring Operators

As indicated in Table IV.C-16, half the results for pouring operators (50 percent) are below 50 µg/m^3. Pouring operator exposures above 50 µg/m^3 are generally due to uncontrolled dust in adjacent operations. Therefore, controlling adjacent operations will reduce the exposure levels of pouring operators. Balancing (adjusting) the overall facility ventilation to prevent airflow patterns that draw dusty air from other processes into the pouring area will achieve an additional level of control.

Pouring operators who monitor automated processes or use cranes can be isolated with operator booths or cabs supplied with fresh air maintained under positive pressure. NIOSH recommended enclosing crane cabs and ventilating them with fresh outside air, as well as controlling silica dust in adjacent operations to control exposures for pouring crane operators (NIOSH HETA 92-090-2296, 1993). A mobile duct system that provides the cab with fresh outdoor air is commercially available for bridge crane operators (Cralley and Cralley, 1989). While the benefit of this control has not been quantified for pouring operators, OSHA reported a result of less than or equal to 13 µg/m^3 (below the LOD) for a furnace operator working in a control room provided with fresh air, less than half the exposure level of a furnace operator working outside the control room at the same foundry (OSHA SEP Inspection Report 121977870).

Pouring operators conducting manual processes might be isolated by creating a pouring room physically separated from other activities. OSHA obtained a result of 22 µg/m^3 for a pouring operator isolated from other operations while exposures for molders exceeded 80 µg/m^3 for the same facility (OSHA SEP Inspection Report 302380522). An alternative approach to isolating pouring operations might be through controlled airflow. The American Foundrymen's Society and ACGIH both describe LEV controls for several different pouring configurations (AFS, 1985; ACGIH, 2010).

Additional Controls for Shakeout Operators

Table IV.C-16 shows that 40 percent of the silica results for shakeout operators are already 50 µg/m^3 or less, but the remaining 60 percent of shakeout operators (those with current exposure levels above 50 µg/m^3) will require additional controls. The selection and relative effectiveness of controls is dependent on the size of the castings. Those facilities mainly working with small or medium-sized castings can effectively control silica levels in the shakeout area by enclosing the process and improving ventilation in a coordinated control effort to reduce exposures.

Several cases demonstrate the value of enclosed and ventilated shakeout equipment, particularly when combined with other dust control measures. An enclosed dust collection system (not further described) was associated with full-shift PBZ readings for shakeout operators of less than or equal to 13 µg/m^3 (2 readings), 30 µg/m^3, and 41 µg/m^3. These readings were obtained at a foundry that had made a systematic effort to identify and abate all sources of dust emission with the establishment of a "Sand Leak Team" consisting of an engineer, maintenance and production supervisors, and workers (ERG # MI-

1483). Another foundry enclosed the shakeout conveyer and exhausted the enclosure at a rate of 8,000 cfm (for a 10-foot segment, or a rate of 800 cfm/linear foot) as part of a comprehensive effort to reduce exposure throughout the facility. With the enclosure in place, results of 13 µg/m^3 and 37 µg/m^3 were obtained for workers in the shakeout area (OSHA SEP Inspection Report 303207518).

Alternatives to vibrating shakeout equipment are available to small and medium-sized casting applications. Such systems include rotary sand/casting separators, rotary media drums, or shotblast machines (Didion, 2003; O'Brien, 2000; South Cast Equipment, 2000). When connected to an appropriate exhaust ventilation system, this equipment (which entirely encloses the process of separating sand from castings) can separate the shakeout operator from the source of exposure. For example, at one of the same foundries mentioned earlier in the discussion of molders, a combination of enclosed and ventilated sand handling and mold dumping areas and a rotary media tumbler substantially reduced shakeout operator exposure levels at a foundry evaluated by OSHA (Irwin, 2003). At this facility, shakeout operators dumped molds onto a shaker conveyer, operated a rotary media drum that removed additional sand from the casting, and then hung the castings on an overhead conveyer. Initially, this process was associated with an operator exposure level that was 380 percent of the calculated PEL (measured as respirable silica-containing dust). The employer then "designed and built an enclosure that ran the length of the shakeout conveyer from the mold dump position to the [media tumbler]" and also increased exhaust ventilation to the area. Once these changes were in place and the facility had been vacuumed and power washed, shakeout operator silica exposure levels decreased to levels in the estimated range of 20 µg/m^3 to 40 µg/m^3 (Irwin, 2003).[115]

For larger castings, enclosing the process is preferred to enclosing the operator because emissions from shakeout operations have been shown to contribute to excessive exposures in adjacent operations. However, enclosing the operator can be effective when the entire process is isolated within the facility. NIOSH evaluated a facility that enclosed an entire shakeout and finishing line in an isolation room. The crane operators worked in a positive pressure cab supplied with fresh air (NIOSH ECTB 233-107c, 2000). Exposures for operators on two different days ranged from the LOD (less than or equal to 12 µg/m^3) to 53 µg/m^3. Furthermore, a Mine Safety and Health Administration (MSHA) evaluation of heavy equipment cabs reported a 90- to 95-percent reduction in respirable dust (inside compared with outside the cab) for well-sealed, filtered cabs with air conditioning. This reduction was associated with an exposure level of 25 µg/m^3 (Haney, 2000). OSHA preliminarily concludes that when large-casting shakeout operations can be conducted remotely, an operator's booth using similar technology would offer the operator a comparable level of protection.

For very large castings that must be de-molded manually, ventilation can still provide some exposure reduction. The use of portable enclosures and portable ventilation systems, as well as ventilated tools, can help reduce exposures (ERG-GI, 2008). OSHA estimates that such controls can reduce exposures below 100 µg/m^3 and will reduce exposures of adjacent operations where shakeout operations are the major source of exposures. Based on information reviewed in ERG-GI (2008), OSHA believes that no more than 5 percent of shakeout operators are involved in producing castings of this size.

Alternatively, silica exposures can be eliminated by substituting non-silica granular molding media for silica sand and using alternative refractory mold coatings (Schleg and Kanicki, 2000; Carbo, 2000). These alternatives are readily available from commercial sources and are associated with silica exposures below the LOD (ERG-GI, 2008; ERG # OH-1460).

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[115] Silica was not sampled, so this estimate is based on the initial 2,930 µg/m^3 (2.93 mg/m^3) and post-abatement 550 µg/m^3 (0.55 mg/m^3) respirable dust results (Irwin, 2003).

Additional Controls for Knockout Operators

As the Table IV.C-16 exposure profile for knockout operators indicates, nearly half (46 percent) of the available results for this job category are already 50 μg/m^3 or less. Major control options for reducing exposures for the remaining 54 percent of these workers include reducing the amount of sand on the castings that enter the knockout area and installing or improving LEV on the tools and workstation where operators remove sand and excess metal from castings.

Foundries have several options for reducing the amount of residual sand adhered to castings that reach knockout operator workstations. Rotary media drums that offer more vigorous or longer shakeout cycles can loosen additional sand. Modern high-frequency vibrating units offer another option. These machines can be used with exhaust ventilation and/or sand reclamation equipment to control dust (Didion, 2000a; ERG-GI, 2008). NIOSH visited a foundry where, on two different product lines, castings were placed through a high-frequency shaking process after the primary shakeout was completed. On one product line, the high-frequency shaker was used after several other cleaning steps; on the second line, castings entered the high-frequency shaker prior to most other cleaning and knockout operations (NIOSH ECTB 233-107c, 2000). These two lines demonstrate that foundries have considerable leeway in assigning the order in which various cleaning and processing steps occur. The sooner that all but the most tightly adhered sand can be removed, the less likely the loose sand will affect the silica exposures of downstream workers.

Some facilities use a combination of controls to reduce exposure levels for workers in this job category. For example, a combination of controls reduced knockout operator exposures to levels of 50 μg/m^3 or less at a foundry visited by the Michigan Department of Public Health's Bureau of Environmental and Occupational Health. The first set of sample results, obtained in 1989, included two full-shift PBZ readings, 95 μg/m^3 and 101 μg/m^3, for "knock off" operators. Between 1989 and 1994, the foundry installed new controls in the knockout area and added some new shakeout equipment. Two samples collected for "knock off"operators in 1994 resulted in full-shift PBZ concentrations of 30 μg/m^3 and 50 μg/m^3. The improvements to the knockout line included the installation of a 50,000-cfm canopy hood exhaust system, a 10,000-cfm make-up air system, baffle plates and side shields, and a new vibrator to the monorail conveyor carrying castings. The vibrating monorail conveyor shook off most excess sand in a ventilated tunnel while transporting the castings to the knockout area, where workers eventually removed residual scrap metal from the castings (ERG # MI-1485).

Saws and grinders used to remove scrap metal can be fitted with LEV or located in partially enclosed, ventilated booths. Hand-held tools used on larger castings also can be fitted with tool-mounted LEV or used in a ventilated booth. These tools are often associated with finishing operations and are discussed under that job category.

As has been discussed for other job categories in ferrous sand casting foundries, substitution of silica-containing mold and core materials with non-silica alternatives that are less toxic than silica would virtually eliminate the silica exposure of knockout operators. Alternative material, including ceramic media, olivine, and zircon sand, are readily available from commercial sources (Carbo, 2000; Foundry Products Supplier A, 2000).

Additional Controls for Abrasive Blasting Operators

Approximately 70 percent of the silica exposure results summarized in Table IV.C-16 for abrasive blasting operators exceed 50 μg/m^3. To the extent that abrasive blasting operators experience secondary exposure from adjacent operations, the exposure levels of these workers will be reduced when the exposures of adjacent workers in other job categories are reduced (e.g., shakeout and knockout processes).

For abrasive blasting operator silica exposures that continue to be elevated once adjacent sources of respirable dust are controlled, the primary control methods involve repairing or enclosing the machines to seal leaks, and augmenting ventilation systems to achieve 500 feet per minute (fpm) air flow through all openings as recommended for blasting cabinets by ACGIH or to achieve the air flow recommended by the machines' manufacturer (ACGIH, 2010). Blasting machine manufacturers offer programs to rebuild and retrofit these machines and also provide long-term service contracts. New abrasive blasting machines are readily available from a variety of commercial sources.

A series of air sampling results demonstrates the value of identifying, enclosing, and ventilating *all* substantial sources of exposure associated with abrasive blasting operations. OSHA visited a gray and ductile iron foundry where the abrasive blasting operator exposures were due to a combination of dust sources. The foundry made incremental modifications and eventually reduced operator silica results by 75 to 85 percent, to levels less than 50 µg/m^3. Initially, in 1994, two workers sorted castings from a conveyer arriving from the shakeout area and loaded and unloaded an automated shot blasting machine (presumably a batch process). The ventilation was poor ("0 CFM") in the sorting area, and results of 178 µg/m^3 and 184 µg/m^3 were obtained for these two operators (OSHA SEP Inspection Report 101548626). The facility replaced the shot blasting machine and associated ventilation, as well as covered and ventilated a section of the conveyer coming from the shakeout. During a second evaluation it was evident that these changes had not reduced the silica exposure levels (195 µg/m^3 and 246 µg/m^3).

Several months later the workers continued to perform similar work, but were now placing castings sorted from the conveyer into skip buckets used to load the blasting machine. During this third evaluation, results of 47 µg/m^3 and 107 µg/m^3 were obtained for the two abrasive blasting operators, whose primary source of exposure was now reportedly dust from the shakeout conveyer and skip buckets. The foundry next added an enclosure over the skip buckets and further covered a sand conveyer next to the shot blasting machine. The shakeout conveyer, however, was noted to be a continuing source of exposure during a fourth evaluation, at which time results of 72 µg/m^3 and 80 µg/m^3 were reported for the abrasive blasting operators. Finally, 21 months after the initial evaluation, the facility added an enclosure and LEV to the exit from the shakeout, and also added LEV to the skip bucket enclosure. These controls, combined with previous modifications (new blasting machine with LEV, enclosed and exhausted sand and shakeout conveyers) were associated with results of 34 µg/m^3 and 47 µg/m^3 for the abrasive blasting operators who continued to sort castings (25 percent of the shift) and operate the shot blasting machine (OSHA SEP Inspection Report 101548626).

Another option for reducing sand on castings before they reach the abrasive blasting operations is to use fully enclosed pre-cleaning equipment prior to abrasive blasting. OSHA visited a facility that manually blasted castings with aluminum oxide in a ventilated booth and obtained an initial exposure of 436 µg/m^3. After changing the process to include pre-cleaning the castings in an automated shot blasting machine before finishing the blasting by hand, the exposure declined to 51 µg/m^3, an 88 percent reduction (OSHA SEP Inspection Report 300409166). At this facility, OSHA also obtained a result of 33 µg/m^3 for an operator who loaded and unloaded an automated shot blasting machine, which was fully enclosed and equipped with properly functioning LEV.

Work practices can affect the silica exposure levels of abrasive blasting operators. Sealed and ventilated abrasive blasting cabinets must remain closed for a period of time after blasting ceases (long enough for the ventilation system to cycle several complete air changes inside the cabinet). This period allows the ventilation system to remove residual airborne dust before the operator opens the door, releasing any contaminant remaining inside. In addition, the use of compressed air for cleaning dusty surfaces should be avoided. Two of the highest results in the exposure profile (1,002 μg/m^3 and 238 μg/m^3) are associated with workers who used compressed air to blow dust from surfaces around steel shot blasting machines (NIOSH HETA 92-044-2265, 1992).

Where very large castings (too large to fit into an abrasive blasting machine) must be blasted with abrasives, foundries should make every attempt to use a ventilated blasting booth designed for this purpose. Although operator exposures might remain elevated, use of an enclosed booth will prevent migration of silica dust to other areas of the facility. Abrasive blasting under these conditions must comply with 29 CFR 1910.94 – Ventilation, and the workers performing this abrasive blasting must be equipped with suitable respirators in accordance with 29 CFR 1910.94 and 29 CFR 1910.134 – Respiratory Protection.

Wet abrasive blasting is an additional control option for abrasive blasting operators working on very large castings (whether in the open or in a booth). Wet abrasive blasting is used on other silica-containing materials, such as concrete, and has the potential to limit silica exposures from this source if adequate water is used during the blasting (NIOSH ECTB 247-11c, 1999). For example, one manufacturer of a water induction nozzle for wet abrasive blasting recommends that water be applied at a rate of 0.75 to 6 liters per minute to control dust (Boride, 2003). The use of water on ferrous castings is rare, but not unprecedented. In 1997 NIOSH visited a gray and ductile iron foundry where finishing operators used water to wet castings while performing grinding (NIOSH HETA 97-0004-2642, 1997).

As noted for other job categories, by replacing silica sand with alternative granular media that is less toxic than silica for mold and core materials, foundries can eliminate these primary sources of silica exposure.

Additional Controls for Cleaning/Finishing Operators

Table IV.C-16 shows that slightly more than one-third (37 percent) of the silica exposure results for cleaning/finishing operators are 50 μg/m^3 or less. The remaining 63 percent of workers in this job category will require additional controls.

Exposure levels of cleaning/finishing operators are dependent on a number of factors, including size and shape of casting, degree of burnt-in sand, extent of defects requiring removal, and whether compressed air is used for cleaning. Therefore, options to reduce exposure focus on controlling these factors. NIOSH has recommended the following general approaches to reducing dust levels in casting cleaning operations: reduce casting defects, pre-clean castings as thoroughly as possible prior to chipping/grinding, apply LEV to these operations, and eliminate the use of compressed air for cleaning (NIOSH-85-116/86-116-1730, 1986; NIOSH HETA 97-0004-2642, 1997). Other control options include the use of wet grinding/finishing methods and process automation (NIOSH ECTB 233-107c, 2000; NIOSH HETA 97-0004-2642, 1997)

Reducing Casting Defects and Pre-Cleaning Castings

ERG-GI (2008) discussed options for reducing casting defects, which can trap mold and core materials that produce silica dust when cleaning/finishing operators chip and grind the defect. Although estimates of the impact on exposure levels of reducing casting defects are not available, OSHA notes that if workers require less time to remove smaller amounts of silica embedded in defects, their silica exposure would potentially decrease proportionally. When residual mold and core material are present, most castings (small and medium sized) can be pre-cleaned using enclosed, automated, and ventilated processes, such as vibrating abrasive media, rotary media drums, or enclosed shot blasting (Huston, 1981; Pangborn, 2000; South Cast Equipment, 2000). Pre-cleaning reduces the amount of time and effort required to clean and finish castings (Didion, 2000b; Huston, 1981). OSHA recorded exposure levels of 27 µg/m^3, 36 µg/m^3, and 40 µg/m^3 for cleaning/finishing operators working with hand-held and stationary grinding equipment on castings that were pre-cleaned using a shot blast machine (OSHA SEP Inspection Report 123187965). Compared with the exposure levels measured before the introduction of pre-cleaning (93 µg/m^3 and 116 µg/m^3), these results represent an exposure reduction of 57 to 77 percent.

Local Exhaust Ventilation

To reduce exposures while using manually operated power tools, NIOSH recommends the following options: 1) vacuum suction system on the tool itself (e.g., a high-velocity low-volume [HVLV] LEV system); 2) mobile extraction hood; 3) stationary side-draft or downdraft LEV benches; and/or 4) retractable ventilation booth for castings that do not fit on benches (NIOSH-85-116/86-116-1730, 1986). However, there are limitations with these systems. Option 1 might interfere with tool operation, and clogging of inlet ports has been identified as a problem; and option 3 does not provide direct capture during cleaning of cavities. Still, LEV can provide substantial exposure reduction. NIOSH also notes that downdraft and/or side draft LEV hoods are preferable to overhead exhaust systems, because overhead exhaust systems can draw silica dust from the point of generation through the worker’s breathing zone (NIOSH EPHB 233-133c, 2002).

Gressel (1997) reported on a study showing a 59 percent (cone grinder) to 77 percent (cup grinder) reduction of respirable dust exposures after workers switched to using a downdraft booth fitted with a turntable to allow manipulation of castings. The system was designed to ACGIH recommendations (reproduced in ACGIH [2010]) and included a new ventilation system that had an exhaust volume of 2,900 cfm. NIOSH recommended the use of such workstations as a means of reducing exposure.

OSHA initially obtained results of 56 µg/m^3 to 81 µg/m^3 for cleaning/finishing operators at a facility using stand grinders and hand-held grinders (OSHA SEP Inspection Report 122040488). The facility installed three dust control booths for the stand grinders and achieved a reduction in the mean exposure of 43 percent (exposures ranging from 23 µg/m^3 to 60 µg/m^3). As a second control measure, the facility later installed a downdraft collection bench for operators using hand-held equipment.[116] Compared with the initial exposure levels, cleaning/finishing operators using the downdraft booths experienced a mean exposure reduction of 69 percent (results of 20 and 24 µg/m^3). Although HVLV hoods for controlling dust emission from portable tools have been available for many years, the foundry industry has not widely accepted them. Historically, HVLV systems involved the use of shrouds fitted to tools, which sometimes obscured the work from the worker’s view and proved cumbersome to move about complex casting shapes (NIOSH-81-114, 1981). Ventilated tools continue to evolve and are becoming more widely available and better accepted in other industries (see the construction industry portion of this technological feasibility analysis). OSHA seeks additional information on the extent to which these tools are now used in the foundry industry.

LEV systems for stationary tools, such as bench grinders, are readily available and have been shown to reduce exposures in foundries. The ACGIH recommends specific LEV designs for seven different styles of grinding equipment (ACGIH, 2010). LEV booths present another option for controlling dust from both stationary equipment and hand tools. As noted under baseline conditions for this job category, exposure results of 30 µg/m^3 were obtained for two operators using separate booths, each with a grinding bench serviced by LEV (ERG # OH-1488). At another facility, OSHA obtained three results

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[116] The downdraft bench dust collection system operated at 4,800 cfm, using 51 cotton sateen filter bags (255 square feet of filter media) that are 99 percent efficient for particles 1 micron or larger (OSHA SEP Inspection Report 122040488).

between 23 µg/m^3 and 60 µg/m^3, and a 43-percent reduction in mean silica exposure when workers used grinding benches equipped with LEV hoods (OSHA SEP Inspection Report 122040488).

A case study completed at a foundry in New York showed that a ventilation system, which had been demonstrated to be effective in controlling emissions from another foundry process (air carbon-arc gouging), could be used to control silica exposures related to grinding with portable tools. Grinding benches were equipped with a “tabletop booth” consisting of a wrap-around design, which provided supply-air on both sides of the worker’s body as well as exhaust ports at the rear of the bench. The foundry reported that tabletop booths operated at exhaust rates as low as 3,000 cfm with 1,500-cfm supply-air have “consistently controlled silica exposures during grinding to below OSHA’s Permissible Exposure Level”(Hughes and Schultz, 1984). OSHA estimates that this type of LEV could provide some exposure reduction, but the effectiveness of this approach depends on a number of variables, including the size and shape of the castings and the amount of grinding necessary.

Eliminate Cleaning With Compressed Air

NIOSH consistently cites the elimination of compressed air for cleaning when recommending methods to reduce silica exposures (NIOSH HETA 92-0089-2368, 1993; NIOSH HETA 97-0004-2642, 1997). ERG-GI (2008) describes an informal review of 26 results for cleaning/finishing operators working at five foundries where NIOSH or OSHA had observed use of compressed air. The review showed that compressed air used by cleaning/finishing operators to blow sand off castings and equipment was associated with elevated exposure results, including a median of 487 for those 26 µg/m^3 results. Furthermore, all 26 results were 230 µg/m^3 and higher. (These results are elevated compared with a median of 196 for all cleaning/finishing operators shown in the Table IV.C-16 exposure profile.) The majority of these results are associated with cleaning/finishing operators using pneumatic hand-held grinding, sanding, and chipping tools. As an alternative to cleaning with compressed air, preferable practices include wet cleaning methods or vacuuming using appropriately filtered vacuums.

As workers use compressed air to clean, accumulated dust in the surrounding work area becomes airborne and can contribute to worker exposure. OSHA visited a foundry with background silica levels of 63 µg/m^3. This background silica concentration would add to the exposures of those workers performing operations that generate silica dust.[117] The foundry made no physical changes in the casting cleaning department, but walls and dust accumulation points in the area were vacuumed and washed. As a result, no background silica dust was detected, and respirable dust levels were reduced 60 to 80 percent in the cleaning/finishing area. This demonstrates the extent to which accumulated dust from poor housekeeping practices and dust spread from other foundry departments can influence cleaning/finishing operator results.

Wet Methods

Wet methods might be the best option for cleaning/finishing operators working on some of the largest castings, which cannot be pre-cleaned using automated methods and which are too large for conventional booths and downdraft tables. Although wet methods are not widely used in ferrous sand casting foundries, this control has been documented in this type of facility. A foundry evaluated by NIOSH in 1996 used wet methods to help reduce dust during chipping and grinding of large grey iron castings ranging in mass from 1 to 28 tons (NIOSH HETA 97-0004-2642, 1997). Although NIOSH noted that a worker frequently used water to wet castings, compressed air was also used to remove sand from internal cavities. As a result, an exposure of 380 µg/m^3 was recorded for the cleaning/finishing operator (NIOSH HETA 97-0004-2642, 1997). OSHA believes that this exposure would have been substantially

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[117] This area sample result (as opposed to a breathing zone result) is not included in the industry profile.

lower if a high-efficiency particulate air (HEPA)-filtered vacuum system had been used instead of compressed air.

Wet methods are successfully used in the stone cutting industry. Kitchen countertop fabricators experienced up to an 88-percent decrease in silica exposures when finishing operators switched to water-fed angle and edge grinders (Simcox et al., 1999).

NIOSH (NIOSH EPHB 282-11a, 2003) investigated a water-spray dust control used by construction workers breaking concrete with jackhammers. Compared with uncontrolled conditions, the use of water spray reduced exposures between 72 and 90 percent (NIOSH EPHB 282-11a, 2003). Williams and Sam (1999) also reported that a water spray nozzle mounted on a hand-held pneumatic chipper decreased respirable dust exposures approximately 70 percent, even in the enclosed environment of concrete mixing trucks.

Beamer et al. (2005) conducted a study of dust suppression using misting nozzles to reduce silica while brick cutting using a stationary saw. Misting at three different flow rates resulted in respirable mass fractions of dust 63 to 79 percent lower than those when free-flowing water was tested. NIOSH completed a similar study evaluating water spray devices to suppress dust created while jack hammering. The study reported a 77-percent reduction in exposures (NIOSH EPHB 282-11c-2, 2004). Foundries can apply these methods to achieve similar exposure reductions (ERG-GI, 2008).

In summary, a number of silica control options are available to cleaning/finishing operators using hand-held and bench tools to remove embedded mold and core materials. As discussed for other job categories, foundries that are able to switch to alternate granular media that is less toxic than silica sand can eliminate this source of exposure for cleaning/finishing operators.

Additional Controls for Material Handlers

Table IV.C-16 shows that the exposure levels of approximately half (47 percent) of material handlers are already 50 µg/m^3 or less. The majority of the remaining operators will likely experience results at this level and lower when effective controls are implemented to reduce silica dust generated from other operations (i.e., sand systems, molding, shakeout, knockout, cleaning/finishing). Where material handlers generate dust through their own activities, additional controls will be required. For example, material handlers can minimize the distance that sand falls and the speed with which they add sand to hoppers, both of which will limit the amount of dust released into the air during these activities (ERG-GI, 2008).

Enclosed operator cabs operating under positive pressure equipped with air filtration and air conditioning offer another option for reducing the exposure of material handlers in facilities that have not implemented controls in high dust generating operations. An MSHA evaluation of heavy equipment cabs reported a 90- to 95-percent reduction in respirable dust (inside compared with outside the cab) for well-sealed, filtered cabs with air conditioning. This reduction was associated with a respirable quartz exposure level of 25 µg/m^3 (Haney, 2000). Exhaust ventilation on the material transfer points served by material handlers offers another control option. Improving or adding enclosures and exhaust ventilation on the bins and hoppers into which material handlers place sand would likely offer the same benefit (68- to 83-percent exposure reduction) achieved by foundries that have made such changes to sand transfer equipment (OSHA SEP Inspection Reports 116154311 and 122040488).

Finally, as noted for other job categories, essentially all silica exposures of material handlers can be eliminated by foundries that are able to substitute non-silica materials that are less toxic than silica as the granular media used in molds and cores.

Additional Controls for Maintenance Operators

The primary silica exposure for maintenance operators occurs during routine patching or repair and periodic replacement of refractory materials. The additional controls described in the following paragraphs address this source of exposure. Additional sources of exposure, from adjacent processes and equipment maintained by the maintenance operator, will be controlled when the exposure levels of workers associated with those processes and equipment are controlled.

The exposure profile suggests that 42 percent of all foundry maintenance operators are currently exposed to silica levels of 50 μg/m^3 or less. The remaining 58 percent will require additional controls, such as use of low-silica-content refractory materials, use of preformed (pre-cast) materials, improved work practices, LEV, or wet methods. In describing these controls, OSHA has drawn from the experiences of contract refractory service providers and other industries, whose workers perform work similar to that of the foundry maintenance operators who patch, maintain, and occasionally replace refractory materials. OSHA anticipates that these controls will be equally effective for controlling silica exposure during refractory furnace maintenance.[118]

Reduced-Silica Refractory Materials

Refractory materials with low silica content (0 to 5-percent silica compared with 90-percent silica) are readily available from commercial sources, although each low-silica refractory material is not necessarily compatible with every application for which refractory materials are used (Foundry Equipment Manufacturer J, 2000). OSHA visited a foundry that reduced the silica exposure of workers who relined furnaces by 90 percent after implementing a comprehensive exposure control program that included switching to a low-silica gunning refractory applied to furnace walls (for exposure levels reported at this facility, see below in the discussion of combined control methods) (ERG-GI, 2008; OSHA SEP Inspection Report 122209679). Since the replacement refractory material was stronger and lasted longer, refractory workers also were able to use less material during cupola repair operations.

When switching from high-silica- to low-silica-content refractories, employers will need to consider the possible hazards of substitutes. For example, under high temperatures and oxidative conditions (as in a furnace), the chromite compounds contained in some refractories can be converted to hazardous chromium VI (ANH, 2004; Brenneman, 2010). Because both installation and removal activities can generate airborne dust, employers must evaluate the need to protect workers from other contaminants found in refractories before *and* after service life.

Automated and Remotely Controlled Processes

Automated refractory demolition and installation methods can reduce the number of workers exposed, the duration of exposure, and possibly the exposure levels of workers who perform large-scale refractory removal jobs. Examples include “pusher” systems installed in coreless induction furnaces to push out refractory linings (Foundry Products Supplier B, 2000a), remote chipping equipment attached to a hydraulically controlled articulated arm commonly available on some types of construction equipment (Refractory Services Provider A, 2003b), and automated systems for installing dry rammable refractory material in coreless induction furnaces (Gradmatic, 1999). For additional discussion of these control options, see Section IV.C.19 – Refractory Repair, which covers the maintenance service contractors who repair and replacement of refractory materials. OSHA believes that, in general, these methods are more useful and more available to workers involved in large-scale refractory replacement than to maintenance

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[118] Although not a control measure, the reliance on professional maintenance contracts has decreased the amount of time foundry employees spend replacing refractory materials (McNeil, 2000; Refractory Products Supplier A, 2000). An industry source confirmed that refractory relining services are used by an estimated 75 percent of all companies, across all industries that use furnaces requiring relining (including foundries) and this number has been constant for the past decade (Refractory Products Supplier A, 2010). These companies offer service contracts to reline and maintain refractories on a schedule, using trained personnel. Professional refractory contractors are better equipped for safe handling of refractory materials (e.g., with remotely controlled equipment, portable exhaust ventilation systems) than foundry workers who might perform this work only occasionally. More consistent installation quality also reduces the frequency of relining. Additionally, some refractory management companies also offer a service to reline furnaces off site (McNeil, 2000). The exposures and additional controls for professional refractory maintenance contractors are addressed under Section IV.C.19 – Refractory Repair.

operators who perform periodic patching and repair. However, this control method is included here because some foundry workers occasionally participate in large-scale removal activities.[119]

Precast Refractory Materials

Relining of induction and other furnace types also might be accomplished using precast refractory materials that are set in place as units, with minimal risk of exposure. Precast refractory materials can look like typical construction bricks, or they can have more sophisticated geometries that facilitate installation. For example, curved shapes can be cast that sit flush against the furnace wall. The custom-made precast materials are sealed with refractory grout, mixed from a powder (Gradmatic, 2000; Refractory Products Supplier A, 2000). When appropriate for a particular application, preformed refractory shapes can reduce installation labor, improve performance, and provide a longer service life compared with some brick and poured materials. When repairs are required, standard shapes mean that replacement parts can be kept on hand and that repairs can be isolated to the worn section of the lining (eliminating the need for complete tear-out) (TFL, Inc., 2009). Because of these and other advantages, companies are more frequently using precast shapes instead of powdered products (monolithics) for certain applications (Gradmatic, 2000), and the growth of precast refractory shapes in the United States is expected to exceed monolothics in 2011 (Business Wire, 2008).

Work Practices

Work practices, such as limiting the number and location of operators working in a furnace at one time, can reduce refractory worker exposures during removal activities. Sweeney and Gilgrist (1998) reported a higher silica exposure level (170 µg/m^3) for a refractory worker operating in a lower position than a second refractory worker (78 µg/m^3) within a 1,100-pound holding furnace for molten aluminum. The authors reported 8-hour TWAs for both exposures, assuming zero exposure for approximately 1 hour of the 8-hour shift. The worker who experienced higher exposure levels reportedly bent over to grab and toss (to discard) the pieces of refractory material debris while the other worker operated the jackhammer. This put the lower worker’s breathing zone closer to the jackhammer’s point of operation and dust generation than the breathing zone of the jackhammer operator. However, both workers were overexposed to the silica-containing respirable dust (Sweeney and Gilgrist, 1998).

Where faulty equipment contributes to awkward work practices, a preventive maintenance program can help reduce worker silica exposures. Workers experienced an exposure reduction of 92 percent when a foundry initiated several control measures, including a preventive maintenance program to ensure proper function of air guns and related equipment used to spray refractory furnace lining materials (OSHA SEP Inspection Report 122209679) (for exposure levels reported at this facility, see the section below discussing combined control methods). In a second foundry, a worker’s silica exposure level decreased after a foundry replaced the missing tool restraint on a pneumatic chipper used to remove the refractory lining from a large ladle. The tool restraint eliminated the need for this worker to lean into the ladle (where dust was generated) to hold the chipping blade in place (Burmeister, 2001). This improvement to the tool, in conjunction with other controls, reduced exposure levels of the worker by 70 percent.

Ventilation (Local Exhaust Ventilation)

Several options are available to control dust generated when refractory workers must chip or apply refractory linings from a position inside the furnace. In addition to using low-silica materials,

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[119] Some furnace linings are replaced monthly, but most are replaced yearly or even every several years.

appropriate controls include temporary general dilution ventilation installed in the furnace, LEV on the chipping tool, and wet methods.

A company that provides refractory overhaul services developed a method for installing temporary LEV in a gas-fired furnace. This method is used for complete lining removals, but also is applicable to smaller patching jobs. The method, associated with silica exposures between 50 µg/m^3 and 100 µg/m^3, involves company-built exhaust fans fitted with air filters (three filters of increasing efficiency in series). Plastic sheeting is used as necessary to ensure that fresh air enters the furnace only from the most advantageous point, causing clean air to flow past the worker's breathing zone (Refractory Services Provider A, 2003a). Fan/filter boxes are set into the opposite and lower end of the furnace to exhaust dusty air from near the chipping point (ERG-GI, 2008). The position of sheeting and boxes might need to be moved in order to continue providing optimal air flow as the work progresses to other sections of the furnace. Although the fan/filter boxes are specially built for this purpose, they are made of materials readily available at hardware stores (Refractory Services Provider A, 2003b).

LEV also is a dust control option for refractory workers who empty bags or mix refractory powders. For smaller jobs, workers who dump bags of silica-containing materials can empty the bags into a movable hopper (or other receptacle), then use a flexible sleeve to guide material from the hopper to the distribution point (e.g., a furnace bottom). A portable exhaust trunk (preferably with a semicircular slot or flanged hood) positioned near the bag dumping hopper can capture a portion of the dust released during that activity. Because additional silica exposure can occur when workers compress empty bags, this task also should be located near a portable exhaust trunk. Bag dumping for large jobs can sometimes be eliminated by obtaining powdered materials in bulk bags (e.g., 1-ton sack) filled by the supplier with the predetermined amount of product required for the job. As a standard feature, bulk bags come fitted with a sleeve through which material is dispensed. Bulk bags and sleeves are used for installing high-silica rammable refractory powder in induction furnaces (Foundry Equipment Manufacturer J, 2000; Gradmatic, 1999). Maintaining the bottom of the sleeve, which releases material, at a level just below the surface of deposited material can keep dust emissions to a minimum.

Workers who mix high-silica refractory materials also would benefit from the use of a portable exhaust hood.

Ventilated Chipping Tools

The benefits of tool-mounted systems for controlling silica have been demonstrated in other industries, including the construction and ready-mix concrete industries. The chipping of refractory materials is similar to chipping concrete, another silica-containing material. NIOSH tested two tool-mounted LEV shrouds for hand-held pneumatic chipping equipment (impact drills), one custom built and the other a commercially available model. Comparing multiple short-term samples, NIOSH found that the shrouds reduced respirable dust by 48 to 60 percent (NIOSH EPHB 282-11a, 2003).

In a separate evaluation, NIOSH showed that this type of LEV system controls dust equally well for larger chipping equipment. NIOSH collected short-term samples while workers used 25- or 30-pound jackhammers to chip concrete from inside concrete mixer truck drums (comparable to a foundry furnace due to the quantity of hardened concrete accumulated over many months and the enclosed working conditions in the drum). During 90- to 120-minute periods of active chipping, mean silica levels decreased 69 percent (from 970 µg/m^3 to 300 µg/m^3) when the workers used a tool-mounted LEV shroud in these enclosed spaces (NIOSH EPHB 247-19, 2001). NIOSH also evaluated a combination of ventilation controls as part of the same study. The tool-mounted LEV shroud plus general exhaust ventilation provided an additional exposure reduction compared with uncontrolled conditions, resulting in a 78 percent decrease in mean silica readings and a 54 percent decrease in respirable dust levels (the difference was due to a lower percentage of silica in the respirable dust sample associated with the combined control). While tool-mounted LEV shrouds on chipping equipment reduces worker exposures, their use is more complicated in very tight spaces (such as some furnaces), where maneuvering the additional air hose can be awkward (Refractory Services Provider A, 2003a).

Wet Methods

Wet methods can be successfully used to control silica exposures in a number of operations, including chipping, sawing, spraying, and handling of dusty refractory materials.

Studies have quantified the benefit of using wet methods to control respirable dust generated during chipping with hand-held equipment. NIOSH (NIOSH EPHB 282-11a, 2003) investigated a water spray dust control used by construction workers breaking concrete with 60- and 90-pound jackhammers. A spray nozzle was fitted to the body of the chipping tool, and a fine mist was directed at the breaking point. Using both a direct reading instrument and a high-flow cyclone and filter media, NIOSH collected 10-minute readings with and without the spray activated, and found respirable dust concentrations were between 72 percent and 90 percent lower when the water spray was used (NIOSH EPHB 282-11a, 2003). Williams and Sam (1999) reported that a water spray nozzle mounted on a hand-held pneumatic chipper decreased respirable dust approximately 70 percent in the worker's breathing zone. Tool-mounted water spray devices can be assembled using materials obtained from a hardware store and include a garden spray nozzle, tubing, clamps, and a control valve (Hoffer, 2007; NIOSH-2008-127, 2008; NJDHHS, no date; Williams and Sam, 1999). NIOSH completed another study evaluating water spray devices to suppress dust created while jack hammering. The study reported a 77-percent reduction in exposures (NIOSH EPHB 282-11c-2, 2004).

Two more sources also show the effect that water-misting devices have on dust control. Beamer et al. (2005) conducted a study of dust suppression using misting nozzles to reduce silica while brick cutting using a stationary saw. The effectiveness of misting at three different flow rates compared with free-flowing water was tested. The respirable mass fractions of dust were reduced by 63 percent with the mist on low (4.8 gallons per hour total flow), 67 percent on medium (8.6 gallons per hour total flow), and 79 percent on high (17.3 gallons per hour total flow). Water-fed saws are readily available and effectively control dust during sawing of concrete, stone, and bricks. Use of a bench-top water-fed masonry saw was associated with a less-than-full-shift (340 minutes) result of 23 μg/m^3 for a worker cutting refractory brick (OSHA SEP Inspection Report 113451538).[120]

Water spray also is useful for suppressing dust during cleanup. After chipping, Refractory Services Provider A (2003b) uses a garden mister to wet refractory debris in the bottom of the furnace. This step helps control dust as the waste is removed from the furnace. The same employer also tested high-pressure water blasting as a refractory removal method; the process controlled dust, although workers found it difficult to manage the amount of water released in the process (Refractory Services Provider A, 2003b). This method could be effective in cases where water can be captured efficiently.

Workers must use caution when introducing water into a furnace. Some refractory materials crumble and become muddy or slippery when wet with excessive amounts of water (Cheng et al., 1992; Refractory Services Provider A, 2003a). Additionally, wetting portions of the furnace lining that will not be removed (when making smaller repairs) requires an extra step to dry the refractory material before the furnace is brought to working temperature. However, despite these complications, wet methods remain the best option for controlling silica dust from high-energy activities such as pneumatic chipping and should be considered when high-silica materials are involved. A spray of fine mist directed at the point of

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[120] This value is not included in the exposure profile because it was less than full shift.

dust generation has been shown to be effective. At an open air location, a flow rate of 350 milliliters (12 ounces) per minute reportedly dried quickly, without adding a substantial amount of water to the work site (NIOSH EPHB 282-11a, 2003). In indoor environments, workers can use a shop vacuum to collect the water (Flanagan et al., 2001), but need to ensure general dilution ventilation is sufficient and treat or duct vacuum exhaust air so that it does not become an additional source of exposure in the work area.

Combined Control Methods

Depending on the sources of respirable dust, a combination of control methods can reduce silica exposure levels more effectively than a single method. A routine cupola relining (removal and replacement) in the ferrous foundry industry demonstrates the benefit of a combination of controls by achieving up to a 92 percent reduction in exposures (ERG-GI, 2008). Before implementing controls, OSHA collected samples for three workers with results of 270 μg/m^3, 368 μg/m^3, and 630 μg/m^3. This facility then substituted refractory material with reduced silica and greater moisture content (8 percent, rather than 4 percent, moisture), improved equipment and materials to reduce malfunction and task duration, wet refractory material before removal, and assigned a consistent team of trained workers to the task. After the foundry made these changes, a consultant collected silica exposure samples on three dates. The values included six results between 30 μg/m^3 and 50 μg/m^3, one of 61 μg/m^3, and a short-term result below the LOD (<70 μg/m^3) (OSHA SEP Inspection Report 122209679).[121] Reduced silica in the respirable dust sample and shorter task times (relining required less time with the improved methods) account for most of the exposure reduction.

A second report on a facility performing refractory relining also demonstrates the benefits of a combination of control measures (Burmeister, 2001). A full-shift silica result of 215 μg/m^3 was obtained while a worker chipped away the old refractory lining using faulty equipment, and then mixed the replacement refractory material. According to the manufacturer's material safety data sheet (MSDS), the ladle lining contained 56-percent silica. Burmeister noted that the "pneumatic chipper lacked a tool retainer, requiring the worker to hold the chipping bit, putting the worker much closer to the source of the exposure than would have been necessary had the pneumatic chipper been equipped with a retainer." The foundry responded to the high exposure result by holding a training meeting and seeking worker input on abatement actions; implementing a "water control system to reduce dust generated during the pneumatic chipping process"; purchasing chisel retainers to eliminate the need for the worker to reach into the ladle during chipping; and purchasing a vacuum to remove dust and debris from the ladle. With these changes in place, a consultant found that exposure was reduced to 74 μg/m^3, representing a 66-percent reduction. OSHA notes that this facility might have achieved still lower silica exposure levels by using LEV or tool-mounted vacuum suction to capture dust, or by managing fresh air flow past the worker's breathing zone.

Additional Controls for Housekeeping Workers

The 29 percent of housekeeping worker exposure values (summarized in Table IV.C-16) that are 50 μg/m^3 or less are often associated with facilities that make an effort to limit silica exposures of workers in other job categories across the facility. OSHA anticipates that many of the 71 percent of housekeeping

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[121] One of the results of 30 μg/m^3 was also below the LOD (ERG-GI, 2008; OSHA SEP Inspection Report 122209679).

workers whose exposures are above 50 µg/m^3 will experience lower exposures once modifications are made to control silica in the dustiest process (i.e., sand systems operations, shakeout, knockout, abrasive blasting, clean/finishing).

For those housekeeping workers who must clean spills during upset conditions and clean areas where dust gradually accumulates over time, additional controls will be required to reduce worker exposures. Appropriate controls include wet methods, HEPA-filtered vacuums, portable exhaust ventilation, and reduced reliance on compressed air for cleaning.

Silica particles do not become airborne as readily when damp as when they are dry. Housekeeping workers can limit their exposures to silica by cleaning up spilled mold and core sand and washes while they are still damp. The material should be contained or removed so that it does not become a source of exposure when it dries. As evidence of the feasibility of this control method, NIOSH obtained six results for housekeeping workers who cleaned up damp, spilled molding sand every 2 to 4 minutes (with each mold cycle). Although their silica results (65 to 90 µg/m^3) were somewhat elevated because of other dust sources in the area, OSHA judges that the exposures were probably lower than if the sand had been allowed to dry before the workers removed it (NIOSH ECTB 233-113c, 2000).

Cleaning up spilled sand and core washes, by containing the waste before it dries, will reduce airborne dust generation. When housekeeping workers encounter dry sand, simply adding moisture will reduce dust generation during cleanup. Vacuuming, shoveling, and scraping generate less dust than dry sweeping (ERG-GI, 2008). Although these alternate methods have not been evaluated in foundries, a study of construction industry workers found that when compared with dry sweeping, exposures were approximately three times lower when construction workers used squeegees to scrape surfaces and approximately five times lower when workers used vacuums (Riala, 1988).

When exposures are controlled across the facility, the use of vacuums for cleaning can provide additional exposure control. However, if vacuums are not sealed properly, they can become a source of dust generation and exposure. Portable vacuums must be emptied frequently according to manufacturers' instructions to ensure adequate suction and prevent the vacuum contents from becoming an additional source of exposure (Echt and Sieber, 2002). Special precautions and work practices will need to be developed to make certain the cleaning of filters does not introduce dust. As an alternative, large stationary or skid-mounted vacuum systems can provide adequate suction with vacuum ports at multiple locations. The suction ports can be positioned near locations where they are most likely to be needed, and the exhaust air and dust will pass through a traditional foundry air-cleaning device, such as a bag house.

Use of compressed air for cleaning also can contribute to workers' silica exposure levels. While low-pressure compressed air is usually considered less of a safety hazard than high-pressure air, any blowing can cause respirable-sized silica particles to become airborne. In a study of construction workers in the United States, Flanagan et al. (2003) made 1-minute measurements using a direct reading dust monitor while 10 workers performed various cleaning tasks. The investigators found that the cleaning equipment associated with the highest respirable dust exposure level was the backpack blower.

Where dust accumulations are prevalent, control efforts should start with a professional-level cleaning to remove silica dust from rafters, walls, and equipment. Irwin (2003) reported on a foundry (described previously) that reduced silica exposure levels in several job categories from levels in the range of 200 µg/m^3 and higher, to 50 µg/m^3 or lower. Among other modifications, "the foundry temporarily shut down while the entire facility was thoroughly vacuumed and power washed down to remove many years of accumulated silica containing dust." The down time was used to make other modifications as well, such as completely renovating the sand-handling system.

Finally, with the substitution of non-silica containing materials for mold and coremaking, silica exposures can be virtually eliminated.

Ferrous Sand Casting Foundries—Feasibility Findings

Feasibility Findings for Sand Systems Operators

Based on a review of OSHA SEP, NIOSH, State, and industry association reports, OSHA preliminarily concludes that the silica exposures of approximately one-third of sand systems operators in ferrous sand casting foundries are maintained at 50 µg/m^3 or less through use of enclosed and ventilated sand processing and transport equipment. OSHA further finds that this level can be achieved for most of the remaining operators by improving or adding enclosures and ventilation to existing equipment. For example, a foundry reduced the silica exposure of the sand systems operator by 83 percent (from 231 µg/m^3 to 40 µg/m^3) by installing LEV and fixing leaks in the mixer (OSHA SEP Inspection Report 122040488).

OSHA also preliminarily concludes that even the highest exposures reported for this job category (the 14 percent that currently experience silica exposures above 250 µg/m^3, as summarized in Table IV.C-16) can be reduced to levels of 50 µg/m^3 or less using these methods (installing LEV and fixing leaks in the mixer) combined with other controls, such as replacing existing equipment with completely enclosed or pneumatic sand processing and transportation equipment, as well as improved work practices and improved housekeeping. A steel foundry that implemented this combination of controls achieved silica exposures of 28 µg/m^3 (NIOSH ECTB 233-107c, 2000).

As an alternative, foundries can virtually eliminate the silica exposures of all workers by substituting for sand with one of the alternate non-silica granular media commercially available for foundries. For example, silica exposures dropped below the LOD for all workers when a foundry in Ohio used olivine sand, a non-silica containing sand (ERG # OH-1460). OSHA notes that employers must evaluate alternate granular media to ensure that workers are adequately protected from any associated hazards.

Feasibility Findings for Molders

Based on information contained in Table IV.C-16, OSHA preliminarily concludes that 50 percent of molders already achieve exposure levels of 50 µg/m^3 or less. These same levels can be achieved for most of the remaining molders (the other 50 percent) through a combination of controls that includes improving the enclosures and ventilation associated with equipment that delivers and processes sand in molding areas, and reducing reliance on poor housekeeping and work practices that disturb dust (e.g., dry sweeping and use of compressed air). This conclusion is based on silica exposure levels of 42 µg/m^3 to 50 µg/m^3 associated with improvements in engineering controls (OSHA SEP Inspection Report 100494079) and a silica exposure level of 40 µg/m^3 or less achieved when a foundry also implemented aggressive housekeeping practices in addition to LEV and work practice controls (Irwin, 2003).

Since a large portion of molder exposures is attributable to adjacent operations, the exposure levels of workers in this job category will be further reduced when facilities control the exposures of adjacent workers in other job categories. OSHA preliminarily concludes that by implementing the controls described above and controlling adjacent sources of exposure, foundries will be able to reduce the exposure levels of all molders to levels of 50 µg/m^3 or less.

Feasibility Findings for Coremakers

Based the information described above, OSHA preliminarily concludes that 57 percent of coremakers' exposures are already less than or equal to 50 µg/m^3. Additional controls will be required to achieve the same level for the remaining 43 percent of coremakers (those with exposure levels exceeding 50 µg/m^3 in Table IV.C-16). The exposure level of most of these remaining coremakers can be reduced to levels of 50 µg/m^3 or less by effective control of silica release from adjacent operations (e.g., shakeout, finishing, sand systems operations). In addition, a professional-level cleaning followed with improved housekeeping (i.e., switching to HEPA-filtered vacuums instead of compressed air) will reduce exposure levels further. A foundry that took steps to control the release of silica and also improved the general ventilation and sand-handling systems within the building reduced coremaker exposure levels 88 percent to 12 µg/m^3 and 24 µg/m^3, which shows that even higher exposures can be reduced (OSHA SEP Inspection Report 303207518). OSHA preliminarily concludes that by implementing the controls described above, foundries will be able to reduce the exposure levels of all coremakers to levels of 50 µg/m^3 or less.

Feasibility Findings for Furnace Operators

OSHA preliminarily concludes that exposure levels of 50 µg/m^3 or less have already been achieved for 62 percent of furnace operators by limiting the spread of silica dust from other areas of the foundry to the furnace area and by augmenting ventilation systems. To reduce all furnace operator exposures to this level, facilities will need to ensure that all existing emission control systems are functioning properly throughout the foundry, or install such systems where feasible to reduce dust generation from tasks specifically performed by furnace operators (OSHA SEP Inspection Report 121977870; NIOSH ECTB 233-107c, 2000; NIOSH HETA 90-0249-2381, 1994).

In foundries where silica-contaminated foundry returns contribute to the exposure of furnace operators, metal scrap can be cleaned using rotary media mills (Didion, 2003). If sand must be added to the furnace (as part of the formulation or to protect the furnace lining from aggressive metals), a retractable enclosing hood will permit the worker to add sand under controlled circumstances (Scholz and Hayes, 2000b).

In the event that furnace operators repair refractory furnace linings, exposures can be reduced using the same controls available to workers in the foundry maintenance operator job category covered elsewhere in this section.

OSHA preliminarily concludes that by implementing the controls described above, foundries will be able to reduce the exposure levels of all furnace operators to levels of 50 µg/m^3 or less.

Feasibility Findings for Pouring Operators

OSHA preliminarily concludes that silica exposure levels of 50 µg/m^3 or less have already been achieved for 50 percent of pouring operators in ferrous sand casting foundries. OSHA further finds that pouring operator exposure levels above 50 µg/m^3 are generally due to uncontrolled exposures in adjacent operations. For those pouring operators whose exposures might still be above 50 µg/m^3 after dust control for adjacent operations has been addressed, additional controls might be implemented. Such controls include isolation of the pouring operation, adjustment of air flow in the facility to prevent dusty air from being drawn into the pouring area, or use of booths and cabs to isolate operators from silica exposures. OSHA preliminarily concludes that by implementing these additional controls, exposure levels for all pouring operators will be reduced to levels of 50 µg/m^3 or less.

Feasibility Findings for Shakeout Operators

Based on Table IV.C-16 and other information presented above, OSHA preliminarily concludes that foundries have already achieved silica exposure levels of 50 µg/m^3 or less for 40 percent of shakeout operators through the use of well-enclosed and ventilated shakeout and related equipment to separate sand from castings. Additional controls will be required for the remaining 60 percent of shakeout operators.

OSHA estimates that by enclosing operations, improving existing ventilation, or installing new systems, exposure levels can be reduced for most shakeout operators to levels of 50 µg/m^3 or less. For example, four shakeout operator exposure results were 41 µg/m^3 or less at three foundries that implemented various dust control measures in the shakeout area (e.g., shakeout enclosure added, ventilation system improved, rotary media mills installed, conveyers enclosed and ventilated) and made other systematic efforts to abate dust emissions (ERG # MI-1483; OSHA SEP Inspection Report 303207518; Irwin, 2003). However, some foundries might find it more practical to replace existing open shakeout equipment with more modern enclosed or automated equipment than to modify ventilation systems around existing open models of shakeout equipment.

While most shakeout operators' exposures will be controlled to the proposed PEL of 50 µg/m^3 by using the controls described above, some operators (an estimated 5 percent of the total) will not be able to use the same methods to reach this level because the casting size or the need to manipulate castings will make it more difficult to enclose or ventilate the process. For these operators, achieving exposures below 100 µg/m^3 is more realistic. Until engineering controls can be developed to manage silica concentrations in their work area, employers might need to provide respiratory protection to protect these shakeout operators.

Finally, exposures for all shakeout operators can be virtually eliminated by substituting non-silica granular media that is less toxic than silica for silica sand in the molding and coremaking processes. As discussed for the sand systems operator job category, these media are commercially available and are associated with silica exposure levels below the LOD for all job categories evaluated (ERG # OH-1460).

Feasibility Findings for Knockout Operators

Based on Table IV.C-16, OSHA preliminarily concludes that exposure levels of 50 µg/m^3 or less have already been achieved for 46 percent of knockout operators. The remaining 54 percent of workers in this job category (i.e., those with current exposure levels exceeding 50 µg/m^3 in Table IV.C-16) will require a combination of additional controls, including limiting the amount of sand loosely adhered to castings entering the knockout process, and LEV or ventilated tools in areas where excess sand and scrap metal are removed. Because loose sand is the greatest source of exposure to knockout operators who experience the highest silica concentrations, OSHA believes that the silica exposure levels for even the most highly exposed operators can be reduced effectively when most of this sand is removed before the casting reaches the knockout area and without releasing silica dust into the work area air.

At a foundry in Michigan a combination of controls that included improved ventilation, better workstation enclosures (e.g., side shields and baffles), and new equipment to shake excess sand off castings (in a ventilated tunnel en route to the knockout area) reduced knockout operator exposures to levels of 30 and 50 µg/m^3 (ERG # MI-1485).

In addition, those operators who work on large castings will require LEV attached to hand tools to reduce exposures (discussed in cleaning/finishing operations). Using LEV-equipped hand tools on large castings where no other controls are feasible will reduce exposures below 100 µg/m^3, but might not reduce exposures below 50 µg/m^3 (ERG-GI, 2008). Therefore, as with shakeout operators, OSHA preliminarily concludes that results of 100 μg/m^3 can be achieved for the approximately 5 percent of knockout operators working on very large castings, but information is insufficient to confirm that exposure levels for these workers can be reduced to levels of 50 μg/m^3 or less.

Alternatively, as discussed for sand systems operators, foundries able to switch to non-silica granular media that is less toxic than silica sand can virtually eliminate the silica exposure of all knockout operators.

Feasibility Findings for Abrasive Blasting Operators

Considering the information described above, OSHA preliminarily concludes that the majority of abrasive blasting operators' exposures can be reduced to levels of 50 μg/m^3 or less by automating and enclosing abrasive blasting operations using properly ventilated equipment and following manufacturer's recommendations for abrasive blasting machine use and maintenance. This conclusion assumes that silica exposures from adjacent sources will be reduced when the exposure of adjacent workers in other job categories is controlled. As seen earlier in this analysis, a gray ductile foundry made modifications that included a new blasting machine with LEV, enclosed and exhausted sand conveyors, an enclosure and LEV to the shakeout exit, and LEV to the skip bucket enclosure. Over a period of almost 2 years, the foundry eventually reduced operator silica results by 75 to 85 percent, to levels less than 50 μg/m^3 (OSHA SEP Inspection Report 101548626). Another facility found an 88-percent exposure reduction to 51μg/m^3 after workers started using automated, fully enclosed shot blasting for pre-cleaning castings (OSHA SEP Inspection Report 300409166).

An estimated 5 percent of abrasive blasting operators manually clean very large castings (the same percentage of shakeout operators are estimated to handle large castings) (OSHA SEP Inspection Report 300409166). To the extent possible, these workers should perform this activity in ventilated blasting booths to limit exposure to other workers. When it is possible, pre-cleaning the casting can reduce the silica exposure levels of the abrasive blasting operator. Furthermore, as discussed in Section IV.C.22 – Abrasive Blasters, which covers abrasive blasting in the construction industry, wet abrasive blasting can substantially reduce silica exposures. Information from construction is applicable to abrasive blasting of large-scale castings. There, blasting must be performed manually because larger-sized pieces cannot be isolated within a blasting cabinet, thus necessitating other means of worker protection. Additionally, like the concrete surfaces abrasively blasted by construction workers, the residual mold material is a hard sand-based substance (in this case held in a clay rather than cement matrix) with high silica content. Furthermore, the foundry abrasive blasting operator works indoors, blasting residual mold material adhered to a casting much like a construction worker blasts indoor concrete walls, tank interiors, or other ground-level structures. Using the methods discussed above, foundries will greatly reduce abrasive blaster exposures, but not necessarily to levels below 50 μg/m^3.

Pre-cleaning small and medium-sized castings in automated shot blasting machines to reduce the amount of residual sand on the castings also can provide a substantial reduction in exposures for these operators when the entire process cannot be accomplished using automated equipment.

As has been noted for other job categories, silica exposures throughout the foundry can be eliminated by replacing silica-containing mold and core materials with alternate granular media that is less toxic than silica sand (see discussion under the sand systems operators job category).

Feasibility Findings for Cleaning/Finishing Operators

OSHA preliminarily concludes that 37 percent of cleaning/finishing operators already have silica exposures of 50 μg/m^3 or less (see Table IV.C-16). The exposures for most of the remaining 63 percent of these workers can be reduced to 50 µg/m^3 or less by using a combination of controls, including using ventilated workstations, effectively pre-cleaning castings, improving housekeeping, and eliminating the use of compressed air for cleaning.

At one foundry, installation of a downdraft dust collection bench (LEV) for workers using hand-held equipment to clean and finish castings reduced exposure levels by a mean of 69 percent (to 20 µg/m^3 and 24 µg/m^3) (OSHA SEP Inspection Report 122040488). At another foundry, pre-cleaning castings using a shot blast machine (prior to performing finishing operations using hand-held and stationary grinding equipment) reduced results by an average of 67 percent (to 27 µg/m^3, 36 µg/m^3, and 40 µg/m^3) (OSHA SEP Inspection Report 123187965).

Although the uncontrolled exposures in these examples were all below 120 µg/m^3, OSHA has preliminarily determined that pre-cleaning castings would be as effective (or possibly more effective) when uncontrolled cleaning/finishing activity results in higher direct silica exposure levels (e.g., 500 µg/m^3 or greater), because of larger quantities of adhered mold material. OSHA bases this determination on the ability of pre-cleaning equipment to prepare castings equally well regardless of the initial quantity of mold material originally adhered to the castings' surface. For a typical casting, the shot blast machines, tumbling media mills, and related equipment (singly or in series) leave only the most ingrained mold material, so cleaning/finishing operators must grind only the trace volume of residual mold material, and the resulting silica exposures are minimized.

Since pre-cleaning and use of dust collection equipment are independent controls, OSHA estimates that foundries that pre-clean castings *and* install LEV can reduce the silica exposure of finishing operators using hand-held equipment by a combined 90 percent (assuming the average exposure reduction for each control is achieved). For example, an exposure of 500 µg/m^3 conservatively can be reduced by 67 percent (to 165 µg/m^3) by thoroughly pre-cleaning castings, and can be further reduced by 69 percent (to 51 µg/m^3) by providing workers with LEV workstations (such as downdraft tables) for a total reduction approaching 90 percent. As noted in the description of baseline conditions, only 23 exposures (11 percent) exceed 500 µg/m^3. Thus, for the remaining 89 percent of workers currently exposed to 500 µg/m^3 or less, implementation of these controls can reduce silica exposures to 51 µg/m^3 or less.

Further dust management efforts can reduce exposures to lower levels. As noted in the section on additional controls for this job category, effective plant cleaning to remove sources of accumulated dust has been shown to reduce background respirable dust exposure levels by 60 to 80 percent (OSHA SEP Inspection Report 303207518). If silica had been evaluated in addition to respirable dust after the cleaning session at this foundry cleaning/finishing department (where the background silica level was 63 µg/m^3), then the post-cleaning background silica value would likely have been 25 µg/m^3 or less (lower by at least 38 µg/m^3, corresponding to a minimum 60-percent reduction). For the cleaning/finishing operator job category, taking the maximum worker exposure levels of 51 µg/m^3 after pre-cleaning castings and installing LEV (calculated for the 89 percent of workers in this job category who currently experience exposure levels of 500 µg/m^3 or less) and subtracting 38 µg/m^3 (to account for improved background silica levels after a complete shop cleaning) results in an exposure level of 13 µg/m^3.

As a final step, eliminating use of compressed air for cleaning will reduce the exposure level of many of the most highly exposed cleaning/finishing operators (those 11 percent with exposures currently exceeding 500 µg/m^3) to levels below 500 µg/m^3. ERG-GI (2008) found that 26 cleaning/finishing results associated with compressed air for cleaning had a median of nearly 500 µg/m^3 (487 µg/m^3), compared with the median of 196 µg/m^3 for cleaning finishing operators as a whole (Table IV.C-16). Use of compressed air for cleaning will be prohibited under the proposed rule and OSHA preliminarily estimates that by eliminating cleaning with compressed air, many of these workers would experience exposure levels closer to the median for the entire job category (i.e., substantially below 500 µg/m^3). At these reduced levels, these workers will benefit from the exposure control methods described in the previous paragraphs to the same extent as the other 89 percent of workers in this job category.

Based on these estimates, OSHA preliminarily concludes that results of 50 µg/m^3 or less can be achieved for most cleaning/finishing operators most of the time.

Feasibility Findings for Material Handlers

Based on the information presented in this section, OSHA preliminarily concludes that 47 percent of material handlers already experience silica exposure levels of 50 µg/m^3 or less. Once foundries have controlled the exposures of workers in other job categories (which contribute the majority of the airborne silica to which material handlers are exposed), the exposures of the vast majority of the remaining 53 percent of material handlers also will be controlled to the same level.

Where material handlers' activities generate silica dust, exposures will be reduced through use of work practices that minimize dust release (minimizing the distance that sand falls during material handling and adding sand slowly to hoppers so that the hopper capacity is not exceeded). If exposures continue to exceed the proposed PEL of 50 µg/m^3, foundries can install enclosed cabs on heavy material-handling equipment. While OSHA believes that material handlers who have exposures of 100 µg/m^3 or less can alter work practices to reduce their exposures, reductions might be insufficient to achieve exposures below 50 µg/m^3. Enclosed, ventilated cabs are associated with exposure reductions of 90 to 95 percent and can reduce even the highest material handler result to a level less than 50 µg/m^3.

As noted for other job categories, OSHA further finds that switching to alternate granular media that is less toxic than silica for molds and cores will essentially eliminate the silica exposures of material handlers.

Feasibility Findings for Maintenance Operators

Considering the information described above, OSHA preliminarily concludes that 42 percent of maintenance operators currently experience exposures of 50 µg/m^3 or less, primarily by using low-silica refractory materials and work practices that limit their exposures and activities to small-scale patching or repair tasks. Refractory repair is the primary source of silica exposure for these workers. While they might also encounter indirect exposure from the activities of workers in other job categories, maintenance operators' exposures from those sources will be eliminated when the other job categories are controlled. Maintenance operators can also encounter silica during upset conditions. When possible, before making repairs maintenance operators should permit housekeeping workers, equipped appropriately for the job, to clean up spilled material.

OSHA also preliminarily concludes that the exposure levels of many of the remaining operators (those with current exposure values of 250 µg/m^3 or less) can be reduced to levels of 50 µg/m^3 or less by using these same methods. A foundry that implemented a comprehensive exposure control program that included switching to low-silica refractory reduced exposure levels by 92 percent (OSHA SEP Inspection Report 122209679). The extent and the consistency of worker exposure reduction will depend on the silica content of the replacements materials and the proportions in which they are used compared with other refractory materials. In foundries that cannot use reduced silica refractory patching products (because of incompatibility with production processes) operators will require other control methods.

OSHA preliminarily concludes that in these cases, facilities will be able to reduce maintenance operator exposure levels if they use a combination of chipping equipment fitted with LEV shrouds (or water spray when possible), work practices that limit exposure, and general exhaust ventilation that improves air circulation within the furnace during small-scale tasks (NIOSH EPHB 247-19, 2001). However, the level of 50 µg/m^3 might not be achieved for all of these workers. NIOSH found that tool-mounted LEV reduced worker silica exposure levels by 78 percent in enclosed concrete mixer drums, but could not reliably maintain exposures to the level of the proposed PEL (50 µg/m^3). OSHA estimates that by using these methods, the exposure levels of most of these operators will be reduced to 50 µg/m^3 or less; however, a small portion will remain between 50 µg/m^3 and 100 µg/m^3.

The exposure level of in-plant maintenance operators engaged in completely replacing refractory linings during overhaul activities also can be reduced using these controls, but to a somewhat lesser extent (to levels of 100 µg/m^3) because of the extent and duration of the project.[122]

Additionally, OSHA estimates greater reduction can be achieved if the process is misted or performed with LEV and if workers are equipped with automated or remotely operated equipment. This combination of controls reduces exposures to levels of 50 µg/m^3 or less (see Section IV.C.19 – Refractory Repair. OSHA anticipates that by using these two controls in combination with use of low-silica-containing refractory materials, pre-wetting, and high-moisture installation, foundries might reduce the exposure of most maintenance operators who maintain or replace refractory materials to levels below 50 µg/m^3.

As a final option, using a comprehensive professional refractory maintenance contract will eliminate direct silica exposure of in-plant maintenance operators from major refractory replacement activities.

Although the primary silica exposure for maintenance operators occurs during maintenance of refractory materials, these workers also are subject to additional sources of exposure from adjacent processes and equipment maintained by the maintenance operator. When the exposure levels of workers associated with those processes and equipment are controlled, maintenance operators' silica exposure from these sources also will be controlled.

Feasibility Findings for Housekeeping Workers

OSHA preliminarily concludes that 30 percent of housekeeping workers' exposures are 50 µg/m^3 or less (Table IV.C-16). The exposure levels of most of the remaining workers (70 percent) will be reduced to 50 µg/m^3 or less when the exposures of workers in other job categories also are controlled.

If housekeepers in a foundry continue to experience elevated exposures after the silica levels associated with other job categories have been controlled, an initial professional-level cleaning to remove residual accumulated silica can reduce exposure levels. A foundry reduced silica exposure in several job categories from levels of 200 µg/m^3 and higher, to 50 µg/m^3 or lower by making a number of modifications, including a thorough cleaning with vacuuming and power washing to remove many years of silica dust accumulation (Irwin, 2003).

Additional controls, such as using HEPA-filtered vacuums, using wet methods to clean up spilled sand (i.e., clean while the sand is still damp), and eliminating use of compressed air, can further reduce exposures during those tasks performed by housekeeping workers that generate additional dust. OSHA

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[122] Based on information reported by Refractory Products Supplier A (2010) that 75 percent of facilities use a professional service for this work (suggesting that the remaining 25 percent perform it using their own workers), OSHA has preliminarily determined that this group of maintenance operators is represented by the 21 percent shown in Table IV.C-16 who currently have exposures exceeding 250 µg/m^3. As noted previously, complete relining occurs only occasionally: monthly for some furnaces and annually (or every 3 years) for other furnaces.

concludes that with implementation of these control strategies, all exposures for housekeeping workers can be reduced below 50 µg/m^3.

Ferrous Sand Casting Foundries—Overall Feasibility Findings

Based on the information presented above, OSHA preliminarily concludes that the exposure levels of most ferrous sand casting foundry workers can be reduced to levels of 50 µg/m^3 or less most of the time by using the controls described.

Characteristics of Relatively Well-Controlled Foundries

OSHA notes that certain practices are more common in foundries that have been relatively successful in controlling the silica exposures of most workers compared with foundries at which elevated exposures occur routinely. As noted previously, ERG identified several facilities that fit into each category (see discussion at the beginning of the Baseline Conditions and Exposure Profile—Ferrous Sand Casting Foundries section). OSHA reviewed OSHA, NIOSH, and State agency documentation for these foundries to look for trends.

The review of relatively well-controlled and poorly controlled foundries shows some clear distinctions between the two groups. The relatively well-controlled facilities were more likely to have installed enclosures and LEV for usually dusty activities, such as for sand-handling equipment, shakeout, knockout, and cleaning/finishing tasks. These foundries were also more likely to have automated processes, such as mold-making or coremaking, routine grinding, shot-blasting, and conveying parts into enclosures for dusty processes (shakeout, shot blast equipment). Workers controlled these processes remotely, sometimes from behind partitions. Additionally, records describing these foundries are more likely to note other special controls in place to reduce airborne silica dust. Examples include adding pneumatic sand transport equipment, using washed lake sand (with low respirable-sized particle content), and purchasing sand additives premixed (because the mixing process released additional dust).

The poorly controlled facilities tend to rely more heavily on general exhaust ventilation (ceiling or wall fans not associated with any specific process). Notes on the facilities often commented on the lack of LEV (or on having LEV installed for a process such as welding, but not for adjacent processes associated with elevated silica levels, such as grinding in the cleaning/finishing area). Sand systems equipment (e.g., sand mill or reclaimer) were more likely to be unventilated and leak. Additionally, equipment that leaked sometimes contributed to the exposure of workers in more than one job category. For example, OSHA reported that the reclaimed sand mill at one foundry contributed to the silica exposure levels of a material handler and several cleaning/finishing operators who worked nearby. Furthermore, these foundries used compressed air extensively, and the practice was associated with multiple job categories.

Overall, these trends point to the overall benefit that the additional controls mentioned throughout this analysis for individual job categories can have on silica exposures across the entire foundry.

Nonferrous Sand Casting Foundries—Description

The job categories, manufacturing processes, and equipment are essentially the same for ferrous and nonferrous sand casting foundries, as are the sources of silica exposure within these foundry types. Only the metal type differs. However, among all sand casting foundries, ferrous foundry workers typically have higher silica exposures than workers in other metal casting facilities. This is primarily due to higher temperatures required for ferrous casting, causing molds that are hotter, drier, and hence dustier during shakeout operations (O’Brien, 1998). For the same reasons, sand-handling and molding sand removal tasks also contribute less exposure to all job categories throughout the foundry. Additionally, some nonferrous metals are compatible with different casting materials than are typically used for ferrous casting. For example, historically olivine sand (with very low silica content) was thought to produce better casting quality for aluminum than for iron, and thus is used more frequently in the aluminum casting sector (Foundry Products Supplier A, 2000).[123]

The median, mean, and range of exposures of nonferrous sand casting workers in 26 foundries are presented by job category in Table IV.C-17. Exposure results in these facilities are generally lower, though within the range of results reported for ferrous sand casting foundries. With one exception (the maximum result for cleaning/finishing workers), the medians and maximum exposure levels in every job category are lower for nonferrous foundries than for ferrous foundries.[124] However, the figures show clear evidence of the potential for elevated silica exposure among nonferrous foundry workers in all 12 job categories.

Comparison of Nonferrous Sand Casting Foundries and Ferrous Sand Casting Foundries by Job Category

For each job category, the following sections discuss similarities and any relevant differences between nonferrous sand casting foundries and ferrous sand casting foundries as they apply to worker activities and exposure levels. The discussion indicates whether the exposure control options and conclusions presented for ferrous sand casting foundries apply in nonferrous sand casting foundries.

It is worth reiterating that lower casting temperatures in nonferrous foundries result in processes that are less dry and dusty than those in ferrous sand foundries. This difference and more frequent use of olivine sand explain the lower range of silica exposures in nonferrous foundries, compared with those reported for ferrous foundries.

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[123] In fact, olivine sand might be equally effective for ferrous castings. A foundry supply business noted that “Olivine has been famous for years in producing excellent non-ferrous castings. Today, more foundrymen are realizing olivine works equally well in iron, manganese and stainless steel” (IFSCO, 2000). Olivine sand contains less than 0.1 percent silica and is “a naturally occurring mineral composed of a solid solution of magnesium ortho silicate, (forsterite, Mg_2SiO_4) and iron ortho silicate (fayalite, Fe2SiO4)” (Reade Advanced Materials, no date).

[124] The maximum value among the data available to OSHA for cleaning/finishing operators in nonferrous sand casting foundries (1,915 μg/m^3) is 3 percent higher than the maximum for ferrous sand casting foundries (1,868 μg/m^3). However, this figure might not indicate increased potential for elevated exposures. Just 1 percent of the cleaning/finishing operators in nonferrous sand casting foundries experienced a result above 250 μg/m^3, while 22 percent of the exposure levels reported for workers in the same job category exceeded 250 μg/m^3 in the ferrous sand casting foundries (see Table IV.C-16 and Table IV.C-17).

Table IV.C-17
Respirable Crystalline Silica Exposure Range and Profile for Nonferrous Sand Casting Foundries (Parts of NAICS 331524, 331525, 331528)

	Exposure Summary			Exposure Range			Exposure Profile				
Job Category	**Number of Samples**	**Mean (µg/m³)**	**Median (µg/m³)**	**Min (µg/m³)**	**Max (µg/m³)**		**<25 (µg/m³)**	**≥25 and ≤50 (µg/m³)**	**>50 and ≤100 (µg/m³)**	**>100 and ≤250 (µg/m³)**	**>250 (µg/m³)**
Nonferrous Sand Casting Sand Systems Operators	8	33	20	13	78		4 50.0%	2 25.0%	2 25.0%	0 0.0%	0 0.0%
Molder	39	43	23	12	441		23 59.0%	9 23.1%	5 12.8%	1 2.6%	1 2.6%
Coremaker	47	38	13	11	940		41 87.2%	3 6.4%	1 2.1%	1 2.1%	1 2.1%
Furnace Operator	4	14	14	13	14		4 100.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Pouring Operator	3	14	14	13	14		3 100.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Shakeout Operator	20	68	50	12	212		4 20.0%	6 30.0%	6 30.0%	4 20.0%	0 0.0%
Knockout Operator	19	27	23	10	64		10 52.6%	7 36.8%	2 10.5%	0 0.0%	0 0.0%
Abrasive Blasting Operator	11	27	14	13	58		6 54.5%	3 27.3%	2 18.2%	0 0.0%	0 0.0%
Cleaning/Finishing Operator	27	111	44	14	1,915		8 29.6%	8 29.6%	10 37.0%	0 0.0%	1 3.7%
Material Handler	2	31	31	16	46		1 50.0%	1 50.0%	0 0.0%	0 0.0%	0 0.0%
Maintenance Operator	0	0	0	0	0		0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Housekeeping Worker	1	66	66	66	66		0 0.0%	0 0.0%	1 100.0%	0 0.0%	0 0.0%
Total Nonferrous Sand Casting	**181**	**50**	**20**	**10**	**1,915**		**104 57.4%**	**39 21.5%**	**29 16.0%**	**6 3.3%**	**3 1.7%**

Notes: All samples are PBZ results for durations of 360 minutes or more and represent 8-hour TWA exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Source: ERG-GI, 2008.

Sand Systems Operator

Processes and activities in nonferrous sand casting foundries are essentially the same as those found in ferrous sand casting foundries. Both types of sand casting foundries use similar quantities of "green sand" (a moldable mixture of sand and clay) for their operations. Additionally, both types of foundries recycle molding sand using automated equipment to crush lumps and incorporate more clay. Eight results summarized in Table IV.C-17 from five reports on nonferrous sand casting foundries show exposures ranging from 13 to 78 µg/m^3, with a median of 20 µg/m^3. The range of these results is within the range reported for ferrous sand casting foundries.

As shown in Table IV.C-17, the exposure levels of 75 percent of sand systems operators in nonferrous sand casting foundries are already at levels of 50 µg/m^3 or less. The remaining 25 percent of workers in this job category require additional controls to achieve exposures less than 50 µg/m^3. OSHA preliminarily concludes that the controls and conclusions for sand systems operators in ferrous sand casting foundries also apply in nonferrous sand casting foundries because both types of foundries use the same equipment and sand in a similar manner and in comparable quantities. Therefore, by implementing those controls as needed according to the exposure profile, nonferrous sand casting foundries will likely be able to reduce the exposure levels of all sand systems operators to levels of 50 µg/m^3 or less.

Molder

Molder activities in nonferrous sand casting foundries are the same as those in ferrous sand casting foundries. The molding equipment, sand type and quantities, and worker activities are nearly identical in both types of foundries.

Table IV.C-17 summarizes 39 results for molders from 11 reports on nonferrous sand casting foundries, indicating that exposure levels for this group range from 12 to 441 µg/m^3. These results have a median of 23 µg/m^3. This range of exposure levels is within the range described for ferrous sand casting foundries, but with results of 50 µg/m^3 or less already achieved for 82 percent of molders. Eighteen percent of molders require additional controls to reduce their exposure to below 50 µg/m^3.

OSHA preliminarily concludes that the controls and conclusions for molders in ferrous sand casting foundries apply in nonferrous sand casting foundries as well. OSHA also preliminarily concludes that by implementing those controls as needed according to the exposure profile, nonferrous sand casting foundries will be able to reduce the exposure levels of all molders to levels of 50 µg/m^3 or less.

Coremaker

Coremaking is identical in nonferrous and ferrous sand casting foundries. In both types of foundries, coremakers oversee transfer of the same type of sand and additives into automated coremaking equipment to make similar types of cores. In addition, they clean and finish the cores. Table IV.C-17 summarizes 47 results from six reports on nonferrous sand casting foundries. Exposures range from 11 µg/m^3 to 940 µg/m^3, with a median of 13 µg/m^3. The range of results is within the range reported for ferrous sand casting foundries.

As shown in Table IV.C-17, the exposure levels of 94 percent of coremakers in nonferrous sand casting foundries are already at levels of 50 µg/m^3 or less. Only 6 percent of these workers require additional controls to reduce their exposures to below 50 µg/m^3. OSHA preliminarily concludes that the controls and conclusions described for coremakers in ferrous sand casting foundries are the same as those for coremakers in nonferrous sand casting foundries; therefore, the remaining coremaker exposures can be controlled to a similar extent by implementing those controls discussed for coremakers in the ferrous sand casting foundries.

Furnace Operator

Furnace operator functions are similar in nonferrous sand casting foundries and ferrous sand casting foundries. Although there are some variations in furnace types that are used for the various nonferrous metals, the furnace design is unlikely to affect operator silica exposure levels. Furnace operator activities, such as controlling and monitoring the furnaces used to pour molten metal, are similar in both types of foundries. Table IV.C-17 summarizes four results for furnace operators from a single report on nonferrous sand casting foundries all with exposure levels below the LODs (in this case 13 $\mu g/m^3$ and 14 $\mu g/m^3$). These results are within the lowest end of the range reported for furnace operators in ferrous sand casting foundries.

Based on Table IV.C-17, OSHA preliminarily concludes that the exposure levels of all (100 percent) of furnace operators in nonferrous sand casting foundries are already at levels of 50 $\mu g/m^3$ or less, and additional controls are not be necessary for this job category. OSHA recognizes that data are limited for furnace operators in the nonferrous sand casting industry. However, median exposures in both nonferrous and ferrous foundries are below 50 $\mu g/m^3$. This supports the preliminary finding that the controls and conclusions described for furnace operators in ferrous sand casting foundries apply to furnace operators in nonferrous sand casting foundries.

Pouring Operator

Pouring operator activities are similar to those in ferrous sand casting foundries. Workers in both types of foundries transfer molten metal into a ladle or holding furnace, and then into molds. Table IV.C-17 summarized results for three pouring operators in two nonferrous sand casting foundries; all exposures were less than the LODs (13 $\mu g/m^3$ and 14 $\mu g/m^3$). These results are within the range reported for ferrous sand casting foundries (ERG-GI, 2008).

Based on Table IV.C-17, OSHA preliminarily concludes that the exposure levels of all (100 percent) of pouring operators in nonferrous sand casting foundries are already at levels of 50 $\mu g/m^3$ or less, and additional controls are not necessary for this job category. As with the furnace operators, data are limited for pouring operator. Since median exposures in both types of foundries discussed are below 50 $\mu g/m^3$, OSHA preliminarily finds that the controls and conclusions described for pouring operators in ferrous sand casting foundries apply to pouring operators in nonferrous sand casting foundries.

Shakeout Operator

Shakeout operators perform the same functions and use the same equipment in nonferrous foundries as in ferrous sand casting foundries. In both types of foundries, these workers monitor equipment that separates castings from the same types of sand mold materials. Table IV.C-17 summarized 20 results for nonferrous foundry shakeout operators obtained from 10 reports on nonferrous sand casting foundries. Exposure levels for this group range from 12 to 212 $\mu g/m^3$, with a median of 50 $\mu g/m^3$. This range of exposure levels is within the range described for ferrous sand casting foundries (ERG-GI, 2008).

As shown in Table IV.C-17, the exposure levels of 50 percent of shakeout operators in nonferrous sand casting foundries are already at levels of 50 $\mu g/m^3$ or less. The remaining 50 percent of these workers require controls to achieve exposures of 50 $\mu g/m^3$ or less. OSHA preliminarily concludes that the controls and conclusions described for this job category in ferrous sand casting foundries are the same as those for shakeout operators in nonferrous sand casting foundries; therefore, the remaining shakeout operators exposures can be controlled to a similar extent by implementing those controls discussed for the equivalent group in the ferrous sand casting foundries. Although not suggested by the exposure profile in Table IV.C-17, it is possible that a few shakeout operators in these foundries might require respiratory protection under the same circumstances as mentioned for shakeout operators in ferrous sand casting foundries.

Knockout Operator

Knockout operator functions are identical in ferrous and nonferrous sand casting foundries. Operators in both types of foundries use hammers and saws to remove sprues, gates, and risers from castings. Although workers in both types of foundries also remove the same type of sand from castings, the lower casting temperatures in nonferrous sand foundries result in processes that are less dry and dusty. Table IV.C-17 summarized 19 results from six reports on nonferrous sand casting foundries. Exposures range from 10 to 64 µg/m^3 with a median of 23 µg/m^3. These exposure levels are within the lower portion of the range reported for ferrous sand casting foundries (ERG-GI, 2008).

As shown in Table IV.C-17, the exposure levels of 90 percent of knockout operators in nonferrous sand casting foundries are already at levels of 50 µg/m^3 or less. Only 10 percent of workers in this job category require additional controls to achieve exposures below 50 µg/m^3. OSHA preliminarily concludes that the controls and conclusions described for this job category in ferrous sand casting foundries are the same as those for knockout operators in nonferrous sand casting foundries; therefore, the remaining knockout operator exposures can be controlled to a similar extent by implementing those controls discussed for this job category in the ferrous sand casting foundries. Although not suggested by the exposure profile in Table IV.C-17, if extremely elevated exposures are encountered, it is possible that a few knockout operators in these foundries might require respiratory protection under the same circumstances as mentioned for the comparable group in ferrous sand casting foundries.

Abrasive Blasting Operator

The activities of abrasive blasting operators in nonferrous sand casting foundries are the same as in ferrous sand casting foundries. Though blasters remove the same type of sand, lower casting temperatures in nonferrous foundries create conditions that are less dry and dusty than in ferrous sand foundries.

Table IV.C-17 summarized results ranging from 13 µg/m^3 to 58 µg/m^3, with a median of 14 µg/m^3. These 11 results, obtained from five reports on nonferrous sand casting foundries are within the range reported for ferrous sand casting foundries (ERG-GI, 2008). Although 18 percent of the results exceed 50 µg/m^3, none exceeds 100 µg/m^3. In contrast, Table IV.C-16 shows that 69 percent of abrasive blasting operators have exposures exceeding 50 µg/m^3 in the ferrous sand casting foundries, with 13 percent of those exceeding 250 µg/m^3.

As shown in Table IV.C-17, the exposure levels of 82 percent of abrasive blasting operators in nonferrous sand casting foundries are already at levels of 50 µg/m^3 or less. The remaining 18 percent of these workers require additional controls to achieve exposures of 50 µg/m^3 or less. OSHA preliminarily concludes that the controls and conclusions described for this job category in ferrous sand casting foundries are the same as those for abrasive blasting operators in nonferrous sand casting foundries; therefore, the remaining abrasive blasting operators exposures can be controlled to a similar extent by implementing those controls discussed for this job category in the ferrous sand casting foundries. Although not suggested by the exposure profile in Table IV.C-17, if extremely elevated exposures are encountered, it is possible that a few abrasive blasting operators in these foundries might require respiratory protection under the same circumstances as mentioned for the comparable group in ferrous sand casting foundries.

Cleaning/Finishing Operator

Cleaning/finishing operators perform the same activities in nonferrous sand casting foundries as in ferrous sand casting foundries. In both types of foundries, these workers use the same tools to grind out similarly constituted residual mold material and to finish the casting. Table IV.C-17 summarized 27 results for cleaning finishing operators in nonferrous sand casting foundries ranging from 14 to 1,915 µg/m^3 with a median of 44 µg/m^3. These results were obtained from three reports on nonferrous sand casting foundries (ERG-GI, 2008). Although widely distributed, this range is within that reported for ferrous sand casting foundries.

As shown in Table IV.C-17, exposure levels of 50 µg/m^3 or less have already been achieved for 96 percent of cleaning/finishing operators in nonferrous sand casting foundries. Only 4 percent of workers in this job category require additional controls to achieve exposures below 50 µg/m^3. OSHA preliminarily concludes that the controls and conclusions described for cleaning/finishing operators in ferrous sand casting foundries are the same as those for cleaning/finishing operators in nonferrous sand casting foundries; therefore, the remaining cleaning/finishing operator exposures can be controlled to a similar extent by implementing those controls discussed for cleaning/finishing operators in the ferrous sand casting foundries.

Material Handler

The activities of material handlers in nonferrous sand casting foundries are the same as in ferrous sand casting foundries. They typically use powered material handling equipment to transport sand, castings, or other materials. Table IV.C-17 summarized two results from two reports on nonferrous sand casting foundries, ranging from 16 µg/m^3 to 46 µg/m^3, with a median of 31 µg/m^3. These results are within the range reported for ferrous sand casting foundries (ERG-GI, 2008).

Based on Table IV.C-17, OSHA preliminarily concludes that the exposure levels of all (100 percent) of material handlers in nonferrous sand casting foundries are already at levels of 50 µg/m^3 or less and additional controls are not be necessary for this job category. With only two exposures, data available for material handlers are limited. However, at 56 µg/m^3, the median exposure for worker in ferrous sand casting foundries is only slightly higher, leading OSHA to find that the controls and conclusions described for material handlers in ferrous sand casting foundries apply to material handlers in nonferrous sand casting foundries in cases where elevated exposures occur.

Maintenance Operator

In both nonferrous sand casting and ferrous sand casting foundries, maintenance operators repair and maintain foundry and sand-handling equipment, including refractory furnace linings. However, maintenance operators who repair nonferrous furnace linings might not need to perform this task as frequently as for ferrous furnaces since the lower melting temperatures of nonferrous metals potentially cause less damage to the linings. OSHA was not able to identify any exposure measurements representing working conditions for maintenance operators in nonferrous sand casting foundries. However, based on the lower exposures reported for other job categories in nonferrous sand casting foundries compared with the exposure median and range of results for equivalent job categories in ferrous sand casting foundries, OSHA preliminarily concludes that exposures for maintenance operators are at the low end of the range for maintenance operators in ferrous sand casting foundries and that exposure levels of 50 µg/m^3 or less likely have already been achieved for these workers. Furthermore, refractory maintenance activities in nonferrous foundries are not likely to result in any greater exposure for maintenance operators than in ferrous foundries. The lower melting temperatures of some nonferrous metals, such as aluminum, are less destructive of furnace linings.

In the event that elevated exposures do occur, OSHA preliminarily concludes that the controls and conclusions for maintenance operators in ferrous sand casting foundries also apply in nonferrous sand casting foundries and that by implementing those controls as needed, nonferrous sand casting foundries will be able to reduce the exposure levels of all maintenance operators to levels of 50 µg/m^3 or less.

Housekeeping Worker

The activities of housekeeping workers in nonferrous sand casting foundries are the same as in ferrous sand casting foundries. A single result of 66 µg/m^3 was obtained from a report on a nonferrous sand casting foundry and is entered in Table IV.C-17. This result is within the range reported for ferrous sand casting foundries (NIOSH HETA 86-0116-1730, 1988).

Although there is only one exposure available for housekeeping workers, the result is only slightly lower than the median value of 75 µg/m^3 for housekeeping workers in ferrous sand casting foundries. Based on information presented above for other job categories (the major sources of silica exposure for housekeeping workers), OSHA has preliminarily determined that silica exposure levels for this job category arise from the same sources in nonferrous sand-casting foundries and are unlikely to exceed (and are likely lower than) the profile presented for housekeeping workers in the ferrous sand-casting industry (Table IV.C-16). Hence, OSHA preliminarily finds that the controls and conclusions for housekeeping workers in ferrous sand casting foundries also apply in nonferrous sand casting foundries. OSHA preliminarily concludes that by implementing those controls as needed according to the exposure profile, nonferrous sand casting foundries will be able to reduce the exposure levels of all housekeeping workers to levels of 50 µg/m^3 or less.

Nonferrous Sand Casting Foundries—Overall Feasibility Findings

OSHA has preliminarily determined that controls identified to reduce worker exposures in ferrous sand casting facilities also will reduce exposures to an equivalent or greater extent in nonferrous sand casting facilities. This conclusion is based on evidence that the same casting methods involving sand are commonly used to cast most metals. As a result, the affected job categories and the sources of exposure are the same for ferrous and nonferrous sand casting foundries, and the same controls will be effective.

Based on the relatively low exposure levels reported for this industry in Table IV.C-17 and the availability of controls for most workers, OSHA preliminarily concludes that exposure levels of 50 µg/m^3 or less can be achieved for all workers in nonferrous sand casting foundries most of the time. This conclusion is based on several points presented in Table IV.C-17 and elsewhere in this section. These points are summarized here. Overall, most workers (80 percent) already have exposures of 50 µg/m^3 or less, and this level has already been achieved for the vast majority of workers in nine out of the 12 job categories. Additionally, the affected job categories, worker duties, sources of exposure, and equipment are the same as in the ferrous sand casting industry, where the silica exposures of most workers can be controlled to 50 µg/m^3 or less most of the time (see the discussion of ferrous sand casting foundries earlier in this section).

Furthermore, exposure levels in this industry tend to be lower than in ferrous sand-casting foundries because the nonferrous metals are typically cast at lower temperatures than ferrous metals, resulting in less drying and fracturing of silica mold and core materials. For these reasons, OSHA has preliminarily determined that the same exposure controls outlined for ferrous sand-casting foundries will be at least as effective in the nonferrous sand casting industry.

Non-Sand Casting Foundries (Ferrous and Nonferrous)—Description

The group of non-sand casting foundries includes facilities that cast any metal primarily using methods other than bonded sand molds. Casting methods include, but are not limited to, unbonded sand molding (e.g., lost foam), investment casting, casting with ceramic and plaster molds, and permanent mold casting (including centrifugal mold processes). Poured metal is shaped by a substance other than sand, typically a sturdy shell-like layer of refractory material. The refractory shell materials contain silica, and permanent molds are often washed with silica mold-release agents. Sand casting foundries sometimes use similar materials to line sand molds and cores, but non-sand casting foundries depend more heavily on these refractory substances in the molding process. Some of these refractory materials contain a substantial amount of silica.

Although sand is not the primary molding material, a reduced amount of sand might be involved in these casting methods. Some processes use loose, unbonded sand to fortify or provide structural support around the refractory mold. Additionally, sand cores might be inserted into any type of mold (Schleg and Kanicki, 2000).

In general, job categories are similar to those in ferrous sand casting foundries. With the exception of molders, workers in non-sand casting foundries perform the same activities, have similar sources of exposure, and are exposed to similar levels of silica in both types of foundries (ERG-GI, 2008). Thus, OSHA preliminarily concludes that the exposure controls described for ferrous sand casting foundries will be equally effective in non-sand casting foundries.

Table IV.C-18 summarizes, by job category, the available full-shift PBZ silica exposure results for non-sand casting foundry workers.

Comparison of Non-sand Casting Foundries and Ferrous Sand Casting Foundries by Job Category

For each job category, the following section discusses relevant differences between non-sand casting foundries and ferrous sand casting foundries as they apply to worker activities and exposure levels. The discussion indicates whether the exposure control options and conclusions presented for ferrous sand casting foundries apply in non-sand casting foundries. Where necessary, the section also describes required modifications to the controls.

Sand Systems Operator

In non-sand casting foundries, the activities of sand systems operators are limited to mixing sand for cores in those facilities that use sand cores and to handling any unbonded core sand returned from the shakeout process. Core sand and refractory materials are not typically reclaimed and reused in non-sand casting foundries. Thus, sand reclamation is less complicated and presumably less dusty than in ferrous sand casting foundries. OSHA was not able to identify any exposure measurements for sand systems operators in non-sand casting foundries; however, the reduced use of sand and the modest exposure levels encountered for most job categories in these foundries suggest that exposure levels for this group would likely be in the lower end of the range reported for ferrous sand casting foundries (ERG-GI, 2008). Because of the decreased amount of sand handling, a fewer number of sand systems operators with lower exposures are likely to be employed in non-sand casting foundries than in sand casting foundries. In some cases, these duties are likely performed by a worker in another job category, such as coremaker or molder.

Table IV.C-18
Respirable Crystalline Silica Exposure Range and Profile for Non-Sand Casting Foundries (Ferrous and Nonferrous)
(Parts of NAICS 331524, 331525, 331528, 331512)

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean (µg/m^3)**	**Median (µg/m^3)**	**Min (µg/m^3)**	**Max (µg/m^3)**		**<25 (µg/m^3)**	**≥25 and ≤50 (µg/m^3)**	**>50 and ≤100 (µg/m^3)**	**>100 and ≤250 (µg/m^3)**	**>250 (µg/m^3)**
Non-Sand Casting											
Sand Systems Operator	0	0	0	0	0.0		0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Molder	23	63	30	9	318		10 43.5%	6 26.1%	3 13.0%	2 8.7%	2 8.7%
Coremaker	6	32	36	10	60		2 33.3%	3 50.0%	1 16.7%	0 0.0%	0 0%
Furnace Operator	2	26	26	17	35		1 50.0%	1 50.0%	0 0.0%	0 0.0%	0 0.0%
Pouring Operator	5	46	18	10	150		3 60.0%	1 20.0%	0 0.0%	1 20.0%	0 0.0%
Shakeout Operator	7	189	220	10	432		1 14.3%	1 14.3%	1 14.3%	2 28.6%	2 28.6%
Knockout Operator	12	88	52	9	598		4 33.3%	2 16.7%	5 41.7%	0 0.0%	1 8.3%
Abrasive Blasting Operator	9	128	13	10	980		6 66.7%	0 0.0%	2 22.2%	0 0.0%	1 11.1%
Cleaning/Finishing Operator	25	70	31	8	820		10 40.0%	10 40.0%	2 8.0%	2 8.0%	1 4.0%
Material Handler	3	41	8	8	107		2 66.7%	0 0.0%	0 0.0%	1 33.0%	0 0.0%
Maintenance Operator	4	14	12	12	20		4 100.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Housekeeping Worker	2	13	13	12	14		2 100.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Total Non-Sand Casting Foundries	**98**	**76**	**28**	**8**	**980**		**45 45.9%**	**24 24.4%**	**14 14.3%**	**8 8.2%**	**7 7.1%**

Notes: All samples are PBZ results for durations of 360 minutes or more and represent 8-hour TWA exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Sources: ERG-GI, 2008.

OSHA preliminarily concludes that for those workers in this industry who do have sand-handling duties (regardless of their job category), the available controls described for sand systems operators in ferrous sand casting foundries will be sufficient to control any exposures that occur in non-sand casting foundries as well. OSHA further concludes that by implementing those controls as needed, non-sand casting foundries will be able to reduce the exposure levels of all sand systems operators to levels of 50 μg/m^3 or less.

Molder

The silica exposures of molders in non-sand casting foundries originate from different mold materials than in sand-casting foundries. Green and chemically bonded sand molding processes are non-existent in non-sand casting foundries. Instead, molders weigh and mix a slurry of refractory material (typically containing substantial quantities of silica as quartz or cristobalite, or both), then repeatedly dip expendable patterns (e.g., foam, wax) in the mold material to form a shell (NIOSH ECTB 233-102c, 1999). Some molders also pour the refractory investment material around a pattern set in a flask. Molders might also sift dry silica-containing sand over dipped patterns to fortify the mold shell as it forms. In foundries using permanent molds, molders spray or pour refractory material into the metal molds (OSHA SEP Inspection Report 109051904; Schleg and Kanicki, 2000; Scholz and Hayes, 2000a). Molders oversee these typically semi-automated molding processes; however, molders might perform these processes manually for small runs or in a facility that performs one of these methods only occasionally.

Additional Exposure Profile Data for Molders

Table IV.C-18 summarized 23 results for molders from 11 reports on non-sand casting foundries ranging from 9 μg/m^3 to 318 μg/m^3, with a median of 30 μg/m^3. The mean, median, and range of results in this group are well within the levels reported for ferrous sand casting foundry molders (ERG-GI, 2008).

Two of the highest results (150 μg/m^3 and 318 μg/m^3) were associated with molders who cleaned permanent centrifugal molds (NIOSH HETA 82-0302-1461, 1984; Scholz and Hayes, 2000a). These exposure levels were attributed to refractory mold release agents, which were applied and then brushed out of the mold after completion of the casting process. NIOSH obtained the highest of these exposures in a facility that had reportedly switched from a silica flour mold release agent to a product containing less than 1.5 percent silica.

Sequential sampling sessions show the effect of switching from silica sand to an alternate granular media even when the foundry uses molding methods other than green sand casting. OSHA obtained results of 50 μg/m^3 and 90 μg/m^3 for molders at a steel investment foundry that compacted unbonded silica sand around lost-foam molds (OSHA SEP Inspection Report 109197897). This facility replaced the silica sand with olivine and reduced exposures to below the LOD (less than or equal to 12 μg/m^3). These are among the lowest results reported for this job category.

Non-sand casting methods can involve refractory investment materials that contain cristobalite instead of, or in addition to, quartz. OSHA obtained a result for a molder that contained respirable cristobalite (129 μg/m^3) in addition to respirable quartz (162 μg/m^3), producing a combined silica result of 291 μg/m^3 (OSHA SEP Inspection Report 109051904). The molder manually emptied bags of silica-containing investment material into a bucket, reaching in to stir the dry ingredients and break up clumps by hand. These results demonstrate the additive effect of quartz and cristobalite on the worker's overall silica result.[125]

Additional Controls for Molders

The controls described for ferrous sand casting foundries apply to non-sand casting foundries as well. Specific controls include improved enclosures and ventilation on sand delivery systems, ventilated workstations, work practices that limit the spread of silica-dust, and substitution of non-silica containing materials where feasible. For further detail, please see the molder job category under Ferrous Sand Casting Foundries earlier in this section.

Additionally, non-sand casting foundries that mix refractory products require ventilated bag-dumping stations and mixing equipment.

Workers who handle powdered silica materials (e.g., empty bags, weigh, mix) can be exposed to dust when it is released from these processes, and when emptied bags are compressed for disposal. One control option involves bag-dumping stations with properly ventilated enclosures, which capture dust released during both bag emptying and bag disposal. While OSHA has not identified any foundry facilities using bag-dumping stations that effectively controlled dust, ERG obtained respirable quartz exposure monitoring data for workers using bag dumping stations to empty 50-pound bags of silica-containing materials into mixers at a paint manufacturing facility (ERG-paint-fac-A, 1999). The stations consisted of hoppers topped with grates that were enclosed by LEV hoods. This ventilation system automatically removed empty bags (by suction) and transferred them to an enclosed storage area. ERG obtained five full-shift PBZ silica exposure readings of less than or equal to 12 $\mu g/m^3$ (LOD) for five workers who emptied bags of silica-containing material using the bag-dumping stations.

ERG also obtained a full-shift PBZ exposure reading of 263 $\mu g/m^3$ for a worker at the same site who used a bag-dumping station equipped with an LEV system that failed to operate for approximately 2 hours (ERG-paint-fac-A, 1999). Without the LEV system operating, the worker was required to manually stack and compress empty bags adjacent to the station, which generated visible dust. The elevated exposure reading obtained for the worker indicates the effectiveness of the LEV system for the bag-dumping stations.

NIOSH evaluated a second type of bag-dumping station equipped with an enclosure, empty bag compactor, bag disposal chute, and LEV system (NIOSH CT-144-19a, 1983). The LEV system ventilated both the enclosure and compactor. NIOSH evaluated the unit by measuring respirable dust levels with real-time aerosol monitors before and while workers emptied bags of crushed limestone into these hoppers. NIOSH determined that the unit effectively controlled respirable dust. Ventilated bag-dumping stations that include a ventilated compactor are readily available from commercial sources (Whirl-air, 2003). OSHA notes that ventilated bag-dumping stations would be equally effective in reducing silica exposures for molders in non-sand casting foundries.

Automated transfer equipment also can reduce dust released as hoppers are filled. OSHA inspected a structural clay facility and found an 86-percent reduction in silica exposures after the facility installed an enclosed, automated sand transfer system (ERG-GI, 2008; OSHA SEP Inspection Report 300523396). Installing such a system can reduce exposures to molders in non-sand casting foundries.

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[125] As described in Section IV.A – Methodology, OSHA is proposing the same permissible exposure limits (PELs) for all three of the major polymorphs of crystalline silica (quartz, cristobalite, and tridymite). On the rare occasions when both quartz and cristobalite are present in a sample, the concentrations of the detected forms are added together.

For those facilities that clean refractory materials from permanent molds, vacuuming in lieu of using compressed air will reduce exposures. Although no data are available comparing the effectiveness of vacuuming molds and brushing in non-sand casting foundries, a study of Finnish construction site workers compared the silica exposure levels for workers dry sweeping or using alternate cleaning methods (ERG-GI, 2008). The study showed that workers who cleaned using vacuums instead of dry sweeping had a five-fold reduction in exposures (Riala, 1988). Such a reduction could result in exposures below 64 µg/m^3 for molders with the highest exposures in non-sand casting foundries and achieve results of 35 µg/m^3 or less for workers with current exposures of 250 µg/m^3 or less.

Feasibility Findings for Molders

As shown in the table, OSHA preliminarily concludes that 70 percent of molders' exposures are 50 µg/m^3 or less. The remaining 30 percent of these workers will require additional controls to achieve exposures of 50 µg/m^3 or less. Although limited data in Table IV.C-18 are available, based on that data and other information described above, by improving or adding ventilation to bag-dumping stations, adding or improving ventilated bag compactors, as well as enclosing and ventilating mixing equipment, OSHA preliminarily concludes that most foundries will be able to achieve results of 50 µg/m^3 or less for molders. This conclusion is based on results from the paint manufacturing industry indicating that a functioning ventilation and bag disposal system at manual charge hoppers can reduce exposure from a level greater than 250 µg/m^3, to less than or equal to 12 µg/m^3 (the LOD) (ERG-paint-fac-A, 1999).

Molders who use vacuums to clean permanent molds can achieve silica exposure levels of 64 µg/m^3 or less. OSHA bases this conclusion on the five-fold reduction of exposures for construction workers who cleaned with vacuums compared with dry sweeping (Riala, 1988) (applying the five-fold reduction to the highest exposure result for molders, 318 µg/m^3 yields 64 µg/m^3; the same reduction in results 250 µg/m^3 or lower would result in values of 35 µg/m^3 or less). OSHA preliminarily concludes that by implementing those controls as needed according to the exposure profile, non-sand casting foundries will be able to reduce the exposure levels of most molders to levels of 50 µg/m^3 or less most of the time.

Coremaker

Coremakers are limited to those facilities that produce or handle sand cores. These cores are essentially the same as cores produced by other types of foundries. Table IV.C-18 summarized six coremaker results from three reports on non-sand casting foundries ranging from 10 µg/m^3 to 60 µg/m^3, with a median of 36 µg/m^3. The range of results is within the lower end of the range reported for ferrous sand casting foundries (ERG-GI, 2008).

Based on the limited available data summarized in Table IV.C-18, OSHA preliminarily concludes that results of 50 µg/m^3 or less have already been achieved for 83 percent of the coremakers in these foundries. The remaining 17 percent of coremakers need additional controls to reduce their exposures to 50 µg/m^3 or less. The controls and conclusions described for coremakers in ferrous sand casting foundries also apply to coremakers in non-sand casting foundries.

Furnace Operator

Furnace operator functions are the same in non-sand casting foundries as in other foundries. Table IV.C-18 summarized two results for furnace operators from a report on non-sand casting foundries. The exposures of 17 and 35 µg/m^3 are within the range reported for furnace operators in ferrous sand casting foundries (ERG-GI, 2008).

Based on the limited information presented in Table IV.C-18, OSHA preliminarily concludes that all furnace operators (100 percent) in non-sand casting foundries already experience results below 50 µg/m^3 and additional controls are not necessary for this job category. However, if elevated exposures do occur, the controls and conclusions described for furnace operators in ferrous sand casting foundries apply equally in non-sand casting foundries.

Pouring Operator

Pouring operator functions in non-sand foundries are the same as those in ferrous sand casting foundries; however, the equipment and materials differ. Pouring operators in non-sand casting foundries use a variety of mold types, including permanent molds for metals such as aluminum (made of a metal with a higher melting temperature) and the types of molds described under the molder job category. Pouring operators using permanent molds can be exposed to silica when molders apply or remove refractory coating from the molds. Table IV.C-18 summarizes five results for pouring operators in non-sand casting foundries. The results range from 10 µg/m^3 to 150 µg/m^3, with a median of 18 µg/m^3. These results are within the range reported for ferrous sand casting foundries (ERG-GI, 2008).

The silica content of mold release agents can influence the exposure levels of workers in the pouring area. Two of the available results for this job category, 36 µg/m^3 and 150 µg/m^3, were obtained for pouring operators at two foundries where workers (molders or pouring operators) applied and removed refractory mold release agents on permanent centrifugal molds (NIOSH HETA 82-0302-1461, 1984; Scholz and Hayes, 2000a). The lower of these results (36 µg/m^3) was associated with a "low silica parting compound" used as the mold release agent.

OSHA preliminarily concludes, based on Table IV.C-18, that 80 percent of pouring operators have exposures of 50 µg/m^3 or less. The remaining 20 percent of these workers require additional controls to bring their exposure to 50 µg/m^3 or less. Based on the information included above, OSHA preliminarily concludes that pouring operator exposure resulting from molders applying and removing refractory coating will be reduced when molding operator exposures are controlled using methods described for molders working with permanent molds in non-sand casting foundries. However, pouring operators involved in cleaning might need to be provided with vacuums to reduce exposures below 50 µg/m^3. Alternatively, foundries can switch to low-silica mold release agents that are less toxic than the high-silica products used for the same purpose.

Shakeout Operator

Shakeout operator functions are generally similar to those in ferrous sand casting foundries. However, in sand casting foundries, manual processes for removing mold and core materials are consolidated into this operation (despite worker job titles associated with knockout operations), while sprue and riser removal are consolidated under the knockout operations.

Table IV.C-18 summarized seven results for shakeout operators from four reports on non-sand casting foundries. Exposures for shakeout operators range from 10 to 432 µg/m^3 with a mean of 189 µg/m^3 and a median of 220 µg/m^3. Four of the seven samples (all from one steel investment foundry) contained cristobalite only (no quartz detected) at levels of 222 µg/m^3, 238 µg/m^3, and 420 µg/m^3, while one result of 100 µg/m^3 included equal parts quartz and cristobalite (OSHA SEP Inspection Report 123186611). This range of exposure levels is within the range described for ferrous sand casting foundries (ERG-GI, 2008).

Based on Table IV.C-18, OSHA preliminarily concludes that exposure levels of 50 µg/m^3 or less have already been achieved for 29 percent of shakeout operators. The remaining 71 percent will require additional controls. OSHA has preliminarily determined that the controls and conclusions for shakeout operators in ferrous sand casting foundries also apply in non-sand casting foundries.

Although not suggested by the exposure profile in Table IV.C-17, it is possible that a few shakeout operators in these foundries might require respiratory protection under the same circumstances as mentioned for shakeout operators in ferrous sand casting foundries.

Knockout Operator

Knockout operator functions are generally the same as in ferrous sand casting foundries. However, as stated earlier, manual processes for removing mold and core materials are consolidated into the shakeout process. Sprue and riser removal activities are consolidated under the knockout operations.

Table IV.C-18 summarizes 12 silica results from six reports on non-sand casting foundries ranging from 9 μg/m^3 to 598 μg/m^3 with a median of 52 μg/m^3. The highest result (598 μg/m^3) was from an investment casting foundry and contained cristobalite but no detectable quartz (ERG-GI, 2008).

Based on Table IV.C-18, OSHA preliminarily concludes that 50 percent of knockout operators already experience silica exposures of 50 μg/m^3 or less. Based on the similarities between knockout operator tasks in this and other types of foundries, OSHA has preliminarily determined that the controls and conclusions for knockout operators in ferrous sand casting foundries apply in non-sand casting foundries as well. The exposure levels of the remaining 50 percent of knockout operators can be controlled using these methods.

Although not suggested by the exposure profile in Table IV.C-17, it is possible that a few knockout operators in these foundries might require respiratory protection under the same circumstances as mentioned for shakeout operators in ferrous sand casting foundries.

Abrasive Blasting Operator

Activities of abrasive blasting operators in non-sand casting foundries are the same as in ferrous sand casting foundries. Table IV.C-18 summarizes nine results from six reports ranging from 10 μg/m^3 to 980 μg/m^3, with a median of 13 μg/m^3. These results are within the range reported for ferrous sand casting foundries (ERG-GI, 2008).

Table IV.C-18 also shows that 67 percent of abrasive blasting operators already experience exposure levels less than the proposed PEL of 50 μg/m^3. The controls and conclusions for abrasive blasting operators in ferrous sand casting foundries also apply to non-sand casting foundries, where investment materials or mold washes can adhere to castings, as do green sand molding materials in sand casting foundries. OSHA preliminarily concludes that by implementing those controls as needed according to the exposure profile, non-sand casting foundries will be able to reduce the exposure levels for the remaining 33 percent of abrasive blasting operators to levels of 50 μg/m^3 or less.

Although not suggested by the exposure profile in Table IV.C-17, it is possible that a few abrasive blasting operators in these foundries might require respiratory protection under the same circumstances as mentioned for shakeout operators in ferrous sand casting foundries.

Cleaning/Finishing Operator

Cleaning/finishing operators perform the same activities in non-sand casting foundries as in ferrous sand casting foundries. As noted above, silica mold materials and washes can remain adhered to castings using non-sand casting methods just as they do in sand casting foundries, although the quantity might be lower (e.g., mold washes are typically used in small quantities as release agents on permanent molds; where so used, these agents are present as trace contaminants on the finished casting, rather than as large chunks or deeply embedded veins). However, regardless of the casting or mold release material used, cleaning/finishing operators use the same tools and processes to remove it from castings.

Table IV.C-18 summarizes 25 results (combined quartz and cristobalite) for cleaning/finishing operators in non-sand casting foundries ranging from 8 µg/m^3 to 820 µg/m^3 with a median of 31 µg/m^3. These results are contained in nine reports on non-sand casting foundries (ERG-GI, 2008). Two of these results, both from foundries using investment casting methods, included cristobalite (one value of 54 µg/m^3, no quartz detected; one result of 210 µg/m^3 that included 150 µg/m^3 quartz and 60 µg/m^3 cristobalite).

Based on Table IV.C-18, the silica exposures of 80 percent of cleaning/finishing operators are already at levels of 50 µg/m^3 or less. Because of the similarities between cleaning/finishing operator activities in this and other types of foundries, OSHA preliminarily concludes that the controls and conclusions provided for cleaning/finishing operators in ferrous sand casting foundries apply in non-sand casting foundries as well. OSHA preliminarily concludes that by implementing additional controls, non-sand casting foundries will be able to reduce the exposure levels for the remaining 20 percent of sand systems operators to levels of 50 µg/m^3 or less most of the time.

In the event that exposure levels of a few operators still remain above 50 µg/m^3, respiratory protection will be necessary for those workers

Material Handler

The activities of material handlers in non-sand casting foundries are the same as in ferrous sand casting foundries. Table IV.C-18 summarizes three results from two reports on non-sand casting foundries. Exposures range from 8 µg/m^3 to 107 µg/m^3, with a median of 8 µg/m^3 and mean of 41 µg/m^3. These results are approximately half the mean and range reported for ferrous sand casting foundries (mean of 80 µg/m^3 and maximum of 280 µg/m^3) (see Table IV.C-16). This difference can be accounted for by the lower potential for material handlers to experience secondary exposure to silica from the activities of workers in other job categories (who also have lower exposure levels in non-sand casting foundries).

Based on Table IV.C-18, the exposure levels of 50 µg/m^3 or less have already been achieved for 67 percent of material handlers. Because the work activities of material handlers are the same within both types of foundries, the controls and conclusions for those workers in ferrous sand casting foundries also apply in non-sand casting foundries. OSHA preliminarily concludes that by implementing those controls as needed according to the exposure profile, non-sand casting foundries will be able to reduce the exposure levels of the remaining 33 percent of material handlers to levels of 50 µg/m^3 or less.

Maintenance Operator

Activities of maintenance operators are the same in non-sand casting foundries as in other types of foundries that cast the same metals and include tasks related to refractory repair. For example, a report on a non-sand casting foundry included four results for maintenance operators performing refractory repair work in a cast iron foundry. These results range from less than or equal to 12 µg/m^3 (the LOD) to 20 µg/m^3, with a median of 12 µg/m^3 (OSHA SEP Inspection Report 301320644). This is the only source of data for maintenance operators in non-sand casting foundries and these results, summarized in Table IV.C-18, are at the lower end of the range reported for ferrous sand casting foundries.

Based on Table IV.C-18, OSHA preliminarily concludes that the exposure levels of all (100 percent) of maintenance operators in non-sand casting foundries are already at levels of 50 µg/m^3 or less and additional controls are not necessary for this job category. However, OSHA acknowledges that the available data might underestimate exposure for maintenance operators in non-sand casting foundries, who have the potential for exposure at the same levels encountered by workers performing the same refractory repair tasks at ferrous sand casting foundries. If elevated exposures do occur, the controls and conclusions described for maintenance operators in ferrous sand casting foundries apply equally to maintenance operators in non-sand casting foundries.

Housekeeping Worker

The activities of housekeeping workers in non-sand casting foundries are also the same as those of the equivalent job category in ferrous sand casting foundries. Two silica results obtained from a report on a non-sand casting foundry were less than or equal to the LOD (12 µg/m^3 and 14 µg/m^3), with a median of 13 µg/m^3. These results, summarized in Table IV.C-18, are within the range reported for ferrous sand casting foundries (OSHA SEP Inspection Report 122480742). Although limited, these results suggest that housekeeping workers in these foundries have little or no excessive secondary exposure to silica from the activities of workers in other job categories.

Based on Table IV.C-17, OSHA preliminarily concludes that the exposure levels of all (100 percent) housekeeping workers in non-sand casting foundries are already at levels of 50 µg/m^3 or less and additional controls are not necessary for this job category. If elevated exposures do occur, the controls and conclusions described for housekeeping workers in ferrous sand casting foundries apply to housekeeping workers in non-sand casting foundries.

Non-Sand Casting Foundries—Overall Feasibility Finding

OSHA has preliminarily determined that controls identified to reduce worker exposures in ferrous sand casting facilities also will reduce exposures to an equivalent or greater extent in non-sand casting facilities. This conclusion is based on evidence that even non-sand casting foundries use sand and other materials that contain silica in casting processes, although often to a lesser extent (e.g., in cores, or to pack investment molds). Additionally, non-sand casting foundry processes involve the same job categories performing generally similar activities as those outlined for ferrous sand casting foundries. As a result, the affected job categories and to a large extent the sources of exposure in non-sand casting foundries are similar to those listed for both ferrous and nonferrous sand casting foundries. Therefore, most of the same controls will be effective. Where production methods diverge (e.g., using mold release agents on permanent molds), additional controls are available as described above.

As indicated in Table IV.C-18, the rather limited available information indicates that exposures of 50 µg/m^3 or less have already been achieved for the vast majority of workers in seven of the 12 job categories (coremakers, furnace operators, pouring operators, cleaning/finishing operators, maintenance operators, housekeeping workers, and possibly sand systems operators). Furthermore, where exposures exceed the proposed 50 µg/m^3, they usually do so moderately. Overall, 70 percent of workers in non-sand casting foundries already experience results of 50 µg/m^3 or less, and nearly half of the remainder (14 percent of the total) have exposures between 50 µg/m^3 and 100 µg/m^3. For only two job categories do more than 10 percent of the workers experience results greater than 250 µg/m^3 (shakeout operators and abrasive blasting operators).

Based on the relatively moderate exposure levels reported for this industry in Table IV.C-18 and the availability of controls for most working conditions, OSHA preliminarily concludes that exposure levels of 50 µg/m^3 or less can be achieved for all workers in non-sand casting foundries most of the time.

Captive Foundries—Description

Captive foundries cast metal using the same range of processes that are found in other foundry sectors. A captive foundry might cast any metal in any quantity, use any molding process, clean castings, and process and reclaim sand using the same range of methods and equipment used by ferrous sand casting, nonferrous sand casting, or non-sand casting foundries (ERG-GI, 2008). Furthermore, the job categories found in captive foundries mirror those found in other foundries. For example, a State industrial commission reviewed data collected from a captive gray iron foundry that produces large truck brake drums. Job categories sampled included those found in ferrous sand casting foundries (i.e., sand system operator, molder, shakeout operator). As another example, OSHA inspected sand casting foundries (both ferrous and nonferrous) belonging to an enameled iron and metal products manufacturer and sampled shakeout operators (OSHA SEP Inspection Report 118115344).

The difference between a captive foundry and other foundries involves the business relationship between the foundry and the organization it supplies, rather than a fundamental difference in the metal casting process. Captive foundries fill specific requirements of their parent companies, whether the need is for large numbers of identical pieces, a small number of customized items, or specialty handling of a wide range of castings. As such, a captive foundry operation is incorporated into the larger manufacturing process of the parent operation. This relationship might be beneficial under some economic conditions; thus, captive foundries might have an increased ability to modernize or add environmental controls. However, as discussed below, this potential is not reflected in exposure levels reported in the limited number of OSHA, NIOSH, and State reports available to OSHA for captive foundries.[126]

Table IV.C-19 summarizes the worker exposure levels for the data (50 results) available to OSHA for captive foundries. Exposures range from 6 μg/m^3 to 286 μg/m^3, with a median of 54 μg/m^3 and a mean of 76 μg/m^3. Exposure results for six of the eight job categories with available data consistently fall within the range of results reported for ferrous sand foundries. Minimum exposure results for abrasive blasting operators and cleaning/finishing operators are just slightly lower than minimums for the same job categories for ferrous sand foundries (all below 14 μg/m^3).

For most job categories, the exposure levels are generally similar to the levels observed for noncaptive foundries using comparable casting processes. Although the median values for some job categories (coremaker, shakeout operator, knockout operator) are higher than those for the same job categories in other foundry sectors, these values might over represent the true median exposures in captive foundries (ERG-GI, 2008). OSHA believes that this could be the case because: 1) in some cases the data are quite limited (just one or two results available) and 2) in order to compensate for the limited number of more recent information sources describing exposure levels in captive foundries, OSHA included data from three NIOSH reports on foundry visits performed in the late 1980s. Thus, Table IV.C-19 contains a substantial number of silica

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[126] OSHA also notes that information contained in some documents does not permit the facilities to be classified as captive or independent foundries. As a result, some information on facilities that are actually captive foundries might appear in the analysis for other foundry types. Table IV.C-19 summarizes data from facilities known to be captive foundries at the time the samples were collected.

Table IV.C-19
Respirable Crystalline Silica Exposure Range and Profile for Captive Foundries

	Exposure Summary			**Exposure Range**		**Exposure Profile**				
Job Category	**Number of Samples**	**Mean (µg/m^3)**	**Median (µg/m^3)**	**Min (µg/m^3)**	**Max (µg/m^3)**	**<25 (µg/m^3)**	**≥25 and ≤50 (µg/m^3)**	**>50 and ≤100 (µg/m^3)**	**>100 and ≤250 (µg/m^3)**	**>250 (µg/m^3)**
Captive Sand Systems Operator	2	116	116	111	120	0 0.0%	0 0.0%	0 0.0%	2 100.0%	0 0.0%
Molder	10	83	49	26	286	0 0.0%	5 50.0%	2 20.0%	2 20.0%	1 10.0%
Coremaker	1	56	56	56	56	0 0.0%	0 0.0%	1 100.0%	0 0.0%	0 0%
Furnace Operator	0	0	0	0	0	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Pouring Operator	0	0	0	0	0	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Shakeout Operator	11	96	77	26	197	0 0.0%	2 18.2%	4 36.4%	5 45.5%	0 0.0%
Knockout Operator	2	112	112	76	149	0 0.0%	0 0.0%	0 0.0%	2 100.0%	0 0.0%
Abrasive Blasting Operator	7	64	30	6	254	3 42.9%	1 14.3%	2 28.6%	0 0.0%	1 14.3%
Cleaning/Finishing Operator	16	56	46	7	185	1 6.3%	11 68.8%	3 18.8%	1 6.3%	0 0.0%
Material Handler	1	22	22	22	22	1 100.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Maintenance Operator	0	0	0	0	0	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Housekeeping Worker	0	0	0	0	0	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Total Captive Foundries	**50**	**76**	**54**	**6**	**286**	**5 10.0%**	**19 38.0%**	**13 26.0%**	**11 22.0%**	**2 4.0%**

Notes: All samples are PBZ results for durations of 360 minutes or more and represent 8-hour TWA exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Sources: ERG-GI, 2008.

results from older reports. These older data that might not reflect modifications made to reduce exposure levels since that time. Despite this potential overrepresentation, the exposure profiles for each job category are reasonably similar to those in ferrous sand casting categories, and therefore, technological feasibility can be compared with other foundries (ERG-GI, 2008). OSHA preliminarily concludes that exposure levels of 50 μg/m^3 or less can be achieved for most of these workers most of the time.

Captive Foundries—Overall Feasibility Findings

OSHA preliminarily concludes that the controls identified to reduce worker exposure to silica in ferrous and nonferrous sand casting foundries and in non-sand casting foundries will be equally effective in reducing silica exposure in captive foundries. This conclusion is based on evidence that the processes, equipment, and worker activities are similar in captive foundries and foundry industry facilities using the same casting method. As a result, the affected job categories and the sources of exposure are the same for the different types of foundries.

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Glass

Description

Silica sand is the main raw material used in the manufacture of glass products, including flat glass, container glass, and fibrous glass, p.408. The glass industry is the largest user of silica sand in the United States, consuming 8.2 million metric tons in 2008, equivalent to 31 percent of all silica sand sold in that year (USGS, 2009).

Industries that manufacture glass products are classified primarily in the following six-digit North American Industry Classification System (NAICS) codes: 327211, Flat Glass Manufacturing; 327212, Other Pressed and Blown Glass and Glassware Manufacturing; and 327213, Glass Container Manufacturing. This section also includes facilities in NAICS 327993, Mineral Wool Manufacturing, that produce fibrous glass and glass wool insulation products directly from sand.

The manufacture of all types of glass involves five main procedures: raw materials mixing, melting, forming, annealing, and finishing, p.17-18, from AP-42, 1986. Depending on the facility and type of glass production, the operations might be highly mechanized or involve manual operations. Mass production glasses (such as flat glass, container glass, and fiberglass) require large amounts of sand and involve automated raw materials handling processes and continuous, enclosed melting processes. Small-run glass manufacture, such as manufacture of specialty glass and art glass, however, involves intermittent production that can utilize a combination of automated and manual operations, p.348. The potential for silica exposures is limited to the so-called “hot end” of the process, where sand, cullet, and other raw materials are unloaded, transferred, and mixed prior to melting. Once melted, the silica in the sand is converted to amorphous silica and no longer presents a significant exposure hazard to workers downstream of the melting stage,. Thus, the two job categories with the potential for silica exposure in the glass products industry are raw material handlers and batch operators (and associated workers). Table IV.C-20 provides information on these job categories and their sources of exposure.

Table IV.C-20

Job Categories, Major Activities, and Sources of Exposure of Workers

in the Glass Industry (NAICS 327211, 327212, 327213, 327993)

Job Category*	Major Activities and Sources of Exposure

Table IV.C-20

Job Categories, Major Activities, and Sources of Exposure of Workers

in the Glass Industry (NAICS 327211, 327212, 327213, 327993)

Material Handler	Overseeing the delivery of sand and other raw materials. • Dust from automatic or manual transfer of sand.
Batch Operators and Associated Workers	Transferring raw materials to weigh stations, mixers, and furnaces; performing housekeeping/maintenance in the vicinity of such operations. • Dust from automatic or manual transfer of sand. • Re-suspension of settled dust during housekeeping/maintenance activities.

*Job categories are intended to represent job functions; actual job titles may differ and responsibilities may be allocated differently, depending on the facility.

Source: ERG-GI, 2008.

Baseline Conditions and Exposure Profile

OSHA reviewed the best available exposure monitoring data, consisting of two NIOSH reports (NIOSH ECTB 233-114c, 1999; NIOSH HETA 97-0265-2781, 2000) and an OSHA Special Emphasis Program (SEP) inspection report (OSHA SEP Inspection Report 300386117), previously described by ERG-GI (2008).[127] The NIOSH reports each summarize a site visit to one of two large flat glass manufacturing facilities. OSHA obtained the SEP data during an inspection at a large glass products facility. The following sections describe the baseline conditions, and Table IV.C-21 summarizes the exposure information for the affected job categories.

Because available data are limited for an industry that utilizes copious amounts of silica sand, ERG attempted to contact more than 50 glass products manufacturers and associations representing manufacturers to gather additional information (ERG-glass contacts log, 1999). Although several manufacturers provided supporting information, none provided data that could be used in developing the exposure profile. OSHA seeks additional good quality information to update both the exposure profile and information related to controls.

Baseline Conditions for Material Handlers

OSHA reviewed six exposure results for material handlers from one OSHA SEP inspection report and two NIOSH reports. The exposure profile, provided in Table IV.C-21, has a full-shift median

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[127] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) derived from samples of 6-hours or longer, assuming the exposure concentration during any unsampled portion of the shift was the same as the concentration during the period sampled. Unless explicitly stated otherwise, all results discussed in the additional controls section meet the same criteria. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

exposure of 130 micrograms per cubic meter (µg/m^3), a mean of 156 µg/m^3, and a range of 46 µg/m^3 to 350 µg/m^3. Details on the highest exposure were not provided.

"Hot-end" material handlers primarily work outdoors to oversee the delivery of sand and other raw materials to the facility. These materials are transported primarily via rail car or truck, with the exception of certain small-run specialty glass producers, which receive sand in smaller containers such as bags or fiber drums. Sand is typically unloaded and transported to storage units by automated equipment, such as pneumatic or gravity conveyors, which material handlers set up and operate. Material handlers may not be required to remain at the unloading site for their entire shift (ERG-GI, 2008).

Baseline Conditions for Batch Operators and Associated Workers

OSHA reviewed six exposure results for batch operators and associated workers from one OSHA SEP inspection report and one NIOSH report (ERG-GI, 2008). The exposure profile, provided in Table IV.C-21, has a full-shift median exposure of 40 µg/m^3, a mean of 75 µg/m^3, and a range of 14 µg/m^3 to 262 µg/m^3.

Table IV.C-21
Respirable Crystalline Silica Exposure Range and Profile for Workers in the Glass Industry (NAICS 327211, 327212, 327213, 327993)

	Exposure Summary			Exposure Range			Exposure Profile				
Job Category	**Number of Samples**	**Mean (µg/m³)**	**Median (µg/m³)**	**Min (µg/m³)**	**Max (µg/m³)**		**<25 (µg/m³)**	**≥25 and ≤50 (µg/m³)**	**>50 and ≤100 (µg/m³)**	**>100 and ≤250 (µg/m³)**	**>250 (µg/m³)**
Material Handlers	6	156	130	46	350		0 0%	1 17%	2 33%	2 33%	1 17%
Batch Operations and Associated Workers	6	75	40	14	262		3 50%	0 0%	2 33%	0 0%	1 17%
Totals	**12**	**116**	**71**	**14**	**350**		**3** **25%**	**1** **8%**	**4** **33%**	**2** **17%**	**2** **17%**

Notes: All samples are personal breathing zone (PBZ) results for durations of 360 minutes or more and represent 8-hour time-weighted average exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Source: ERG-GI, 2008.

Batch operators and associated workers are responsible for transferring raw materials to weigh stations, mixers, and furnaces. Sand is transferred from storage units to weigh hoppers and is then sent to enclosed mixers, where other dry materials and water are added. After batches are mixed, they are transferred to storage units or conveyed directly to enclosed furnaces. Depending on the size and type of glass production facility, the batching systems can be fully automated or can involve manual operations. OSHA estimates that up to 10 percent of batch operations involve manual charging of mixers and furnaces (ERG-GI, 2008).

Other workers in the batch area may inspect equipment and perform maintenance operations or perform housekeeping activities. Housekeeping might involve dry sweeping, shoveling, vacuuming, and/or using compressed air to remove spilled sand and debris from floors, conveyors, and other surfaces. Based on the available literature and personal communications with representatives of glass products manufacturers, OSHA finds that few facilities have implemented engineering controls to minimize exposures associated with maintenance operations (NIOSH ECTB 233-114c, 1999; ERG-GI, 2008). Based on these same sources, however, OSHA estimates that 75 percent of facilities use dust suppressants and high-efficiency particulate air (HEPA)-filtered vacuums (OSHA SEP Inspection Report 300386117; NIOSH ECTB 233-114c, 1999; ERG-GI, 2008).

Additional Controls

Additional Controls for Material Handlers

As indicated in the exposure profile, OSHA estimates that 17 percent of material handlers have exposures below 50 μg/m^3. For the remaining workers, additional controls will be required to reduce exposures below current levels. Control options include using cleaned, larger, rounded grain sand containing fewer fine particles (e.g., sized and washed sand, which is widely available from sand suppliers) as the process permits; fully enclosing and ventilating all conveyers and transfer points used in sand handling; implementing general dust control measures to minimize dusty conditions that exacerbate exposure levels; and educating workers on adequate work practices.

A glass product manufacturing facility with an actively enforced silica control program outlined steps the company takes to maintain worker exposures to levels below 50 μg/m^3 (Glass Products Manufacturer G[a], 2000):

- Purchase size-selected sand which exceeds respirable size (20 micrometer [μm] to 250 μm). The sand is pre-washed to remove finer particles before it is delivered to the plant. Thus, if spilled, very little becomes airborne.
- Use fully ventilated conveyors, buckets, and lifts for all dry sand handling.
- Minimize silica handling through process automation.
- Observe workers frequently to ensure more healthful and efficient work practices.
- Provide ventilation systems with routine preventive maintenance to ensure that process ventilation and exhaust points are functioning properly.
- Conduct routine air sampling following a coordinated strategy.
- Train workers to be aware of silica in their work environment and to notify supervisors when necessary.

Through aggressive air sampling, the company determined that only about one in a thousand personal breathing zone results exceed the American Conference of Governmental Industrial Hygienists' (ACGIH's) Threshold Limit Value (TLV) of 50 µg/m^3 when the above steps are followed (Glass Products Manufacturer G, 2000).

When sand particle size must be small for production purposes (e.g., glass fiber production), another facility achieves low silica results by using a pneumatic sand conveyance system instead of conveyer belts. Avoiding the use of conveyer belts for moving silica materials is one of several aspects of the facility's design to which managers attribute personal air sampling results that are "typically below the limit of detection" (LOD) (Glass Products Manufacturer D, 2000). In addition, this facility, an OSHA Voluntary Protection Program (VPP) site, trains workers to watch for and respond appropriately to leaks and uses careful clean-up methods.

Information, including that from the VPP site, indicates that by using a combination of these methods all glass manufacturing facilities can achieve levels below 50 µg/m^3 for all their workers, including material handlers, on a regular basis (ERG-GI, 2008).

Additional Controls for Batch Operators and Associated Workers

OSHA estimates that exposure levels for approximately half the workers involved in batch operations are already below 50 µg/m^3. For the remaining workers, additional controls will be required to reduce exposures below current levels. The same control methods described previously for material handlers also will benefit workers in the batch area to an equal extent. At the two facilities described above, these practices resulted in low silica exposure levels for all workers, including workers in batch areas.

During the OSHA SEP inspection, results of 14 µg/m^3 and 59 µg/m^3 were obtained for two workers who operated automated equipment to weigh materials and transfer them to mixers (OSHA SEP Inspection Report 300386117). Further exposure reductions might be possible by fully enclosing and ventilating all conveyors and transfer points, and isolating batch operators in enclosed and ventilated control booths. Some facilities with manual batch operations might reduce exposures by installing automated batch handling equipment.

OSHA notes that exposures to workers engaged in batch area-related maintenance and housekeeping tasks also can be controlled below 50 µg/m^3. Reduction of dust leakage, spillage, and other sources of silica material in the batch area (as described above) should serve to generally reduce dust levels. Routine, diligent housekeeping should reduce dust accumulation and limit the potential for re-suspended dust. Using HEPA-filtered vacuums and dust suppressant during housekeeping activities rather than dry sweeping and using compressed air also will reduce exposures.

The practice of adding moisture to the batch ingredients, reportedly practiced by up to 60 percent of the industry, also can have a beneficial effect on worker exposure (Glass Products Manufacturer G[a], 2000). Because the moisture is added for process reasons, with an additional benefit to hygiene, OSHA estimates that glass manufacturers who are able to implement this procedure have already done so.

Feasibility Finding

Feasibility Finding for Material Handlers

Based on the best available information, OSHA estimates that 83 percent of material handlers require additional controls. The employers of all material handlers in the glass manufacturing industry can achieve silica levels of 50 µg/m^3 or less for those workers through a combination of engineering and administrative controls. Appropriate engineering controls include automated and ventilated equipment for unloading raw materials from shipping containers and transferring them to storage units. Other modifications may include fully enclosing and ventilating all sand conveyance devices (including the transfer points) and implementing administrative controls (such as active dust management procedures, which involve workers in the process).

OSHA expects that using the control methods discussed will achieve levels below 50 µg/m^3 for even highly exposed workers.

Feasibility Finding for Batch Operators and Associated Workers

OSHA preliminarily concludes that employers can reduce exposures below 50 µg/m^3 for the 50 percent of batch area workers who require additional controls using the same combination of administrative and engineering controls described for material handlers. Such controls would include automated and ventilated equipment for transferring raw materials to mixers and furnaces, and administrative procedures for managing released sand.

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Jewelry

Description

The jewelry manufacturing industry uses silica-containing materials in casting and finishing operations. Worker exposure to silica can occur during investment casting[128] involving the use of investment casting compounds, which are powdered refractory materials that often contain quartz or cristobalite (NIOSH HETA 81-365-1083, 1982). Workers in this industry also perform abrasive blasting using silica sand as abrasive media for cleaning the investment material from castings, which can result in worker exposure. Workers performing lapidary operations (cutting, polishing, and engraving precious stones) are potentially exposed to silica generated by gemstones (such as agate, amethyst, aventurine, jasper, and quartz crystal) and by abrasives used for grinding and polishing jewelry products (White et al., 1991). In general, jewelers typically perform small-scale, bench-top operations, using relatively small amounts of silica-containing materials. Facilities manufacturing jewelry are classified in the six-digit North American Industry Classification System (NAICS) codes: 339911, Jewelry (except costume) Manufacturing; 339913, Jewelers' Material and Lapidary Work Manufacturing; and 339914, Costume Jewelry and Novelty Manufacturing (ERG-GI, 2008).

Table IV.C-22 summarizes the major activities and sources of exposure for jewelers, the single job category with potential exposure to silica in this industry. ERG-GI (2008) contains a more detailed process description.

Table IV.C-22

Job Category, Major Activities, and Sources of Exposure of Workers

in the Jewelry Industry (NAICS 339911, 339913, 339914)

Job Category*	Major Activities and Sources of Exposure

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[128] "Investment casting" is form of metal casting that involves enclosing a three-dimensional pattern in a heat-resistant ceramic mold called investment material. Lost-wax casting is an example of a type of investment casting commonly used in jewelry production facilities and dental laboratories (ERG-dental-lab-A, 2000).

Table IV.C-22

Job Category, Major Activities, and Sources of Exposure of Workers

in the Jewelry Industry (NAICS 339911, 339913, 339914)

Jeweler	Mix investment material and cast jewelry products. • Dust released during manual transfer and mixing of silica-containing investment material. • Dust generated while separating castings from investment material. Cleaning and abrasive blasting of jewelry. • Dust from abrasive blasting operations involving silica-containing media and/or castings coated with silica-containing investment material. Cutting, grinding, and/or polishing of jewelry. • Dust from grinding or polishing of jewelry with silica-containing abrasives. • Dust from cutting, grinding, or polishing of gemstones containing silica.

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the facility.

Source: ERG-GI, 2008.

Baseline Conditions and Exposure Profile

To evaluate silica exposures of jewelers, OSHA reviewed personal breathing zone (PBZ) respirable quartz exposure monitoring data from two OSHA Special Emphasis Program (SEP) inspection reports (OSHA SEP Inspection Reports 106860455 and 301312252), previously described in ERG-GI (2008). The exposure monitoring data presented in these reports were not collected over full work shifts; however, the reports indicate that activities associated with potential exposure were not performed during the unsampled portions of the workers' shifts. As a result, ERG (2008) calculated 8-hour time-weighted average (TWA) exposures based on the reported data and assuming no exposure during the unsampled period. In this manner, an 8-hour TWA of 15 micrograms per cubic meter (μg/m^3) was calculated for a jeweler who performed abrasive blasting of gold and silver using an unventilated glovebox blasting cabinet and silica sand media (originally 21 μg/m^3 for a 349 minute sample). According to the inspection report, visible airborne dust leaked from the cabinet while it was in operation. The worker performed blasting operations for approximately 5 to 20 percent of each shift.

An 8-hour TWA of less than or equal to 12 μg/m^3 was calculated for a jeweler at another site who performed abrasive blasting of metallic medals for approximately 15 percent of the shift (originally less than or equal to 77 µg/m^3 [the level of detection {LOD}] for a 76 minute sample[129]). The jeweler used garnet media (a substitute abrasive blasting media that contains less than 0.5 percent silica [Universal Minerals, Inc., 2008]) in an unventilated glovebox cabinet. The cabinet leaked media through holes during the blasting operation and released visible airborne dust when opened by the worker (to remove or reposition medals). The room had open windows, and the jeweler used a floor fan for comfort. Table IV.C-23 summarizes these two results.[130]

To provide additional insight into the exposure profile for this industry, for which so few other suitably documented data are available, OSHA considered supplemental data that were not as fully documented. OSHA reviewed historic PBZ results obtained during OSHA inspections and reported in OSHA's Integrated Management Information System (IMIS) database.[131] Only positive IMIS results with silica detected in the sample (16 of the 34 total results for this industry) are included in this descriptive analysis because the volume-adjusted reporting limit concentrations for the nondetectable samples are not available (i.e., IMIS does not contain sufficient information to determine the LODs).[132,133] OSHA identified sixteen personal air sampling results containing detectable silica.

Despite the limitations associated with IMIS data (limited documentation of worker activity, sample duration, materials being handled, exposure controls in use at the time, and other or adjacent sources of silica exposure), these results confirm that jewelry workers can be exposed to silica at levels greater than 50 µg/m^3, although the majority of the results (56 percent) are below this value. Results range from 4 µg/m^3 to 565 µg/m^3, with a median of 39 µg/m^3 (see Table IV.C--24). Seven results (43 percent)

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[129] The elevated LOD (less than or equal to 77 µg/m^3) is a function of the extremely short sample duration (76 minutes).

[130] Two additional results from a New Jersey Department of Health (NJDOH) report and a NIOSH report, previously described by ERG-GI (2008), are excluded from the exposure profile. Both results are reported as below the LOD, but supporting information is insufficient to determine the LOD. In addition, the NIOSH sample covered only some of the worker's potential sources of silica exposure and likely does not represent total exposure for that day. One jeweler conducted polishing inside a booth equipped with LEV, while the other jeweler worked without ventilation (ERG-GI, 2008).

[131] OSHA searched the IMIS database for data collected from 1979 to 2002 and identified results associated with Standard Industrial Classification (SIC) codes 3911 (Jewelry, Precious Metal), 3915 (Jewelers' Findings and Materials, and Lapidary Work), and 3961 (Costume Jewelry and Costume Novelties, Except Precious Metal).

[132] Because this database does not include the sample duration or air volume, the LOD is not quantifiable for samples with results in which silica was not detected (i.e., the upper limit of the LOD cannot be known).

[133] In a separate action, to avoid counting the same samples twice, OSHA also excluded from the IMIS review the two results from OSHA's SEP for silica, which are already individually summarized in Table IV.C-23 and discussed previously.

exceed 50 µg/m^3, and 5 results (31 percent) exceed 100 µg/m^3. Job titles connected with the IMIS exposure data (including investment operator, caster, pourer) indicate that most of the workers were engaged in some phase of the casting process, although one elevated exposure was associated with a worker described as a grinder. The true median of all 34 IMIS entries is likely to be considerably lower because silica was nondetectable in an additional 18 results (52 percent of the total IMIS entries for jewelers). Nevertheless, in this case, the IMIS data present the most meaningful overview of this industry.

The potential extent to which OSHA's review of IMIS data might overestimate jeweler exposures is suggested by Yassin et al. (2005), who analyzed a different subset of IMIS data while examining the coating engraving industry. This industry includes a percentage of workers in the jewelry manufacturing industry described in ERG-GI (2008), although the exact percentage of jewelers is not reported. In their study, Yassin et al. (2005) *included* results below the LOD and recorded them as 0 µg/m^3. The authors report a geometric mean of 75 µg/m^3 calculated from IMIS data collected between 1988 and 2003 for 75 workers in the coating engraving industry (SIC code 3479). This mean reported by Yassin et al. (2005) is lower than that presented in Table IV.C-24 and represents the maximum amount by which OSHA might be overestimating jewelers' silica exposures by excluding the nondetectable results.

Based on the information presented here and in ERG-GI (2008), baseline controls may include LEV for finishing operations or use of substitute media for abrasive blasting operations, but generally only a single control is in place. Facilities often use unventilated glovebox abrasive blasting cabinets. Activities associated with silica exposure are often performed for less than 20 percent of each shift. In the absence of more definitive information, OSHA preliminarily concludes that the values summarized in Table IV.C-24 represent the baseline conditions in this industry.

Table IV.C-23
Respirable Crystalline Silica Exposure Range and Profile for Workers in the Jewelry Industry (NAICS 339911, 339913, 339914)

	Exposure Summary			Exposure Range			Exposure Profile				
Job Category	**N**	**Mean (μg/m³)**	**Median (μg/m³)**	**Min (μg/m³)**	**Max (μg/m³)**		**<25 (μg/m³)**	**≥25 and ≤50 (μg/m³)**	**>50 and ≤100 (μg/m³)**	**>100 and ≤250 (μg/m³)**	**>250 (μg/m³)**
Jeweler	2	13.5	13.5	12	15		2 100%	0 0%	0 0%	0 0%	0 0%

Note: All samples are personal breathing zone (PBZ) results for durations represent 8-hour time-weighted average exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Source: ERG-GI, 2008.

Table IV.C-24
Respirable Crystalline Silica Exposure Range and Distribution of Supplemental IMIS Results for Workers in the Jewelry Industry (NAICS 33991, 339913, 339914)

	Exposure Summary			Exposure Range			Exposure Profile				
Job Category	**N**	**Mean (μg/m³)**	**Median (μg/m³)**	**Min (μg/m³)**	**Max (μg/m³)**		**<25 (μg/m³)**	**≥25 and ≤50 (μg/m³)**	**>50 and ≤100 (μg/m³)**	**>100 and ≤250 (μg/m³)**	**>250 (μg/m³)**
Jeweler	16	108	39	4	565		6 38%	3 19%	2 12%	3 19%	2 12%

Notes: All results are from personal breathing zone samples. This summary includes only results for which silica was detected. LODs cannot be determined from the available information for other results in the IMIS database. For each applicable silica result presented in IMIS as Exposure-Type "T" (time-weighted average), the silica concentration was calculated based on the reported 8-hour TWA PEL and the reported respirable dust exposure level.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Source: OSHA IMIS, 1979 to 2002.

Additional Controls

Based on the limited available data, OSHA estimates that up to 44 percent (see Table IV.C-24) of workers require additional controls to reduce the exposures of jewelers to levels of 50 μg/m^3 or less. Where necessary, options for additional controls include the following:

- Use of covered containers and LEV during investment mixing.
- Use of wet methods and/or LEV when separating investment material from castings (e.g., breaking molds under a water stream or mist).
- Use of a properly designed and ventilated abrasive blasting cabinet.
- Use of alternative low-silica or silica-free blast media.
- Use of clean blast media for each session (to avoid recycling media contaminated with refractory material unless it can be cleaned).
- Improved work practices (such as allowing the blasting cabinet ventilation to clear the equipment of dust before opening the cabinet).
- Use of wet methods and/or LEV during finishing operations.
- Improved housekeeping (such as use of a high-efficiency particulate air (HEPA)-filtered vacuum, daily where necessary).

Although no information is available quantifying the effectiveness of each method in reducing silica exposures, jewelers employing at least one control often achieved levels of silica below 25 μg/m^3 (see earlier discussion of baseline conditions for this industry). In addition, dental technicians who perform work similar to that of jewelers (mixing investment material, casting precious and semi-precious metals, cleaning and finishing small castings, and abrasive blasting in cabinets) use several similar exposure controls that should be equally effective in the jewelry industry. Based on the similarity of the tasks and the scale of these operations in these two industries, OSHA preliminarily concludes that control options available in dental laboratories will be just as effective in jewelry manufacturing facilities.

At one dental laboratory, technicians use a covered and sealed mixer to blend water with powdered silica investment materials (70 percent silica). After casting, the investment mold is cracked and castings removed (called "divesting") under a stream of water to suppress dust. Workers also use water-fed and ventilated grinding equipment, perform abrasive blasting with new (clean) media in a ventilated cabinet, and work at benches fitted with LEV (ERG-dental-lab-A, 2000). Three dental technicians working with these controls had exposures of less than or equal to 10 μg/m^3 (LOD in this case).

Other dental laboratory industry data also suggest that jewelers who perform similar tasks are unlikely to experience elevated exposure levels. Ninety-seven percent of the sample results for dental technicians, summarized in the exposure profile associated with Section IV.C.6 – Dental Laboratories in this technological feasibility analysis, are less than the proposed permissible exposure limit (PEL) of 50 μg/m^3, with 17 (55%) of the results below the LOD. The single result that exceeded 50 μg/m^3 (58 μg/m^3) was obtained for a dental technician trainee divesting castings, working with wax, and performing abrasive blasting. The next highest result, 40 μg/m^3, represents the exposure of a dental technician at a different laboratory performing investing, casting, sandblasting, grinding, and polishing. Similar results have been obtained internationally. Kim at al. (2002) collected 22 samples for dental lab workers performing investment casting and abrasive blasting to create small metal castings and obtained results ranging from 3 μg/m^3 to 51 μg/m^3, with a mean of 15 μg/m^3. Based on the similarities between the processes used by dental laboratory technicians and those performed by jewelers, OSHA preliminarily concludes that by using similar control methods, jewelry manufacturing establishments may be able to lower workers' exposure levels.

Feasibility Finding

OSHA preliminarily concludes that jewelry manufacturing facilities already achieve respirable silica levels of 50 μg/m^3 or less for most of their workers. Based on information summarized in Table IV.C-24, OSHA finds that *at least* 56 percent of jewelers' exposures are already below that level. This percentage likely underestimates the number of jewelers with exposures less than 50 μg/m^3, because nondetectable results were excluded from the IMIS data summarized in Table IV.C-24. Furthermore, two partial-shift samples obtained during OSHA inspections at two different jewelry manufacturing establishments resulted in silica concentrations of 21 μg/m^3 and less than the LOD (in this case 77 μg/m^3, because of the particularly brief sample duration), respectively.[134] These values also support OSHA's assertion that more than 56 percent of jewelers already experience exposure levels less than 50 μg/m^3.

For any jewelers (fewer than 44 percent) with exposures above 50 μg/m^3, OSHA preliminarily finds that by implementing one or more controls, employers of all jewelers can achieve exposures below 50 μg/m^3 for workers in this job category. Control options include LEV for mixing and finishing operations, sealed equipment or wet methods for handling silica-containing investment casting materials, ventilated abrasive blasting cabinets, and alternative (low- or nonsilica) abrasive blasting media.

The effectiveness of these controls is demonstrated by silica exposure levels below the LOD (10 μg/m^3 in this case) obtained for all workers in a dental laboratory that employed small-scale metal casting, finishing, and abrasive blasting processes that were nearly identical to those used in jewelry manufacturing (ERG-dental-lab-A, 2000).[135]

References

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[134] The worker's 8-hour TWA based on the LOD is 12 μg/m^3, assuming that the sample encompassed the worker's total silica exposure for the day (no further silica exposure during the shift).

[135] At this dental laboratory, workers performing casting mixed refractory investment powder in a sealed mixer and used wet dust suppression methods to break open investment molds. Additionally, one worker performing abrasive blasting used a bench-top abrasive blasting cabinet similar to that used by jewelers, while all workers used bench-top ventilation hoods and a water-fed bench grinder when cleaning small metal dental appliances or working with silica-containing plasters (ERG-dental-lab-A, 2000).

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Landscape Contracting

Description

Landscape contractors are primarily engaged in providing landscape care and maintenance services, including installation of trees, shrubs, plants, lawns and gardens. As part of landscaping projects, some landscape contractors also might construct walkways, retaining walls, patios, fences, ponds, or similar structures. Some landscape workers might be exposed to silica during masonry-related activities such as using masonry saws to cut bricks or paving tiles. Establishments providing landscaping services are classified in six-digit North American Industry Classification System (NAICS) code 561730, Landscaping Services (ERG-GI, 2008).

Only landscape and horticultural service workers performing masonry-related construction activities have the potential for silica exposure. These landscape service workers could be exposed to silica while cutting silica-containing landscaping materials using diamond blades when installing “hardscapes,” such as retaining walls, patios, and walkways (Quinn, 2004). Common hardscape materials cut by workers preparing landscapes include brick, concrete, or stone in the form of curbs, block, or pavers (12 to 40 percent quartz) (NIOSH ECTB 233-118c, 1999; Thorpe et al., 1999). Although the quantity of this work varies with the operation and nature of the firm’s services, OSHA estimates that, overall, these activities represent a relatively minor portion of the industry’s labor time, as the vast majority of workers are engaged primarily in lawn maintenance services (e.g., mowing, trimming, planting, mulching, fertilizing, leaf removal). Only a small share of the industry is engaged routinely in installation of hardscapes where block and brick cutting operations occur. If a firm generates a majority of its revenues from this type of construction activity, the establishment is classified as a construction establishment, and not as a landscape architecture establishment. Table IV.C-25 describes the major activities and sources of exposure of workers in the landscape contracting industry.

Table IV.C-25

Job Category, Major Activities, and Sources of Exposure of Workers in the Landscape Contracting Industry (NAICS 561730)

Job Category*	Major Activities and Sources of Exposure
Landscape Worker	Sawing and cutting bricks, paving tile, and stone during installation of walkways, retaining walls, patios, fences, ponds, or other hardscapes. Performing landscape care and lawn maintenance services. • Dust generated by cutting action of the abrasive blade during masonry cutting.

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the landscaping employer.

Source: ERG-GI, 2008.

Baseline Conditions and Exposure Profile

No exposure data specific to landscape or horticultural service workers were identified. Further, there were no Integrated Management Information System (IMIS) observations for landscape workers for silica exposure. Data are available for analogous activities conducted by masonry cutters in the construction industry; however, OSHA estimates that landscape service workers face less frequent exposures than construction workers engaged in masonry cutting activities.[136] Further, virtually all such exposures would occur outdoors, eliminating the potential for elevated exposures in nonventilated enclosures. In addition, landscape workers might work at a greater number of sites performing smaller assignments than construction workers. This reduces the amount of time spent sawing and increases the amount of time spent on preparation and cleanup and in transit.

Based on a review of saw manufacturing and published literature, OSHA preliminarily concludes that landscape workers preparing hardscapes typically use portable saws and most commonly use hand-held saws (Contractor Depot, no date; Meeker et al., 2009; Page Landscapers, 2008). Meeker et al. (2009) note that hand-held saws are increasingly used as a direct substitute for water-fed stationary saws.[137]

In Section IV.C.27 – Masonry Cutters Using Portable Saws, OSHA examines the specific occupational category of masonry cutters using hand-held saws. In that section, OSHA identified 56 8-hour time-weighted average (TWA) personal breathing zone (PBZ) silica readings for masonry cutters using hand-held saws outdoors. The results range from 12 micrograms per cubic meter (µg/m^3) to 1,472 µg/m^3, with a median of 134 µg/m^3 and a mean of 177 µg/m^3.[138] Forty-three results (77 percent) exceed 50 µg/m^3, and 36 results (64 percent) exceed 100 µg/m^3. The highest exposure, 1,472 µg/m^3, was recorded

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[136] Because these results are drawn directly from the construction industry, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) calculated assuming no additional exposure during any unsampled portion of the shift. For additional information on data handling for general industry and the construction industry, see Section IV.A – Methodology.

[137] According to Meeker et al. (2009), “Historically, stationary wet saws served as the primary tool bricklayers used to cut masonry units such as brick. However, contractors have increasingly used portable masonry abrasive cutters, often referred to as ‘chop saws,’ in lieu of the stationary wet saw. Stationary wet saws require the user to be on the ground to make cuts. Some contractors, therefore, view the use of portable masonry saws as a productivity gain because they can be used without getting down from scaffolding. However, gasoline-powered equipment is prohibited on suspended scaffolding [reference 29 CFR 1926.451(d)(14) – Scaffolds]. In addition, portable abrasive cutters are heavy, generate high dust levels, and pose an increased safety risk for accidental cuts and amputations if not used correctly. The stationary wet saw also offers many ergonomic advantages compared with the portable saw.” Meeker et al. (2009) go on to explain that with a stationary saw, the operator is able to work in an upright position and does not have to bear any of the saw’s weight. In contrast, operators using hand-held saws often adopt a bent posture and must support the full weight of the saw while cutting objects at ground level.

[138] Sources of exposure monitoring data: Lofgren, 1993; NIOSH ECTB 233-117c, 1999; NIOSH ECTB 233-118c, 1999; NIOSH ECTB 233-121c, 1999; NIOSH HETA 2005-0030-2968, 2008; NIOSH HETA 2005-0031-3055, 2008; NIOSH HETA 2003-0209-3015, 2006; NIOSH-WV-Route 6, 1992; NJDHSS, 2000; OSHA SEP Inspection Reports 122376791 and 300591047/L2809; Shields, 2000.

for a worker who cut concrete for approximately 5 hours, but also operated a jackhammer for approximately 45 minutes of the 451-minute sampling period.

OSHA obtained 48 measurements for workers using hand-held saws to cut concrete or masonry outdoors with no dust controls. For this subgroup, the median silica result was 150 µg/m^3. This is substantially greater than the median of 24 µg/m^3 obtained for eight results from other outdoor workers who used similar saws with wet methods of dust control.

OSHA preliminarily concludes that baseline conditions for landscape workers performing masonry work are dry-cutting outdoors using hand-held saws. The median exposure level for masonry cutters in the construction industry working under these conditions is 150 µg/m^3. OSHA acknowledges that these results from the construction industry might overestimate the actual exposure of landscape workers because, as noted previously, these workers face less frequent exposures and might saw for shorter amounts of time (when completing small assignments) than construction workers engaged in stone and masonry activities. However, these remain the best data available to OSHA.

Table IV.C-26 summarizes the exposure information for landscape workers.

Additional Controls

Wet methods and local exhaust ventilation (LEV) are additional controls for landscape workers performing masonry activities. The exposure data available to OSHA from the construction industry shows that 75 percent of 8-hour TWA exposure results for masonry cutters using hand-held saws are 50 µg/m^3 or less when workers use water-fed saws outdoors. In contrast, 85 percent of workers experienced exposures *greater than* 50 µg/m^3 when no dust controls were in place. The use of wet methods reduced the median exposure by 84 percent compared with no dust controls.

Investigators have evaluated wet methods of dust control specifically for hand-held saws and report worker silica exposure level reductions of at least 90 percent (ranging from 90 to 96 percent) (Thorpe et al., 1999). For a complete discussion, refer to Section IV.C.27 – Masonry Cutters Using Portable Saws. All but three of the 48 exposure results presented in Table IV.C-26 for workers dry cutting outdoors are below 500 µg/m^3. The smallest exposure reduction reported for wet methods (90 percent) will bring all but those three exposures (or 93 percent of all the hand-held saw operators who currently perform uncontrolled cutting) to levels of 50 µg/m^3 or less.

Table IV.C-26
Respirable Crystalline Silica Exposure Range and Profile for Workers in the Landscape Contracting Industry (NAICS 561730)

	Exposure Summary			Exposure Range			Exposure Profile				
Job Category	**N**	**Mean (μg/m^3)**	**Median (μg/m^3)**	**Min (μg/m^3)**	**Max (μg/m^3)**		**<25 (μg/m^3)**	**≥25 and ≤50 (μg/m^3)**	**>50 and ≤100 (μg/m^3)**	**>100 and ≤250 (μg/m^3)**	**>250 (μg/m^3)**
Landscape Worker[A]											
Outdoors, no dust controls	48	200	150	12	1,472		4 8.33%	3 6.25%	6 12.50%	28 58.33%	7 14.58%
Outdoors, wet methods	8	37	24	12	101		5 62.50%	1 12.50%	1 12.50%	1 12.50%	0 0.00%
Totals	**56**	**177**	**134**	**12**	**1,472**		**9** **16.07%**	**4** **7.14%**	**7** **12.50%**	**29** **51.79%**	**7** **12.50%**

Notes: This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

[A] No data are available for landscape workers. Data presented in this table describe the exposures of masonry cutters in the construction industry who operate hand-held saws outdoors. Equipment, materials, and sources of exposure are identical for these two job categories. In general, however, masonry cutters likely conduct outdoor sawing more frequently than landscape workers and might perform sawing for longer durations. Thus, OSHA assumes that landscape contractor workers are exposed to silica levels no greater than, and probably less than, those presented here. Masonry cutting is only a small fraction of the work performed by landscape contractors, who more typically perform lawn care services (e.g., planting, mulching, grading). Specialized landscape workers performing masonry cutting represent a small fraction of the total labor force employed by landscape contractors.

The sample results summarized here are PBZ results. Because these data are drawn directly from the exposure profile for construction industry workers who use hand-held saws, all results represent 8-hour TWA exposures (based on samples obtained over periods of approximately 1 to 8 hours) with the assumption that no additional exposure occurred during any unsampled portion of the shift. For additional information on data handling for general industry and the construction industry, see Section IV.A – Methodology.

Sources: Section IV.C.27 – Masonry Cutters Using Portable Saws.

To further reduce exposures, workers should carefully manage the slurry produced with wet methods (e.g., by capturing it before it dries using a wet vacuum with high-efficiency particulate [HEPA] filtration) and use good work practices (e.g., standing away from the slurry spray coming off the saw blade).

Hand-held saws also can be equipped with LEV air extraction systems. OSHA was not able to obtain extended-period exposure monitoring data indicating the effectiveness of LEV-equipped saws under workplace conditions for this or the construction industry. However, experimental data indicate that such saws might help control silica exposure. In some tests, LEV-equipped saws offered as much (or more) dust control as wet methods, but this is an inadequate basis on which to determine whether outdoor workers using such saws can reliably achieve levels below 50 µg/m^3 (again, for a complete discussion, refer to Section IV.C.27 – Masonry Cutters Using Portable Saws).

Feasibility Finding

Based on the conclusions for masonry cutters using hand-held saws outdoors, OSHA preliminarily concludes that wet methods can control the silica exposure of most landscape workers using hand-held saws to levels of 50 µg/m^3 or less, provided that the water is consistently applied in an appropriate manner and in sufficient quantities. The median exposure of masonry cutters using hand-held saws outdoors with wet methods is 24 µg/m^3.

Additional controls, such as wet methods, will be required for, at most, the 77 percent of landscape workers performing masonry-related construction activity who are exposed to silica levels exceeding 50 µg/m^3 (Table IV.C-26).[139] This preliminary finding is based on the assumption that landscape workers most likely experience lower levels of exposure than do workers in the construction industry. Workers who currently perform dry-cutting with hand-held saws will need to switch to water-fed saws (including, as an option, water fed stationary masonry saws). Where workers currently experience exposure levels above 50 µg/m^3 while using wet sawing methods, additional controls include increased attention to the rate and position of water used for wet dust suppression; carefully managing slurry (capturing it before it dries and adding HEPA filtration to vacuums); using work practices that position the worker away from the slurry spray coming off the saw blade; and controlling silica exposure from adjacent sources (including other saws).

When wet methods are not possible, LEV-equipped hand-held saws might reduce silica exposures substantially, but the evidence is insufficient to confirm that they can reliably maintain worker exposures below 50 µg/m^3. If LEV is used, respiratory protection might be required until the reliability of LEV can be confirmed over extended work periods.

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[139] As noted above, only a small percentage of landscape workers perform such activities.

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Mineral Processing

Description

The nonmetallic mineral processing industry includes those establishments that are primarily engaged in calcining (processed by burning or incinerating), dead burning, or otherwise processing beyond beneficiation[140] clays, ceramic and refractory minerals, barite, slag, roofing granules, and miscellaneous nonmetallic minerals (U.S. Department of Commerce, 2002). For example, establishments might batch, blend, extrude, and package dry and de-aired moist clays. These facilities are classified in the six-digit North American Industry Classification System (NAICS) 327992, Ground or Treated Mineral and Earth Manufacturing. Many of the raw materials processed by this industry contain varying amounts of naturally occurring silica and include nonmetallic minerals such as clay, diatomaceous earth, graphite, and mica (ERG-GI, 2008).

The nonmetallic mineral processing industry produces intermediate or finished products from mined or quarried nonmetallic minerals. All production-related workers have the potential for silica exposure. Depending on the specific establishment, production workers might perform one or more jobs, including loader/material handler, operator (e.g., crusher, screener, batch, mixer, dryer), bagger, laborer, or housekeeper (ERG-GI, 2008). The activities and equipment used by workers also can vary by facility depending on whether operations are performed manually or by fully automated systems. Consequently, job function and associated exposure to silica varies by establishment. Table IV.C-27 provides detail on exposures to these workers.

Table IV.C-27

Job Category, Major Activities, and Sources of Exposure of Workers

in the Mineral Processing Industry (NAICS 327992)

Job Category*	Major Activities and Sources of Exposure

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[140] Beneficiation is the process whereby the extracted material is reduced to particles that can be separated into mineral and waste, the former suitable for further processing or direct use (U.S. Department of Commerce, 2002).

Production Worker	Dumping dry materials. • Dust generated during manual breaking and dumping of dry materials. • Dust generated by disposal of empty bags. Transferring, mixing, and packaging dry materials. • Dust from transferring or processing dry materials (e.g., with conveyors, elevators, mixers, blenders, screeners). • Dust from manual mixing or packaging of dry materials. Performing housekeeping duties. • Dust raised by using inappropriate cleaning methods (e.g., dry sweeping, shoveling).
*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the facility. Source: ERG-GI, 2008.	

Baseline Conditions and Exposure Profile

Baseline Conditions for Production Workers

OSHA reviewed full-shift personal breathing zone (PBZ) silica exposure monitoring data from two sources: 1) an OSHA Special Emphasis Program (SEP) inspection report on a facility using mineral raw materials to mix the clays it provides to the pottery industry and 2) a NIOSH Health Hazard Evaluation (HHE) report on a manufacturer producing mineral granules for eventual use by the roofing tile industry[141]. Both reports were previously described by ERG (ERG-GI, 2008). The data and information from these reports provide the basis for the industry exposure profile.

OSHA reviewed a total of 34 exposure results associated with mineral processing.[142] These results, summarized in Table IV.C-28, are the best data available to OSHA. The exposures in the 34

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[141] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) derived from samples of 6-hours or longer, assuming the exposure concentration during any unsampled portion of the shift was the same as the concentration during the period sampled. Unless explicitly stated otherwise, all results discussed in the additional controls section meet the same criteria. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

[142] ERG (ERG-GI, 2008) reported on a larger number of results (40 rather than 34 described here) because quartz and cristobalite results for six samples were each counted as an independent value (e.g., as a total of 12 values). Because these analytes both represent forms of silica, for the present analysis OSHA has combined the paired quartz and cristobalite values to create a total silica result for each of the six workers exposed to both mineral forms. Cristobalite was not detected in the other 28 samples.

samples range from 26 micrograms per cubic meter (μg/m^3) to 221 μg/m^3, with a median of 50 μg/m^3 and a mean of 57 μg/m^3. Six results (18 percent) exceed 50 μg/m^3, and two results (6 percent) exceed 100 μg/m^3.

OSHA conducted an inspection at a small ceramic and pottery clay manufacturing company and noted several issues with dust control (OSHA SEP Inspection Report 116178096). During the inspection, the dustiest operation OSHA observed was breaking and dumping bags of raw materials into a hopper on an elevated work platform. Although the hopper was partially enclosed and ventilated, the task produced substantial amounts of dust. A worker who spent a portion of the shift dumping bags of dry silica-containing material at this station and spent the remaining portion dry sweeping experienced the highest exposure of 221 μg/m^3. Near the bag-dumping station, two other workers ran the clay batch operation, which involved dry sweeping, packaging dry product, and moving bags of raw material with an open lift truck. These two workers had exposure levels of 80 μg/m^3 and 83 μg/m^3. OSHA also noted that product bag-filling areas did not have local exhaust ventilation (LEV) during the inspection, but that mixing and blending containers, and material conveyors and elevators, were enclosed (OSHA SEP Inspection Report 116178096).

Following the inspection, the facility made several improvements to its engineering controls. These included the installation of ventilated bag-disposal hoppers; a new LEV system with a commercially available dust collector (Donaldson, 2009) for dry batch operations; and the addition of high-efficiency particulate air (HEPA) after-filters for two existing dust collectors. Improvements also were made to existing LEV ductwork and hoods to improve capture efficiency and exhaust flow. After the engineering improvements were completed, three full-shift PBZ follow-up exposure levels were reported at less than or equal to the limit of detection (LOD) [in this case 31 μg/m^3], 26 μg/m^3, and 44 μg/m^3.[143] Two of these samples (less than or equal to 31 μg/m^3 and 44 μg/m^3) were collected on workers who spent part of their shift performing bag dumping. Overall, the improved engineering controls reduced the mean silica exposure by 74 percent.

NIOSH conducted an HHE at a company that produces roofing granules from nepheline-syenite (NIOSH HETA 91-0091-2418, 1991). Although nepheline-syenite is reported to not contain silica, two bulk samples collected during the course of the NIOSH investigation contained 1 to 2 percent silica (as cristobalite). The facility processes the raw material into uniform-sized granules by using a system of crushers and production screeners. The granules are then transported by conveyor to the coloring department where the product is colored, heat-cured, and transferred to storage silos.

NIOSH collected 28 full-shift PBZ samples at the roofing granule manufacturer: six samples collected during the initial visit and 22 during the follow-up survey. NIOSH reported that five of the six samples (83 percent) from the initial visit included cristobalite (the sixth contained quartz).[144] Three (50 percent) of those six samples exceeded 50 μg/m^3 as total silica, and all were samples that contained cristobalite. A helper in the crushing and screening department who performed general cleaning within

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[143] Results reported as "none detected" are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

[144] In keeping with OSHA's standard data handling for this analysis, the quartz LOD was conservatively assumed to represent the level of quartz in an individual sample and, when detected, cristobalite values were added to the quartz levels to create a total silica result.

the department and assisted with screen changing had the highest exposure at 111 µg/m^3. Two other workers in the crushing and screening department experienced exposures of 58 µg/m^3. Both workers assisted in changing screens; one of them, the screen man, also constructed screens while the other, the bin tender, monitored mineral flow in and out of silos. Although most processes and conveyors were enclosed, NIOSH investigators observed process leaks and poor housekeeping practices (e.g., piles of dust located throughout the facility) that could expose workers to silica-containing dusts (NIOSH HETA 91-0091-2418, 1991). NIOSH also noted that its monitoring data might not be representative of typical worker exposures at the plant because of upset conditions created by a power failure. Plant management reported that dust concentrations were higher than normal.

During the follow-up survey, NIOSH obtained 22 full-shift exposure levels below the NIOSH recommended exposure limit (REL) of 50 µg/m^3. Although NIOSH noted that “most” exposures were below LOD of 20 µg/m^3, the report does not specify how many. For the purposes of the exposure profile, OSHA took the most conservative approach and used an exposure 50 µg/m^3 for all 22 samples. NIOSH also noted that one of the three production lines in the crushing and screening department was not operating because of mechanical problems, which might have caused silica concentrations to be lower than usual (NIOSH HETA 91-0091-2418, 1991).

Based on a review of the available information, OSHA finds that baseline conditions typically include some form of exhaust ventilation and process enclosures, although these controls might be inadequately maintained and function inefficiently (NIOSH HETA 91-0091-2418, 1991; OSHA SEP Inspection Report 116178096). In the absence of other information, OSHA finds that the results represented in Table IV.C-28 offers the best available indication of exposure levels under baseline conditions.

Additional Controls

Additional Controls for Production Workers

Based on the available information, OSHA estimates that most production workers (82 percent) already experience exposures below 50 µg/m^3; however, additional controls will be required to reduce the exposures of the remaining 18 percent of production workers to this level. Appropriate control options include equipping existing bag-dumping stations with well-ventilated enclosures and ventilated bag-disposal equipment; modifying and/or improving maintenance to existing process equipment enclosures and LEV to ensure optimal dust control; and more diligent housekeeping to reduce dust accumulation in association with low dust-producing cleaning methods (i.e., HEPA-filtered vacuuming and wet methods). Implementation of these controls might involve installing new equipment or improving current equipment (ERG-GI, 2008).

Local Exhaust Ventilation

As previously discussed, the highest exposure level in the industry profile (221 µg/m^3) is associated with bag-dumping and disposal operations at a pottery clay manufacturing company (OSHA SEP Inspection Report 116178096). After this establishment made engineering improvements to its dry batch operations, the silica exposure of the production worker whose activities include bag dumping, bag disposal, and dry sweeping was reduced by about 80 percent, from 221 µg/m^3 to 44 µg/m^3 (based on one sample collected before improvements and one sample collected after). Engineering improvements included the installation of ventilated bag-disposal hoppers and a new (presumably enhanced) LEV system with dust collectors that serviced the bag-dumping and disposal hoppers, and other dry batch processing equipment (blenders and elevators). Additionally, HEPA final-filters were added to two existing dust collectors and improvements were made to existing LEV ductwork and hoods to improve capture efficiency and exhaust flow.

Table IV.C-28
Respirable Crystalline Silica Exposure Range and Profile for Workers in the Mineral Processing Industry (NAICS 327992)

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean (μg/m^3)**	**Median (μg/m^3)**	**Min (μg/m^3)**	**Max (μg/m^3)**		**<25 (μg/m^3)**	**≥25 and ≤50 (μg/m^3)**	**>50 and ≤100 (μg/m^3)**	**>100 and ≤250 (μg/m^3)**	**>250 (μg/m^3)**
Production Worker											
Before engineering improvements	3	128	83	80	221		0 0%	0 0%	2 67%	1 33%	0 0%
After engineering improvements*	3	34	31	26	44		0 0%	3 100%	0 0%	0 0%	0 0%
Production Worker											
Other conditions	28**	52	50	30	111		0	25	2	1	0
							0%	89%	7%	4%	0%
Totals	**34**	**57**	**50**	**26**	**221**		**0**	**28**	**4**	**2**	**0**
							0%	**82%**	**12%**	**6%**	**0%**

Notes: All samples are personal breathing zone (PBZ) results and all except one are for durations of 360 minutes or more and represent 8-hour time-weighted average exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

* Because the available data are limited, the exposure profile includes one PBZ sample result (collected for 354 minutes) that is less than full shift (i.e., 360 minutes).

** NIOSH reported 22 of these samples as less than 50 μg/m^3, with most concentrations being below the LOD of 20 μg/m^3; however, the number of observations actually below the LOD is not provided. For this exposure profile, OSHA used an exposure of 50 μg/m^3 for all 22 samples and placed them in the <25 μg/m^3 and ≤50 μg/m^3 category, recognizing that this conservative approach overestimates the exposure of some workers.

Sources: NIOSH HETA 91-0091-2418, 1991; OSHA SEP Inspection Report 116178096.

Exposure levels for two other workers in the production area of the pottery clay manufacturer also were reduced after the engineering improvements. Full-shift PBZ exposure results for the two workers were initially 80 µg/m^3 and 83 µg/m^3. After improvements were made to control dust from the bag-dumping station and other dry batch process equipment, exposure levels were less than the LOD (in this case 31 µg/m^3) and 26 µg/m^3 (an average reduction of about 65 percent). These workers worked near the dry batch bag-dumping operation and performed dust-producing activities such as moving bags of raw material with an open lift truck, dry sweeping, and packaging dry product.

Comparable information regarding the effectiveness of properly designed and maintained equipment for controlling dust generated during bag dumping and disposal exists for other industries. Two results, both less than or equal to 15 µg/m^3 (LOD), were reported by the New Jersey Department of Health (NJDOH) for workers in a porcelain fixtures facility who manually emptied 50-pound bags of silica and other raw materials containing silica into a LEV-equipped mixer hopper (ERG # NJ-1412).

Additionally, ERG obtained respirable quartz exposure monitoring data for workers using bag-dumping stations with an automated bag-disposal feature at a paint manufacturer (ERG-paint-fac-A, 1999). The stations consist of hoppers topped with grates enclosed by LEV hoods. Full-shift PBZ exposure levels were less than or equal to 12 µg/m^3 (LOD) for five workers who emptied bags of silica-containing materials at these stations. In contrast, a full-shift PBZ exposure level of 263 µg/m^3 was obtained for a worker at a bag-dumping station where the LEV system failed for approximately 2 hours (ERG-paint-fac-A, 1999). This suggests that an effective LEV system can reduce silica exposure levels by at least 95 percent.

A NIOSH report also describes a bag-dumping station with an effective LEV system (NIOSH CT-144-19a, 1983). NIOSH evaluated the unit by measuring PBZ respirable dust levels with real-time aerosol monitors before and while workers emptied bags of crushed limestone and found no statistically significant elevation of PBZ respirable dust over background levels. OSHA requires additional data to better characterize the effectiveness of LEV and bag-dumping systems. Ventilated bag-dumping stations that include a ventilated compactor are readily available from commercial sources (Carolina Conveying, 2010; Chicago Conveyor, 2004; Flexicon, 2009; Vac-U-Max, 2006a; Whirl-air, 2003).

Process Enclosure and Maintenance

Properly enclosed, ventilated, and maintained process equipment (e.g., conveyors, elevators, mixers, blenders, screeners) are necessary to control silica-containing dusts during material transfer and other process-related operations. NIOSH investigators noted process leaks in and around enclosures and less than optimal LEV in a roofing granule manufacturer. NIOSH recommendations included implementing a preventive maintenance program and replacing process enclosures that are removed for inspection or maintenance purposes as soon as the work is completed (NIOSH HETA 91-0091-2418, 1991). In a similar manner, OSHA recommended specific operating and maintenance procedures following an inspection at the pottery clay manufacturer previously discussed (OSHA SEP Inspection Report 116178096). Recommendations included: 1) sealing all holes in the elevators, pug mills, and other vessels holding or transporting product; and 2) routine preventive maintenance on equipment, including LEV filter changes.

Although data comparing exposure levels before and after the above described recommendations are not available, enclosing, ventilating, and maintaining dry-process operations will reduce worker exposure to silica by limiting the quantity of dust released into the workplace.

Feasibility Finding

Feasibility Finding for Production Workers

Based on the best available data described in the exposure profile, OSHA preliminarily concludes that a substantial majority of the production workers in this industry (82 percent) have already achieved exposure levels of 50 µg/m^3 or less through the use of process enclosures and ventilation. OSHA estimates the remaining workers in this job category (18 percent) will require additional controls to reach this level.

Appropriate controls include properly designed and maintained LEV and enclosures and good housekeeping practices. As previously discussed, effective ventilation and process enclosures routinely control worker exposures to levels below 50 µg/m^3. A properly enclosed and ventilated bag-dumping station that incorporates a ventilated bag-disposal feature decreases exposure to not only the worker dumping bags, but also to other workers in the vicinity of the bag-dumping operation. These methods are already in use at some facilities (ERG-GI, 2008). For example, results of 80, 83, and 221 µg/m^3 were brought below the proposed permissible exposure limit (PEL) of 50 µg/m^3 (to 26, 31, and 44 µg/m^3) at the clay production plant when engineering controls were improved (OSHA SEP Inspection Report 116178096). Professional-level cleaning in association with improved housekeeping procedures significantly decrease exposure levels for workers engaged in cleaning activities, as well as for most workers working in areas where dust has been allowed to accumulate. In summary, OSHA preliminarily concludes that all mineral processing facilities can achieve exposure levels of 50 µg/m^3 or less all workers by implementing currently available controls for some workers.

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Paint and Coatings

Description

Finely ground quartz and cristobalite are used as pigments and fillers in the manufacture of paints and allied products such as stains, powder coatings, glazes, and vitreous enamels. These products are manufactured by establishments classified in the six-digit North American Industry Classification System (NAICS) code 325510, Paint and Coating Manufacturers.

Material handlers receive powdered silica components in bulk or in bags and transport them within the plant. Either material handlers or mixer operators weigh the silica ingredients, and mixer operators are responsible for adding ingredients to the blending equipment. Housekeeping activities can be performed by workers in either job title. Once powdered ingredients are combined with a liquid in blending equipment, OSHA expects that little or no further potential for exposure to silica exists in the manufacturing plant. The production of special vitreous coatings (glass frit, glazes, and enamels) are described in Sections IV.C.14 – Porcelain Enameling and IV.C.15 – Pottery but are also relevant to this industry; see ERG-GI (2008) for examples.

Based on information presented in ERG-GI (2008), OSHA estimates that one-third of the industry uses silica, and less than 10 percent of the silica used in paint manufacturing is in the form of cristobalite.

Based on information from one facility site visit and two OSHA Special Emphasis Program (SEP) inspection reports described in ERG-GI (2008), OSHA finds that material handlers and mixer operators are the two job categories that have potential exposure to silica.

Table IV.C-29 summarizes the job categories, major activities, and primary sources of silica exposure of workers in this industry.

Table IV.C-29

Job Categories, Major Activities, and Sources of Exposure of Workers in the Paint and Coatings Industry (NAICS 325510)

Job Category*	**Major Activities and Sources of Exposure**
Material Handler	Oversee delivery of raw materials and their transportation through the facility. • Dust from open transferring of silica-containing raw materials (such as sand and clay) manually or by lift truck. • Dust from manual weighing of silica-containing materials. • Dust from sweeping, brushing (housekeeping).
Mixer Operator	Add wet and dry ingredients to milling, mixing, and dispersion equipment. • Dust from opening and manually emptying bags of silica-containing materials into hoppers. • Dust from manual weighing of silica-containing materials. • Dust from sweeping, brushing (housekeeping).

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the facility.

Source: ERG-GI, 2008.

Baseline Conditions and Exposure Profile

The following sections describe baseline conditions for each affected job category, based on an ERG site visit report and two OSHA SEP inspection reports[145]. Although limited, these represent the best data available to OSHA for workers in the paint and coatings manufacturing industry.

Baseline Conditions for Material Handlers

Based on descriptions of material handlers' activities and equipment discussed in ERG's 2008 analysis, OSHA finds evidence that baseline conditions for this group of workers include considerable manual handling of packaged and bulk raw materials, as well as the use of local exhaust ventilation in the raw materials weighing area at some facilities.

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[145] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) derived from samples of 6-hours or longer, assuming the exposure concentration during any unsampled portion of the shift was the same as the concentration during the period sampled. Unless explicitly stated otherwise, all results discussed in the additional controls section meet the same criteria. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

Seven silica results from an ERG site visit and one result from an OSHA SEP inspection characterize material handler exposure levels and are described in more detail in ERG's report (2008). As shown in Table IV.C-30, all eight results for material handlers are below 50 micrograms per cubic meter (μg/m³).

Baseline Conditions for Mixer Operators

OSHA reviewed baseline conditions for mixer operators from three facilities (seven from the ERG site visit and three from two typical paint batch mixing facilities inspected by OSHA), as described by ERG (2008), and determined that exposures are due primarily to airborne dust generated as: 1) bags are opened, 2) materials are transferred into hoppers, and 3) empty bags are compressed for disposal. Table IV.C-30 summarizes 10 full-shift results for mixer operators, two of which exceed 250 μg/m³. One result (263 μg/m³) is from a 447-minute sample associated with a mixer operator manually transferring raw materials (emptying 50-pound bags) during a period of ventilation system failure that ERG observed (ERG-paint-fac-A, 1999).[146] At that manufacturing site, the plant-wide combination local exhaust ventilation (LEV) and bag disposal system worked well for the first shift monitored but became clogged (reduced or no airflow) during the subsequent shift on which ERG obtained the elevated result. The other six results from this site were collected while the ventilation system was still functioning and resulted in exposure levels below 25 μg/m³. Two results at a similarly low level were also reported at a second facility visited by OSHA, for which the ventilation status was not documented (OSHA SEP Inspection Report 116187857). At the third paint manufacturing plant, OSHA obtained another elevated result of 413 μg/m³ for a mixer operator working in an area where LEV was being considered, suggesting that LEV was not present on the date that the sample was collected (OSHA SEP Inspection Report 17621905). The median exposure level for mixer operators is 78 μg/m³.

Detailed information on housekeeping practices at the paint manufacturing facility visited by ERG indicate that a mixer operator used a brush to dry sweep into the tank any silica powder that accumulated on tank rims near bag dumping stations. Another operator used a hose to wash away powder spilled to the floor. Floors at this facility were also cleaned using a wet vacuum truck, operated by workers in the material handler job category (ERG-paint-fac-A, 1999). Workers performing these activities during a shift when the exhaust ventilation system was functioning were among those who experienced exposure levels less than 25 μg/m³.

The data appearing in Table IV.C-30 come from three facilities where air monitoring was conducted because the industrial hygienist had reason to believe that the facility was using silica. For facilities that use silica, Table IV.C-30 is the exposure profile and summarizes the baseline exposure data available to OSHA for this industry.

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[146] OSHA notes that although workers handled quartz and cristobalite powder during this site visit, only quartz was detected in the samples from the site.

Table IV.C-30

Respirable Crystalline Silica Exposure Range and Profile for Workers in the Paint and Coatings Industry (NAICS 325510)

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean (µg/m^3)**	**Median (µg/m^3)**	**Min (µg/m^3)**	**Max (µg/m^3)**		**<25 (µg/m^3)**	**≥25 and ≤50 (µg/m^3)**	**>50 and ≤100 (µg/m^3)**	**>100 and ≤250 (µg/m^3)**	**>250 (µg/m^3)**
Material Handler	8	12	13	10	13		8 100%	0 0%	0 0%	0 0%	0 0%
Mixer Operator	10	80	13	12	413		8 80%	0 0%	0 0%	0 0%	2 20%
Totals	**18***	**49**	**13**	**10**	**413**		**16 89%**	**0 0%**	**0 0%**	**0 0%**	**2 11%**

Notes: All samples are personal breathing zone (PBZ) results for durations of 360 minutes or more and represent 8-hour time-weighted average exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry

All data for this exposure profile are from facilities that use silica in their operations.

Sources: ERG-paint-fac-A, 1999; OSHA SEP Inspection Reports 116187857 and 17621905.

Additional Controls

Additional Controls for Material Handlers

No additional controls are required for material handlers. If exposure controls were to become necessary, such methods might include substitution of low-silica-containing material and improved ventilation at weighing stations. The effectiveness of these options is described briefly for mixer operators.

Additional Controls for Mixer Operators

Based on the ERG report, OSHA lists the primary controls for mixer operators as bag dumping stations equipped with well-ventilated enclosures and bag compactors (ERG, 2008). At a site mentioned previously, ERG monitored mixer operator exposure and obtained results less than 12 µg/m³ and 13 µg/m³, the sample limits of detection (LODs), while workers produced batches of paint by emptying 50-pound bags of quartz and cristobalite powder into hoppers during periods when the combined exhaust ventilation and bag disposal systems were working properly.[147] These values are 95 percent lower than the result of 263 µg/m³ obtained by ERG during another shift at the same plant when these controls malfunctioned. Based on that site visit, OSHA estimates that properly functioning and adequate LEV will reduce exposures from levels exceeding 250 µg/m³ to less than the limit of detection of 12 or 13 µg/m³ (a 95 percent reduction) (ERG-paint-fac-A, 1999).

High-efficiency particulate air (HEPA)-filtered vacuums offer an alternative to dry brushing and sweeping in plants where exhaust ventilation is insufficient to control dust during these activities. These vacuums supplement wet washing and wet sweeping that already occurs in paint and coatings manufacturing facilities (ERG-paint-fac-A, 1999).

Another control option involves substituting low-silica-containing materials (e.g., calcium carbonate) for materials with a higher silica content; however, this option might require reformulating affected products (ERG, 2008).

Feasibility Finding

Feasibility Finding for Material Handlers

OSHA estimates the preliminary baseline exposure level for all material handlers to be less than 25 µg/m³. This finding is based on the eight sample results (all under 25 µg/m³) included in the exposure profile. Thus it is clearly feasible for paint and coatings manufacturers to maintain material handler exposures below 50 µg/m³.

Feasibility Finding for Mixer Operators

OSHA estimates that exposures for mixer operators can be reduced to below 50 µg/m³. Based on the exposure profile, facilities will need to provide ventilated bag dumping stations and bag disposal equipment for 20 percent of mixer operators. To eliminate dry brushing until ventilation systems are

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[147] Results reported as "none detected" are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

operating effectively, mixer operators might need access to HEPA-filtered vacuums to clean tank rims and areas that cannot be washed with water immediately after spills occur.

Overall Feasibility Finding for Paints and Coatings Manufacturing Facilities

In summary, OSHA preliminarily concludes that by implementing additional controls for some mixer operators, paints and coatings manufacturers can achieve exposure levels of 50 μg/m³ or less for most of their workers most of the time.

References

[ERG-GI] Eastern Research Group, Inc., 2008. Technological Feasibility Study of Regulatory Alternatives for a Proposed Crystalline Silica Standard for General Industry, Volume 1 and 2.

[ERG-paint-fac-A] Eastern Research Group, Inc., 1999. Site Visit to Paint Facility A. July 6.

[OSHA SEP Inspection Report 116187857] OSHA Special Emphasis Program Inspection Report 116187857.

[OSHA SEP Inspection Report 17621905] OSHA Special Emphasis Program Inspection Report 17621905.

Porcelain Enameling

Description

Porcelain enamel is a boro-silicate layer usually applied to metal products as a protective or decorative coating. Porcelain enameling is used in a variety of industries to produce such products as architectural panels, bathtubs, barbeques, boilers, chemical vessels, cookers, heat-exchange panels and tubes, holloware, microwave ovens, street signs, water heaters, and washing machines (Faust, 1994). Industries that can be involved with porcelain enameling (either as a service to another manufacturer or as a part of the manufacturing process) are classified in the six-digit North American Industry Classification System (NAICS) codes 332812, Metal Coating, Engraving (except Jewelry and Silverware), and Allied Services to Manufacturers; 332998, Enameled Iron and Sanitary Ware Manufacturing; 332323, Ornamental and Architectural Metal Work Manufacturing; 339950, Sign Manufacturing; and 335211, 335221, 335222, 335224, and 335228, industries involved in household appliance manufacturing (e.g., stoves, refrigerators, microwave ovens, water heaters).

The application of the enamel on the base material is performed in various ways, including manual or automatic dipping, slushing, flowcoating, manual or automatic spraying, electrostatic wet spraying, electro-deposition, and electrostatic dry powder spraying. Porcelain enamel is produced from ground frit, a silicate glass composed of approximately 50 percent amorphous silicon dioxide, and additive ingredients. For many applications (but not all), these additives include crystalline silica or crystalline silica-containing materials such as feldspar and quartz (Hlavac, 1983; Porcelain Enamel Institute, 2004). For the purposes of this analysis, porcelain enamels can be divided into two categories: 1) clay-containing porcelain enamels that typically include 2 to 10 percent silica and are always applied as a wet slurry (these cannot be applied electrostatically) and 2) porcelain enamels classified as powder coatings, which contain no clay or silica and can be applied by electrostatic/electro-deposition processes (Porcelain Enamel Institute, 2004). This discussion focuses solely on manufacturers of enamels that contain silica.

Establishments that perform porcelain enameling typically employ enamel preparers who mix the enamel and coatings applicators who apply the enamel to metal products. In facilities with small enameling operations, the same operator might mix the coating and apply it to products. See Table IV.C-31 for a description of job categories, major activities, and sources of exposure. Further process detail can be found in ERG-GI (2008). The steps used for both the porcelain enamel preparation and many of the application processes are generally similar to those used to produce and apply glazes in the pottery industry. The major difference between the porcelain enamel used on metals and the glaze applied to pottery is that metal enamels contain more boron and less silica (2 to 10 percent silica in metal enamels compared with 23 percent in pottery glaze), which allows enamels to fuse at a lower temperature and accommodate the greater thermal expansion of metals (ERG-GI, 2008).

Table IV.C-31

Job Categories, Major Activities, and Sources of Exposure of Workers in the Porcelain Enameling Industry (NAICS 332323, 332812, 332998, 335211, 335221, 335222, 335224, 335228, and 339950)

Job Category*	Major Activities and Sources of Exposure
Enamel Preparer	Combine frit and other raw ingredients; transfer enamel slurry to other areas of the plant. • Dust from milling and/or mixing of silica-containing materials. • Dust from manual weighing and bag dumping of silica-containing materials.
Porcelain Applicator	Apply enamel to products (manually or automated); transfer products between conveyers; perform housekeeping. • Dust from handling products coated in dried enamel. • Dust from dried overspray and dripped slurry from the application process.

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the facility.

Source: ERG-GI, 2008.

Baseline Conditions and Exposure Profile

Little data exist to characterize silica exposures during porcelain enameling. In the absence of more completely documented exposure information for this industry, OSHA has relied on Integrated Management Information System (IMIS) data, as well as the general exposure information provided by a contact within the industry (Porcelain Industries, 2004a). Drawbacks associated with IMIS data include limited documentation of worker activity, sample duration, materials being handled, exposure controls in use at the time, and other or adjacent sources of silica exposure. However, IMIS data remain the best available source of exposure data for workers involved in porcelain enameling. ERG (ERG-GI, 2008) searched IMIS data for silica sampling associated with porcelain enameling between 1979 and 2002, and identified three exposure results (as respirable dust containing silica) for enamel preparers and 23 results for porcelain applicators between 1985 and 1992. The data were used to calculate 8-hour TWA silica values (see the related note in Table IV.C-32).

Baseline Conditions for Enamel Preparers

The three silica personal breathing zone (PBZ) results for enamel preparers (millers, mixers) from the IMIS database were 0 micrograms per cubic meter (µg/m^3), 46 µg/m^3, and 56 µg/m^3 (see Table IV.C-32). The limit of detection (LOD) for the low value (reported as 0) is likely less

Table IV.C-32
Respirable Crystalline Silica Exposure Range and Distribution of IMIS Results for Workers in the Porcelain Enameling Industry (NAICS 332323, 332812, 332998, 335211, 335221, 335222, 335224, 335228, and 339950)

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean (µg/m^{3})**	**Median (µg/m^{3})**	**Min (µg/m^{3})**	**Max (µg/m^{3})**		**<25 (µg/m^{3})**	**≥25 and ≤50 (µg/m^{3})**	**>50 and ≤100 (µg/m^{3})**	**>100 and ≤250 (µg/m^{3})**	**>250 (µg/m^{3})**
Enamel Preparer	3	34	46	0	56		1 33.3%	1 33.3%	1 33.3%	0 0.0%	0 0.0%
Porcelain Applicator	23	234	23	0	2300		12 52.2%	3 13.0%	5 21.7%	0 0.0%	3 13.0%
Totals	**26**	**211**	**26**	**0**	**2300**		**13** **50.0%**	**4** **15.4%**	**6** **23.1%**	**0** **0.0%**	**3** **11.5%**

Notes: For each applicable silica result presented in IMIS as Exposure-Type "T" (time-weighted average), the silica concentration was calculated based on the reported 8-hour TWA PEL and the reported respirable dust exposure level. The resulting silica values are 8-hour TWAs.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Source: ERG-GI, 2008.

than the median, but the precise value cannot be determined (ERG-GI, 2008).[148] One silica PBZ result (33 percent) exceeds 50 µg/m^3.

These results support the statement made by a representative of a facility specializing in porcelain enameling for contract customers (hereafter, Porcelain Facility A). At that establishment, air sampling conducted by a State Plan state OSHA program on at least two occasions showed an 8-hour time-weighted average (TWA) exposure level well below 100 µg/m^3 for workers preparing porcelain enamels with minimal exposure to silica over the remainder of the shift. However, the Facility A representative also noted that task-based sampling had shown that airborne silica concentrations could exceed 100 µg/m^3 during one of this worker's activities: the 1-hour task of mixer charging (by bag dumping) (Porcelain Industries, 2004a).[149] This information confirms that enamel preparer exposure levels can be relatively low over the course of an enamel preparer's shift, but indicates that elevated exposures can occur for limited periods.

Based on limited information provided by NIOSH and contacts within the industry, OSHA believes that most facilities performing porcelain enameling currently use automated systems to move some raw materials (such as frit) to the mixer, but that enamel preparers are most likely to introduce those additives used in smaller quantities (such as silica-containing ingredients) by dumping bags directly into a hopper at the mixer opening (NIOSH 149-19a, 1984; Porcelain Enamel Institute, 2004; Porcelain Industries, 2004a). Some form of exhaust ventilation is often available at the mixer opening or hopper; however, the ventilation does not necessarily offer complete dust control during mixer charging (as evidenced by reports of measurable silica exposure levels during mixer charging) (Porcelain Industries, 2004a). Although relatively brief (e.g., 1 hour per day), mixer charging can be the most significant source of worker silica exposure associated with porcelain enameling (Porcelain Industries, 2004a).

The exposures summarized in Table IV.C-32 for enamel preparers represent the best available information on the exposure levels associated with this job category and, in the absence of more detailed information, also represent baseline conditions for enamel preparers.

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[148] For this technological feasibility analysis, ERG (ERG-GI, 2008) and OSHA typically remove IMIS results that were below the LOD, because that limit cannot be determined with the information available in the IMIS database. However, as an exception, a few specific "none detected" results in the porcelain enameling industry are included in this exposure profile. This is because the data for porcelain enameling were few enough to permit individual handling of those few results that are reported as "0" exposure for silica (resulting in a respirable dust permissible exposure limit [PEL] of 5 milligrams per cubic meter [mg/m^3]) and that also had very low respirable dust concentrations (no greater than a few hundred mg/m^3) and so were likely not analyzed for silica (because of limitations of the analytical equipment). Very low respirable dust concentrations would be associated with low silica exposure levels, even if that respirable dust were to contain a high percentage of silica. For example, one of these "0" µg/m^3 results also indicated that a porcelain applicator's exposure to respirable dust was 70 µg/m^3. Even if the respirable dust on the filter had contained 33 percent silica (a high percentage that occurs only rarely in any industry), the worker's silica exposure level would have been 23 µg/m^3 (well below the median of 46 µg/m^3. OSHA recognizes that a high level of uncertainty is associated with these results, but believes that in this case the additional values contribute to a more informed profile of the industry in the absence of other data that is more completely documented.

[149] The 8-hour TWA averages higher task-based concentrations (such as occurred during bag dumping) with lower levels that occurred during the rest of the shift.

Baseline Conditions for Porcelain Applicators

The 23 silica PBZ results for porcelain applicators identified in IMIS were obtained in nine facilities and show a median silica exposure of 23 μg/m^3 and a mean of 234 μg/m^3, with a range of 0 to 2,300 μg/m^3 (see Table IV.C-32). These workers were primarily employed by appliance manufacturers with job titles such as porcelain sprayer, porcelain applicator, enameler, rework sprayer, and enamel sprayer. Eight results (35 percent) exceed 50 μg/m^3; three (13 percent) exceed 100 μg/m^3; and two (9 percent) exceed 1,000 μg/m^3.

The IMIS data indicates that one facility was inspected by OSHA in three different years. Both porcelain applicator results exceeding 1,000 μg/m^3 were obtained in 1985 at the first inspection of this facility, along with two results of 47 μg/m^3 and 91 μg/m^3. At the two subsequent inspections, silica exposures for applicators were controlled below 50 μg/m^3. Results of 3 μg/m^3, 4 μg/m^3, 6 μg/m^3, and 22 μg/m^3 were reported in 1989, and results of 22 μg/m^3 and 23 μg/m^3 were reported in 1992. No data on controls are available for this facility.

At Porcelain Facility A, described in the previous section on Baseline Conditions for Enamel Preparers, all air sampling results for workers associated with the porcelain application line were reportedly below 100 μg/m^3 (Porcelain Industries, 2004a). These results are associated with exhaust ventilation along the length of the spray application line. Only summary exposure data is available to OSHA from Porcelain Facility A (no individual results).

Regardless of the application method used (e.g., spray, dip, flowcoat), silica-containing porcelain enamels are typically applied as a slurry (Porcelain Enamel Institute, 2004). This wet application reduces exposure because silica particles cannot become airborne until dry, and when dry, porcelain enamel adheres tightly to the surface to which it is applied (Porcelain Industries, 2004a). Limited information provided by a contact within the industry indicates that ventilation is used extensively while porcelain applicators coat objects and subsequently handle the parts. All application is performed in ventilated booths (e.g., a spray booth) (Porcelain Industries, 2004a). Based on the experiences of other industries, some of the ventilation systems and booths might require maintenance or modification to operate efficiently. Thus, OSHA concludes that baseline conditions for porcelain applicators include wet application methods and use of exhaust ventilation (which might or might not be functioning optimally). The exposures summarized in Table IV.C-32 for porcelain applicators represent the best available information on the exposure levels associated with this job category and, in the absence of more detailed information, also represent baseline conditions for porcelain applicators.

Additional Controls

Additional Controls for Enamel Preparers

As indicated in the exposure profile, OSHA estimates that 66 percent of enamel preparers (two out of three) already achieve exposure levels of 50 μg/m^3 or less, in part because of the limited amount of time required to add the silica-containing materials (generally less than 10 percent of all raw materials) and to the use of ventilated mixers/mill charging equipment. If elevated exposures do occur, facilities should be able to reduce exposures to 50 μg/m^3 or less by improved design or maintenance of existing ventilation systems at bag dumping and mixer charging stations, process automation, improved housekeeping, and substitution. These controls have proven effective in the porcelain enameling industry and in other industries with analogous job categories, such as those that manufacture pottery or structural clay (see the related Section 15 – Pottery and Section 21 – Structural Clay). Coatings preparers in these industries are exposed to silica during transfer and mixing of sand, feldspar, and other coatings or glaze ingredients. Both the pottery and structural clay industries use a substantially greater percentage of silica (also in the form of quartz or feldspar) in product coatings than are used by the porcelain enameling industry. Because of the similarity of the tasks, equipment, and materials, OSHA believes that control methods employed by coatings preparers in the pottery and structural clay industries will function equally well in the porcelain enamel industry.

Local Exhaust Ventilation

Bag-dumping stations with properly ventilated enclosures, which capture dust release during both bag emptying and bag disposal, have been used in the pottery and structural clay industries. An example from the pottery industry demonstrates the value of the booth alone. A coatings preparer used a booth and also a weigh scale outside the booth to mix glazes. An initial value of 143 μg/m^3 was reduced to 51 μg/m^3 after the baghouse ventilation system was repaired.[150] A consultant evaluating the plant during the second (post-repair) sampling date recommended that silica at this facility be reduced to its lowest possible level by taking further steps such as limiting use of compressed air for cleaning (this comment suggests that compressed air was used regularly in the plant) (OSHA SEP Inspection Report 300977352). OSHA preliminarily concludes that by moving the weigh scale into the booth (or adding exhaust ventilation to the scale area), and by reducing reliance on compressed air for cleaning, the exposure of this coatings preparer could be reduced to a level consistently below 50 μg/m^3.

A bag-dumping station with fully functioning local exhaust ventilation (LEV) was found to reduce silica exposure by at least 95 percent in a paint manufacturing facility where workers emptied 50-pound bags of silica-containing materials (ERG-paint-fac-A, 1999). The station consists of hoppers topped with grates enclosed by LEV hoods. After each bag is emptied, the worker releases it and suction automatically pulls the bag into the ventilation system and transfers it to an enclosed storage area. Other types of bag dumping stations also are effective at reducing respirable dust (NIOSH CT-144-19A, 1983). Ventilated bag dumping stations are readily available from commercial sources (Carolina Conveying, 2010; Chicago Conveyor, 2004; Flexicon, 2009; Vac-U-Max, 2006a; Whirl-air, 2003).

Process Automation

Although information specific to enamel preparers is not available, the effectiveness of automated systems for transferring silica-containing materials is illustrated by exposure monitoring data obtained for material handlers at two pottery facilities. The exposure for a material handler who was monitoring automated equipment adding silica-containing raw materials to a mixer was almost 66 percent lower (29 μg/m^3 versus 85 μg/m^3) than the exposure of a material handler manually adding bags of raw materials to the mixer. At another facility, OSHA obtained a reading of 23 μg/m^3 for a material handler monitoring automated equipment that transferred dry silica sand from the storage silo and pumped a slurry of ball clay and kaolin into a mixer (ERG-GI, 2008).

An example from the structural clay industry is also instructive. At a facility inspected by OSHA, an 86 percent reduction in respirable quartz exposure readings occurred after management installed an enclosed, automated sand transfer system, despite having an incorrectly sized conveyer. With tightly sealed components, it is likely that exposures would be reduced further (ERG-GI, 2008).

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[150] As noted in Section IV.A – Methodology, unless explicitly stated otherwise, all results discussed in the additional controls section meet the same criteria. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

Improved Housekeeping

Dust released during mixer charging can contribute substantially to enamel preparer exposure in facilities where poor housekeeping has allowed dust to accumulate. Some cleaning procedures (e.g., dry sweeping) can aggravate the situation by stirring up dust and causing it to become airborne. A thorough, professional-level cleaning in association with improved housekeeping procedures (e.g., use of a high-efficiency particulate air [HEPA]-filtered vacuum) to maintain cleanliness can reduce exposures in facilities where dust has been allowed to accumulate. An example from the structural clay industry demonstrates the benefit of diligent housekeeping practices on worker silica exposure levels. A dramatic exposure reduction (in some cases a greater than 10-fold reduction) was associated with professional-level cleaning to remove dust accumulations on the floor and structural surfaces of raw material handling areas (Brick Industry Consultant A, 2003).

Surface cleaning with HEPA vacuums instead of compressed air has proven beneficial in the pottery industry (another industry using similar silica-containing mineral powders). In a pottery industry facility, the use of compressed air to clean silica dust from the surface of molds was replaced with the use of a vacuum and abrasive pad (OSHA SEP Inspection Report 301527909). Using these methods, and despite uneven functioning of the LEV at two workstations, the facility reduced silica exposures substantially so that four results for workers at these stations were below 40 µg/m^3 (three results equal to 30 µg/m^3 and one of 40 µg/m^3). In contrast, NIOSH had measured exposure levels at this facility 12 years earlier, before the plant instituted dust control measures (NIOSH HETA 84-066-1883, 1988). At that time three of 31 results (10 percent) exceeded 100 µg/m^3, and 6 (20 percent) exceeded 50 µg/m^3.

Substitution

The use of enamels with reduced crystalline silica content represents an additional control option. By preparing coatings with low-silica ingredients, enamel preparers' exposures to silica might be reduced. Coatings producers typically use quartz and feldspar as ingredients in coatings to increase durability and chemical resistance; however, coatings with reduced crystalline silica content can be formulated by replacing quartz with materials such as feldspar (lower crystalline silica content) and frit (amorphous silica), which contain less crystalline silica (ERG-GI, 2008). Porcelain enamels with less than 3 percent crystalline silica are common (Porcelain Industries, 2004b).

Combination of Controls

Using several of the controls discussed above (LEV, process automation, housekeeping, and substitution) simultaneously can lead to greater exposure reductions. Porcelain Facility A uses both ventilation and good housekeeping to keep exposures low. At Porcelain Facility A, enamel preparers charge milling equipment for 1 hour per day, then monitor mills and transport the resulting enamel slurry as needed within the facility for the remainder of the shift. Exhaust ventilation holds the milling equipment under negative pressure to minimize dust release during charging and mixing (for details see ERG-GI [2008]). In addition to ventilating the milling equipment, Porcelain Facility A uses a vacuum fitted with a HEPA filter for all cleaning. To minimize the generation of airborne dust, workers avoid dry sweeping and only shovel or scrape materials that are damp.

A company representative reported that air monitoring conducted by OSHA at this facility found that the 8-hour TWA exposure level of porcelain preparers was well below 100 µg/m^3. Airborne silica concentrations could, however, exceed this level during the bag dumping task (Porcelain Industries, 2004a, 2004b). Exposures might have been still lower during this task if the bag dumping station had been designed differently and included ventilated equipment to dispose of empty bags.

Additional Controls for Porcelain Applicators

Based on data summarized in Table IV.C-32, the silica exposure levels for most porcelain applicators (65 percent) are already less than 50 µg/m^3. Additional controls will be necessary to reduce the exposures of the remainder of the operators (35 percent) to this level. Available controls include LEV, automation, diligent housekeeping practices, and use of low-silica enamels. Implementation of these controls might involve installing new equipment or improving current equipment.

Local Exhaust Ventilation

A common exposure control option includes the use of well-ventilated, well-enclosed booths for enamel application. In order for the booths to be effective, it is important to follow recommended exhaust rates. The American Conference of Governmental Industrial Hygienists (ACGIH) specifies ventilation designs for both large and small spray booths, including recommended air flow rates across the across the entire face of the booth (100 to 150 feet per minute) (see Section 13.75 and VS-75-01 through VS-75-06 in ACGIH [2010]).

The effectiveness of this method in other industries that use similar, but higher, silica content coatings than the porcelain enamel industry is demonstrated by exposure monitoring data obtained at a pottery manufacturing facility visited twice by NIOSH (NIOSH ECTB 171-11b, 1989; NIOSH CT-171-11c, 1992). Median exposure readings were 44 percent, 88 percent, and 67 percent lower on the manual, semiautomatic, and automatic lines, respectively, after the facility improved booths and LEV systems used for manual and automated spraying operations (repairing holes and openings, increasing airflow rates). On the semiautomatic and automatic lines NIOSH recorded eight results, the highest of which was 66 µg/m^3, with a median of 30 µg/m^3 and including four values of 23 µg/m^3 or lower. On the manual spray line, where exposure levels remained higher (up to 507 µg/m^3), reports indicate that operators used compressed air hoses to blow dust off prior to applying glaze during both site visits. It is possible that exposures on the manual spray line could be reduced further by removing dust from work pieces with vacuums and wet sponges as is done by operators on the semiautomatic spraying line.

In this facility, workers who used automated coatings application equipment had a median silica exposure level 64 percent lower than workers performing manual spraying. When the automated spray equipment is well enclosed and associated with a functioning ventilation system, operator results can be even lower (ERG-GI, 2008).

Porcelain applicators should ensure that they are making optimal use of LEV. Porcelain Facility A encourages workers who apply enamel to avoid positioning themselves between the enamel spray and the ventilation system. During manual spraying, small items are positioned by hand within the booth so the spray is directed into the booth and toward the ventilation take-off. For large items, the facility provides a turntable support that allows porcelain applicators to rotate the item to spray all sides of the object while maintaining the spray direction pointing into the ventilated booth (Porcelain Industries, 2004a). The workers also use great care to avoid dislodging enamel powder when handling items that are coated with dry porcelain enamel (e.g., when transferring parts to the furnace conveyer line).

Improved Housekeeping

Dust released from dried coatings and coatings residues (e.g., drips, spills, and overspray) can contribute substantially to the silica exposure of porcelain applicators in facilities where poor housekeeping has allowed dust to accumulate. Improper cleaning procedures (e.g., dry sweeping) can aggravate the situation by stirring up dust and causing it to become airborne. A thorough, professional-level cleaning in association with improved housekeeping procedures (e.g., use of a HEPA-filtered vacuum) to maintain cleanliness can reduce exposures in facilities where dust has been allowed to accumulate. An example from the structural clay industry demonstrates the benefit of diligent housekeeping practices on worker silica exposure levels. A dramatic exposure reduction (in some cases a greater than 10-fold reduction) was associated with professional-level cleaning to remove dust accumulations on the floor and structural surfaces of raw material handling areas (Brick Industry Consultant A, 2003).

Substitution

As discussed previously, the use of enamels with reduced crystalline silica content represents an additional control option. For further information see the previous section on Substitution under Additional Controls for Enamel Preparers.

Combination of Controls

Using several of the controls discussed above (LEV, housekeeping, and substitution) simultaneously can lead to greater exposure reductions. Porcelain Facility A uses ventilation, good work practices, and diligent housekeeping to keep exposures low. Porcelain Facility A makes extensive use of ventilation along the entire coatings application line. Both automated and manual spray enamel application are performed inside spray booths fitted with exhaust ventilation designed for the spray booths. At this site, most operations occur in large, ventilated, walk-in spray booths, although porcelain applicators sometimes apply the coating standing outside a smaller ventilated booth. In addition to using ventilated booths, Porcelain Facility A takes several steps to minimize the amount of dust that becomes airborne. Workers remove enamel residue from spray booths while it is still damp, using shovels and scrapers to recover the material for reuse. A company representative notes that no visible dust is generated during this process. Additionally, this facility uses a large HEPA-filtered vacuum to capture any dried porcelain enamel that workers encounter outside the ventilated booths. Sweeping and shoveling dry materials is not permitted and the HEPA-filtered vacuum is used for general housekeeping throughout the facility. According to a facility representative, during a visit to their facility, OSHA determined that the exposure levels of porcelain applicators were well below the current PEL, as calculated based on the OSHA general industry standard for silica in respirable dust (Porcelain Industries, 2004a, 2004b). The facility representative also reported that OSHA did not find it necessary to reevaluate the exposure of porcelain applicators during a repeat visit to this site.

Feasibility Finding

Feasibility Finding for Enamel Preparers

Based on the exposure profile, OSHA has determined that two-thirds of enamel preparer exposures currently experience silica exposure levels of 50 μg/m^3 or less, and the remaining third are only slightly higher than 50 μg/m^3. OSHA preliminarily concludes that the proportion of enamel preparers with exposures below this level can be increased by encouraging workers to use HEPA-filtered vacuums instead of compressed air for cleaning. Using these methods, a pottery manufacturing facility, where similar silica dusts are present, reduced silica exposures to levels below 40 μg/m^3 (three results equal to 30 μg/m^3 and one of 40 μg/m^3) (OSHA SEP Inspection Report 301527909). When facilities implement this control, OSHA preliminarily concludes that levels of 50 μg/m^3 or less can be achieved for most enamel preparers most of the time.

Where additional controls are required, options for enamel preparers include adding or improving maintenance on bag dumping stations and ventilated bag disposal equipment, process automation, improved housekeeping, and substitution. These methods have reduced exposure levels in other industries that prepare vitreous coatings or use similar materials to form products. OSHA believes that these methods will be equally effective in the porcelain enameling industry and can reduce the exposure for all enamel preparers to levels below 50 µg/m^3.

Feasibility Finding for Porcelain Applicators

Based on the exposure profile, OSHA has determined that approximately two-thirds (65 percent) of coatings operators already experience exposures below 50 µg/m^3. Low exposures, in this and related industries, are attributed to use of low-silica enamels; enclosed, well-ventilated automatic spray equipment; appropriately enclosed and ventilated booths for manual operations; and diligent housekeeping. OSHA concludes that exposure levels for the remaining coatings operators (35 percent) can be reduced to below 50 µg/m^3 using similar controls. The two highest exposures for this job category (2,300 µg/m^3 and 2,006 µg/m^3) were both obtained in 1985 at the same facility where OSHA later recorded six silica concentrations between 3 µg/m^3 and 23 µg/m^3 for porcelain applicators in 1989 and 1992, demonstrating that even the highest exposures for this job category have been successfully controlled to levels below 50 µg/m^3. Although information on control methods is not available for that facility, they most likely include some combination of the methods listed above. For example, in the related pottery industry, similar combinations of controls have reduced silica exposures to a median of 30 µg/m^3 on the automatic glaze and semiautomatic spraying lines (on the semiautomatic line, where an 88 percent silica exposure reduction was reported, employees worked near the glaze spray in a position similar to a manual spray line in the porcelain enameling industry) (NIOSH ECTB 171-11b, 1989; NIOSH CT-171-11c, 1992). As noted above, the silica content of enamel is lower (by at least half) than for pottery glazes and the OSHA data indicates that correspondingly lower silica exposure levels have been achieved for porcelain applicators in the porcelain enameling industry.

Overall Feasibility Finding for Porcelain Enameling Workers

OSHA preliminarily concludes that the porcelain enameling industry can control the silica exposure of all workers in this industry to levels of 50 µg/m^3 or less using the methods described above.

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Pottery

Description

Silica-containing materials are the primary ingredients in the manufacture of pottery products, which include vitreous china, fine earthenware, and porcelain electrical supplies. The principal raw materials used in the manufacturing processes include a variety of quartz-containing clays (especially ball clay and china clay), flint, and feldspar. For example, an establishment making vitreous china products used a mixture of ball clay (29 percent silica) and feldspar (12 percent silica). Facilities also might use silica-containing materials to prepare glazes that are applied to the product. Facilities manufacturing pottery products are classified in the six-digit North American Industry Classification System (NAICS) codes 327111, Vitreous China Plumbing Fixtures and Bathroom Accessories; 327112, Vitreous China, Fine Earthenware, and Other Pottery Products; and 327113, Porcelain Electrical Supply Manufacturing (ERG-GI, 2008).

Pottery product manufacture typically begins with the mixing of clay raw material with water in a mill. The clay mass is mixed into "slip," a slurry. The slip is then transferred into molds. After setting, the pottery pieces are removed from the molds and finished (smoothed, trimmed, or ground). Glazes are mixed and applied to the pottery. The pieces are then fired in kilns and packaged (ERG-GI, 2008).

Workers in all phases of pottery product manufacture have potential for silica exposure (ERG-GI, 2008). The primary job categories with potential exposures are material handler, forming line operator, finishing operator, coatings preparer, and coatings operator. Certain workers regularly perform tasks associated with multiple job categories. Table IV.C-33 summarizes the major activities performed by workers and the sources of exposure in each job category. Further detail can be found in ERG-GI (2008).

Table IV.C-33

Job Categories, Major Activities, and Sources of Exposure of Workers in the Pottery Industry (NAICS 327111, 327112, and 327113)

Job Category	Major Activities and Sources of Exposure
Material Handler	Transferring silica-containing raw materials (e.g., clay, silica sand, feldspar) from storage silos to weigh hoppers via front-end loader or forklift; mixing clay slip. • Dust generated from transfer of materials. • Dust from manually opening and dumping bags of silica-containing raw materials.
Forming Line Operator	Transferring slip into molds; removing formed pottery pieces; cleaning molds for reuse; applying mold parting compound. • Dust from cleaning molds. • Dust from applying the mold parting compound.
Finishing Operator	Shaping, smoothing, trimming of dried or fired pottery pieces, typically using hand-held equipment. • Dust from finishing dried pottery pieces.
Coatings Preparer	Transferring silica-containing materials (e.g., clay, silica sand, feldspar) to weigh hoppers or mixers; mixing glazes. • Dust generated from transfer of materials. • Dust from manually opening and dumping bags of silica-containing raw materials.
Coatings Operator	Applying glazes to pieces, typically by hand-dipping or spraying. • Silica-containing aerosol during glaze spraying.

Note: Job categories are intended to represent job functions; actual job titles might differ and responsibilities might be allocated differently, depending on the facility.

Source: ERG-GI, 2008.

Baseline Conditions and Exposure Profile

To evaluate silica exposures of pottery production workers, OSHA reviewed full-shift personal breathing zone (PBZ) respirable quartz exposure monitoring data from six OSHA Special Emphasis Program (SEP) inspection reports, three NIOSH site visit reports, and two site visit reports by the New Jersey Department of Health (NJDOH), summarized previously in ERG-GI (2008). Two of the reports describe one facility evaluated first by NIOSH (NIOSH HETA 84-066-1883, 1988) and then later by OSHA (OSHA SEP Inspection Report 301527909). A second facility was visited twice by NIOSH over the course of several years (NIOSH CT-171-11c, 1992; NIOSH ECTB 171-11b, 1989). OSHA also reviewed 12 additional facility reports from the states of Michigan, New Jersey, and Ohio for historical reference. These reports were also reviewed previously in ERG-GI (2008).[151]

The vast majority of the results used for this exposure profile represent quartz concentrations. However, a few of the results (less than 5 percent) from one facility evaluated by NIOSH represent a combination of quartz and cristobalite (NIOSH HETA 84-0066-1883, 1988).

While OSHA generally relies on information from reports produced in the 1990s or later for this technological feasibility analysis, OSHA has determined that most sources of data on silica exposure of pottery workers in the United States date back to the late 1980s. Therefore, OSHA has included information from those earlier reports in the exposure profile for the pottery industry. OSHA acknowledges that the resulting exposure profile might overestimate current exposures in pottery facilities. The ceramics industry as a whole has seen marked decreases in respirable dust and silica exposure levels and greater attention to exposure controls since the 1980s.

For example, in Europe, the Institute for Occupational Safety and Health of the German Social Accident Insurance (BGIA) (2008) notes, “The quartz dust situation has been improved over time in all areas of the porcelain industry.” BGIA provides evidence of 75 percent to 90 percent (or greater) decline in mean, median, and peak airborne silica concentration in all pottery and ceramics production areas at dozens of facilities over the three decades, ending in 2004.

Furthermore, the U.S. Environmental Protection Agency (EPA) issued a 2007 National Emissions Standard for Hazardous Air Pollutants for Clay Ceramics Manufacturing Area Sources, which includes specific provisions for managing emissions at these facilities, including inspecting and testing ventilation systems associated with pottery kilns and glaze spray booths (40 CFR 63.11435-.11445, 2007). This rule went into effect in 2007, and OSHA believes that the daily, weekly, and yearly inspection requirements for ducts, bag houses, and other dust control systems likely has now eliminated many of the problems with ventilation system integrity that NIOSH and OSHA found during the earlier workplace air sampling visits.

In addition to the data sources reviewed by ERG-GI (2008), OSHA has also identified a more recent NIOSH report (NIOSH HETA 2007-0127-3068, 2008) describing a small storefront pottery operation with four full-time workers and several part-time assistants. Because workers’ activities could not be classified by job category (they all encompassed most job categories), exposure information has not been included in the exposure profile. However, the available results indicate that exposures are relatively low at this type of facility despite a lack of local exhaust ventilation (LEV). Only one of five workers evaluated had a measurable full-shift exposure, no results exceeded the proposed permissible exposure limit (PEL) of 50 micrograms per cubic meter (µg/m^3) (one result was at 50 µg/m^3 and the other four out of five sample results

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[151] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) derived from samples of 6-hours or longer, assuming the exposure concentration during any unsampled portion of the shift was the same as the concentration during the period sampled. Unless explicitly stated otherwise, all results discussed in the additional controls section meet the same criteria. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

were below the limit of detection [LOD], in this case 12 μg/m^3).[152] Although task-based samples results (1 to 2 hours duration) did indicate the potential for exposure to occur during brief periods when workers handle bags of clay and mix clay, workers that perform dusty jobs also perform many other tasks during their shifts.[153] Thus, their cumulative silica exposure is rarely detectable and did not exceed the proposed PEL of 50 μg/m^3. These results suggest that the limited amount of materials and equipment used in small shops pose a lower risk than similar activities in a large manufacturing operation. For example, at the storefront facility visited by NIOSH, workers reprocessed clay and mixed glazes from 10-gallon buckets. In contrast, at a large industrial pottery facility one worker produced four 9,000-pound batches of clay on one shift.

Baseline Conditions for Material Handlers

Based on ERG-GI (2008), OSHA preliminarily finds that the silica exposures of material handlers result primarily from airborne dust generated as materials are transferred into hoppers or bins, bags are brushed, empty bags are handled for disposal, and vehicles re-suspend settled dust.

As shown in Table IV.C-34, the 21 results for material handlers are summarized by a median value of 33 μg/m^3 and a range of 10 μg/m^3 to 1,101 μg/m^3. Of the 18 material handler results with information on engineering control status, 11 (10 μg/m^3 to 180 μg/m^3) are associated with local exhaust ventilation (LEV) reported as relatively functional in areas where materials are dumped, both manually and using front-end loaders. An additional five results (67 μg/m^3 to 1,101 μg/m^3) were associated with no LEV or LEV described as inadequate.[154] The remaining two results (23 μg/m^3 and 29 μg/m^3) made full or partial use of automated processes. Overall, these results suggest that while elevated exposures can occur in facilities with LEV systems that appear functional, those elevated exposures are less frequent and less severe than in plants where ventilation is documented to perform poorly.

The highest result for this job category (and also this industry), a value of 1,101 μg/m^3, was obtained when OSHA monitored a material handler shoveling dry clay into a mill that formed clay slip. No ventilation was installed in the mill area, and the material handler also shared the work space with a coatings preparer (another job category with potential to generate substantial silica dust). A lower result of 67 μg/m^3 was obtained for a second worker at the same plant. This worker shoveled a different clay (ball clay) in the mill area and controlled the addition of water and other ingredients from silos (OSHA SEP Inspection Report 103010542). The available information is insufficient to determine with certainty whether factors other than the clay type caused the results to vary so much.

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[152] Results reported as "none detected" are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

[153] NIOSH recommended that the facility improve the building central ventilation and air circulation and also install exhaust ventilation hoods in the areas where the most dust was generated (NIOSH HETA 2007-0127-3068, 2008).

[154] For the current purposes, inadequate ventilation systems are characterized by insufficient air flow, leaking ducts, inappropriate hood shape or position, or other factors that make dust collection less efficient.

Table IV.C-34
Respirable Crystalline Silica Exposure Range and Profile for Workers in the Pottery Industry (NAICS 327111, 327112, and 327113)

	Exposure Summary			Exposure Range			Exposure Profile				
Job Category	**Number of Samples**	**Mean (μg/m^3)**	**Median (μg/m^3)**	**Min (μg/m^3)**	**Max (μg/m^3)**		**<25 (μg/m^3)**	**≥25 and ≤50 (μg/m^3)**	**>50 and ≤100 (μg/m^3)**	**>100 and ≤250 (μg/m^3)**	**>250 (μg/m^3)**
Material Handler											
No information about controls available	3	25	21	20	33		2 66.7%	1 33.3%	0 0.0%	0 0.0%	0 0.0%
No LEV or LEV documented as being inadequate (manual bag dumping or power equipment operation)	5	506	530	67	1,101		0 0.0%	0 0.0%	1 20.0%	1 20.0%	3 60.0%
LEV in use and reportedly functional (manual bag dumping or power equipment operation)	11	50	27	10	180		5 45.5%	2 18.2%	3 27.3%	1 9.1%	0 0.0%
Fully or partially automated process (transferring material or charging mixture)	2	26	26	23	29		1 50.0%	1 50.0%	0 0.0%	0 0.0%	0 0.0%
Material Handler Subtotals	**21**	**152**	**33**	**10**	**1,101**		**8** **38.1%**	**4** **19.0%**	**4** **19.0%**	**2** **9.5%**	**3** **14.3%**
Forming Line Operator											
No information about controls available	41	72	59	6	238		12 29.3%	6 14.6%	8 19.5%	15 36.6%	0 0.0%
No LEV	4	38	30	22	68		1 25.0%	2 50.0%	1 25.0%	0 0.0%	0 0.0%
LEV in use	45	43	40	10	130		10 22.2%	28 62.2%	4 8.9%	3 6.7%	0 0.0%
Forming Line Operator Subtotals	**90**	**56**	**40**	**6**	**238**		**23** **25.6%**	**36** **40.0%**	**13** **14.4%**	**18** **20.0%**	**0** **0.0%**
Finishing Operator	26	75	52	10	180		4	9	5	8	0

Table IV.C-34

Respirable Crystalline Silica Exposure Range and Profile for Workers in the Pottery Industry (NAICS 327111, 327112, and 327113)

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean (µg/m³)**	**Median (µg/m³)**	**Min (µg/m³)**	**Max (µg/m³)**		**<25 (µg/m³)**	**≥25 and ≤50 (µg/m³)**	**>50 and ≤100 (µg/m³)**	**>100 and ≤250 (µg/m³)**	**>250 (µg/m³)**
							15.4%	34.6%	19.2%	30.8%	0.0%
Coatings Preparer	19	252	124	24	983		1 5.3%	1 5.3%	6 31.6%	5 26.3%	6 31.6%
Coatings Operator											
Manual (including semiautomatic) spraying	29	184	125	17	668		5 17.2%	2 6.9%	3 10.3%	11 37.9%	8 27.6%
Automated spraying	8	59	46	12	163		2	2	3	1	0
							25.0%	25.0%	37.5%	12.5%	0.0%
Coatings Operator Subtotals	**37**	**157**	**106**	**12**	**668**		**7** **18.9%**	**4** **10.8%**	**6** **16.2%**	**12** **32.4%**	**8** **21.6%**
Totals	**193**	**108**	**50**	**6**	**1,101**		**43** **22.3%**	**54** **28.0%**	**34** **17.6%**	**45** **23.3%**	**17** **8.8%**

Notes: All samples are PBZ results for durations of 360 minutes or more and represent 8-hour time-weighted average (TWA) exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to further define the distribution of worker exposure in these job categories.

ERG-GI (2008) erroneously reported 195 results for this industry. The correct value in 2008 was 191. Here OSHA has added two additional results for finishing operators for an industry total of 193 results. Additionally, there were minor errors in the distribution of results in the 2008 exposure profile, corrected in the present version.

Sources: ERG-GI, 2008; NIOSH HETA 84-066-1883, 1988.

Both quartz and cristobalite contribute to the overall silica concentrations of two other results that also exceeded 250 µg/m^3. These results, summarized in Table IV.C-34, are 530 µg/m^3 and 700 µg/m^3. Information on the specific percentage of cristobalite in the dust sample is not available. The source document, NIOSH HETA 84-066-1883 (1988), indicates that these samples were obtained on two consecutive days for a worker operating an unenclosed front-end loader to scoop dry flint, ball clay, and feldspar into enclosed, ventilated weigh hoppers feeding an open system that conveyed raw materials to mixing equipment. The report suggests that housekeeping was poor, based on a comment that settled dust was disturbed by the loader activity. Additionally, the NIOSH investigator noted that the LEV at the hoppers (with air flow velocity of 155 feet per minute across the enclosure) was “overwhelmed” by the amount of dust released during the material transfer. Based on descriptions of exhausted enclosures for material transport recommended by ACGIH (2010),[155] OSHA has preliminarily determined that, in this case, the LEV system was not designed and used to best advantage; the LEV system could be upgraded to increase dust capture, and work practices could be improved to transfer raw materials in a manner that reduces airborne dust.

Although ERG-GI (2008) reported that most of the facilities for which information is available have some form of ventilation system (not necessarily effective) and considered that the baseline condition, OSHA has determined that, across the industry, baseline conditions are best represented by the cross-section of facilities reviewed for the exposure profile. Thus, the median (33 µg/m^3) for material handlers presented in Table IV.C-34 also represents the baseline condition for material handlers.

Baseline Conditions for Forming Line Operators

As shown in Table IV.C-34, the median full-shift PBZ respirable quartz value for 90 forming line operator results is 40 µg/m^3, with a mean of 56 µg/m^3 and a range of 6 µg/m^3 (as reported) to 238 µg/m^3. Thirty-one results (34 percent) exceed 50 µg/m^3, and 18 (20 percent) exceed 100 µg/m^3. All of the results for forming operators are associated with operations involving wet or liquid (slip) clay mixtures, although many operators also handle dry materials, such as mold coating compounds and dried clay slip residue in molds. Of the 49 results for which engineering control status could be established, 45 (92 percent, ranging from 10 µg/m^3 to 130 µg/m^3) were associated with the use of LEV. Such ventilation, however, was not always functioning optimally. In fact, in some cases, workers at workstations without LEV (e.g., four results ranging from 22 µg/m^3 to 68 µg/m^3) experienced lower exposures than some forming line operators who had the benefit of LEV. The available information is insufficient to explain these differences, which could relate to work practices, plant cleanliness, or the amount of silica particles in materials.

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[155] ACGIH (2010, Chapter 13.50) recommends a minimum air flow of 150 feet per minute (fpm) across bin and hopper openings for manual loading operations; however, ACGIH also recommends air velocity of one-and-a-half to two times that rate depending on the material flow rate (a front-end loader will add materials at a much greater material flow rate than manual transfers), dustiness (the material at this site was apparently very dusty), and the height the material falls (influenced by either hopper design or by material handler work practices). Furthermore, ACGIH recommends that the enclosure be “large enough to accommodate the ‘splash’ effect.” For some dust controls, ACGIH suggests increasing the baseline air flow rate from 150 fpm to 250 fpm when the materials handled include toxic dusts.

As for the material handler job category above, OSHA has preliminarily determined that for the purposes of this analysis, baseline conditions are best represented by the median for this job category as a whole. The values summarized in Table IV.C-34 by this median (40 µg/m^3) describe the full range of current exposure levels for forming line operators.

Baseline Conditions for Finishing Operators

The exposure profile for finishing operators is based on 26 results obtained from three OSHA SEP inspection reports, one NIOSH report, and a report from the NJDOH described by ERG-GI (2008). Two of the values extracted from the NIOSH report were not previously included in ERG's (ERG-GI, 2008) exposure profile, but were identified as finishing operators during the present review and are included in OSHA's current exposure profile. As Table IV.C-34 indicates, the median full-shift PBZ respirable quartz exposure for finishing operators is 52 µg/m^3, and results range from less than or equal to 10 µg/m^3 to 180 µg/m^3. Thirteen (50 percent) results exceed 50 µg/m^3, and eight (31 percent) exceed 100 µg/m^3. All of the finishing operators' results are associated with manual finishing tools or handling of formed pottery pieces. Of the 23 values for which engineering control status could be determined, all were associated with some form of LEV in the work area.

The lowest value for this job category (reported as 10 µg/m^3) was obtained by a consultant to a pottery facility that had been visited by OSHA. This result is associated with a worker using manual and machine-controlled grinding wheels to square off the bottoms and backs of sanitary ware (e.g., ceramic bathroom fixtures). At least part of this work was conducted in a ventilated booth (OSHA SEP Inspection Report 300977352). On the same day, two other results were also obtained for finishing operators at this facility. One of these workers used hand tools and steel wool pads to smooth unfired ceramic pieces, which reportedly generated a lot of visible dust (no booth mentioned), resulting in an exposure level of 53 µg/m^3. Although the other worker used a ventilated booth to perform similar work, that individual also used compressed air to remove the dust, and the consultant again noted visible dust in the air, leading to a result of 55 µg/m^3 (OSHA SEP Inspection Report 300977352).

Although ERG-GI (2008) found that baseline working conditions include LEV (often poorly functioning, but available in most facilities), OSHA preliminarily finds that a range of working conditions best represents the baseline for the job category (e.g., the conditions under which results summarized in Table IV.C-34 were obtained). Therefore, the median of 52 µg/m^3 for this job category represents the baseline exposure level.

Baseline Conditions for Coatings Preparers

As shown in Table IV.C-34, the median for 19 full-shift PBZ respirable quartz result for coatings preparers is 124 µg/m^3, and these results range from less than or equal to 24 µg/m^3 to 983 µg/m^3. More than half (58 percent) of coatings preparer exposure levels available to OSHA exceed 100 µg/m^3. All of the results for this job category are associated with manual transfer of dry, silica-containing materials into mixing equipment.

The highest reading, 983 µg/m^3, was obtained for a coatings preparer who manually emptied bags of glaze components into a large, unventilated mixer located in one area of the slip house

(OSHA SEP Inspection Report 103010542). Also in the same space was a material handler (making slip) whose exposure level of 1,101 µg/m^3 was the highest of the values in the material handler exposure profile. The actions of both workers contributed to extremely high silica dust levels in the space.

At a site visited by NIOSH, coatings preparers batched glazes (containing an average of 23 percent silica) by manually emptying bags of silica sand, feldspar, and other materials into ball mills that mixed the materials with water (NIOSH ECTB 171-11b, 1989). NIOSH obtained exposure readings of 292 µg/m^3, 279 µg/m^3, 145 µg/m^3, 124 µg/m^3, 116 µg/m^3, and 76 µg/m^3 for coatings preparers at this facility. To charge the mills, the coatings preparers emptied the bag contents through openings in the mills and manually compressed the bags, generating visible airborne dust. Instead of LEV, the facility had attempted to control coating preparers' exposures by placing a charged fogger above the mills. The fogger sprayed charged water droplets intended to reduce dust levels by electrostatically capturing airborne particles.

Three years later, NIOSH returned to collect additional air samples at the same facility (NIOSH CT-171-11c, 1992). The process and conditions were similar to those reported during the first visit, except that the fogger had been removed; however, LEV had not yet been installed. The maximum exposure levels were notably higher and the range greater during the second visit (692 µg/m^3, 687 µg/m^3, 651 µg/m^3, 78 µg/m^3, 57 µg/m^3, and less than or equal to 24 µg/m^3 [the LOD in this case]) compared with the first, when the fogger was in use.

Exposures are substantially lower when workers prepare coatings at ventilated workstations. OSHA obtained an exposure reading of 86 µg/m^3 for a coatings preparer who mixed three 3,000-pound batches of glaze (OSHA SEP Inspection Report 300180916). The coatings preparer manually weighed the glaze components, including silica sand and kaolin, in bags or buckets under an LEV hood. The coatings preparer then manually emptied the bags or buckets into an opening in a ball mill. At another facility, OSHA obtained results of 60 µg/m^3 and 41 µg/m^3 for coatings preparers using an LEV system that OSHA deemed only partially functional (OSHA SEP Inspection Report 300977352). These coatings preparers batched glazes by manually weighing materials and then manually loading them into a mixer hopper. The hopper was loaded inside a booth equipped with LEV. However, according to the inspection report, the scale used for weighing materials was located outside the booth. Additionally, the LEV system did not generate a sufficient exhaust rate. OSHA concurs with ERG's assumption that exposure readings would have been lower had the ventilation system functioned at the level recommended by ACGIH (2010).

As with the job categories discussed previously, OSHA has preliminarily determined that the baseline condition is best represented by the range of conditions under which coatings preparers worked when air samples included in the exposure profile were obtained. Therefore, the median value for this job category (124 µg/m^3) presented in Table IV.C-34 represents the baseline exposure level for coatings preparers.

Baseline Conditions for Coatings Operator

As Table IV.C-34 shows, the median silica exposure for the 37 exposure results for coatings operators is 106 µg/m^3, with results ranging from 12 µg/m^3 to 668 µg/m^3. Twenty-four results

(70 percent) exceed 50 µg/m^3, and most of those (54 percent of the total) also exceed 100 µg/m^3. All of the results were obtained while workers used spray methods to apply silica-containing glazes onto pottery pieces. At all facilities from which results are available to OSHA, the spray operations took place in LEV-equipped booths; however, some of the booths were documented as performing poorly.

Not surprisingly, silica exposure levels are generally higher when workers use manual spray equipment, rather than automated equipment. Twenty-nine results (median 125 µg/m^3) are associated with manual or semiautomatic spraying, while eight results (median 46 µg/m^3) were obtained while workers tended automated spraying processes. Automated processes tend to allow the worker to stand at a greater distance from the exposure source. Exposures occur primarily when particles of silica-containing coatings are released by pressurized spray nozzles, but fail to adhere to the pottery pieces and drift into coatings operators' breathing zones.

Based on the conditions described for this job category, OSHA has preliminarily determined that the baseline conditions for coatings operators across the industry are best represented by the range of conditions in effect for results summarized in the exposure profile. Thus, the baseline exposure level is represented by the median exposure for this job category (106 µg/m^3).

Additional Controls

Material Handler

Additional controls will reduce exposures for the 43 percent of material handlers whose exposure levels exceed 50 µg/m^3, as indicated in Table IV.C-34. Control options include LEV (including well-ventilated process equipment [e.g., mixers] and bag or loader dumping stations equipped with well-ventilated enclosures and, as needed, attached bag compactor); enclosed and ventilated cabs for front-end loaders; improved housekeeping; and automated transfer of silica-containing materials. Implementation of these controls might involve installing new equipment or improving current equipment.

Local Exhaust Ventilation

Data presented in the exposure profile (Table IV.C-34) suggest that ventilated material transfer stations are associated with reduced worker exposures. Although some results remain above the proposed PEL of 50 µg/m^3 when workers have access to LEV described as functional, the results are markedly lower (median exposure level 27 µg/m^3) than when workers use material transfer stations where LEV is clearly inadequate or missing (median exposure level 530 µg/m^3). Adjustments that improve the ventilation system, changes in work practices (e.g., while crushing empty bags or dumping materials from a loader scoop), and housekeeping (as discussed later in this section) will all further reduce material handler exposure levels.

As an example, material handlers performing manual bag dumping can be exposed to dust that is released when emptied bags are compressed for disposal (ERG-GI, 2008). During the first of two visits to a pottery facility, NIOSH noted that coatings preparers compressed bags, generating visible dust. Therefore, OSHA believes that it is likely that the same practice was used by other workers, including material handlers, who also handled bags of raw materials in the same facility. Although no data exist for the pottery industry, a bag-dumping station with fully functioning LEV and automated bag disposal was found to reduce silica exposure by at least 95 percent in a paint manufacturing facility where workers emptied 50-pound bags of silica-containing materials (ERG-paint-fac-A, 1999). Silica results were below the LOD (12 µg/m^3) for five workers using these stations. In contrast, when the ventilation/bag disposal system failed for 2 hours during the shift, a silica exposure level of 263 µg/m^3 was recorded (ERG-paint-fac-A, 1999). At this plant, the bag-dumping stations consist of hoppers topped with grates enclosed by LEV hoods. After each bag is emptied, the worker releases it and suction automatically pulls the bag into the ventilation system and transfers it to an enclosed storage area (eliminating manual bag crushing). As an alternative, ventilated bag compactors also eliminate manual bag crushing. Both bag dumping stations and bag crushing equipment are readily available from commercial sources (Carolina Conveying, 2010; Chicago Conveyor, 2004; Flexicon, 2009; Vac-U-Max, 2006a, 2006b; Whirl-air, 2003). Ventilated hoppers for receiving materials transferred by front-end loader function similarly but on a larger scale. OSHA anticipates that both types will control silica exposures to a similar extent when designed according to ACGIH (2010) recommendations (see the note in the discussion of baseline conditions for material handlers in this industry).

Additionally, ventilation can be augmented along conveyer systems. Such control methods include covering conveyers and increasing ventilation at existing enclosed transfer points to meet the ACGIH recommended air velocity of 250 fpm/ft^2 across all openings in the enclosures (ACGIH, 2010). OSHA has not identified specific examples from the pottery industry; however, in other industries that convey quantities of dusty silica sand, enclosed or pneumatic conveying systems are an effective part of comprehensive respirable dust management, which results in reduced exposure levels.

Enclosed Cabs

The use of well-ventilated cab enclosures for lift trucks or front-end loaders also can reduce exposure for material handlers. Although data documenting the effectiveness of such enclosures at pottery manufacturing facilities are not available, data from other sources suggest a 90 to 99.5 percent reduction in respirable dust (inside compared with outside the cab) with well-sealed, air-conditioned, and filtered cabs (ERG-GI, 2008). Operators working in heavy equipment cabs designed to meet the American Society of Agricultural Engineers' (ASAE) standard should experience exposure reductions in this general range. Although these cabs require regular maintenance to function properly and concerns exist regarding the construction standards of new heavy equipment, OSHA estimates that appropriately fitted and maintained cabs would offer an exposure reduction of at least 90 percent (the low end reported for larger equipment) for material handlers, including those using front-end loaders (ERG-GI, 2008).

Improved Housekeeping

Poor housekeeping contributes substantially to worker exposure levels in material handling areas, and a thorough, professional-level cleaning in association with improved housekeeping procedures (to maintain cleanliness) can reduce exposures where dust has been allowed to accumulate. For one material handler, poor housekeeping was reported as the primary source of silica exposure (OSHA SEP Inspection Report 300384435). In the structural clay industry, another industry with similar material handling requirements, a professional cleaning of a brick manufacturing facility dramatically reduced exposure levels (by 90 percent or more in some cases) for workers in areas where raw materials were transported or handled (raw material storage, near grinding equipment and conveyers, during bag dumping, and at raw material hoppers). In these areas most worker exposures were reduced to less than 50 µg/m^3 without other abatement efforts (ERG-GI, 2008). In addition to regular housekeeping procedures, spillage of raw materials can sometimes be prevented by modifying conveyor belts (e.g., using troughed belts or V-rollers).

Automated Equipment

Results at pottery manufacturing facilities with both manual and automated material transfer systems illustrate the effectiveness of the automated equipment. In one facility, exposure was almost 66 percent lower (29 µg/m^3 versus 85 µg/m^3) for a material handler tending automated equipment and adding silica-containing raw materials to a mixer compared with a material handler manually adding bags of raw materials to the mixer (OSHA SEP Inspection Report 300384435). Both workers were working in areas with functioning LEV (although this notation does not mean that the LEV was functioning optimally). At another facility, OSHA obtained a reading of 23 µg/m^3 for a material handler monitoring automated equipment to transfer dry silica sand from the storage silo and pump a slurry of ball clay and kaolin into a mixer (OSHA SEP Inspection Report 300180916).

Forming Line Operator

Generally low exposures experienced by many forming line operators can be attributed to the fact that most materials are handled in a wet state and the wide-spread use of LEV during the production phase. However, additional controls will reduce exposures for the 34 percent of forming line operators whose exposure levels exceed 50 µg/m^3. Control options include improved or added LEV, eliminating the use of compressed air, using vacuums to remove residual clay from molds, and employing equipment that reduces the release of airborne dust when workers apply mold parting compound.

Eliminating Use of Compressed Air for Cleaning

Changes in controls and work practices were implemented at one work site in order to reduce exposure of forming line operators. The use of compressed air to clean molds was replaced with the use of a vacuum and abrasive pad (OSHA SEP Inspection Report 301527909). Additionally, the bags previously used to dust molds with talc (a parting compound containing trace amounts of silica) were redesigned to release talc from only one end in the direction of the molds. Primarily through the elimination of compressed air for cleaning, and despite uneven functioning of the LEV at two workstations, the facility reduced silica exposures substantially so that four results for workers at these stations were below 40 µg/m^3 (three results equal to 30 µg/m^3 and one of 40 µg/m^3). ERG-GI (2008) suggested that exposures would have been lower still if the LEV were more effective. In fact, worker exposures at the same facility were lower (10 µg/m^3 and 20 µg/m^3) at a third workstation that was equipped with LEV (OSHA SEP Inspection Report 301527909). In contrast, NIOSH had measured exposure levels at this facility 12 years earlier, before the plant instituted dust control measures (NIOSH HETA 84-066-1883, 1988). At that time three of 31 results (10 percent) exceeded 100 µg/m^3, and 6 (20 percent) exceeded 50 µg/m^3.

Finishing Operator

Table IV.C-34 shows that half of finishing operators (50 percent) are exposed to silica levels greater than 50 µg/m^3, and will require additional controls to achieve the proposed PEL. Appropriate controls include improved maintenance of or modifications to existing LEV and using wet methods to perform finishing operations, as discussed in the following paragraphs.

Local Exhaust Ventilation

OSHA does not have data that demonstrate the effectiveness of properly designed LEV in reducing exposure for potter finishing operators, primarily because many systems installed at pottery facilities appear to have been poorly designed or maintained. However, exposure monitoring data from the foundry industry for cleaning/finishing operators provide good evidence that properly designed LEV systems can reduce exposure for pottery finishing operators. Like pottery finishing operators, foundry workers that perform similar work also use grinding equipment to remove residual silica material, typically a mixture of sand and clay, from castings. An OSHA SEP inspection report documents full-shift PBZ respirable quartz readings for foundry industry grinders of 56 µg/m^3, 80 µg/m^3, and 81 µg/m^3 (mean of 72 µg/m^3) (OSHA SEP Inspection Report 122040488). After installation of a downdraft dust collection bench, OSHA collected readings of 20 µg/m^3 and 24 µg/m^3 (mean of 22 µg/m^3) for two grinders (OSHA SEP Inspection Report 122040488).[156] The downdraft benches were associated with a 69 percent reduction in mean silica concentration.[157] Exposure levels also decreased when the foundry added LEV to bench grinders. ACGIH (2010) typically offers recommended designs for booths and other ventilation-based engineering controls.

In addition, tool-mounted LEV systems for hand-held grinding equipment can be helpful for reducing exposure. In the construction industry, a tool-mounted LEV system operating at 70 cubic feet per minute (cfm) (consisting of a grinder-mounted shroud, a 2-inch diameter flexible hose, and an industrial vacuum equipped with a cyclone and a high-efficiency particulate air [HEPA] filter) reduced silica exposure by 94 percent (Croteau, 2000). OSHA notes that in this study both the uncontrolled and controlled silica exposure levels were extremely high during 15-minute periods of intensive grinding; therefore, it is not clear that the same percentage reduction would result from tool-mounted LEV in the pottery industry, where peak exposures for finishing operators are not as extreme (among the data available to OSHA, 180 µg/m^3 is the maximum value for this job category). However, recent information regarding tuckpointing grinders (angle grinders used to remove mortar between bricks, historically among the construction tasks for which silica dust is most difficult to control) suggests that lower exposure levels (less than 50 µg/m^3 under certain conditions) can be achieved with these and other tools

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[156] OSHA described the system as a two-station Torit Model DDHV-45 Downdraft Bench dust collecting system designed to operate at 4,800 cfm. The system was 99 percent efficient for particles 1 micron or larger, used 51 cotton sateen filter bags, and provided 255 square feet of filter media (OSHA SEP Inspection Report 122040488).

[157] The reduction was calculated by dividing the mean exposure before the downdraft collection benches were installed by the mean exposure after installation (22 µg/m^3 ÷ 72 µg/m^3).

with LEV when workers are equipped with more powerful vacuums that provide greater LEV airflow and suction over an extended work period than traditional shop vacuums (Collingwood and Heitbrink, 2007; Heitbrink and Santalla-Elías, 2009). For further discussion, see Section IV.C.32 – Tuckpointers and Grinders. Based on this information, OSHA has preliminarily determined that tool-mounted LEV can provide similar exposure reductions (e.g., to levels of 50 µg/m^3 and less) for finishing operators in the pottery products industry when pottery manufacturers ensure that LEV shrouds are correctly matched to the grinding tools and that vacuums provide sufficient suction for the duration of the task.

For additional dust control, tool-mounted LEV can also be used in conjunction with ventilated downdraft tables, booths, or both.

Wet Methods

Exposures also can be reduced by performing finishing operations on pottery pieces that are still slightly damp instead of dry, because silica particles are less likely to become airborne when pieces are wet. Wet finishing operations can be conducted using sponges and abrasive pads, or by moistening the outer layer of the pottery prior to abrading it. Operators also might perform finishing tasks on a piece that has not completely dried. At one pottery facility, exposure levels were four-and-a-half times higher when operators finished fully dried pottery pieces compared with partially dried pieces with slight moisture content (OSHA SEP Inspection Report 103010542; see also ERG-GI [2008] for an expanded description). OSHA calculates that this difference is equivalent to an 88 percent change in exposure level.

The other wet finishing process option, wet sanding of dried pottery, is similar to a process used in the construction industry. Drywall finishers using a damp abrasive sponge experience a 60 percent reduction in respirable dust levels compared with dry sanding (Young-Corbett and Nussbaum, 2009). OSHA estimates that pottery grinders would receive similar benefits in reducing respirable dust and that silica would be reduced proportionally. Although moistened pieces would likely require additional drying time, because only the surface layer of clay would be dampened, drying time would still be less than for the original wet casting (ERG-GI, 2008).

Coatings Preparer

All but two of 19 results used in the exposure profile (and at least one result from each of the six facilities evaluated) exceed 50 µg/m^3. Based on Table IV.C-34, OSHA preliminarily determines that most coatings preparers (89 percent) will require additional controls to achieve the same levels. The available information suggests that some LEV is often present at pottery facilities, but in most plants the LEV is applied to only a portion of the potentially dusty operations. Therefore, OSHA has preliminarily determined that control options include consistent use of bag dumping stations equipped with well-ventilated enclosures and ventilated bag disposal equipment, ventilated mixing equipment, and improved housekeeping. Reducing reliance on compressed air for cleaning also will help limit exposures. Implementation of these controls might involve installing new equipment or improving current equipment.

Local Exhaust Ventilation

Exhaust ventilation effectively captures dust that is released when workers empty bags of raw materials, crush the bags, weigh the materials, and dump the materials into hoppers or mixing equipment.

Bag emptying stations can reduce exposure levels somewhat even when they are not performing optimally, but they provide better dust capture when the ventilation system is fully functional. To reduce coatings preparer exposure levels to the lowest levels, workers must make all raw material transfers within ventilated enclosures or use equipment fitted with effective LEV. These principles were demonstrated by OSHA at a pottery manufacturing plant where a coatings preparer used a ventilated booth (with low airflow) to empty bags of powdered raw materials into a hopper, but also used a weigh scale outside the booth to measure some ingredients. An initial silica value of 143 µg/m^3 was reduced to 40 µg/m^3 and 51 µg/m^3 after the baghouse ventilation system was repaired.[158] A consultant evaluating the plant during the second (post-repair) sampling date recommended that silica at this facility be reduced to its lowest possible level by taking additional steps such as limiting use of compressed air for cleaning (suggesting that compressed air was still used regularly in the plant after the ventilation system was repaired) (OSHA SEP Inspection Report 300977352). In this example, the workers' exposure levels were reduced to approximately one-third of the original value simply by repairing the existing ventilation system.

OSHA notes that exposures could have been reduced further if the facility had taken two additional steps: 1) moving the weigh scale into the booth (or adding exhaust ventilation to the scale area), and 2) reducing reliance on compressed air for cleaning. As discussed below, exposure levels can be greatly reduced by both these modifications.

A dramatic reduction in exposure was recorded at the facility where previously OSHA had obtained the highest result for a coatings preparer (983 µg/m^3, as shown in Table IV.C-34) (OSHA SEP Inspection Report 103010542). At the time of the original sample, this worker manually lifted bags of raw materials and, from a position on a platform, dumped them into an unventilated mixer in an area where another dusty operation also took place.

As part of a four-part abatement plan, the facility made substantial changes to the way materials were handled during coating production. After hiring engineering consultants to evaluate the areas where OSHA found elevated exposure, the facility installed two new dust collector systems in the glaze-making area. These included one hood under which the worker now filled a portable hopper with measured raw materials and another hood at the hatch of the ball mill into which the materials were poured. To minimize ergonomic stressors, the filled hopper was lifted by a mechanical hoist to the overhead platform (level with the mill hatch) and emptied into the mill. Equipment leaking dust in other parts of the plant were also repaired. After these changes had been made (but prior to a planned comprehensive cleaning of the area) a consultant obtained a

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[158] This less-than-full shift result of 143 µg/m^3 was obtained as a 325-minute sample, so not included in the exposure profile (OSHA SEP Inspection Report 300977352).

silica result of 47 µg/m^3 for a coatings preparer.[159] A general area sample also collected in the glaze-making area resulted in a respirable quartz concentration of 34 µg/m^3 (OSHA SEP Inspection Report 103010542).

The value of ventilated bag dumping systems was discussed previously with respect to material handlers, where it was noted that workers using a bag-dumping station (with ventilated bag disposal equipment) in a paint manufacturing facility experienced silica exposure reductions of at least 95 percent (from 263 µg/m^3 to 12 µg/m^3). A second type of bag-dumping station equipped with an enclosure, empty bag compactor, bag disposal chute, and LEV system also was found by NIOSH to effectively control dust released during bag opening, emptying, and disposal (ERG-GI, 2008). As noted previously, ventilated bag-dumping stations and ventilated compactors are readily available from commercial sources (Carolina Conveying, 2010; Chicago Conveyor, 2004; Flexicon, 2009; Vac-U-Max, 2006a, 2006b; Whirl-air, 2003).

Eliminating Use of Compressed Air for Cleaning

As noted in the discussion of additional controls for pottery industry forming line operators, a pottery facility visited by OSHA eliminated use of compressed air for removing dust from pottery pieces, substituting a vacuum instead.[160] Despite uneven functioning of the LEV at two workstations, this modification reduced silica exposures substantially. Four results for workers at these stations were below 40 µg/m^3 (three results of 30 µg/m^3 and one of 40 µg/m^3) (OSHA SEP Inspection Report 301527909). Previously three of 31 results (10 percent) for forming line operators exceeded 100 µg/m^3, and 6 (20 percent) exceeded 50 µg/m^3 (NIOSH HETA 84-066-1883, 1988).

Good Housekeeping

Although there are no data describing the efficacy of housekeeping measures in the pottery industry, exposure monitoring data from the structural clay manufacturing industry provide strong evidence that housekeeping measures can reduce exposures for coatings preparers in the pottery industry. In the structural clay manufacturing and pottery industries, the same exposure reduction challenges arise for workers who transfer and mix sand and other coatings or glaze ingredients. As previously noted, a survey at a brick manufacturing facility revealed dramatic exposure reduction (90 percent, to levels usually less than 50 µg/m^3) after a professional-level cleaning removed dust accumulations on the floor and structural surfaces of raw material handling areas (ERG-GI, 2008). OSHA has preliminarily determined that coatings preparers in the pottery industry would benefit equally from housekeeping measures, based on the similarity in raw materials used in the structural clay and pottery industries (quartz sand and powdered silica-containing materials).

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[159] Both the coatings preparer and the glaze-making area samples were full-shift duration (exactly 360 minutes) (OSHA SEP Inspection Report 103010542). However, ERG confirmed that the personal sample was associated with this (pottery) facility too late to include in the exposure profile.

[160] The facility also modified talc bags to make them less dusty; however, the talc contained only trace amounts of silica (OSHA SEP Inspection Report 301527909).

For example, in the china manufacturing facility at which the highest coatings preparer result was recorded (983 μg/m^3), the four-phase exposure abatement program included a thorough cleaning of all surfaces in the area where workers blend coatings (OSHA SEP Inspection Report 103010542). This phase had not been completed at the time of the last results available to OSHA from this facility (47 μg/m^3, as presented in the discussion of LEV for coatings preparers). Based on the experience in the structural clay manufacturing industry, OSHA has preliminarily determined that the silica exposure of this pottery industry coatings operator would have been even lower after the planned cleaning.

Coatings Operator

OSHA has preliminarily determined that additional controls are required for the 70 percent of coatings operators identified in Table IV.C-34 as currently experiencing exposure levels greater than 50 μg/m^3. Appropriate controls include the use of low-silica coatings; well-enclosed, well-ventilated booths; and well-enclosed, well-ventilated automated coatings application machinery. Implementation of these controls might involve installing new equipment or improving current equipment.

Local Exhaust Ventilation and Automation

Well-ventilated, well-enclosed booths for coatings application can reduce worker exposure. The effectiveness of this method is demonstrated by exposure monitoring data obtained at a facility visited twice by NIOSH (NIOSH CT-171-11c, 1992; NIOSH ECTB 171-11b, 1989). During the initial site visit, silica sample results of 113 μg/m^3, 125 μg/m^3, 152 μg/m^3, 192 μg/m^3, 195 μg/m^3, 253 μg/m^3, 259 μg/m^3, 319 μg/m^3, and 434 μg/m^3 were obtained for operators on the semiautomatic spraying line (manual spraying of pieces mechanically transported through the booth[s] on this line). The facility then improved the booths by repairing holes or openings that could allow particles to escape or decrease the efficiency of the LEV systems by disrupting airflow. The facility also made improvements to the LEV system to increase airflow rates in the booths. NIOSH returned to evaluate operator exposure and collected five samples. On the same semiautomic spraying line, four of the five results (80 percent) were less than the LOD (less than 25 μg/m^3 in each case), and one result was 66 μg/m^3.[161] These results were obtained for operators on the semiautomatic spraying line. The median exposure for these results is 88 percent lower than the original values obtained on this line.

The facility made similar repairs to two other spraying lines (one fully manual and the other fully automatic), which also reduced worker exposure levels. However, the improvement was not as dramatic, resulting in median values 44 and 67 percent lower on the manual and automatic lines, respectively (NIOSH CT-171-11c, 1992). However, NIOSH noted that even after ventilation system upgrades on the fully manual line, workers used compressed air to blow dust off pottery pieces prior to applying glaze and likely contributed to worker silica exposure levels (this practice had been eliminated from the semiautomatic line by providing workers with damp sponges to remove dust from the pottery pieces) (NIOSH CT-171-11c, 1992). OSHA preliminarily finds that additional exposure reduction will be possible by eliminating use of

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[161] After repairs to the booths and ventilation system, silica exposure levels were one reading of 22 μg/m^3 (the LOD in this case), three readings of 23 μg/m^3 (the LOD for these samples), and one reading of 66 μg/m^3 (NIOSH CT 171-11c, 1992).

compressed air for removing dust from pieces (switching to vacuum system or damp sponges), making additional adjustments to further enclose the spray lines (particularly the fully automated line), reducing overspray through careful work practices and using modern high-volume-low-pressure (HVLP) spray nozzles, and limiting worker exposure while adjusting spray machines.

OSHA found in the technological feasibility analysis for the standard on hexavalent chromium that paint spray booths intended for small and medium-sized parts (including the sizes of pottery pieces, but excluding large objects the size of aircraft) are capable of controlling worker exposure to hexavalent chromium (a component of paint present in some pigment particles) to levels well below the PEL of 5 μg/m^3 (one-tenth the proposed silica PEL of 50 μg/m^3) (71 FR 10099-10385). Spray booths were found to be an effective control even for paint containing greater than 10 percent chromate (OSHA H054A, no date). OSHA has preliminarily determined that well-designed and effectively maintained spray booths are equally effective for silica particles in glazes as they are for chromate-containing paints. In demonstrating the effectiveness of spray booths for silica-containing coatings, OSHA notes that glazes can be 30 or more percent quartz. However, this higher percent silica is offset by the less restrictive proposed PEL for silica compared with hexavalent chromium. Although the level of chromate (hexavalent chromium) in the paints discussed above is three times lower than the amount of silica in the pottery industry coatings, the hexavalent chromium PEL is also 10 times lower than the proposed PEL of 50 μg/m^3 for silica. Thus, OSHA preliminarily concludes that spray booths will protect pottery industry coating operators from excessive silica exposure at least as well as the booths protect painters from chromates.[162]

Automation offers another exposure control option for coatings operators. As shown in Table IV.C-34, among all data available to OSHA for this job category, coatings operator silica exposure levels are dramatically lower for workers tending automated equipment than for those using manual processes. Workers in this job category will also benefit from improved housekeeping.

Feasibility Finding

Material Handler

Based on information presented in Table IV.C-34, OSHA preliminarily concludes that results of 50 μg/m^3 or less have already been achieved for more than half (57 percent) of the material handlers in this industry by using LEV at workstations. OSHA also preliminarily concludes that by using appropriately designed, well-maintained ventilation systems and good housekeeping practices, pottery production facilities can reduce the exposures of most of the remaining material handlers (43 percent) to 50 μg/m^3 or less.

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[162] Note that the chromate-containing paints (often corrosion control coatings) and silica-containing glazes mentioned here are generally applied as aerosols, using the same spray coating guns (e.g., high-velocity low-pressure [HVLP], or other spray guns) (Spray Gun Industry-corrosion, no date; Spray Gun Industry-glaze, no date), and producing spray mist with similar aerodynamic properties. The particles from both types of coatings will respond in a similar manner in an airstream created by ventilation controls. Thus, this control will be similarly effective for both types of coatings.

OSHA made this determination by analyzing the impact of controls that could be applied to the highest exposures (530 µg/m^3 and 700 µg/m^3 for a worker filling hoppers using a front-end loader, and 1,101 µg/m^3 for a worker manually shoveling clay, as described in the discussion of baseline conditions for this job category). By improving ventilation at raw material transfer points (e.g., well-ventilated bag-dumping station with ventilated bag disposal unit or a ventilated receiving hopper designed using criteria recommended by ACGIH [2010]), OSHA has preliminarily determined that worker exposures will be reduced by 95 percent, so that the highest silica value (1,101) will be reduce to 55 µg/m^3 and all of the 20 other results (95 percent of all results) summarized in the exposure profile will be reduced to levels well below 50 µg/m^3.

This conclusion is based on the ability of effective raw material handling stations to reduce silica exposure levels by 95 percent compared with worker exposures while the ventilation system was not operating at a paint manufacturer (ERG-paint-fac-A, 1999). Workers in both the paint manufacturing and pottery industries handle sacks of raw materials that often contain silica as a high percentage of the material. This similarity suggests that properly functioning raw material handling stations would also be an effective control in the pottery industry.

Since poor housekeeping practices also contribute to material handler exposure (and in at least one case was the primary source of exposure at a pottery facility), a thorough professional-level cleaning followed by a continuing housekeeping program to prevent dust from accumulating, in combination with improved ventilation at material transfer points, will reduce the exposure of all material handlers to levels below 50 µg/m^3. For example, as described under additional controls for this job category, a thorough professional-level cleaning reduced worker exposure by 90 percent, to levels below 50, at a facility in the structural clay industry.

Silica results for material handlers will also be reduced when the silica exposures of workers in other job categories are controlled to levels of 50 µg/m^3 or less. For example, the highest exposure for a material handler 1,101 µg/m^3, was obtained while the material handler worked in the same area as a coatings preparer, who also had a very high exposure (983 µg/m^3) (OSHA SEP Inspection Report 103010542). The coatings preparer exposure was reduced by 95 percent (to 47 µg/m^3) by installing engineering controls, suggesting that this contributing source of exposure for the material handler was also reduced by 95 percent (although not directly evaluated, the material handler's own activities might still have generated some airborne silica).

In the event that a pottery products facility finds it necessary to reduce exposures further, other options included switching to automated raw material transfer and, for workers using vehicular equipment, adding enclosed cabs for the operators.

Forming Line Operator

Based on Table IV.C-34 and information presented in this section, OSHA preliminarily concludes that the exposure levels of two-thirds of forming line operators (66 percent) are already below 50 µg/m^3. Employers can achieve this same level for the remaining 34 percent of operators through a combination of LEV, use of vacuums in place of compressed air, and redesigned equipment used for applying mold release agents. Air samples collected by OSHA and a consultant resulted in values of 40 µg/m^3 or less for forming line operators who used some combination of these controls while removing, cleaning, and dusting molds (OSHA SEP

Inspection Report 301527909). Previously three of 31 results (10 percent) for forming line operators at that facility exceeded 100 µg/m^3, and 6 (20 percent) exceeded 50 µg/m^3 (NIOSH HETA 84-066-1883, 1988).

Finishing Operator

Based on Table IV.C-34 and information contained in this section, OSHA has preliminarily determined that exposure levels of 50 µg/m^3 or less have already been achieved for half (50 percent) of finishing operators, primarily through use of existing ventilated workstations. Furthermore, OSHA preliminarily concludes that the exposure levels of the remaining finishing operators (50 percent), can reduce exposures below 50 µg/m^3 by improving LEV at workstations, using tools equipped with adequate LEV, and wet methods. OSHA made this determination by estimating: 1) that even the maximum exposure level among the data available to OSHA (180 µg/m^3) will be reduced by 69 percent (to 56 µg/m^3) when existing ventilation systems are upgraded to be at least as effective as a downdraft table, and 2) that all results can be further reduced to levels of 50 µg/m^3 or less when ventilation system upgrades (or downdraft tables) are combined with wet methods (e.g., wet sanding or damp abrasive sponge) for at least part of the workshift. Compared with dry sanding, exposure levels are 60 percent lower when workers perform drywall finishing using these methods (Young-Corbett and Nussbaum, 2009). Exposure values can be reduced by both methods sequentially. For example, first the highest level for this job category can be reduced by 69 percent when ventilation systems are upgraded (as shown above, the resulting value is 56 µg/m^3). Then, an additional 60 percent reduction, achieved by switching to wet sanding, will result in a value of 34 µg/m^3.

As another option, finishing operators can use an alternative method of finishing partially dried pieces with a slight moisture content, before the pieces are completely dry. This method is already used by a pottery facility at which the technique reduced worker exposure levels by 88 percent (OSHA SEP Inspection Report 103010542).

Coating Preparer

Based on Table IV.C-34, OSHA has preliminarily determined that only 11 percent of coating preparers currently have exposures at or below 50 µg/m^3. However, considering the information contained in this section, OSHA preliminarily concludes that most employers of coatings preparers can achieve exposure levels of 50 µg/m^3 or less for all workers in this job category most of the time by using a combination of ventilated manual and mechanical material handling systems that control dust throughout the measuring and transfer process (e.g., bag dumping, weighing, bag disposal), diligent housekeeping beginning with a professional level cleaning, and eliminating compressed air for cleaning.

This conclusion is based in part on a result of 51 µg/m^3 obtained for a coatings preparer at a pottery facility where workers manually loaded dry silica-containing glaze components into a weigh hopper inside a booth equipped with recently repaired LEV. Prior to repair, OSHA collected an exposure of 143 µg/m^3 for a 325-minute sample (less than full shift) (OSHA SEP Inspection Report 300977352). The weigh scale was outside the booth, and the worker used compressed air for cleaning, both of which likely contributed to the exposure level, even after the LEV was repaired. OSHA preliminarily concludes that either moving the weigh scale into the booth (or adding ventilation at the scale) or eliminating compressed air for cleaning would be sufficient to reduce the measured exposure of 51 µg/m^3 to a level of 50 µg/m^3 or less. The benefit of eliminating compressed air for cleaning (a practice prohibited under the proposed rule) is described in the discussion of pottery industry forming line operators.

Furthermore, at a second facility where OSHA originally recorded the highest exposure for a coatings preparer (983 μg/m^3), the worker silica exposure level dropped to 47 μg/m^3 after the facility installed exhaust ventilation hoods: at the bag dumping position and at the mill opening (OSHA SEP Inspection Report 103010542). OSHA preliminarily concludes that the result would have been even lower after the facility completed a planned comprehensive cleaning. Exposure reductions of 90 percent, to levels usually less than 50 μg/m^3, were associated with professional-level cleaning to remove dust accumulations on the floor and structural surfaces of raw material handling areas in the structural clay industry (ERG-GI, 2008).

Coating Operator

Based on information contained in the exposure profile (Table x. EP), OSHA finds that approximately one-third (30 percent) of pottery facilities already achieve exposure levels of 50 μg/m^3 or less for these workers by using enclosed, well-ventilated automatic spray equipment and appropriately enclosed and ventilated booths for manual operations. OSHA preliminarily concludes that the exposure levels of the remaining coatings operators can be reduced below 50 μg/m^3 most of the time using similar controls. NIOSH found that improvements to LEV systems and booths, which resulted in better enclosure and ventilation of manual spraying operations, reduced 80 percent of coatings operator exposures on a semiautomatic spray line to levels well below 50 μg/m^3 (NIOSH CT-171-11c, 1992). Silica exposure levels were somewhat higher on other production lines, where workers continued to use compressed air for cleaning pottery pieces prior to coating them. Furthermore, OSHA found that spray booths are an effective means of controlling aerospace painter exposures to hexavalent chromium (PEL of 5 μg/m^3, one-tenth of the proposed PEL of 50 μg/m^3 for silica, when workers spray paint small and medium size objects (the size range of pottery pieces) (71 FR 10099-10385, 2006).

OSHA preliminarily concludes that pottery coatings operator exposure levels can be reduced to 50 μg/m^3 or less using similar equipment and by eliminating the use of compressed air for removing dust, a practice that will be prohibited under the proposed rule.

In the event that employers find that exposures continue to exceed the proposed PEL of 50 μg/m^3, additional options include work practices and equipment that limit overspray (e.g., HVLP spray nozzles and, for fully manual spraying, turn tables), as well as rigorous housekeeping.

The exposure levels of coatings operators can be reduced even further through automation. OSHA bases this conclusion on a respirable quartz exposure reading of 13 μg/m^3 obtained by an industrial hygiene consultant for a coatings operator who monitored enclosed, ventilated, automated equipment at a facility that automated all spraying operations following an OSHA SEP inspection (OSHA SEP Inspection Report 300977352).

Overall Feasibility Finding

Based on the information presented in this section, OSHA preliminarily concludes that, in all job categories in industrial-scale pottery production, by using the controls described above, silica exposure levels of 50 μg/m^3 or less can be achieved for most workers, most of the time.

Furthermore, OSHA preliminarily concludes that silica exposure levels of 50 μg/m^3 or less are already achieved for most workers at small storefront pottery operations that use a relatively small amount of raw materials and clay. None of the five results obtained by NIOSH at such a shop exceeded the proposed PEL of 50 μg/m^3, despite the lack of LEV (NIOSH HETA 2007-0127-3068 [2008]). If elevated exposures do occur, the same methods available to larger facilities (LEV, wet methods, improved housekeeping) can be instituted on a smaller scale and will benefit workers in these smaller facilities equally well.

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Railroads

Description

Railroad track maintenance-of-way workers are responsible for maintaining the overall surface of the roadbed including the rails, ties, and ballast (rock), and other components associated with the railroad track right-of-way. Potential exposure to silica-containing dust might occur during maintenance activities involving both the manual and automated manipulation of ballast (NIOSH HETA 90-341-2288, 1993; NIOSH HETA 92-0311, 2001). Although the Federal Railroad Administration (FRA) is responsible for certain aspects of the safety of railroad track maintenance of way workers (e.g., ensuring that track men are not hit by trains or other equipment moving over the rails), hazards “not related to the conditions and procedures necessary to achieve the safe movement of equipment over the rails” are deemed non-operational concerns, which fall under OSHA’s jurisdiction (FRA, 1978). OSHA considers exposure to silica during ballast handling activities to be a non-operational hazard. FRA acknowledges that for occupational hazards under OSHA’s jurisdiction, general industry standards for toxic and hazardous substances usually apply (FRA, 1978).[163] This industry is classified in six-digit North American Industry Classification System (NAICS) codes 482111, Line-Haul Railroads, and 482112, Short Line Railroads.

Railroad track is most often supported by a bed of material called ballast. Ballast transmits and distributes the load of the track and rolling equipment evenly across the roadbed; controls movement of the track; maintains proper track cross-level, surface, and alignment; and provides drainage for the track. Today, most railroads use crushed stone (especially granite, traprock, and limestone) or slag for ballast on main-line tracks. In 2001, granite (25 to 40 percent silica) accounted for approximately 46 percent of the total crushed stone sold for railroad ballast within the United States (ERG-GI, 2008). Railroad track maintenance-of-way activities might be associated with potential exposure to silica because of the use of silica-containing material for railroad ballast. Potential exposure to silica-containing dust might occur when silica-containing ballast is disturbed or otherwise manipulated during track maintenance activities.

The major job categories associated with potential silica exposure during track maintenance include ballast dumpers and heavy equipment (machine) operators. Table IV.C-35 presents job activities and major sources of exposure for affected job categories. See ERG-GI (2008) for detailed process descriptions.

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[163] “The OSHA regulations apply according to their terms, except with respect to the shipment or transportation of hazardous substances, which is controlled by the Department of Transportation Hazardous Materials Regulations, and the regulation of air contaminants in locomotive cab and caboose environments” (FRA, 1978).

Table IV.C-35

Job Categories, Major Activities, and Sources of Exposure in the Railroads Industry (NAICS 482111 and 482112)

Job Category*	Major Activities and Sources of Exposure
Ballast Dumper	Walks alongside moving ballast cars and manually or automatically (via radio remote control) opens hopper doors on moving ballast cars and dumps ballast alongside the track. • Dust clouds generated when dry ballast falls from hopper cars.
Machine Operator	Operates heavy equipment used for track bed maintenance (surfacing activities). Includes ballast regulator (to level, shape, and dress ballast), broom (to sweep tracks), and tamper (to pack down ballast under the ties) machines. • Dust generated during direct manipulation of the ballast.

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the facility.

Source: ERG-GI, 2008.

Baseline Conditions and Exposure Profile

To evaluate the silica exposures of workers in the railroad transportation industry, OSHA reviewed full-shift personal breathing zone (PBZ) respirable quartz exposure monitoring data from two NIOSH reports (NIOSH HETA 90-341-2288, 1993; NIOSH HETA 92-0311, 2001), previously described in ERG-GI (2008).[164] Full-shift area samples reported by these studies are also discussed. OSHA also reviewed one study from the published literature (Tucker et al., 1995), but exposure data from this study were not incorporated into the exposure profile because of a lack of sampling details (e.g., exact sample duration, PBZ result).

Baseline Conditions for Ballast Dumpers

The exposure profile for ballast dumpers is based on 26 full-shift respirable quartz readings from one NIOSH report (NIOSH HETA 92-0311, 2001). As indicated in Table IV.C-36, the median full-shift exposure for ballast dumpers is 25 micrograms per cubic meter (μg/m^3), with a mean of 68 μg/m^3 and a range from 11 μg/m^3 to 370 μg/m^3. Twenty-three percent of these readings exceed 50 μg/m^3, and 15 percent exceed 100 μg/m^3.

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[164] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) derived from samples of 6-hours or longer, assuming the exposure concentration during any unsampled portion of the shift was the same as the concentration during the period sampled. Unless explicitly stated otherwise, all results discussed in the additional controls section meet the same criteria. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

Table IV.C-36
Silica Exposure Range and Profile for Workers in the Railroads Industry (NAICS 482111 and 482112)

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean ($\mu g/m^3$)**	**Median ($\mu g/m^3$)**	**Min ($\mu g/m^3$)**	**Max ($\mu g/m^3$)**		**<25 ($\mu g/m^3$)**	**≥25 and ≤50 ($\mu g/m^3$)**	**>50 and ≤100 ($\mu g/m^3$)**	**>100 and ≤250 ($\mu g/m^3$)**	**>250 ($\mu g/m^3$)**
Ballast Dumper	26	68	25	11	370		13 50.0%	7 26.9%	2 7.7%	2 7.7%	2 7.7%
Machine Operator											
Ballast Regulator	38	89	45	9	370		8 21.1%	13 34.2%	9 23.7%	3 7.9%	5 13.2%
Broom Operator	21	90	60	10	440		2 9.5%	5 23.8%	8 38.1%	5 23.8%	1 4.8%
Tamper Operator	35	54	40	9	310		10 28.6%	15 42.9%	6 17.1%	3 8.6%	1 2.9%
Other Operator*	6	31	29	20	50		1 16.7%	5 83.3%	0 0.0%	0 0.0%	0 0.0%
Total	100	74	46	9	440		21 21.0%	38 38.0%	23 23.0%	11 11.0%	7 7.0%
Totals	**126**	**73**	**40**	**9**	**440**		**34** **27.0%**	**45** **35.7%**	**25** **19.8%**	**13** **10.3%**	**9** **7.1%**

Notes: All samples are PBZ results for durations of 360 minutes or more and represent 8-hour time-weighted average (TWA) exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

*Includes scrap buggy operator (four samples), yard cleaner operator (one sample), and undercutter operator (one sample).

Sources: NIOSH HETA 90-341-2288, 1993; NIOSH HETA 92-0311, 2001.

NIOSH investigators reported that some ballast was wet because the railroad company required that ballast be washed at the quarry before being loaded into hopper cars. Although some ballast was observed to be wet as it was dumped, pockets of dry ballast were still a source for dust. In general, most cars of ballast were observed to be dry, and dust was created when the ballast was dumped (NIOSH HETA 92-0311, 2001). A Mine Safety and Health Administration contact (2003) familiar with the industry reports that ballast material is probably not washed by quarries on a regular basis and likely depends on the size of the quarry operation as well as the tonnage of the ballast order.

Based on ERG-GI (2008), OSHA finds that the baseline condition for ballast dumpers is best represented by the median for all exposure levels for this job category, as summarized in Table IV.C-36. This is because the data obtained does clearly point to one work condition that occurs most of the time. Thus, the exposure level associated with baseline conditions for ballast dumpers is 25 μg/m^3. In the absence of more detailed information, OSHA considers the results summarized in Table IV.C-36 for ballast dumpers to be the best information available for baseline exposure levels for this job category.

Baseline Conditions for Machine Operators

The exposure profile for machine operators is based on 100 full-shift respirable quartz readings from two NIOSH reports (NIOSH HETA 90-341-2288, 1993; NIOSH HETA 92-0311, 2001). As indicated in Table IV.C-36, the median full-shift PBZ respirable quartz exposure for machine operators is 46 μg/m^3, with a mean of 74 μg/m^3 and a range from 9 μg/m^3 to 440 μg/m^3. Forty-one percent of the quartz readings for machine operators exceed 50 μg/m^3, and 18 percent exceed 100 μg/m^3. Additional controls will be required for these workers.

Sample field observations and information were not provided with these exposure data; hence it is not possible to determine the specific exposure factors associated with these findings. However, it is possible to break down machine operator exposures by machine type (see Table IV.C-36). Although broom operators have a marginally greater potential for exposure to elevated concentrations of silica, they are followed closely by ballast regulators and tamper operators. Limited exposure data (six results) for three other types of machine operators (scrap buggy operator, undercutter operator, and yard cleaning operator) showed exposures to be below 50 μg/m^3 for these workers. However, NIOSH noted that the large amounts of ballast manipulated by undercutting and yard cleaning machines and heavy dust clouds created indicate the potential for these machine operators and adjacent workers to experience overexposure (NIOSH HETA 92-0311, 2001).

NIOSH identified 22 individual full-shift respirable PBZ results for machine operators associated with equipment operator cabs that had been modified (air conditioned, pressurized, and well-sealed) to reduce operator exposure to silica (NIOSH HETA 92-0311, 2001). An analysis of the data for ballast regulators, the only subcategory with comparable numbers of readings for modified and unmodified cabs (n = 14 for both), suggests that the modified cabs provide a moderate degree of protection. The use of modified ballast regulator cabs resulted in a 40 percent reduction in the median full-shift PBZ respirable quartz exposure and a 52 percent reduction in the mean. However, three full-shift PBZ samples for ballast regulator operators in modified cabs exceeded 100 μg/m^3, including a maximum exposure of 330 μg/m^3. NIOSH (NIOSH HETA 92-0311, 2001) investigators suggest that inadequate cab maintenance (broken cab window covered with plastic) might be responsible for at least one of these readings. Elevated operator readings in modified cabs are most likely indicative of a problem with one or more of the dust control features (ERG-GI, 2008).

In addition to the 100 PBZ samples included in the exposure profile for machine operators, 27 full-shift area respirable quartz readings were collected on ballast regulators, brooms, tampers, and a scrap buggy. Samples were taken either inside the cab or within approximately three feet of the operator's

PBZ. Results range from 11 μg/m^3 to 140 μg/m^3, with a median of 50 μg/m^3 and a mean of 54 μg/m^3 (NIOSH HETA 90-341-2288, 1993; NIOSH HETA 92-0311, 2001). Thirteen results (48 percent) exceed 50 μg/m^3, and three results (11 percent) exceed 100 μg/m^3. An additional very high reading of 2,040 μg/m^3 is associated with a less-than-full-shift (225 minute) sample on a back broom. Although these area samples are not direct measures of worker exposure, and are not included in the exposure profile, they illustrate potential significant exposure.

A report by Tucker et al. (1995) confirms the potential for overexposure among maintenance-of-way machine operators. Twenty percent of 81 full-shift PBZ samples collected on ballast regulator and broom operators on timber and surfacing gangs were greater than 100 μg/m^3. Twenty-five percent of the samples collected on track broom operators (a subset of broom operators) exceeded 100 μg/m^3.

Additional Controls

Additional Controls for Ballast Dumpers

The available data indicate that the exposure levels of 77 percent of ballast dumpers are already less than or equal to 50 μg/m^3. For the other 23 percent of ballast dumpers who require additional controls, OSHA recommends substitution of low-silica or silica-free ballast material for high-silica railroad ballast; use of dust suppression; and improved work practices in conjunction with remotely controlled dumping.

Substitution

The silica released during ballast dumping depends in part on the silica content of the ballast material. Ballast material with high silica content (e.g., granite, sandstone, quartzite) will generate dust with high silica content, whereas ballast material with low silica content (e.g., slag products, limestone) will generate dust with reduced silica content. For example, a worker exposed to 1,000 μg/m^3 of respirable dust containing 25 percent silica (e.g., granite) would have a silica exposure reading of 250 μg/m^3. However, if the dust were 1 percent silica (e.g., slag), the worker would have an exposure of only 10 μg/m^3. Slag products are reported to contain less than

1 percent silica (NIOSH HEW Publication No. 75-120, 1974), and the FRA specifies crushed slag as a suitable material for ballast (FRA, 2002).[165]

Dust Suppression

Washing ballast before it is loaded into hopper cars reduces the amount of fine particulate matter generated during dumping. Although there are no data for the railroad industry quantifying the effectiveness of washing ballast, Burgess (1995) reports that in other industries the use of washed sand results in silica exposures that are generally lower than when sand is not pre-washed. Similarly, Plinke et al. (1992) report that increased moisture content decreases the amount of dust generated and that water sprays should be applied to material *before* it reaches a transfer point so that dust has time to absorb the water. Washing ballast would help achieve both of these goals.

However, ballast wetted at the supplier's site might dry prior to reaching the dumping site, as observed by NIOSH (NIOSH HETA 92-0311, 2001). One option is to apply an additional layer of blanketing foam or other sealing chemical suppressant to the top of the rail car at the load-out station. Sealing in the wetted ballast might reduce evaporation and provide an additional type of dust suppression. This chemical sealant system has been used effectively by a quarry in the United Kingdom to eliminate dust emissions during transit, although benefits during dumping were not considered (ECS, 2007). The automated spray bar technology used to seal open rail cars with foam is commercially available in the United States (Midwest-coal-car, 2009).

Alternatively, other types of chemical dust suppressants could be added to the ballast mixture while it is being washed. Some types of chemical dust suppressants (e.g., polymers) have residual benefits, meaning that the dust suppressing properties remain active even after the moisture has evaporated. Another option is to wash the ballast with an organic synthetic fluid that never evaporates and retains its dust-suppressing properties indefinitely (Midwest-Edwards, 2009). Other additives, such as road salts, also can be mixed with the dry ballast. A study by Addo and Sanders (1995) examined three chemical dust suppressants (lignosulfate, calcium chloride, and magnesium chloride) applied to an unpaved roadway for 4.5 months[166]. The study found that compared with an untreated roadway, the suppressants reduced fugitive dust emissions by 50 to 70 percent. In another comparison study, KTA-Tator-Phase 3 (1999) found that silica sand treated with three different types of dust suppressants (names and types unspecified) reduced silica levels during abrasive blasting by 70 percent compared with untreated silica sand. Dust suppressants that help agglomerate small particles and reduce airborne respirable dust from sand should also be helpful where workers handle larger aggregate. OSHA preliminarily concludes that some of this benefit will translate to the less intense activity of ballast handling.

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[165] A NIOSH-sponsored study evaluated the dust generated when various materials (including several types of slag) were used as grit for abrasive blasting. This study concluded that, while low in silica, the dust from slags "have substantially higher levels of some other health-related agents (metals), as compared to silica sand" (KTA-Tator-Phase 2., 1998). Because ballast-handling can also generate airborne dust, OSHA notes that when low-silica aggregates such as slag are used as ballast, employers must evaluate the need to protect workers from other contaminants. See also Section IV.C.22 – Abrasive Blasters.

[166] Individual product information lists products as having little or no environmental impact however specific details of chemical composition are proprietary and OSHA does not possess additional information (Midwest – Edwards, 2009).

If additional dust suppression is necessary at the railroad site, wet methods might include pouring or spraying water over loaded hoppers immediately prior to dumping or spraying the ballast with water as dumping occurs. Because of the difficulty and cost of hauling large quantities of water along the length of the track, the most efficient approach would be to direct water misting/spray systems at the dumping operation. Adding a surfactant to the water, which reduces surface tension and allows the water to better encapsulate particles, also might increase the efficacy of the system (Midwest-Edwards, 2009).

Although OSHA is unaware of commercially available original equipment options including spray systems for railroad ballast cars, OSHA suggests that employers could install mobile spray systems on ballast cars (consisting of a water tank, pump, and directional spray nozzles, as used for mobile rock-crushing equipment [e.g., Komatsu America, 2010]). Water spray application systems can direct water up to 150 feet from the source (Midwest-Edwards, 2009), or approximately two to three railcars. OSHA does not have exposure reduction data specific to the spraying of railroad ballast with water and/or wetting agents; however, ERG-C (2008) reports that a directional mist adjusted for maximum dust control reduced operator exposure by 70 to 90 percent for small-scale high-energy crushing activities (workers breaking concrete with jackhammers). OSHA estimates that a directional mist applied during dumping activities could be equally effective in reducing exposure.

Engineering Controls in Conjunction With Work Practices

Remote operation of hydraulic dump doors on ballast cars has the potential to limit worker exposure to silica during ballast dumping. However, the premise of the control is creating distance between the source of the dust and the worker, not eliminating the dust source. Thus, remote operation ballast dumping requires the use of safe work practices in order to be effective. These include staying upwind of dust sources and avoiding dust clouds generated during remote operation dumping. Although workers observed by NIOSH (NIOSH HETA 92-0311, 2001) experienced difficulties in following these practices, OSHA believes that they can be accommodated in all but the most challenging circumstances. For example, workers should always be able to move up and down the length of the track (and away from the dust source). Even in the confines of narrow right-of-ways, and, with practice, workers can become proficient at monitoring dumping operations from an increased distance from the railcar. Radio remote controls for ballast cars are commercially available, and manufacturer's literature suggests that exposure to silica dust is one of several hazards that operator freedom of movement can help to control (Cattron-Theimig, Inc., no date). As an additional benefit of these remote controls, a major rail equipment manufacturer who adopted the system stated that the remote control system reduced personnel injury (Cattron Group, 2010). Although no quantitative exposure reduction data exist regarding worker positioning in relation to ballast dust, OSHA concludes that exposures will be reduced when workers do not position themselves within or downstream of silica-containing dust clouds.

Additional Controls for Machine Operators

As indicated in Table IV.C-36, additional controls are required for the 41 percent of machine operators who currently experience silica exposures above 50 $\mu g/m^3$. These controls include those recommended for ballast dumpers (substitution of low-silica ballast material for high-silica railroad ballast, washing ballast before loading into hopper cars, use of wet methods or chemical dust suppression before ballast is manipulated by machinery) and the use of properly sealed and ventilated enclosed cabs with positive pressure and filtered air.

Dust Suppression

If necessary, the entire track area can be re-wetted or re-coated with dust suppressant after dumping and prior to performing maintenance operations (for example, if maintenance occurs months or years after the last aggregate dump). However, applying water or chemical suppressants prior to or during dumping will provide dust suppression for multiple dusty operations occurring over days or weeks (e.g., dumping, followed shortly by maintenance). Although no data are available for the railroad industry, very limited data from Sections IV.C.24 – Heavy Equipment Operators and IV.C.3 – Concrete Products (see especially material handlers) suggest that the use of dust suppressants applied to the yard or aggregate piles (including chemical suppressants, water) might limit machine operator exposure to respirable dust that contains silica.

Engineering Controls

OSHA recognizes that some track maintenance equipment are unable to be equipped with cabs. In those situations, the use of material substitution and/or effective dust suppression might be the primary additional control(s) for reducing exposure. However, for the remaining machine operators, enclosed cabs represent a primary control for reducing exposure.

Data presented by NIOSH (NIOSH HETA 92-0311, 2001) clearly show the significance of the exposure reduction that might be achieved with a properly enclosed and sealed operator cab. Two full-shift area samples obtained simultaneously inside and outside of a modified (air-conditioned, pressurized, and properly sealed) ballast regulator cab showed a 97 percent reduction in the concentration of respirable quartz inside the cab. The respirable quartz reading inside the modified cab was less than or equal to 14 $\mu g/m^3$ (sample limit of detection [LOD]), while the corresponding reading outside the modified cab was 440 $\mu g/m^3$.[167] These findings are consistent with Hall et al. (2002), who demonstrated reductions of greater than 90 percent with simultaneous testing inside and outside cabs.

Cab design features discussed in ERG-GI (2008) include enclosed cabs that are air-conditioned, tightly sealed, and positively pressurized, and that pass outdoor makeup air through a high-efficiency filter. NIOSH also recommends several additional cab design features and emphasizes the importance of maintenance and cleanliness (NIOSH 2009-123, 2009). Cabs employing several of these recommendations have achieved efficiencies exceeding 90 percent (Cecala et al., 2005; NIOSH 528, 2007).

An alternative to cabs is the use of dust control kits that are sometimes available from the manufacturer. These kits install local exhaust ventilation designed to reduce the amount of ballast dust released by the activities of heavy equipment during track maintenance. One kit investigated and described in ERG-GI (2008) exhausts dust-laden air from in and around the equipment housing, passes it through a filtration system, and then discharges it to the outside of the housing. According to the manufacturer, these kits are suitable for certain types of track maintenance machines and are usually ordered with the purchase of new equipment. Of the heavy equipment examined here, dust control kits would only be available for brooming equipment. Information regarding the effectiveness of these kits in reducing worker exposure to silica is not available from the manufacturer (HTT, 2003).

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[167] Results reported as "none detected" are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

Broom operators have the greatest potential for elevated exposure, and as an alternative to modifying broom operator cabs, consideration might be given to retrofitting one or more types of broom machines to allow operation by remote control. Brooming operations do not require highly skilled operators and can be easily automated (ERG-GI, 2008).

Feasibility Finding

Feasibility Finding for Ballast Dumpers

Table IV.C-36 shows that 77 percent of ballast dumper exposures are already 50 μg/m^3 or less, and the median for this job category is 25 μg/m^3. Based on this and other information described above, OSHA preliminarily concludes that the silica exposures of all ballast dumpers in the railroad transportation industry can be reduced below 50 μg/m^3. Additional controls will be needed for the 23 percent of ballast dumpers who currently have exposures above 50 μg/m^3. Employers who provide low silica content ballast and dust suppressants (e.g., wet methods), and who require safe work practices will reduce ballast dumpers' silica exposure below 50 μg/m^3. Safe work practices include administrative controls encouraging ballast dumpers to stand at a distance from the dump point (also a good practice to avoid physical injury) and adapting ballast car doors for remote operation, a feature already commercially available to this industry (Cattron-Theimig, no date).

Feasibility Finding for Machine Operators

Based on the information discussed above, OSHA preliminarily concludes that the silica exposures of all machine operators in the railroad transportation industry can be reduced to levels of 50 μg/m^3 or less most of the time. This conclusion is based in part on the finding that 59 percent of machine operator exposures are already at or below this level (see Table IV.C-36). Additional controls will be necessary for the other 41 percent of machine operators who currently experience exposure levels above 50 μg/m^3. When additional controls are needed, employers who provide low silica content ballast, dust suppressants, properly sealed and ventilated cabs with positive pressure and filtered air, and automated broom machines can reduce their machine operators' silica exposure below 50 μg/m^3. This conclusion is based on evidence showing that a well-ventilated and maintained cab can reduce exposures by more than 90 percent. Reducing the highest machine operator reading (440 μg/m^3) by 90 percent, a conservative estimate, yields an exposure of 44 μg/m^3. If the broom machine is too small for an enclosed cab, automated equipment in conjunction with safe work practices can reduce operator exposure below 50 μg/m^3.

Overall Feasibility Finding

OSHA preliminarily concludes that the railroad transportation industry can achieve exposures below 50 μg/m^3 for all workers in this industry through the use of appropriate additional controls as described above.

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Ready-Mix Concrete

Description

Silica-containing materials are used as fine and coarse aggregate ingredients in the manufacture of ready-mixed concrete (ready-mix concrete), which is typically made by mixing portland cement with aggregates and water. The most commonly used silica-containing aggregates include sand, gravel, and crushed stone (U.S. EPA, 2001). Ready-mixed concrete refers to concrete that is delivered to the customer in a freshly mixed and unhardened state (NRMCA-what-is-rmc, 2003). Ready-mixed concrete is produced as a truck mixed (dry batch) or as a central mixed concrete (wet batch). At dry batch facilities, the raw materials (cement and aggregate) and water are added directly to the truck, and the concrete is completely mixed in the truck mixer in the plant yard, while driving to the job site, or at the job site. At wet batch plants, the concrete is prepared in a plant mixer and then discharged after blending into a truck for delivery to the job site (NRMCA-production-of-rmc, 2003).

Concrete batch plants are dispersed nationally and are usually located in areas convenient for the delivery of raw materials (cement and aggregates). A typical facility includes storage areas for the raw materials; tanks and conveyors for holding, mixing, and dispensing raw materials; a computerized control room to weigh, mix, and load materials into trucks; a dispatch room to schedule pickups and deliveries; a yard area to wash and park trucks; a maintenance garage; and offices (Clark et al., 2001). Ready-mixed concrete facilities are classified in the six-digit North American Industry Classification System (NAICS) 327320, Ready-Mix Concrete Manufacturing.

Workers at both dry and wet batch concrete plants perform similar activities. The job categories with potential for exposure to silica include material handler, batch operator, quality control technician, maintenance worker, and truck driver (NIOSH ECTB 233-101c, 1999; Ready-Mixed Contact A, 1999). Table IV.C-37 summarizes the major activities and primary sources of silica exposure in this industry.

Baseline Conditions and Exposure Profile

The following sections describe baseline conditions and the exposure data for each affected job category based on two NIOSH research reports, two OSHA Special Emphasis Program (SEP) inspection reports, and unpublished consultant data obtained from the Georgia and Illinois state consultation programs (NIOSH ECTB 233-101c, 1999; NIOSH EPHB 247-19, 2001; OSHA SEP Inspection Reports 116152638 and 301301313; Wickman et al., 2003; Williams and Sam,

Table IV.C-37

Job Categories, Major Activities, and Sources of Exposure for Workers in the Ready-Mix Concrete Industry (NAICS 327320)

Job Category*	Major Activities and Sources of Exposure
Material Handler	Transferring dry aggregate and cement to bins, hoppers, and storage piles. • Dust from transferring silica-containing raw materials by open material handling equipment, conveyor, or bucket elevator. • Dust from outside piles of aggregates (yard dust).
Batch Operator	Controlling release, weighing, and transfer of aggregates, cement, and water to mixers (plant and/or truck) and discharging of central mixed concrete into haul trucks. • Dust from manual batch operations (approximately 10 percent of ready-mixed concrete facilities have manual batch operations).
Quality Control Technician	Collecting and testing samples of dry raw materials (such as sand and gravel) and concrete. • Dust from collecting and testing samples of raw materials and prepared concrete. • Dust from outside piles of aggregates (yard dust). • Dust from recirculation of settled dust at the plant and construction sites.
Truck Driver	Occasionally (e.g., twice per year) entering and cleaning interior of mixer drum to remove hardened concrete.** • Dust from removing hardened concrete from mixer drums using pneumatic chippers.
Maintenance Operator	Performing maintenance and repair on equipment throughout plant; in some cases using hand tools (such as sledgehammers) to remove residual concrete from inside plant mixing drum. • Dust from changing parts or maintaining equipment in aggregate conveyors and batch plant. • Dust from cleaning cement chute and removing residual concrete from plant mixer.

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the facility.

**Truck mixer drum cleaning is typically performed by truck drivers, but is an infrequent task. Alternatively, this task is increasingly performed at some plants by contractors that specialize in removing hardened concrete from ready-mixed truck drums (NRMCA, 2009). Instead of infrequent exposure, contractors receive regular silica exposure from this activity, perhaps on a daily basis.

Sources: ERG-GI, 2008; NRMCA-what-is-rmc, 2003; NRMCA-production-of-rmc, 2003; NRMCA, 2009.

1999), previously described in ERG-GI (2008).[168] Although limited, these sources represent the best data available to OSHA for workers in the ready-mixed concrete manufacturing industry. Table IV.C-38 summarizes the exposure information for the affected job categories.

Baseline Conditions for Material Handler

The exposure profile shown in Table IV.C-38 suggests that 25 percent of material handlers might be exposed to silica at levels exceeding 50 micrograms per cubic meter (μg/m^3). The eight full-shift results obtained for workers whose job functions include material handling with heavy equipment include two with exposures slightly greater than 50 μg/m^3 (52 μg/m^3 and 57 μg/m^3); the remaining six respirable quartz exposure results were below 13 μg/m^3, the highest sample limit of detection (LOD) reported for these exposures (OSHA Inspection Number 301301313; Wickman et al., 2003).[169] These findings are supported by unpublished consultant data obtained by ERG, which found exposures that were undetectable or "well below the OSHA PEL [permissible exposure limit]" (the data were not included in the exposure profile because documentation is incomplete), and 13 less-than-full-shift (less than 360 minutes) samples presented in NIOSH, OSHA, and Georgia state consultation program documents. Eleven of the 13 less-than-full-shift samples found exposures below the OSHA PEL; the remaining exposures were 71 μg/m^3 and 79 μg/m^3 for the duration of the task, but resulted in 8-hour time-weighted average (TWA) exposure levels less than 50 μg/m^3 (ERG-GI, 2008).

OSHA finds that the baseline condition for material handlers is best represented by the median for all exposure levels for this job category, as summarized in Table IV.C-38. This is because the data obtained does clearly point to one work condition that occurs most of the time. Thus, the exposure level associated with baseline conditions for material handlers is 13 μg/m^3. Of the 8 samples collected for this job category, there are 2 samples associated with enclosed cabs, two samples associated with open cabs, and the rest are associated with various or unspecified conditions (OSHA Inspection Number 301301313; Wickman et al., 2003). In the absence of more detailed information, OSHA considers the results summarized in Table IV.C-38 for ballast dumpers to be the best information available for baseline exposure levels for this job category.

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[168] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) derived from samples of 6-hours or longer, assuming the exposure concentration during any unsampled portion of the shift was the same as the concentration during the period sampled. Unless explicitly stated otherwise, all results discussed in the additional controls section meet the same criteria. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

[169] Results reported as "none detected" are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

Table IV.C-38
Silica Exposure Range and Profile for Workers in the Ready-Mix Concrete Industry (NAICS 327320)

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean (μg/m^3)**	**Median (μg/m^3)**	**Min (μg/m^3)**	**Max (μg/m^3)**		**<25 (μg/m^3)**	**≥25 and ≤50 (μg/m^3)**	**>50 and ≤100 (μg/m^3)**	**>100 and ≤250 (μg/m^3)**	**>250 (μg/m^3)**
Material Handler	8	23	13	10	57		6 (75%)	0 (0%)	2 (25%)	0 (0%)	0 (0%)
Batch Operator	3	11	11	11	12		3 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Quality Control Technician	2	11	11	11	11		2 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Truck Driver (when cleaning hardened concrete from mixer drum)[A]	3	3,467	393	205	9,804		0 (0%)	0 (0%)	0 (0%)	1 (33%)	2 (67%)
Maintenance Operator	5	27	11	11	58		3 (60%)	1 (20%)	1 (20%)	0 (0%)	0 (0%)
Totals	**21**	**513**	**12**	**10**	**9,804**		**14 (66.7%)**	**1 (4.8%)**	**3 (14.3%)**	**1 (4.8%)**	2 (9.5%)

Notes: All samples are personal breathing zone (PBZ) results for durations of 360 minutes or more and represent 8-hour TWA exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

[A] Truck drivers are included here based on their task of removing hardened concrete from the mixer drum, which they perform rarely (e.g., twice per year), but which is associated with extremely high silica exposure levels. This task is sometimes performed by contractors that specialize in removing hardened concrete from ready-mixed concrete trucks. Instead of infrequent exposure, contractors receive regular silica exposure from this activity, perhaps on a daily basis.

Source: ERG-GI, 2008.

Higher exposures to silica might occur if material handling equipment is operated without completely enclosed, sealed, and properly maintained cabs (e.g., one or more cab windows left open, or ineffective filters for a cab air conditioning system). Some material handlers perform other yard-related tasks in addition to transfer of dry aggregate. Such tasks might include operating a hopper or material conveyor. Depending on the task and the level of dust control, somewhat higher silica exposures might occur. However, these exposures can be controlled with water and other dust suppressants within and around the plant.

Baseline Conditions for Batch Operator

As shown in Table IV.C-38, all three full-shift PBZ results for batch operators are below 50 µg/m^3 and less than 12 µg/m^3, one of the LODs reported (NIOSH ECTB 233-101c, 1999; OSHA Inspection Number 11615263814; Wickman et al., 2003). Limited additional results representative of batch operators support this finding and are described in greater detail in ERG's report (ERG-GI, 2008). Additionally, according to industry contacts, about 90 percent of batch operations are automated, and the associated operator exposure is believed to be minimal. Although manual batch operations might still occur at some ready-mixed facilities, OSHA was not able to obtain information regarding potential operator exposure to silica during manual batch mixing. An area sample collected beneath a dry-loading hopper might represent the worst case for batch mixers (as well as truck drivers). The result for this 296-minute sample was 19 µg/m^3 (Wickman, 2004), suggesting that silica exposure during manual batch mixing is low.

Using information obtained in NIOSH, OSHA SEP inspection reports, and unpublished consultant reports, OSHA finds that baseline conditions for ready-mixed batch operators include working within an enclosed booth or office, and that their exposure to silica is typically nondetectable or very low (NIOSH ECTB 233-101c, 1999; OSHA Inspection Number 11615263814; Wickman et al., 2003). All three results in the exposure profile are associated with these baseline conditions.

Baseline Conditions for Quality Control Technician

The exposure information for quality control technicians is limited and based on two exposure results reported in one NIOSH case study assessment (NIOSH ECTB 233-101c, 1999). Both full-shift exposure results (obtained over a 2-day period) are less than the sample LODs and substantially less than 50 µg/m^3. The quality control technician's work tasks included performing office work (100 percent of the workshift on the first day of sampling), dry sweeping the office area, collecting aggregate samples (70 percent of the workshift on the second day of sampling), and conducting offsite visits to construction sites. At the construction sites, technicians work primarily with samples of wet or already-cured concrete.

Task-related exposure for quality control technicians is expected to be limited because silica dust-producing activities are often conducted inside a laboratory fume hood (aggregate and concrete testing) or minimized through the use of wet methods (water and other dust suppressants to minimize yard, traffic, and other dust that might be generated adjacent to or by the quality control technician). Additionally, in an earlier NIOSH survey (NIOSH-IHS, 1995) of six ready-mixed plants, no silica was detected in a 234-minute area sample obtained in the laboratory of one plant. Road dust from the plant lots was the only apparent source of silica. Based on these findings, OSHA estimates that under baseline conditions (local exhaust ventilation [LEV] in the laboratory and controlling adjacent sources of dust) quality control technicians are not likely to be exposed to silica concentrations that exceed 50 µg/m^3.

Baseline Conditions for Truck Driver

Truck drivers spend most of the shift on the road delivering concrete, and thus their exposure from sources at the concrete plant or construction sites is minimal and is not addressed as part of this analysis.[170] However, truck drivers occasionally perform maintenance to remove hardened concrete from the inside of the concrete truck mixing drums. This activity is typically performed twice per year (NRMCA, 2009),[171] but on those occasions the activity subjects truck drivers to extremely high silica exposure levels. The exposure profile for truck drivers includes only results associated with truck drum cleaning (which requires additional controls).

The exposure profile for truck drivers is based on three full-shift PBZ results obtained from a NIOSH research report and unpublished consultant data from the Georgia onsite consultation program (NIOSH EPHB 247-19, 2001; Wickman et al., 2003). All three of the results exceed 100 µg/m^3. The highest result (9,804 µg/m^3) is associated with a driver who used a pneumatic chisel to chip (break up) hardened concrete inside a truck mixer for 362 minutes. Two additional full-shift sample results (205 µg/m^3 and 393 µg/m^3) are based on approximately 90 minutes of chipping time inside truck mixers with a jackhammer (pneumatic hammer).

OSHA also reviewed a large number of partial-shift samples (less than 360 minutes sample time) for workers cleaning truck mixers (ERG-GI, 2008; Strelec, 2008). The 33 partial-shift results range from 69 µg/m^3 to 7,740 µg/m^3, with a median of 770 µg/m^3. Assuming no additional exposure throughout the remainder of the workshift, the 8-hour TWA exposures for the partial-shift samples range from 11 µg/m^3 to 4,894 µg/m^3, with a median of 148 µg/m^3. Seventy-six percent (25 samples) of the 8-hour TWAs exceed 50 µg/m^3, and 67 percent (22 samples) exceed 100 µg/m^3 (ERG-GI, 2008; Strelec, 2008). These partial-shift results generally support the exposure profile in indicating that most results are well above 50 µg/m^3.

Truck drivers who remove hardened concrete from inside truck mixer drums rarely use any dust controls (ERG-GI, 2008; Strelec, 2008). If mechanical ventilation is used, it usually consists of a fan placed over the charge hopper or within the concrete discharge chute to exhaust air out of the mixer drum (ERG-GI, 2008). However, daily truck rinsing (after the mixer is completely discharged and again at the end of the day) is an indirect baseline control that affects the amount of concrete buildup and the resulting airborne silica concentrations when truck drivers do eventually chip concrete from mixer drums. All three results in the exposure profile are associated with baseline conditions, including the practice of rinsing the

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[170] Based on the assumption that truck drivers spend more than 75 percent of the shift (6 of every 8 hours) making deliveries away from the plant, OSHA estimates that typical exposure levels for normal workshifts that do not involve truck drum cleaning would be less than 25 percent of the levels experienced by material handlers in this industry. As indicated in Table IV.C-38, the maximum exposure level for material handlers is 57 µg/m^3; 25 percent of that value results in an estimated maximum daily exposure level of about 14 µg/m^3 for truck drivers. While it is possible that some truck drivers occasionally experience some silica exposure at customer sites (where they deliver concrete), OSHA preliminarily concludes that these exposure levels are also minimal: concrete delivery trucks spend only a few minutes at the site (although they might need to wait on an adjacent road until they can be unloaded), and they are typically on the perimeter of the site where construction dust levels are lowest.

[171] Results of a 2008 NRMCA benchmarking survey (NRMCA, 2009) showed that mixing truck drums were typically cleaned every 6.7 months (average for more than 6 dozen establishments in the ready-mixed concrete industry that responded to the survey).

drum to some extent every day. Therefore, OSHA preliminarily concludes that the median exposure for truck drivers presented in Table IV.C-38 (393 μg/m^3) represents the baseline condition for this job category.

Baseline Conditions for Maintenance Operator

As shown in Table IV.C-38, the median full-shift PBZ respirable quartz level for maintenance workers is 11 μg/m^3 (LOD) with a mean of 27 μg/m^3 (NIOSH ECTB 233-101c, 1999). No silica was detected in three of the five full-shift exposure results for maintenance workers. The other two full-shift results are somewhat higher (43 μg/m^3 and 58 μg/m^3), but less than 100 μg/m^3. These two values reflect work conducted inside the in-plant mixer to remove hardened concrete (with a sledgehammer) during a portion of the work shift.[172] From the information presented in Table IV.C-38, OSHA estimates that approximately 20 percent of maintenance workers might be exposed to silica at levels exceeding 50 μg/m^3 during such activities. This percentage could be higher if pneumatic tools are used, especially pneumatic chippers and chisels; however, the relative convenience of both rinsing and chipping in-plant mixing equipment (compared with truck drums) means less dusty manual methods often suffice for the in-plant equipment.

Based on information obtained from NIOSH-EPHB 247-19 (2001) and Wickman (2004), OSHA finds that maintenance workers also have the potential for silica exposure while working in the plant yard; while working on or near the aggregate conveyors and batch plant; and during the routine removal of hardened concrete inside the plant mixer. Baseline exposure controls include using water and other dust suppression methods to control adjacent sources of dust; using LEV at the loading point of the concrete batch mixing drum; and scheduling preventive maintenance activities for nonproduction intervals. No engineering controls are used while removing concrete residues from inside the mixing drum (ERG-GI, 2008). All three results in the exposure profile are associated with these baseline conditions. Therefore, OSHA preliminarily concludes that the median exposure level for maintenance operators presented in Table IV.C-38 represents the baseline condition for this job category.

Additional Controls

Additional Controls for Material Handler

The baseline conditions for this job category are associated with a median exposure level of 13 μg/m^3; however, Table IV.C-38 indicates that 25 percent of material handlers at ready mix concrete plants experience exposures greater than the proposed PEL of 50 μg/m^3 and will require additional controls to meet this level. Additional controls for material handlers include the use of properly enclosed, ventilated cabs (with air conditioning) in conjunction with dust suppression methods. Cab research conducted by NIOSH (Cecala et al., 2003; Cecala et al., 2005; NIOSH ECTB 233-101c, 1999; NIOSH ECTB 233-127c, 2000; NIOSH HETA 92-0311, 2001) indicates that the use of cabs reduced respirable dust or silica exposures to levels less than 50 μg/m^3, representing 90 to 97 percent reductions compared with silica readings outside the cabs. Where material handling equipment might not be properly sealed and ventilated, and for other yard-related tasks performed by material handlers, the use of effective dust suppression methods will likely reduce silica exposures below the proposed PEL. Exposure observations

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[172] Facilities use in-plant mixers to mix concrete that is then delivered by many trucks, so an in-plant mixer regularly mixes many more batches than does an individual mixing truck. Furthermore, the in-plant mixers have a more open, accessible design than mixing truck drums (although both can meet the criteria for confined spaces). Maintenance operators tend to chip hardened concrete from the in-plant mixers more frequently and for much shorter periods of time than truck drivers chipping concrete from mixing truck drums.

for material handlers at concrete manufacturing facilities that implemented yard dust management controls (e.g., dust suppressants, wetted yard dust, power sweeping) show that levels substantially below 50 µg/m^3 were achieved in almost all cases (NIOSH ECTB 233-112c, 1999; NIOSH ECTB 233-125c, 2000). As shown in Table IV.C-38, the highest result for material handlers is 57 µg/m^3. Therefore, OSHA preliminarily concludes that even a modest improvement in cabs (e.g., ensuring proper sealing and ventilation) and dust management will result in material handler exposure levels less than the proposed PEL of 50 µg/m^3.

Additional Controls for Batch Operator

The three full-shift PBZ exposure results available for batch operators are below the individual sample LODs and well below 50 µg/m^3. OSHA does not expect that the routine activities of batch operators will expose the operators to silica concentrations in excess of 50 µg/m^3, because the batch operator's workstation (i.e., a booth or office) is typically isolated from plant operations. Therefore, additional exposure controls are not required for this job category (ERG-GI, 2008).

If batch operators at the 10 percent of plants with manual batching processes (not automated) experience elevated exposures, silica levels can be reduced by automating the batching process (including adding an operator’s booth) and installing engineering controls such as LEV at the mouth of the concrete batching drum and spray bars on conveyers.[173] As noted previously, automation is the norm for this industry and is already incorporated into the vast majority of plants (90 percent). Automation and LEV used together, as at a concrete ready-mixed wet/dry batch plant described in NIOSH ECTB 233-101c (1999), reduced batch operator silica exposures to levels less than the LOD (reported as 11 µg/m^3) on two sampling dates, each covering the entire 8- to 9-hour shift. Automation permitted the operator to spend most of the shift in the booth. However, silica results obtained for other workers at this plant suggest that the engineering controls also did a good job controlling dust: most silica results for all job categories were below the respective LODs (all 13 µg/m^3 or less) and just one result exceeded the proposed PEL of 50 µg/m^3 (58 µg/m^3 for the maintenance operator who chipped hardened concrete from the in-plant mixer barrel).

Additional Controls for Quality Control Technician

The data and information available to OSHA suggest that the exposure levels of quality control technicians are currently well below 25 µg/m^3. Additional controls are therefore not required for this job category.

Additional Controls for Truck Driver

The exposure data available to OSHA suggests that most truck drivers who remove hardened concrete inside ready-mixed truck mixers have silica exposure levels greater than 100 µg/m^3 on the rare occasions when they perform this task (e.g., twice per year)[174]. Many of these exposures are of short duration and high intensity with some exposures approaching 10,000 µg/m^3. Additional controls are

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[173] The LEV system is described as an unflanged, tapered hood (32 inches by 32 inches) with an average face velocity of 480 feet per minute [3400 cubic feet per minute]. The system is powered by a 40-horse power squirrel cage fan and connected to a bag house containing 48 4-inch bags with a reverse pulse jet cleaning system. The bags are changed annually, but inspected for leaks daily.

[174] Contractors that perform this work might experience the same exposures more frequently.

required to reduce truck driver exposure while removing hardened concrete from inside truck mixers with pneumatic tools. These controls currently include: 1) wet methods, 2) mechanical ventilation, 3) a combination of wet methods and mechanical ventilation, and 4) administrative controls. These options are discussed in the paragraphs below.

Wet Methods

Wet methods for dust control during mixer cleaning include spraying the drum interior with water before and during cleaning and/or using a pneumatic tool equipped with a water spray nozzle. Exposure reductions associated with this method of control range from 70 to 98 percent and are discussed in detail in ERG-GI (2008), which also addresses possible constraints associated with the use of wet methods (such as freezing hazards, slip hazards, and electrical hazards).

Specifically, Williams and Sam (1999) report that a hand-held pneumatic chipper equipped with a water supply hose and spray nozzle reduced worker exposure to silica by 70 percent during concrete truck drum cleaning. Workers periodically spray the interior surface of the drum and have a continuous water spray directed at the chisel point during chipping. The water flow rate is operator adjusted and is described as a controlled mist that does not generate excess water (Sam, 2004). Williams and Sam further report that workers were very comfortable using the water-equipped chipper and that all workers noticed a substantial reduction in dust during chipping. When using this technique, all electrical cords connected to lights or fans near the drum must be plugged into a ground-fault circuit interrupter (Williams and Sam, 1999).

The use of high-pressure and ultra-high-pressure water-blasting (or water-jetting) is an optional cleaning procedure that might be an effective alternative for some ready-mixed concrete companies. High-pressure pump manufacturers market water-jetting cleaning applications for the interior and exterior of concrete mix trucks (Cat, 2003; Gardner Denver, 2003). Additionally, a single-operator ultra-high pressure water wash system for removing hardened concrete inside mixer drums was recently commercialized (Blasters Ready Jet, 2010a). The boom-mounted washer is operated wirelessly from a work platform. No human entry into the mixer drum is required, thus eliminating the dangerous and labor-intensive job of chipping away dried concrete by hand. Limited PBZ sampling conducted by the company in 2009 suggests that the ultra-high-pressure water wash system substantially reduces silica exposures associated with cleaning the interior of mixer drums. Six partial-shift PBZ dust samples (three total dust and three respirable dust samples with sampling durations of 60, 80, and 95 minutes) obtained during "one-pass" demonstration tasks yielded no silica on any of the samples (Blasters Ready Jet, 2010b).[175] OSHA observes that the maximum concentration of *respirable dust* (150 µg/m^3) measured during these test periods suggests that even if silica had been present on the sample filter as a relatively high percentage (e.g., 25 percent)[176] of the respirable dust, the maximum concentration of silica would have been 38 µg/m^3 during periods of intensive drum cleaning.

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[175] OSHA notes that although silica was not detected, depending on the method used to obtain the samples, the LOD could be as high as 100 µg/m^3 for the samples with the shortest duration.

[176] The hypothetical "worst case" value of 25 percent silica in the sample is approximately twice the level reported in respirable dust during truck drum cleaning. NIOSH (NIOSH EPHB 247-19, 2001) found 7 to 13 percent silica in respirable dust air samples obtained over 6 days for truck drivers chipping concrete from mixing truck barrels on two dates. Strelec (2008) reported 7.6 and 16 percent silica in respirable dust samples obtained during truck drum cleaning.

Mechanical Ventilation

Investigators have evaluated various types of mechanical ventilation (LEV, general exhaust ventilation, forced dilution ventilation, and LEV in combination with general exhaust ventilation) alone or in combination with wet methods. For example, in an evaluation of ventilation techniques for cleaning residual concrete from ready-mixed truck drums, NIOSH investigators found that workers who used general exhaust ventilation alone reduced silica concentrations by 25 percent (from 970 µg/m^3 to 730 µg/m^3) (NIOSH, EPHB 247-19, 2001).

The most substantial silica reductions obtained using exhaust ventilation are associated with test scenarios that provided workers with: 1) a combination of LEV-equipped chipping tools and general exhaust ventilation, which achieved a 78 percent reduction in geometric mean, from 970 µg/m^3 to 220 µg/m^3 (NIOSH-EPHB 247-19, 2001); or 2) forced dilution ventilation alone, which resulted in an 81 percent reduction in the median respirable quartz level (reduced from 5,378 µg/m^3 to 1,029 µg/m^3 as calculated from results obtained by Wickman et al. [2003]). However, Williams and Sam (1999) found that the placement of fans was critical and is not effective if air flow direction moves contaminated air across workers' breathing zones.

Combined Control Methods

Strelec (2008) described a ready-mixed concrete facility where a combination of engineering controls, including a water misting device and a push/pull ventilation system, reduced breathing zone silica results. Although the silica level decreased from 1,264 µg/m^3 to 128 µg/m^3, the result still exceeded OSHA's current general industry PEL.[177] Based on information presented by the author, OSHA estimates that the engineering controls, the reduced level of silica in the dust and other work site factors contributed in equal measure to the change in silica exposure level.[178]

Administrative Controls

Administrative controls primarily include implementing good mixer drum rinsing procedures and increasing the frequency of rinsing to prevent or reduce the amount of concrete buildup. Good drum rinsing procedures include a rinse after each load is poured and a triple rinse at the end of each work shift. Additionally, Williams and Sam (1999) reported that construction site conditions can cause a driver to pour concrete from the truck slowly, which can result in excess concrete beginning to harden on the drum wall. In that case, three-quarters-inch aggregate loaded into the drum and rotated for 30 minutes will scour the hardening concrete from the inner surface of the drum and reduce the amount of buildup (the aggregate can then be used in the next batch of concrete).

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[177] At the time of OSHA's initial inspection (exposure levels 1,264 µg/m^3), the facility, which employed 33 truck drivers, had hired two workers from a local temporary employment agency to remove concrete from multiple truck drums (Strelec, 2008). These exposures correspond to the temporary workers.

[178] OSHA calculated the 8-hour TWA concentration of the workers' silica exposure based on the 8-hour TWA respirable dust concentration and the percent quartz in the respirable dust, both provided by Strelec (2008). Before controls, respirable dust was 7,900 µg/m^3 (7.9 mg/m^3) containing 16 percent quartz (1,264 µg/m^3 silica). After controls were initiated, respirable dust was 1,690 µg/m^3 (1.69 mg/m^3) containing 7.6 percent quartz (128 µg/m^3 silica).

OSHA believes work practices that reduce the amount of concrete buildup in drums will reduce the amount of time required later to remove the hardened concrete from the drum. All other factors being equal, a shorter period of drum cleaning during the shift will result in a correspondingly lower full-shift silica exposure level.

Additional Controls for Maintenance Operator

Although the exposure data available to OSHA suggest that 80 percent of maintenance operators in this industry have silica exposures less than 50 µg/m^3, one situation in particular can result in higher levels. Additional controls are required where maintenance operators experience elevated exposures while removing hardened concrete from inside plant mixer drums. The controls available for in-plant concrete mixers are similar to those for concrete mixer trucks. Such controls might include the use of polyurethane drum liners, good rinsing procedures to remove residual concrete before it dries and builds up, increasing the frequency of mixer cleaning, wet methods, and various types or combinations of mechanical ventilation when hardened concrete must be chipped from drums. Wet methods and mechanical ventilation controls applicable to maintenance operators are described in the earlier discussion on truck drivers.

Polyurethane drum liners are available for plant mixers and reportedly reduce the buildup of hardened concrete. Industry sources indicate that polyurethane-lined drums generally require weekly rather than daily clean out. Reducing the amount of concrete buildup should reduce worker exposure to silica during cleaning because less time will be required to remove the buildup (ERG-GI, 2008). OSHA was unable to obtain exposure data demonstrating the potential reduction in silica exposure that might be achieved because of the use of polyurethane-lined drums in plant mixers.

As noted with truck mixer drums, increasing rinse frequency and using good drum rinsing procedures (e.g., rinsing mixers with high pressure water after each batch of concrete) minimizes concrete buildup and the amount of cleaning required to remove hardened concrete (ERG-GI, 2008). In turn, the reduced cleaning time should reduce exposure to silica.

Depending on the method utilized, the additional controls described for truck drivers reduced silica exposures by 25 to 98 percent during drum cleaning. For example, in an evaluation of ventilation techniques for cleaning residual concrete from ready-mixed truck drums, NIOSH investigators found that workers who used general exhaust ventilation alone reduced silica concentrations by 25 percent, from 970 µg/m^3 to 730 µg/m^3 (NIOSH EPHB 247-19, 2001). Assuming that this control would reduce exposure to maintenance operators cleaning plant mixers by a similar amount, the highest levels reported in the exposure profile for maintenance operators removing hardened concrete with a sledge hammer (43 µg/m^3 and 58 µg/m^3) might be reduced by 25 percent to values below 50 µg/m^3 (32 µg/m^3 and 44 µg/m^3, respectively).

Feasibility Finding

Feasibility Finding for Material Handler

Based on the available information, OSHA finds that most material handlers (75 percent) in this industry are currently exposed to silica at levels less than 25 µg/m^3. For the remaining workers, OSHA concludes that the primary option for reducing exposure below the proposed PEL is the use of enclosed operator cabs that are well sealed and ventilated with positive pressure and filtered air. An additional option that will reduce exposures below 50 µg/m^3 is the application of effective dust suppression methods (in yards and during raw material handling), exclusively or in conjunction with enclosed operator cabs.

Cab research conducted by NIOSH (Cecala et al., 2003; Cecala et al., 2005; NIOSH ECTB 233-101c, 1999; NIOSH ECTB 233-127c, 2000; NIOSH HETA 92-0311, 2001) indicates that the use of cabs reduced respirable dust or silica exposures to levels less than 50 µg/m^3, representing 90 to 97 percent reductions compared with silica readings outside the cabs. Exposure observations for material handlers at concrete manufacturing facilities that implemented yard dust management controls show that levels substantially below 50 µg/m^3 were achieved in almost all cases (NIOSH ECTB 233-112c, 1999; NIOSH ECTB 233-125c, 2000).

The data in Table IV.C-38 show that the highest exposure for material handlers is 57 µg/m^3. Therefore, OSHA concludes that even a modest improvement in cabs (e.g., ensuring proper sealing and ventilation) and dust management will result in exposure levels less than the proposed PEL of 50 µg/m^3 for all material handlers.

Feasibility Finding for Batch Operator

The available exposure data suggest that most batch operators are not exposed to silica levels in excess of 25 µg/m^3. The three full-shift PBZ exposure results available to OSHA are less than 25 µg/m^3, and one partial shift (321 minutes) PBZ exposure result from an unpublished consultant report is 26 µg/m^3. Additional exposure controls do not appear to be necessary for this job category. However, in the event that a batch operator is exposed to elevated levels of silica (e.g., because of dust levels at the central mix area or dust tracked into the batch operator's work station), the facility can achieve exposures of 25 µg/m^3 or less for that worker by improving housekeeping and seals on the operator's booth or by improving maintenance on dust controls in the central mix area.

Feasibility Finding for Quality Control Technician

The two full-shift PBZ results for quality control technicians are below 25 µg/m^3. Based on these results and the available information, OSHA does not expect that the routine activities of quality control technicians will generate exposures that exceed 25 µg/m^3. Additional exposure controls do not appear to be necessary for this job category. However, if technicians are exposed to silica while obtaining samples in the raw materials storage areas, their exposure will be reduced when exposures in other job categories are controlled. Other control options for these workers include: 1) implementing administrative policies that allow quality control technicians to avoid dusty plant process areas until dust subsides; and 2) adding LEV (e.g., a laboratory fume hood) in the laboratory.

Feasibility Finding for Truck Driver

As indicated in Table IV.C-38, the silica levels of all truck drivers are greater than 100 µg/m^3, but only on the rare occasions (e.g., twice per year) when the truck drivers chip hardened concrete from their truck mixing drums. However, contractors who move from plant to plant chipping concrete from truck drums perform this activity regularly, perhaps daily.

After reviewing the information presented in this section and in ERG-GI (2008), OSHA preliminarily concludes that the exposure levels of one-third of the truck drivers (those with current exposure levels between 100 µg/m^3 and 250 µg/m^3, as shown in Table IV.C-38) can be reduced to levels of 50 µg/m^3 or less most of the time by using any of the methods listed below along with forced ventilation. Wickman et al. (2003) reported forced air alone reduced exposures by 81 percent; however, OSHA believes that to reliably achieve reductions to this extent, employers will need to combine forced air with either LEV or wet methods.

Additionally, OSHA preliminarily concludes that the exposure levels of most of the remaining two-thirds of truck drivers can be reduced to silica levels that fall between approximately 100 µg/m^3 and 300 µg/m^3 most of the time. The control methods (listed below) that have been used to reach this range of silica exposure are all associated with exposure reductions of at least 70 percent (compared with uncontrolled levels typically less than 1,000 µg/m^3). Furthermore, this range of exposure levels has been achieved by several investigators using various combinations of controls for workers who spent at least half of the sampling period (and usually the entire period) chipping concrete from inside truck mixing drums. The combination of controls described here will reduce most workers' exposures during concrete-mixing truck drum cleaning to levels for which a half-facepiece respirator with an assigned protection factor (APF) of 10 will provide adequate protection.

Examples of controls for truck drivers:

- LEV-equipped chipping tool plus general exhaust ventilation: Silica levels reduced to 220 µg/m^3 (NIOSH EPHB 247-19 [2001]).
- Water misting device and push/pull ventilation system: Silica levels reduced to 128 µg/m^3 (Strelec, 2008).
- Periodic spraying of the interior surface of the drum and directing continuous water spray at the chisel point during chipping: Silica levels reduced to "less than the PEL" (100 µg/m^3 or somewhat less, calculated using OSHA's general industry standard for respirable dust containing silica) (Williams and Sam, 1999).

Additional evidence from Wickman et al. (2003) suggests that forced air dilution ventilation alone can reduce exposure levels to a substantial extent (81 percent), but does not necessarily bring the worker exposure levels down to the same TWA concentration (1,029 µg/m^3) from uncontrolled levels well above 5,000 µg/m^3. However, OSHA believes that this method in combination with one of the methods listed above can achieve results in the same range of approximately 100 µg/m^3 to 300 µg/m^3 for these truck drivers as well (a result of 5,000 µg/m^3 reduced to 1,029 µg/m^3 through forced air dilution might be further reduced by at least 70 percent to 308 µg/m^3 or less by using one of the listed methods). Alternative cleaning techniques, such as high- or ultra-high-pressure water blasting, which is available from a single-source supplier, might also be effective under some circumstances.

Until control methods for truck drivers have been further refined, OSHA preliminarily concludes that facilities will need to provide respiratory protection for these workers.

Feasibility Finding for Maintenance Operator

Based on Table IV.C-38, OSHA finds that the exposure levels of 80 percent of maintenance operators are currently well below 50 µg/m^3. By using one or more additional controls, the remaining operators will achieve results below 50 µg/m^3. Appropriate controls include using polyurethane drum liners, employing good rinsing procedures to remove residual concrete before it dries and builds up, increasing the frequency of mixer cleaning (to reduce the amount of hardened concrete that needs to be removed), using forced dilution or general exhaust ventilation, and using pneumatic tools equipped with LEV or a water spray. Alternative cleaning techniques, such as high- or ultra-high-pressure water blasting, also might effectively control worker exposures to silica during *in-plant* mixer cleaning and eliminate the need to send workers inside the mixer to manually remove hardened concrete buildup. Substantially higher exposure levels that might be associated with the use of pneumatic tools to clean in-plant mixers would require the same controls or combinations of controls as outlined for truck drivers.

Overall Feasibility Finding

OSHA preliminarily concludes that material handlers, batch operators, quality control technicians, and maintenance operators can achieve exposures of less than 50 µg/m^3 most of the time with the controls described in this section. However, OSHA estimates that only one-third of truck drivers are likely to achieve exposures of less than 50 µg/m^3. Based on the available information, respiratory protection will be necessary for the remaining truck drivers.

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Refractories

Description

The refractory products manufacturing industry uses silica-containing materials to produce a wide range of heat-resistant products. Refractory products include oven and furnace linings, investment materials used for casting molten substances (metals and glass), and insulation for high-temperature processes and equipment. Facilities manufacturing refractory products are classified in six-digit North American Industry Classification System (NAICS) codes 327124, Clay Refractory Manufacturing, and 327125, Nonclay Refractory Manufacturing.

The manufacturing facilities in this industry typically produce one or more of the following three distinct product forms: 1) pre-formed refractory items such as fire bricks and custom shapes; 2) glass-like refractory ceramic fibers (RCF);[179] and 3) unshaped powder products, called monolithic refractories. The monoliths are typically sold in sacks and intended to be either cast in place or applied as mortars or coatings at customer facilities (ERG-GI, 2008).[180]

Within each of these general forms, a variety of product types exist, including refractories based on compounds of silica, aluminum, chromium, magnesium, or other minerals. Some examples of common raw ingredients for refractory materials include aluminum silicate clays, aluminum oxide ore, chromium compounds, ceramic frit, ground quartz, and calcined materials (the calcining process can convert any amorphous silica to cristobalite). Refractory materials contain silica either as a key component or as a minor contaminant. For example, new silica-based refractory products can contain upwards of 50 percent ground quartz and cristobalite, while high aluminum clay refractory products might only contain a fraction of a percent of silica. Additionally, this industry recycles a substantial amount of fired refractory material, which might contain cristobalite, as a raw ingredient for new product. As a result of this wide variability in composition, silica exposure can be variable from day to day and product to product within an individual production facility (ERG-GI, 2008).

Workers are potentially exposed to silica throughout all phases of production: when they manually manipulate and mix silica-containing raw ingredients; use dry casting methods to form bricks and shapes; finish cast shapes with grinders and saws; charge or tend melting furnaces used to form ceramic fibers; and package dry powdered refractory materials. See Table IV.C-39 for a description of the major activities and sources of exposures for affected job categories (material handler, forming operator, finishing operator, ceramic fiber furnace operator, and packaging operator). For detailed process descriptions, see ERG-GI (2008). Note that the raw materials, job activities, and production methods used in this industry are similar to those employed by the Structural Clay Products, Concrete Products, Glass Products, and Pottery Products industries (also described in this report).

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[179] Refractory ceramic fiber production accounts for approximately 1 percent (800 million pounds per year) of the total U.S. man-made vitreous fiber manufacture. In total, about 800 workers are involved in RCF manufacturing (RCFC, 1999).

[180] In the mid-1990s, monolithic refractories accounted for 50 percent of the refractories market. Significant improvements in this product type over the previous 20 years account for the widespread acceptance (Heine, 1996).

Table IV.C-39

Job Categories, Major Activities, and Sources of Exposure of Workers in the Refractories Industry (NAICS 327124 and 327125)

Job Category*	Major Activities and Sources of Exposure
Material Handler	Operating forklifts and loaders to transport materials; transferring, weighing, and dumping raw materials by hand or using automated equipment; charging and operating mixing and milling machines. • Dust from manual emptying of bags of silica-containing materials into batch bins, hoppers, mixers, and milling machines. • Dust disturbed during transfer of silica-containing materials using open conveying equipment. • Dust released while operating unventilated, open mixing, or blending equipment.
Forming Operator	Transferring dry or wet mixed ingredients into molds and compacting using automated or manually operated equipment; removing formed product from molds; cleaning molds. • Dust that becomes airborne during compacting of dry silica-containing ingredients using vibrating machinery or mechanical presses. • Dust disturbed during cleaning of molds, surfaces, and floors using brooms or compressed air. Using automated processes to extrude and cut refractory clay brick. • Dust from spilled clay and handling dried bricks (unfired).
Finishing Operator	Cutting, shaping, and grinding products by hand or with semi-automated equipment. • Dust from grinding and sawing fired products by hand or with automated equipment. • Dust disturbed during cleaning of floors and surfaces using brooms or compressed air.
Ceramic Fiber Furnace Operator	Charging melting furnaces with silica-containing ingredients and raking raw materials; operating fiber production equipment; performing housekeeping in the furnace area. • Dust released while charging furnaces with raw materials.[181] • Dust disturbed during cleaning of floors and surfaces using brooms or compressed air.

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[181] Newly manufactured RCF contain little or no silica. Thus, handling raw ingredients presents the greatest opportunity for exposure to silica. Once the raw ingredients are melted (to the amorphous form), silica exposure is unlikely to occur.

Table IV.C-39

Job Categories, Major Activities, and Sources of Exposure of Workers in the Refractories Industry (NAICS 327124 and 327125)

Packaging Operator	Filling bags with loose, dry powder or aggregate products using automated or semi-automated equipment; handling filled bags manually or using automated equipment. • Dust escaping from bag packing equipment. • Dust emitted from newly filled bags during stacking and palletizing activities. • Dust disturbed during cleaning of floors and surfaces using brooms or compressed air.

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the facility.

Source: ERG-GI, 2008.

Baseline Conditions and Exposure Profile

To evaluate silica exposure in refractory product manufacturing facilities, OSHA reviewed personal breathing zone (PBZ) respirable quartz exposure monitoring data from two OSHA Special Emphasis Program (SEP) inspection reports and a NIOSH report, previously described in ERG-GI (2008).[182] Each of these facilities produces multiple product forms (e.g., shapes or bricks, ceramic fibers, packaged monolithic refractory materials). Table IV.C-40 summarizes the full-shift exposure monitoring results for each of the affected occupational categories. Note that the exposure profile for forming operators is based on surrogate data. Exposure monitoring data for each job category are discussed in detail below.

Baseline Conditions for Material Handlers

The 27 PBZ silica results for material handlers range from 13 to 526 micrograms per cubic meter (μg/m^3), with a median of 34 μg/m^3 and mean of 77 μg/m^3. Twelve results (44 percent) exceed 50 μg/m^3, and six results (22 percent) exceed 100 μg/m^3. These results were obtained at the three facilities during manufacture of a variety of products (shapes, bricks, fibers, aggregate).

The six results above 100 μg/m^3 were obtained from all three facilities and are associated with manual bag dumping. These six results range from 120 μg/m^3 to 526 μg/m^3, with a median of 164 μg/m^3

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[182] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) derived from samples of 6-hours or longer, assuming the exposure concentration during any unsampled portion of the shift was the same as the concentration during the period sampled. Unless explicitly stated otherwise, all results discussed in the additional controls section meet the same criteria. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

and mean of 220 µg/m^3. Quartz values were reported for all of these samples, but one contained cristobalite as well. The result for this sample (170 µg/m^3 of total silica) was composed of respirable cristobalite at 100 µg/m^3 and respirable quartz at 70 µg/m^3; however, the report offered no information on the percentages of these types of silica in the materials that this worker handled. Respirable dust concentrations associated with these six elevated samples range from 3,000 µg/m^3 (3 mg/m^3) to 11,000 µg/m^3 (11 mg/m^3), suggesting incomplete dust control during the bag dumping task at all three facilities (ERG-GI, 2008).

Although several silica results below 25 µg/m^3 were obtained for workers dumping bags at some of the same workstations where elevated results were obtained, these values were generally associated with handling of materials with very low silica levels (i.e., silica levels below the limit of detection (LOD), which was less than 1 percent in the sample) and lower respirable dust concentrations (between 1,000 µg/m^3 [1 mg/m^3] and 3,000 µg/m^3 [3 mg/m^3]). These findings likely represent variations in work practices or respirable-size silica content of materials dumped. Other silica results below 25 µg/m^3 were obtained for material handlers operating transportation equipment (e.g., forklift, mullite dump truck) and overseeing automated material conveyance (ERG-GI, 2008).

Table IV.C-40
Respirable Crystalline Silica Exposure Range and Profile for Workers in the Refractories Industry (NAICS 327124 and 327125)

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean (μg/m³)**	**Median (μg/m³)**	**Min (μg/m³)**	**Max (μg/m³)**		**<25 (μg/m³)**	**≥25 and ≤50 (μg/m³)**	**>50 and ≤100 (μg/m³)**	**>100 and ≤250 (μg/m³)**	**>250 (μg/m³)**
Material Handler	27	77	34	13	526		9 33.3%	6 22.2%	6 22.2%	5 18.5%	1 3.7%
Forming Operator[A]	22	47	30	6	238		10 45.5%	6 27.3%	3 13.6%	3 13.6%	0 0.0%
Finishing Operator	8	13	13	13	14		8 100.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Ceramic Fiber Furnace Operators	4	13	14	12	14		4 100.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Packaging Operator[B]	12	32	24	10	118		6 50.0%	5 41.7%	0 0.0%	1 8.3%	0 0.0%
Totals	**73**	**50**	**30**	**6**	**526**		**37** **50.7%**	**17** **23.3%**	**9** **12.3%**	**9** **12.3%**	**1** **1.4%**

Notes: All samples are PBZ results for durations of 360 minutes or more and represent 8-hour time-weighted average (TWA) exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

[A] These data for forming operators are surrogate data from the structural clay, pottery, and concrete products industries. Detailed information of the calculation of the surrogate dataset is described in text.
[B] Excludes one less-than-full-shift sample that was previously reported for a packaging operator in ERG-GI (2008).

Sources: ERG-ceramic-tile, 2001; ERG-GI, 2008.

All three facilities had local exhaust ventilation (LEV) installed for some of their mixing and charging operations. The four results for material handlers definitively associated with LEV are less than or equal to 14 µg/m^3 (the LOD), 36 µg/m^3, 53 µg/m^3, and 87 µg/m^3 (OSHA SEP Inspection Reports 301529053 and 302110408).[183] However, the LEV air velocity provided at one of the facilities was below that recommended by ACGIH (2010) (OSHA SEP Inspection Report 302110408). NIOSH (NIOSH-site-5, 2001) indicated that the facility it visited was equipped with a "dust control ventilation system" in the mixing area, but that it operated intermittently and "disbursed dust from holes in the duct elbows" that had been worn through by abrasion. The report did not indicate which sampling results (if any or all) were associated with LEV at the workstation.

Based on the available literature, OSHA has preliminarily determined that baseline conditions for material handlers include routine manual bag dumping. Ventilation systems for mixing and dumping equipment, if available, have been observed to function sub-optimally (ERG-GI, 2008). In the absence of more definitive information, OSHA has preliminarily determined that the results for material handlers summarized in Table IV.C-40 were obtained under baseline conditions, thus the exposure profile for this job category represent the baseline exposures for material handlers, represented by the median of 34 µg/m^3.

Baseline Conditions for Forming Operators

OSHA identified only one silica result for a forming operator in a refractory products facility: a state agency consultant found no silica in a composite sample associated with a forming operator at a facility that OSHA evaluated (OSHA did not evaluate the forming operator exposures individually). The consultant reported the result as a range of values "0 to 60 µg/m^3" (the LOD in this case, due to a short duration sample) (OSHA SEP Inspection Report 301529053). The report mentions LEV in other plant areas, but not in the forming area, leading OSHA to conclude that LEV was not present for this activity.

In contrast, results from the structural clay, pottery products, and concrete products manufacturing industries offer particularly robust exposure profiles for forming operators in these industries and provide an indication of possible exposure levels associated with forming operators in the refractory products industry. In these three industries, forming operators also perform the same tasks of extruding clay, pressing clay dust into molds, and molding wetted ceramic/concrete slip or slurry, all of which involve silica-containing materials. Based on information presented in ERG-GI (2008), OSHA has preliminarily determined that data from these industries is relevant to the refractory products manufacturing industry and has constructed a surrogate data set of 22 values for this job category based on an appropriately weighted ratio of

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[183] Results reported as "none detected" are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

the 145 results for forming operators from these other industries.[184] Certain refractory ingredients might contain a notable amount of silica, while more commonly factory-cast refractory products (e.g., alumina refractories) contain a very small percentage of silica (typically less than 1 percent [e.g., C-E Minerals, 2006; Washington Mills, 2005]). In contrast, the major ingredients for pottery slip, nonrefractory clay, and concrete most often contain an intermediary amount of silica: up to 30 percent quartz (ERG-GI, 2008). OSHA acknowledges that upper and lower exposure levels anticipated in the refractory products industry might be higher or lower than those in the surrogate industries. Nevertheless, OSHA has determined that this surrogate exposure profile is based on the best data available to represent the forming operators in the refractory products industry.

The 22 values in the surrogate dataset have a median silica exposure of 30 µg/m^3 and a mean of 47 µg/m^3, and range from 6 µg/m^3 to 238 µg/m^3. Six results (27 percent) exceed 50 µg/m^3, and three results (14 percent) exceed 100 µg/m^3.

Some of the highest results from the original datasets (upon which the surrogate exposure profile is based) are associated with workers operating low-moisture clay powder presses at a structural clay (ceramic tile) manufacturing facility where the exhaust ventilation system did not fully capture visible dust at any of the product lines and the ventilation system was disconnected entirely at one press, where the most visible dust was released. In addition, an automated air jet blew residual clay powder from the press mold several times per minute, and dust-laden air entered the pressing area from the nearby spray-drying room (ERG-ceramic-tile, 2001). Another elevated result, the highest value for a forming operator (238 µg/m^3), was obtained in the pottery industry, where forming operators removed products from molds after casting and cleaning the molds (ERG-GI, 2008).

In the absence of more detailed information about baseline conditions for forming operators at refractory product manufacturing facilities, OSHA has relied on information from reports on both the refractory manufacturer mentioned above and the structural clay, concrete, and pottery industry facilities described by ERG-GI (2008). These conditions appear to cover a wide range of working environments, including forming areas without ventilation and some with ventilation that is not operating effectively. OSHA preliminarily determines that the results summarized in the exposure profile were obtained under this range of conditions and that the surrogate median of 30 µg/m^3 can serve as the baseline median for this group of workers.

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[184] OSHA constructed a surrogate data set for forming operator exposure in the refractory products industry based on all 42 results for forming operators in the concrete products industry, all 90 results for forming operators in the pottery products industry, and a subset of 13 results for forming operators from the structural clay industry (excluding results for workers involved with decorative coatings application, as these workers have an additional source of silica exposure not found in the refractory products industry). The mean, median, minimum, and maximum exposures as well as the exposure distribution were calculated from these 145 results from the structural clay, pottery products, and concrete products industries. However, so as to maintain a realistic balance in the exposure profile between the number of forming operators and other refractory product workers, the surrogate data were weighted to fit the refractory product industry by using the following ratio: the number of forming operator results in the surrogate industries (i.e., 145) to the total number of results from all other job categories excluding forming operators in the surrogate industries (i.e., 330 [including workers applying decorative coatings in the structural clay industry]). This ratio was applied to the 51 results in the refractory products industry for job categories other than forming operators; thus, OSHA determined that 22 results are appropriate to represent the proportion of forming operators in the refractory products industry. These 22 theoretical results were distributed across the exposure profile according to the percent distribution calculated from the entire surrogate dataset. No discrete values were assigned to these results.

Baseline Conditions for Finishing Operators

Eight full-shift finishing operator results were identified for a refractory products manufacturing facility visited by NIOSH. On the days that sampling was conducted, finishing operators performed manual grinding on low-temperature fire brick (hydrous aluminum silicate clay and plaster) at ventilated grinding stations. All eight exposures were below the LOD (13 µg/m^3 to 14 µg/m^3), and silica was present only in modest quantities (ERG-GI, 2008).

These results for finishing operators are associated with LEV, which was present on all the manual grinding stations. The adjacent automated grinding machines, drill presses, and saws (not operated during the evaluation) were also fitted with LEV. NIOSH determined that air velocity 1 inch from the 36-inch grinding wheels was 300 feet per minute, with half the grinder/LEV stations operating (volumetric airflow was not provided). However, settled dust in the area and high respirable dust results suggest that the LEV did not completely capture grinding dust. Dust control is further reduced when workers manually open dampers to the remaining grinding stations when those other machines are also in use. Dry sweeping also contributes to the workers' dust exposure (ERG-GI, 2008). LEV or ventilated booths were also associated with manual grinders and automated grinders (respectively) at a second refractory brick manufacturing plant evaluated by NIOSH, but for which no PBZ silica samples were obtained (NIOSH CT-144-19A, 1983).

Based on the information from these two NIOSH reports, OSHA preliminarily concludes that LEV is a baseline condition in the finishing areas of refractory product manufacturing facilities and that the exposure levels summarized in Table IV.C-40 for finishing operators are associated with the baseline condition and a median of 13 µg/m^3.

Baseline Conditions for Ceramic Fiber Furnace Operators

Four results were identified for ceramic fiber furnace operators. Although limited, these represent the best data available to OSHA for ceramic fiber furnace operators in the refractory products industry. NIOSH collected these air samples on two consecutive days at a facility that manufactured refractory fibers. The four results for the furnace operator and production assistant all were less than or equal to the limits of detection (12 µg/m^3 to 14 µg/m^3), despite the fact that silica sand quartz accounted for 50 percent of the ingredients added to the furnace (NIOSH ECTB 233-109, 1999). The furnace operator spent 75 percent of the time in a control room and occasionally checked on equipment or collected samples outside the booth. The assistant spent both shifts working and cleaning around the furnace and fiber production equipment. The furnace was equipped with a low-volume ventilation system (designed to remove heat rather than air contaminants). The production assistant charged the furnace by dumping silica flour into the charge hopper from 2-ton sacks suspended from a pallet jack (NIOSH ECTB 233-109, 1999).

The high-quality sand required for the delicate process of vitreous fiber production is one factor that might contribute to the low silica exposure of furnace operators. Clean, uniform sand particles optimize melting and minimize impurities that can cause problems in the production process or reduce product quality. NIOSH indicated that the silica flour used in spun ceramic fibers was of mesh number 140 or less (meaning the maximum particle size was relatively large compared with respirable-size particles [ERG-GI, 2008]).

The glass manufacturing industry typically uses automated equipment to charge melting furnaces (see Section IV.C.9 – Glass); however, it was not observed at the refractory product facility visited by NIOSH (NIOSH ECTB 233-109, 1999). Based on limited information contained in a NIOSH report, OSHA preliminarily finds that baseline conditions for furnace operators include a control booth for the operator and only heat extraction ventilation on the furnace. Silica ingredients for fiber production are typically sized larger than the respirable range, which might limit respirable-size particles fed to the furnace (ERG-GI, 2008). The results summarized for this job category in exposure profile were obtained under baseline conditions; therefore, the baseline condition is represented by the median value (14 µg/m^3) provided in Table IV.C-40.

Baseline Conditions for Packaging Operators

OSHA identified 12 full-shift silica results for packaging operators in three refractory product manufacturing facilities. The results range from less than or equal to 10 µg/m^3 (the LOD) to 118 µg/m^3, with a median of 24 µg/m^3 and mean of 32 µg/m^3. Only one result (eight percent) exceeds 50 µg/m^3, whereas seven results (58 percent) are 25 µg/m^3 or less.

The highest exposure, 118 µg/m^3, was associated with a worker who spent the 8-hour shift alternating between tending a bag-packing machine and charging blending equipment with the ingredients needed for the next product to be packaged by the bag-packing machine. This latter activity involved manually dumping bags of raw materials into the ventilated charge hopper. A significant source of exposure for this worker was an adjacent bulk-bag filling station, which leaked a substantial amount of dust that was subsequently pulled through the worker’s breathing area by the charge hopper ventilation. Operators at other unventilated bag-packing stations who did not charge hoppers had exposures of 23 µg/m^3, less than or equal to 30 µg/m^3, and 41 µg/m^3 (ERG-GI, 2008).[185] OSHA recommended that the employer add LEV to all packing stations.

NIOSH results from a second facility also suggest that bag dumping and mixing activities are a greater source of exposure than packaging. NIOSH reported four packaging operator results (bag-packing only): one at 19 µg/m^3, and three below the LOD. However, a supervisor who also managed the mixing area had an exposure of 38 µg/m^3 (twice that of highest packaging operator result) (ERG-GI, 2008).

Based on the information from ERG-GI (2008) and NIOSH, OSHA preliminarily concludes that baseline conditions for packaging operators in this industry typically include unventilated bag-packing equipment and potential exposure from adjacent uncontrolled or inadequately controlled processes. The majority of the results summarized in exposure profile were obtained under these conditions. As a result, OSHA estimates that the median exposure level for packaging operators in this industry (24 µg/m^3) represents the baseline exposure level.

Additional Controls

Additional Controls for Material Handlers

As noted in the exposure profile, OSHA preliminary finds that 44 percent of material handlers in this industry currently are exposed to silica levels above 50 µg/m^3 and require additional controls, including improved ventilation at bag dumping stations, associated ventilated bag compactors, and increased use of automated equipment to charge hoppers and mixing equipment.

One control option involves bag dumping stations with properly ventilated enclosures, which capture dust release during both bag emptying and bag disposal. Although no exposure information was identified for refractory products facilities using such bag dumping stations, comparable respirable quartz exposure monitoring data exist for workers using bag dumping stations to empty 50-pound bags of silica-containing materials at a paint manufacturing facility (ERG-paint-fac-A, 1999). A bag dumping station

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[185] At this facility, ingredients for the products the workers packaged could contain up to 20 percent quartz, but were typically in the range of 0.5 to 5 percent quartz (NIOSH ECTB 233-109, 1999).

with fully functioning LEV was found to reduce silica exposure by at least 95 percent. The stations consisted of hoppers topped with grates that were enclosed by LEV hoods. After each bag is emptied, the worker releases it, and suction automatically pulls the bag into the ventilation system and transfers it to an enclosed storage area. Other types of bag dumping stations also have been proven effective (ERG-GI, 2008). Ventilated bag stations are readily available from commercial sources (Carolina Conveying, 2010; Chicago Conveyor, 2004; Flexicon, 2009; Vac-U-Max, 2006a; Whirl-air, 2003).

Automated material transfer equipment also can help reduce dust released as hoppers are filled. A result below the LOD (13 μg/m^3) was obtained for a material handler monitoring automated transfer of raw materials (NIOSH ECTB 233-109, 1999). Although the value of this result is limited by the low silica content of the respirable dust sample (less than 1 percent, the LOD), results obtained in similar industries further demonstrate the value of automated equipment for reducing exposure. For example, at a structural clay facility inspected by OSHA, an 86-percent reduction in respirable quartz exposure readings occurred after management installed an enclosed, automated sand transfer system (OSHA SEP Inspection Report 300523396). The inspection report noted that sand leaked from the conveyor leading to the hopper because it was not the correct size. With tightly sealed components, exposures could be reduced further.

Additional Controls for Forming Operators

Although exposure results are not available for forming operators, surrogate data from related industries suggest that an estimated 73 percent of forming operators already experience exposures below 50 μg/m^3. By controlling dust release from adjacent operations (bag dumping and mixing performed by material handlers), OSHA estimates that roughly half of the operators exposed above 50 μg/m^3 (no more than 14 percent) might achieve the lower level. For the remaining forming operators (13 percent), additional controls include improving maintenance on existing LEV at forming stations or installing new LEV systems, and using wet methods or a high-efficiency particulate air (HEPA)-filtered vacuum rather than compressed air to clean molds.

In particular, combination “push-pull” ventilation—designed to exhaust contaminated air near the source, while supplying a similar amount of clean air behind or above the worker’s head—has been demonstrated to be very effective. Experimental data from Heine et al. (1996) using a dusty flour showed that compared with general ventilation alone, breathing zone total dust concentrations were reduced by 98 percent (from 42 mg/m^3 to 1 mg/m^3 or less) when the work surface was fitted with exhaust ventilation (at the front, side, or as a downdraft) in combination with local clean air supply above the workers head. Although information on the effectiveness of this type of system in refractory product facilities was not available, OSHA believes this type of “push-pull” ventilation system would be similarly effective for reducing levels of silica for refractory products forming operators that work at specific stations.

As noted previously, some of the highest silica exposures, 141 μg/m^3, 144 μg/m^3, and 188 μg/m^3, obtained from a ceramic tile facility with widespread problems of dust control, were associated with poorly functioning LEV and an automated air jet which blew residual clay from molds on an automated clay dust press machine. Improved maintenance on the existing LEV (reconnecting and repositioning exhaust ducts) would improve dust control at individual presses. Further control options focus on limiting dust emitted from the mold cleaning process, which occurs every few seconds. For example better enclosure of the area around the mold and increased exhaust ventilation rate will capture more of the dust disbursed during mold cleaning. Alternatively, use of a HEPA-filtered vacuum brush to clean residual clay from the molds (rather than compressed air) would reduce airborne concentrations of silica; however, this control strategy would require changes to the automated press design.

Additional Controls for Finishing Operators

The exposure profile indicates that finishing operators’ silica results are well below 50 µg/m^3. However, OSHA expects that the exposure profile might underestimate the potential for exposure for finishing operators in the refractory products industry. This is because all of the data in the exposure profile were collected at a single facility during work with alumina-based refractory products that contained only a small percentage of silica. If operators work on materials containing a modestly higher proportion of silica, the existing exhaust ventilation systems will continue to maintain exposures at or below 50 µg/m^3. However, at the limited number of facilities where finishing operators cut or grind high-quartz or high-cristobalite materials (used especially for shaped products such as fire bricks, no data available for the exposure profile), exposures are likely to be significantly higher. At these facilities, additional controls might be required. Appropriate engineering controls associated with finishing equipment include LEV and water-fed equipment.

Although no data are available for cleaning/finishing operators in the refractory products industry, exposure monitoring data from the foundry industry (use grinding equipment to remove residual refractory mold material, typically a mixture of sand and clay, from metal castings) provide good evidence for the effectiveness of LEV. The use of downdraft benches was associated with a 69-percent reduction in mean silica concentration for grinders (OSHA SEP Inspection Report 122040488). Limited data are available to support the use of water-fed equipment with refractory products. OSHA reported a silica concentration of 25 µg/m^3 in the breathing zone of a construction worker using a water-fed stationary masonry saw to cut refractory fire brick during a 340-minute sampling period (less than full shift) (OSHA SEP Inspection Report 113451538). For further discussion of water-fed finishing equipment and LEV, refer to the section on additional controls for finishing operators in Section IV.C.3 – Concrete Products.

LEV combined with wet methods was associated with manual grinders at a second refractory brick manufacturing plant evaluated by NIOSH (NIOSH CT-144-19A, 1983). There, the automated grinders were partially enclosed in a ventilated cabinet, and cutting was performed using a water-fed saw. Although no PBZ silica samples were obtained at this facility, OSHA SEP inspection reports from the stone and stone products industry suggest that a combination of controls can reduce silica levels. For example, the median full-shift PBZ silica exposure level was 30 µg/m^3 for eight sawyers at four facilities that implemented housekeeping in combination with other control measures, such as enclosing the saw in a booth with a fan; pre-washing stone; managing slurry; increasing water flow for wet processes; and controlling dust from adjacent processes (ERG-GI, 2008).

Additional Controls for Ceramic Fiber Furnace Operators

The data in the Table IV.C-40 suggest that the exposure levels of furnace operators handling quartz-containing batch mixes are less than 25 µg/m^3. The exposure results summarized in the exposure profile were obtained using sized ingredients that minimized the amount of respirable particles. Furthermore, a chemical glass manufacturing facility also reported results below the LOD during delivery and transport of size-separated bulk quartz that included a uniform range of particles considerably larger than respirable size (ERG-GI, 2008). Thus, where raw materials containing larger-than-respirable-size particles are used, additional controls would not be required for this job category.

Additional Controls for Packaging Operators

As suggested by Table IV.C-40, most packaging operator exposure levels are below 50 µg/m^3. Ninety-two percent of packaging operators in the refractory products industry already experience exposures of this level or less. However, the results for 8 percent of the workers in the job category (1 of 12) exceed this level. Information presented in ERG-GI (2008) suggests that the exposure levels of most of these workers will be reduced when silica emissions from adjacent operations (e.g., material handling) are better controlled. In some cases, the bag-packing equipment might also require additional controls, which can include adding to and improving existing ventilation at bag filling equipment and hoppers, installing a dual nozzle system on bag filling equipment, and using effective bag valves.

As described in the baseline conditions discussion, the single packaging operator result exceeding 50 µg/m^3 is associated with adjacent unventilated and leaking bulk bag filling equipment. This worker also manually dumped bags of silica-containing material to charge the bag filling equipment. OSHA recommended that the employer add ventilation to the bag filling equipment (ERG-GI, 2008). Additional sources of exposure at typical bag-packaging equipment, noted in a report on the concrete products industry, can include dust generated while bags are filled; when filled bags are dropped and impact the conveyor; and when workers use compressed air to clean their clothing (ERG-GI, 2008). Recommendations for reducing exposures included repairing leaks in the LEV system, installing LEV hoods on the fill nozzles, reducing the distance that filled bags must fall to the conveyor, and prohibiting the use of compressed air to clean clothing.

OSHA SEP inspection results illustrate the effectiveness of well-designed LEV for analogous packaging tasks. At a concrete products facility, installation of a more powerful fan motor and new filter bag for the bag filling machine LEV and moving the hoods closer to the packaging operator’s position reduced respirable dust exposure by 92.5 percent. After these improvements, a packaging operator had a full-shift silica exposure of less than or equal to 11 µg/m^3 (LOD). An inspection at another facility obtained a full-shift exposure reading of 12 µg/m^3 (LOD) for a worker who operated a dry concrete mix bagging machine equipped with a dust collection system (ERG-GI, 2008). Another type of ventilation for bag filling operations, an overhead air supply island system (OASIS) (described in ERG-GI [2008]), has been shown to reduce respirable dust exposure by 98 percent and 82 percent for packaging operators at two mineral processing facilities. OSHA estimates that OASIS would be similarly effective at reducing silica exposures of packaging operators in the refractory products industry.

A dual nozzle system for bag filling machines can also reduce exposures for packaging operators. This system consists of an inner fill nozzle (to load the bag with material) surrounded by an outer nozzle (to depressurize the filled bag and remove dust from bag valve, thereby preventing dust release). This type of system has been shown to reduce respirable dust levels by 83 percent at a mineral processing facility (ERG-GI, 2008). The use of bag valves that seal effectively and prevent product leakage from filled bags is another way to control exposure. Respirable dust exposures were reduced by more than 60 percent with the use of 6-inch extended polyethylene valves compared with standard paper valves, and by more than 45 percent with the use of 4-inch foam valves (ERG-GI, 2008). OSHA estimates that a dual nozzle system and effective bag valves can be used to reduce silica exposures of packaging operators in the refractory products industry.

Bags that break during filling can be a notable source of silica dust and can contribute to operator exposures of two to three times the current permissible exposure limit (PEL). On a busy production line, improperly handled or low-quality bags might break frequently, up to 10 to 20 times an hour (ERG-GI, 2008). In addition, leakage from bags which are inappropriate for the product type can also be a major source of exposure. Workers should be trained on proper techniques for filling and handling bags as well as provided with high-quality bags of a type recommended for the product type, filling equipment, and subsequent handling requirements (ERG-GI, 2008). In one dry concrete bagging facility, changing the type of bag used in packaging from a three-ply bag perforated throughout to a two-ply bag perforated only on the inner layer reduced respirable dust by 83 percent (Klein, 2009).

Feasibility Finding

Feasibility Finding for Material Handlers

OSHA estimates that more than half (56 percent) of all material handlers in this industry already achieve exposure levels of 50 µg/m^3 or less. OSHA finds that by improving or adding ventilation at bag dumping stations and adding ventilated bag compactors, as well as by enclosing and ventilating mixing equipment, the remaining material handlers also will be able to achieve this level. This conclusion is based on results from the paint manufacturing industry indicating that a well-functioning ventilation and bag disposal system at manual charge hoppers can reduce exposures by 95 percent (ERG-paint-fac-A, 1999). Based on the exposure profile, a similar reduction in the Refractory Products industry would yield a maximum exposure of 26 µg/m^3, well below the proposed PEL of 50 µg/m^3.

Based on the information included in this section, OSHA preliminarily concludes that the enclosure and ventilation controls alone will effectively reduce the exposure level of all material handlers to the desired level. However, in the event that further controls are needed for material handlers working with specific refractory materials with very high silica content, automated material transfer equipment is another option. An 86-percent exposure reduction (observed in the structural clay industry for an enclosed, automated sand transfer system) would reduce all but the highest exposure below 50 µg/m^3.

Feasibility Finding for Forming Operators

Based on exposure data from comparable job activities in related industries, OSHA estimates that most forming operators (73 percent) already experience exposure levels below 50 µg/m^3. OSHA finds that by controlling dust released during adjacent material handling activities, increasing maintenance on existing LEV systems in the forming area, and using wet methods to clean molds, this level can be achieved for most forming operators most of the time.

Feasibility Finding for Finishing Operators

Table IV.C-40 indicates that finishing operator exposures are already well below the proposed PEL of 50 µg/m^3. Thus, additional controls are not required for most finishing operators. However, if finishing operators experience exposure levels greater than those indicated in the exposure profile (e.g., when they cut or grind high-silica products), their exposure levels can be reduced through improved LEV on saws and grinders, such as that recommended by ACGIH (2010).

Feasibility Finding for Ceramic Fiber Furnace Operators

Based on the best available exposure monitoring data, OSHA preliminarily concludes that the exposure of all ceramic fiber furnace operators is already less than 50 µg/m^3. Thus, additional controls are not required. However, if higher exposure levels are encountered, the use of sized ingredients can limit the number of respirable particles.

Feasibility Finding for Packaging Operators

As suggested by the information presented in Table IV.C-40, silica levels for most (92 percent) packaging operators are already below 50 µg/m^3. For the remaining packaging operators, whose exposures exceed 100 µg/m^3, OSHA finds that improved workstation ventilation can control exposure to levels of 50 µg/m^3 or less. If further controls are required, a dual-nozzle filling system and/or the use of effective bag valves can reduce exposures. In some cases, the exposure levels of packaging operators will be reduced when facilities control adjacent sources of airborne silica associated with other job categories.

Overall Feasibility Finding

Based on information presented above, OSHA preliminarily concludes that the exposures of all workers in the refractory products manufacturing industry can be controlled to below 50 μg/m^3. This level has already been achieved for many (73 percent) of the workers in this industry.

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Refractory Repair

Description

Refractory materials, also known as refractories, are typically used to line refractory equipment where commercial production processes exceed temperatures of 1,000 degrees Fahrenheit. These readily available refractories are produced with raw materials that include silica-containing minerals such as quartz, cristobalite, bauxite, and fireclay. Refractory materials are used in the construction of furnaces, boilers, cupolas, hot gas stacks, ladle linings, smelting pits, and incinerators. High-temperature applications requiring refractory equipment occur in a wide range of industries, including brick and pottery manufacturing, glass manufacturing, metal casting (foundries), smelting operations, steel production, chemical plants, and waste incineration.

While some facilities utilize their own maintenance workers to repair and replace refractory materials, others subcontract this work to firms that specialize in refractory repair. In-plant foundry workers who handle refractory material are covered in Section IV.C.8 – Foundries. Other industries (as well as most foundries planning to completely reline furnaces) are more likely to use the services of contractors. These workers, who specialize in refractory repair and are addressed in this section, are classified under the six-digit North American Industry Classification System (NAICS) code 423840, Industrial Supplies Merchant Wholesalers. Additionally, the increased automation of many industries means they no longer have enough workers to rapidly perform a large refractory replacement and achieve proper installation (Glass Products Manufacturer G, 2000; Turner and McKelvie, 1997). The use of contractors is common; up to 75 percent of all companies across all industries use a contract service to reline their furnaces (Refractory Products Supplier A, 2010).

Workers who repair and replace refractory materials as their primary activity are typically employed by refractory repair and replacement services contractors. Table IV.C-41 summarizes the job categories, major activities, and primary sources of silica exposure for workers performing refractory repairs. These workers travel to customers' facilities, or, less frequently, customers' equipment is brought to them for refractory relining.

Table IV.C-41

Job Categories, Major Activities, and Sources of Exposure of Workers in the Refractory Repair Industry (NAICS 423840)

Job Category*	**Major Activities and Sources of Exposure**
Contract Refractory Worker	Removing old or damaged refractory material from furnaces and other equipment. • Dust generated by using hand-held or hydraulically controlled demolition tools (e.g., chisels, jackhammers, rakes). Preparing new refractory materials for installation. • Dust released when mixing dry ingredients. • Dust generated by dry cutting bricks with saw. Installing new dry refractory materials. • Dust released by emptying sacks of product. • Dust raised by compacting product with vibrating tools. • Dust released by applying product with air gun. Installing new refractory brick or precast shapes using refractory mortar or grout to seal surfaces and cracks. • Dust raised when handling dry, powdered mortar. Performing cleanup and housekeeping activities. • Dust raised from dry sweeping, shoveling, and transporting silica-containing debris and materials.

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the facility.

Source: ERG-GI, 2008.

The relining process involves two basic steps: 1) removal of the old or damaged lining (or portion thereof), and 2) installation of new or replacement refractory material. The refractory materials are chipped and torn out using hammers, jackhammers, pneumatic chisels (hand-held or mounted on wheeled equipment), and rakes (Grady, 2000; Maxim et al., 1999; Refractory Services Provider A, 2003b). Refractory workers then use shovels, brooms, buckets, and cranes to transfer the resulting waste materials to waste bins. Although refractory workers use remote mechanical removal processes (e.g., hydraulically controlled chisels attached to a small tractor) for as much as 70 percent of their work, nearly all refractory removal jobs require some work with hand-held tools (Refractory Services Provider A, 2003b). Workers use hand tools exclusively in tight spaces and around delicate portions of the equipment.

New linings are applied by various methods; the method depends on the type of lining being installed. In some cases, workers pour and ram (i.e., compact using gas- or electric-powered vibrating equipment) low-moisture powdered refractory materials. These materials also can be blown into place using air guns that introduce a small amount of water into the spray as a "shotcrete"-type operation. Alternatively, refractory workers (sometimes classified as masons) position prefabricated refractory ceramic shapes, bricks, bats, or tiles and use refractory mortar (mixed from powdered product received in sacks) to seal the spaces between the shapes (Grady, 2000). Other lining materials are mixed (in a bucket or tote) from powder and liquid ingredients by refractory workers who then trowel or pour the resulting "plastic" paste into position, in processes similar to plastering or casting concrete. Workers typically perform much of refractory installation work manually, within arm's length of the worker's breathing zone and often within the enclosed confines of the furnace or oven (which might be classified as a confined space).

Refractory workers employed by refractory product suppliers are likely to service a range of industries and work with diverse refractory materials (Glass Products Manufacturer G, 2000; Refractory Products Supplier B, 2004). Refractory workers typically perform a variety of activities during a work shift (e.g., set up, tear out, installation, and cleanup). Several sources suggest that workers rarely remove (demolish) refractory material for a full shift; up to 2 hours per day is more typical, particularly if the job is small (OSHA SEP Inspection Report 122209679; Refractory Services Provider A, 2003a).

Baseline Conditions and Exposure Profile

OSHA has determined that the best available personal breathing zone (PBZ) silica monitoring data for the refractory repair industry are found in two OSHA Special Emphasis Program (SEP) inspection reports (OSHA SEP Inspection Report 108048900, previously described in ERG-GI [2008]; OSHA SEP Inspection Report 300989381).[186] The five results, which are summarized in Table IV.C-42, range from 30 micrograms per cubic meter (µg/m^3) to 196 µg/m^3, with a median of 49 µg/m^3 and mean of 80 µg/m^3. These limited results include three values (60 percent) less than or equal to 50 µg/m^3.

The three results below the proposed permissible exposure limit (PEL) were obtained by OSHA while workers relined a furnace at a customer's facility (ERG-GI, 2008; OSHA SEP Inspection Report 300989381). During the refractory removal process, the workers used a jackhammer and shovel to chip the lining and collect debris. One worker used a crane to transport refractory waste to a trash receptacle, while the other used a "wet vacuum" (and changed the vacuum filter). The samples were also analyzed for cristobalite, but none was detected in the any of the samples. The remaining two results, 90 µg/m^3 and 196 µg/m^3 as quartz (cristobalite was not analyzed), were obtained at a refractory service provider's work site where workers were reconditioning a furnace. These elevated results are associated with two workers who used a jackhammer and crowbar to remove the refractory furnace lining during the entire shift (ERG-GI, 2008; OSHA SEP Inspection Report 108048900).

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[186] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) derived from samples of 6-hours or longer, assuming the exposure concentration during any unsampled portion of the shift was the same as the concentration during the period sampled. Unless explicitly stated otherwise, all results discussed in the additional controls section meet the same criteria. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

Table IV.C-42
Respirable Silica Exposure Range and Profile for Workers in the Refractory Repair Industry (NAICS 423840)

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean ($\mu g/m^3$)**	**Median ($\mu g/m^3$)**	**Min ($\mu g/m^3$)**	**Max ($\mu g/m^3$)**		**<25 ($\mu g/m^3$)**	**≥25 and ≤50 ($\mu g/m^3$)**	**>50 and ≤100 ($\mu g/m^3$)**	**>100 and ≤250 ($\mu g/m^3$)**	**>250 ($\mu g/m^3$)**
Refractory Worker Baseline conditions (manual or semi-remote mechanical processes, general ventilation)	5	80.0	49.0	30.0	196.0		1 20.0%	2 40.0%	1 20.0%	1 20.0%	0 0.0%

Notes: All samples are PBZ results for durations of 360 minutes or more and represent 8-hour time-weighted average (TWA) exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Sources: ERG-GI, 2008; OSHA SEP Inspection Report 300989381.

OSHA also examined other full-shift results for maintenance workers who maintain refractory material in the foundry industry, discussed in greater detail in Section IV.C.8 – Foundries in this technological feasibility analysis (ERG-GI, 2008). OSHA considers much of the information on refractory removal and relining activities by in-plant workers at foundries (and other industrial facilities) to be relevant to contract refractory workers because the workers use common equipment and materials to perform similar activities and processes. The data suggest that in-plant workers in foundries might experience a wider range of exposure than seen in the exposure profile for contract refractory workers (results for the in-plant foundry workers range from less than 50 μg/m^3 to 5,851 μg/m^3). The highest silica reading associated with refractory repair at a foundry was obtained for a maintenance operator who dumped buckets of a dry silica refractory product into a furnace and used vibrating equipment to compact the powder. Other elevated exposures include 265 μg/m^3, 215 μg/m^3, 324 μg/m^3, 456 μg/m^3, and 786 μg/m^3 (ERG-GI, 2008).

These examples from the foundry industry indicate that, at times, refractory removal and relining activities can result in exposures well above 200 μg/m^3 and exceed the levels identified for refractory workers providing contract services. However, OSHA believes the most elevated foundry results might not be typical of the highest exposures likely to be experienced by contract refractory workers. Contract refractory service providers perform the same work on a daily basis and, compared with foundry workers, are more experienced and better equipped to reduce exposure levels during removals by using engineering controls and installing refractory materials in a manner that is less likely to generate dust.

Researchers have extensively studied refractory ceramic fibers (RCF), a special class of refractory material that is typically manufactured containing little or no silica, but can become contaminated with silica where refractory cements are used or if the RCF is exposed to extremely high temperatures. Thus, silica exposures are not expected to occur during installation of RCF, but could be possible during after-service removal activities. Two older studies previously described by ERG (ERG-GI, 2008) reveal that elevated silica exposures can (but do not always) occur during removal of RCF (Cheng et al., 1992; Gantner, 1986); however, more recent data suggests that elevated silica exposure is not common during RCF removal work (Maxim et al., 1999).

In a study designed to investigate possible silica exposure during removal of after-service RCF, Maxim et al. (1999) reviewed 158 personal air samples collected by the Refractory Ceramic Fiber Coalition during 42 different RCF removal projects involving industrial furnaces. The sampling period specifically covered removal of RCF only, and removals typically were completed in less than one full work shift (mean of 260 minutes sample duration). The authors reported a notably lower range of exposures for RCF removal compared with the older studies. All but 14 of the 158 results were below the limit of detection (LOD) for quartz, which ranged from 10 μg/m^3 to 100 μg/m^3.[187] The 14 samples that did contain measurable respirable quartz included 11 results below 30 μg/m^3 and 3 results above 50 μg/m^3 (90 μg/m^3, 100 μg/m^3, and 440 μg/m^3). These results were excluded from the exposure profile because individual sample durations were not provided. Maxim et al. (1999) calculated the mean task-based TWA quartz concentration to be 43 μg/m^3 after conservatively replacing results below the LOD with the LOD value. Cristobalite was detected in three of the 158 samples, suggesting that under conditions of real use, deteriorating RCF forms cristobalite less often than previously suggested. OSHA notes that workers involved in this study might have had additional silica exposure if they removed other non-RCF

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[187] Results reported as “none detected” are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

refractory materials during the same shift, but after-service RCF does not appear to be a significant source of silica exposure for most workers.

OSHA obtained additional information about baseline controls in the refractory material and repair industry from the published literature and industry members. Up to 70 percent of refractory work is performed using hydraulically controlled tools mounted on equipment outside the furnace and a few feet away from the point where dust is generated (Refractory Services Provider A, 2003b). Another semi-remotely controlled process involving a hydraulic “pusher” system is increasingly common for removing refractory lining from cylindrical induction furnaces. Manufacturers now build this capability into all induction furnaces over 4 tons and sell approximately 50 percent of new furnaces with this option (Foundry Products Supplier C, 2000a; Foundry Products Supplier C, 2010).

The ventilation systems routinely associated with high-temperature equipment cannot be considered an effective control for refractory workers. These ventilation systems are designed to exhaust rising fumes or gas during heating and are inadequate to control silica dust generated during periodic refractory replacement activities. The overhead design that is most effective for capturing rising heat exhaust is inappropriate for capturing dust generated on the walls and floor of the furnace because it pulls contaminated air through the worker’s breathing zone. Facilities for which OSHA has process information rarely report that exhaust ventilation is used to reduce the spread of silica (or refractory ceramic fibers). Thus, OSHA estimates that few refractory workers operate with the benefit of local exhaust ventilation (LEV).

Some refractory workers use vacuums for cleanup (Burmeister, 2001; OSHA SEP Inspection Report 300989381). Other sources report at least occasional use of wet dust control methods during refractory demolition or installation, and OSHA assumes that water-fed masonry saws are typically used for cutting firebrick (Burmeister, 2001; OSHA SEP Inspection Report 113451538; Refractory Services Provider A, 2003a, 2003b).

Based on a review of inspection reports, published literature, and industry contacts, OSHA has determined that refractory workers most commonly perform a combination of manual processes and semi-remote mechanical processes in areas with only general ventilation. These are considered the baseline conditions. The median exposure for this job category (49 µg/m^3), presented in Table IV.C-42, is based on results obtained while workers repaired and replaced refractory materials under these baseline conditions.

Additional Controls

The exposure profile suggests that 60 percent of all contract refractory workers are currently exposed to silica levels below 50 µg/m^3. The remaining 40 percent will require additional controls, such as use of low-silica-content refractory materials, preformed materials, local exhaust ventilation, and wet methods; increased use of semi-remote or automated removal processes; improved work practices; and additional worker training. In describing these controls, OSHA has drawn from the experiences of foundries and other industries, whose workers perform work similar to that of contract refractory workers. OSHA expects that these controls will be equally effective for controlling silica exposure during refractory demolition and installation.

Reduced-Silica Refractory Materials

Refractory materials with low silica content (0-5 percent silica compared with 90 percent silica) are readily available from commercial sources, although each low-silica refractory material is not necessarily compatible with every application for which refractory materials are used (Foundry Equipment Manufacturer J, 2000). OSHA visited a foundry that reduced the silica exposure of workers who relined furnaces by 90 percent after implementing a comprehensive exposure control program that included switching to a low-silica gunning refractory applied to furnace walls (for exposure levels reported at this facility, see below in the section on combined control methods) (ERG-GI, 2008; OSHA SEP Inspection Report 122209679). Because the replacement refractory material was stronger and lasted longer, refractory workers also were able to use less material during cupola repair operations.

When switching from high-silica- to low-silica-content refractories, employers will need to consider the possible hazards of substitutes. For example, under high temperatures and oxidative conditions (as in a furnace), the chromite compounds contained in some refractories can be converted to hazardous chromium VI (ANH, 2004; Brenneman, 2010). Because both installation and removal activities can generate airborne dust, employers must evaluate the need to protect workers from other contaminants found in refractories before and after service-life.

Automated and Remotely Controlled Processes

Automated refractory demolition and installation methods can reduce the number of workers exposed, the duration of exposure, and possibly the exposure levels of refractory workers. A “pusher” system installed in coreless induction furnaces allows refractory linings to be automatically pressed out by push plates installed in furnace bottoms. The refractory materials are pushed or extruded out of the furnace, which has been tipped to lie horizontally. Waste falls directly into a disposal bin positioned at the furnace mouth (Foundry Products Supplier B, 2000a). New induction furnaces fitted with push equipment are commercially available, accounting for 50 percent of new furnace sales, and all larger induction furnaces (over 4-ton capacity) have built-in push capability (Foundry Products Supplier C, 2000a; Foundry Products Supplier C, 2010). Additionally, existing furnaces might be retrofitted (Foundry Products Supplier C, 2000a).

Although the push process is reportedly quite dusty, it requires fewer workers and substantially less time than traditional removals. For properly equipped induction furnaces, a “push” removal can be completed in 15 to 30 minutes, while traditional methods might take up to 2 full days of using chipping hammers operated by foundry workers standing or crouching inside the furnace (Foundry Products Supplier B, 2000b; Foundry Products Supplier C, 2000b; Gradmatic, 2000). No data are available to quantify the exposure reduction that a pusher system provides; however, a rough estimate can be made by comparing the relative time spent on the task under each removal method. Assuming that each method generates comparable breathing zone silica concentrations, a 30-minute push process would expose the worker for just 6 percent of a 480 minute shift; thus, exposure would be 94 percent lower for workers using the push process (97 percent lower if the traditional method would take 2 days). In reality, it is also likely that some additional cleanup would be necessary for both removal methods.

For furnaces that cannot be fitted with pusher systems, large amounts of refractory material can be removed using chipping equipment attached to a hydraulically controlled articulated arm commonly available on some types of construction equipment. The operator remains outside the furnace and manipulates the arm from inside the equipment cab. The arm can be fitted with a camera to allow the worker to see the work area. Although this method is not suitable for very small furnaces or work around delicate instrument controls, one company that uses such methods estimates that 70 percent of large-scale lining removal jobs are performed this way (Refractory Services Provider A, 2003b). OSHA estimates that the increased distance between the source of the dust and the worker’s breathing zone and a well-ventilated cab would each substantially reduce worker exposure. Although no data are available for the refractory repair industry, researchers have shown that well-ventilated cabs fitted and maintained to minimize dust can reduce in-cab dust levels by more than 90 percent (Cecala et al., 2005).

Automation also is an option for reducing exposures during furnace relining. Grady (2000) described an automated system for installing dry rammable refractory material in coreless induction furnaces. With this system, 70 percent fewer workers are required to complete the job, and the reported exposure levels during furnace relining ranged from less than or equal to 10 µg/m^3 to 20 µg/m^3 at five foundries using the automated equipment (Gradmatic, 1999). Exposure levels were "significantly above OSHA's PEL" during conventional relining processes using rammable refractories, which involved workers dumping and sieving powdered refractory material, then manually tamping the material in the bottom of the furnace (Gradmatic, 1999; Grady, 2000).

Precast Refractory Materials

Relining of induction and other furnace types also might be accomplished using precast refractory materials that are set in place as units, with minimal risk of exposure. Precast refractory materials can look like typical construction bricks, or they can have more sophisticated geometries that facilitate installation. For example, curved shapes can be cast that sit flush against the furnace wall. The custom-made precast materials are sealed with refractory grout, mixed from a powder (Gradmatic, 2000; Refractory Products Supplier A, 2000). When appropriate for a particular application, preformed refractory shapes can reduce installation labor, improve performance, and provide a longer service life compared with some brick and poured materials. When repairs are required, standard shapes mean that replacement parts can be kept on hand and that repairs can be isolated to the worn section of the lining (eliminating the need for complete tear-out) (TFL, Inc., 2009). Because of these and other advantages, companies are more frequently using precast shapes instead of powdered products (monolithics) for certain applications (Gradmatic, 2000), and the growth of precast refractory shapes in the United States is expected to exceed monolothics in 2011 (Business Wire, 2008).

Work Practices

Work practices, such as limiting the number and location of operators working in a furnace at one time, can reduce refractory worker exposures during removal activities. Sweeney and Gilgrist (1998) reported a higher silica exposure level (170 µg/m^3) for a refractory worker operating in a lower position than a second refractory worker (78 µg/m^3) within an 1,100-pound holding furnace for molten aluminum. The authors reported 8-hour TWAs for both exposures, assuming zero exposure for approximately 1 hour of the 8-hour shift. The worker who experienced higher exposure levels reportedly bent over to grab and toss (to discard) the pieces of refractory material debris while the other worker operated the jackhammer. This put the lower worker's breathing zone closer to the jackhammer's point of operation and dust generation than the breathing zone of the jackhammer operator. However, both workers were overexposed to the respirable dust containing silica (Sweeney and Gilgrist, 1998).

Where faulty equipment contributes to awkward work practices, a preventive maintenance program can help reduce worker silica exposures. Workers experienced an exposure reduction of approximately 90 percent when a foundry initiated several control measures, including a preventive maintenance program to ensure proper function of air guns and related equipment used to spray refractory furnace lining materials (OSHA SEP Inspection Report 122209679). (For exposure levels reported at this facility, see the section below on combined control methods.) In a second foundry, a worker's silica exposure level decreased after a foundry replaced the missing tool restraint on a pneumatic chipper used to remove the refractory lining from a large ladle. The tool restraint eliminated the need for this worker to lean into the ladle (where dust was generated) to hold the chipping blade in place (Burmeister, 2001). This improvement to the tool, in conjunction with other controls, reduced exposure levels of the worker by 70 percent.

Local Exhaust Ventilation

Several options are available to control dust generated when refractory workers must chip or apply refractory linings from a position inside the furnace. In addition to using low-silica materials, appropriate controls include temporary LEV installed in the furnace, LEV on the chipping tool, and wet methods.

A company that provides refractory overhaul services developed a method for installing temporary LEV in a gas-fired furnace. This method is used for complete lining removals, but also is applicable to smaller patching jobs. The method, associated with silica exposures between 50 µg/m^3 and 100 µg/m^3, involves company-built exhaust fans fitted with air filters (three filters of increasing efficiency in series). Plastic sheeting is used as necessary to ensure that fresh air enters the furnace only from the most advantageous point, causing clean air to flow past the worker's breathing zone (Refractory Services Provider A, 2003a). Fan/filter boxes are set into the opposite and lower end of the furnace to exhaust dusty air from near the chipping point (ERG-GI, 2008). The position of sheeting and boxes might need to be moved in order to continue providing optimal air flow as the work progresses to other sections of the furnace. Although the fan/filter boxes are specially built for this purpose, they are made of materials readily available at hardware stores (Refractory Services Provider A, 2003b).

LEV also is a dust control option for refractory workers who empty bags or mix refractory powders. For smaller jobs, workers who dump bags of silica-containing materials can empty the bags into a movable hopper (or other receptacle), then use a flexible sleeve to guide material from the hopper to the distribution point (e.g., a furnace bottom). A portable exhaust trunk (preferably with a semicircular slot or flanged hood) positioned near the bag dumping hopper can capture a portion of the dust released during that activity. Because additional silica exposure can occur when workers compress empty bags, this task also should be located near a portable exhaust trunk. Bag dumping for large jobs can sometimes be eliminated by obtaining powdered materials in bulk bags (e.g., 1-ton sack) filled by the supplier with the predetermined amount of product required for the job. As a standard feature, bulk bags come fitted with a sleeve through which material is dispensed. Bulk bags and sleeves are used for installing high-silica rammable refractory powder in induction furnaces (Foundry Equipment Manufacturer J, 2000; Gradmatic, 1999). Maintaining the bottom of the sleeve, which releases material, at a level just below the surface of deposited material can keep dust emissions to a minimum.

Workers who mix high-silica refractory materials also would benefit from the use of a portable exhaust hood which is similar to the portable exhaust trunk discussed above (both are forms of LEV). The hood is able to capture some of the dust released while workers mix materials. Information from Section IV.C.15 Pottery, shows that the silica exposure of a coatings preparer (mixes silica-containing material) was reduced from 983 µg/m^3 to 47 µg/m^3 after exhaust ventilation was installed at the raw material hopper and the ball mill hatch (ball mill is a type of mixing equipment), and dust leaks were sealed elsewhere in the plant (OSHA SEP Inspection Report 103010542).

Ventilated Chipping Tools

The benefits of tool-mounted systems for controlling silica have been demonstrated in other industries, including the construction and the ready-mixed concrete industries. The chipping of refractory materials is similar to chipping concrete, another silica-containing material. NIOSH tested two tool-mounted LEV shrouds for hand-held pneumatic chipping equipment (impact drills): one custom built, the other a commercially available model. Comparing multiple short-term samples, NIOSH found that the shrouds reduced respirable dust by 48 to 60 percent (NIOSH EPHB 282-11a, 2003).

In a separate evaluation, NIOSH showed that this type of LEV system controls dust equally well for larger chipping equipment. NIOSH collected short-term samples while workers used 25- or 30-pound jackhammers to chip concrete from inside concrete mixer truck drums. During 90- to 120-minute periods of active chipping, mean silica levels decreased 69 percent (from 970 µg/m^3 to 300 µg/m^3) when the workers used a tool-mounted LEV shroud in these enclosed spaces (NIOSH EPHB 247-19, 2001). NIOSH also evaluated a combination of ventilation controls as part of the same study. The tool-mounted LEV shroud plus general exhaust ventilation provided an additional exposure reduction compared with uncontrolled conditions, resulting in a 78 percent decrease in silica readings and a 54 percent decrease in respirable dust levels (the difference was due to a lower percentage of silica in the respirable dust sample associated with the combined control). These ventilated chipping tools do reduce worker exposures from both impact drills and jackhammers. However, compared with equipment without LEV shrouds, their use is more complicated in very tight spaces (such as some furnaces), where maneuvering the additional air hose can be awkward (Refractory Services Provider A, 2003a).

Wet Methods

Wet methods can be successfully used to control silica exposures in a number of operations, including chipping, sawing, spraying, and handling of dusty refractory materials.

Studies have quantified the benefit of using wet methods to control respirable dust generated during chipping with hand-held equipment. NIOSH (NIOSH EPHB 282-11a, 2003) investigated a water spray dust control used by construction workers breaking concrete with 60- and 90-pound jackhammers. A spray nozzle was fitted to the body of the chipping tool, and a fine mist was directed at the breaking point. Using both a direct reading instrument and a high-flow cyclone and filter media, NIOSH collected 10-minute readings with and without the spray activated, and found respirable dust concentrations were between 72 percent and 90 percent lower when the water spray was used (NIOSH EPHB 282-11a, 2003). Williams and Sam (1999) reported that a water spray nozzle mounted on a hand-held pneumatic chipper decreased respirable dust approximately 70 percent in the worker’s breathing zone. Tool-mounted water spray devices can be manufactured using materials obtained from a hardware store and include a garden spray nozzle, tubing, clamps, and a control valve (Hoffer, 2007; NIOSH 2008-127, 2008; NJDHHS, no date; Williams and Sam, 1999). NIOSH completed another study evaluating water spray devices to suppress dust created while jack hammering. The study reported a 77 percent reduction in exposures (NIOSH EPHB 282-11c-2, 2004).

Two more sources also show the effect that water misting devices have on dust control. Beamer et al. (2005) conducted a study of dust suppression using misting nozzles to reduce silica while brick cutting using a stationary saw. The effectiveness of misting at three different flow rates compared with free-flowing water was tested. The respirable mass fractions of dust were reduced by 63 percent with the mist on low (4.8 gallons per hour total flow), 67 percent on medium (8.6 gallons per hour total flow), and 79 percent on high (17.3 gallons per hour total flow). Water-fed saws are readily available and effectively control dust during sawing of concrete, stone, and bricks. Use of a bench-top water-fed masonry saw was associated with a less-than-full-shift (340 minutes) result of 23 µg/m^3 for a worker cutting refractory brick (OSHA SEP Inspection Report 113451538).[188]

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[188] This value is not included in the exposure profile because it was less than full shift.

Water spray also is useful for suppressing dust during cleanup. After chipping, Refractory Services Provider A (2003b) uses a garden mister to wet refractory debris in the bottom of the furnace. This step helps control dust as the waste is removed from the furnace. The same employer also tested high-pressure water blasting as a refractory removal method; the process controlled dust, although workers found it difficult to manage the amount of water released in the process (Refractory Services Provider A, 2003b). This method could be effective in cases where water can be captured efficiently.

Workers must use caution when introducing water into a furnace. Some refractory materials crumble and become muddy or slippery when wet with excessive amounts of water (Cheng et al., 1992; Refractory Services Provider A, 2003a). Additionally, wetting portions of the furnace lining that will not be removed (when making smaller repairs) requires an extra step to dry the refractory material before the furnace is brought to working temperature. However, despite these complications, wet methods remain the best option for controlling silica dust from high-energy activities such as pneumatic chipping and should be considered when high-silica materials are involved. A spray of fine mist directed at the point of dust generation has been shown to be effective. At an open-air location, a flow rate of 350 milliliters (12 ounces) per minute reportedly dried quickly, without adding a substantial amount of water to the work site (NIOSH EPHB 282-11a, 2003). In indoor environments, workers can use a shop vacuum to collect the water (Flanagan et al., 2001), but need to ensure that general dilution ventilation is sufficient and to treat or duct vacuum exhaust air so that it does not become an additional source of exposure in the work area.

Combined Control Methods

Depending on the sources of respirable dust, a combination of control methods can reduce silica exposure levels more effectively than a single method. A routine cupola relining (removal and replacement) in the ferrous foundry industry demonstrates the benefit of a combination of controls by achieving up to a 92-percent reduction in exposures (ERG-GI, 2008). Before implementing controls, OSHA collected samples for three workers with 8-hour TWA results of 270 µg/m^3, 368 µg/m^3, and 630 µg/m^3. This facility then substituted refractory material with reduced silica and greater moisture content, improved equipment and materials to reduce malfunction and task duration, wet refractory material before removal, and assigned a consistent team of trained workers to the task. After the foundry made these changes, a contractor collected silica exposure samples on three dates. The eight 8-hour TWA exposures included six exposures between 30 µg/m^3 and 50 µg/m^3, one exposure of 61 µg/m^3, and one exposure below the LOD (<70 µg/m^3) (ERG-GI, 2008; OSHA SEP Inspection Report 122209679).[189] Reduced silica in the respirable dust sample and shorter exposure times (relining required less time with the improved methods) account for most of the exposure reduction.

A second report on a facility performing refractory relining also demonstrates the benefits of a combination of control measures (Burmeister, 2001). A full-shift silica result of 215 µg/m^3 was obtained while a worker chipped away the old refractory lining using faulty equipment, and then mixed the replacement refractory material. According to the manufacturer's material safety data sheet, the ladle lining contained 56-percent silica. Burmeister noted that the "pneumatic chipper lacked a tool retainer, requiring the worker to hold the chipping bit, putting the worker much closer to the source of the

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[189] One of the results of 30 µg/m^3 was also below the LOD (ERG-GI, 2008; OSHA SEP Inspection Report 122209679).

exposure than would have been necessary had the pneumatic chipper been equipped with a retainer." The foundry responded by holding a training meeting and seeking worker input on abatement actions, implementing a "water control system to reduce dust generated during the pneumatic chipping process," purchasing chisel retainers (thereby eliminating the need for the worker to reach into the ladle during chipping), and purchasing a vacuum to remove dust and debris from the ladle. With these changes in place, a consultant found that exposure was reduced to 74 μg/m^3, representing a 66-percent reduction. OSHA notes that this facility might have achieved still lower silica exposure levels by using LEV or tool-mounted vacuum suction to capture dust, or by managing fresh air flow past the worker's breathing zone.

Feasibility Finding

Based on the information described above and in Table IV.C-42, OSHA preliminarily concludes that exposure levels of 50 μg/m^3 or less have already been achieved for 60 percent of refractory workers by implementing a combination of engineering and work practice controls. The other 40 percent of these workers will require additional controls to meet this level.

Depending on the sources of respirable dust, a combination of control methods can reduce exposure levels more effectively than a single method. These controls include:

- Increased reliance on remote and semi-automated methods for replacing refractory materials.
- Use of portable exhaust ventilation units configured to capture dust as it is generated and design of ventilation to direct fresh air flow past the workers' breathing zone.
- Use of chipping equipment fitted with water mist nozzle or LEV exhaust hood on the tool.
- Use of upgraded spray guns that allow workers better control of the refractory/water mix during spray application.
- Improved worker training.
- Substitution of high-silica refractories with low-silica-content refractory materials and precast refractory shapes that minimize airborne silica exposures.

Use of automated or remotely operated methods can reduce refractory worker exposure levels to 50 μg/m^3 or less. Automated equipment used to install powdered refractory material in an induction furnace reduced foundry worker silica exposures during this operation from "significantly above the OSHA PEL" to 20 μg/m^3 or below (Grady, 2000). This technology is available from a single-source supplier and might be effective in some circumstances.

Additionally, in the foundry industry, the use of a combination of controls has been demonstrated to reduce worker exposures by 66 to 90 percent of the original value, resulting in exposure levels below 50 μg/m^3 in most cases. Two foundries replacing refractory linings using combinations of controls obtained six 8-hour TWA silica exposure results less than 50 μg/m^3 and three results between 51 μg/m^3 and 77 μg/m^3 (the LOD, in the case of this sample) (Burmeister, 2001; OSHA SEP Inspection Report 122209679). OSHA believes that because of more ready access to specialized equipment, such as portable exhaust systems, tool mounted vacuum suction, and water spray tool fittings, contractors performing refractory removals on a regular basis can be expected to achieve lower silica exposure levels (i.e., all results less than 50 µg/m^3) than refractory repair workers (maintenance operators) who previously performed most of this refractory removal work in the foundry industry. For example, Refractory Services Provider A (2003b) described remote chipping equipment attached to a hydraulically controlled articulated arm and used as an exposure control by full-time refractory repair workers, but which is unlikely to be available to a foundry maintenance operator. Furthermore, the trend toward greater use of pre-cast refractory shapes will reduce the exposure level of those who install these materials.

In summary, OSHA preliminarily concludes that refractory repair services can achieve silica exposure levels less than 50 µg/m^3 for most refractory repair contractors most of the time by using a combination of controls.

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Shipyards (Maritime Industry)

Description

The maritime industries encompass all types of facilities that build, repair, salvage, dock, or load ships and boats. Abrasive blasting with silica abrasive is the principal source of silica exposure in the maritime industries and primarily occurs in ship maintenance and repair yards (shipyards). OSHA believes that most other processes performed on maritime industry facilities that can result in worker silica exposure are construction-related activities, which are covered elsewhere in this technological feasibility analysis. Examples of such activities include milling road pavement; grinding, drilling, and sawing concrete or masonry structures; and using jackhammers and impact drills on concrete. For a complete and discussion of construction activities covered by the analysis, please Sections IV.C.22 through IV.C.33.

Ship repairers and boat builders are classified under the North American Industry Classification System NAICS codes 336611, Ship Building and Repairing, and 336612, Boat Building. Shipyard workers generally use abrasive blasting to clean rust, paint, and adhesions from metal surfaces and to etch the surface in order to leave a profile or anchor pattern for paint and coating adhesion.

In the maritime sector, abrasive blasting is acknowledged to be the most effective and efficient means of surface preparation. However, in general, across all U.S. industries, silica sand use in abrasive blasting has declined (USGS, 1998; USGS, 2009). This change is evident in the maritime industry, where other abrasive media have replaced silica sand in many shipyard applications (NIOSH HETA 97-0260-2716, 1997). For instance, the U.S. Navy banned the use of silica sand or any abrasive media containing more than 1 percent silica by weight for abrasive blasting of ship hulls, through its military specification MIL-A-22262B(SH) Amendment 2 in 1996.[190] Moreover, the American National Standards Institute (ANSI) design standard on exhaust systems for abrasive blasting operations at fixed location enclosures prohibits the use of silica sand as an abrasive blasting agent in such operations (ANSI/AIHA Z9.4-1997). This move away from silica sand abrasive is not universal. While many larger shipyards have switched to nonsilica media, some smaller shipyards, with fewer resources, continue to use sand for practical and economic reasons (MACOSH, 2010).

The primary job categories in the maritime industries with potential for exposure to silica during abrasive blasting with silica-containing materials are painters and painters' helpers. However, any workers near the abrasive blasting operation have potential for substantial silica exposure. As in other industries that conduct abrasive blasting, in the maritime industry workers sometimes perform abrasive blasting in an enclosed area, such as in the ballast or bilge tanks or the ship's holds, while on other occasions the work is performed on the ship exterior.

Table IV.C-43 summarizes the job categories, major activities, and primary sources of silica exposure of workers in the maritime industry.

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[190] This specification supersedes one dated April 1993 restricting the use of abrasive blasting media containing greater than 1 percent silica.

Table IV.C-43

Job Categories, Major Activities, and Sources of Exposure of Workers in Shipyards (Maritime Industry) Industry (NAICS 336611, 336612)

Job Category*	**Major Activities and Sources of Exposure**
Painter	Using abrasive blasting equipment to clean and etch surfaces to leave a profile for paint adhesion. • Dust generated from the use of silica-containing abrasive blast media. • Dust generated from abrasive blasting of silica-containing paint. Using sanding equipment to prepare surfaces for application of certain types of paint. • Dust generated from sanding silica-containing paint.
Painter's Helper	Dry sweeping residue generated from abrasive blasting operations. • Dust raised by sweeping spent abrasive material (housekeeping).

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the facility.

Sources: NIOSH ECTB 233-110c, 1999; OSHA SEP Inspection Report 300316627.

Baseline Conditions and Exposure Profile

To evaluate workers' silica exposures, OSHA reviewed personal breathing zone (PBZ) respirable quartz exposure monitoring data from a single NIOSH report (NIOSH ECTB 233-110c, 1999).[191] Although limited, these are the best data available to OSHA. In this report, NIOSH describes a facility, the primary business of which is the construction of marine vessels designed for oceanographic research. The company employs 1,000 workers, 2 to 20 of whom are exposed to silica daily. Painters perform sandblasting with beach sand and typically spend the balance of the shift painting. The designated areas for abrasive blasting and painting movable parts have a hoisted screen curtain and rails to position pieces to be worked. While no controls were in place while NIOSH performed its assessment, the facility indicated that the designated abrasive blasting/painting area location was selected so that prevailing winds would carry aerosol away from the workers (NIOSH ECTB 233-110c, 1999).

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[191] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) calculated assuming no additional exposure during any unsampled portion of the shift. Unless explicitly stated otherwise, all results discussed in the additional controls section are also 8-hour TWAs calculated the same way. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A–-Methodology.

OSHA is concerned that the data presented in NIOSH ECTB 233-110c (1999) for the maritime vessel construction facility (used to develop the exposure profile) do not provide a representative sample of maritime workers overall. These workers are not employed under larger navy contracts, where blast media with silica content greater than 1 percent is prohibited. Nor are they employed by small marina-based shipyards, which are more likely to use silica sand as blast media, but in which individual workers are more likely to have diverse duties and for whom abrasive blasting constitutes only a small portion of any work shift. The demand for maintenance in small shipyards is great. For example, in the United States there are potentially 59,000 smaller fishing vessels requiring routine repair and maintenance.[192] OSHA hopes to obtain additional information on exposures to maritime workers through the rulemaking process.

Baseline Conditions for Painters

Based on descriptions of painters' activities and equipment in the source mentioned above, OSHA preliminarily concludes that baseline conditions for this group of workers involve the use of compressor-powered equipment with dry silica-containing abrasive blast media, but no exposure controls beyond the respiratory protection (supplied-air helmets) required under 29 CFR 1915.34(c)(3)(i) – Mechanical Paint Removers (for general industry 29 CFR 1910.94 and 1910.134). Painters typically perform blasting for 10 to 70 percent of every shift. Painting also can account for a similar percentage of a shift (15 to 70 percent) (NIOSH ECTB 233-110c, 1999).

Table IV.C-44 summarizes the best available data for painters who perform abrasive blasting at maritime facilities in addition to their painting duties. The four exposure measurements for painters have a median of 463 micrograms per cubic meter (μg/m^3), a mean of 1,013 μg/m^3, and a range of 26 μg/m^3 to 3,100 μg/m^3. The highest silica exposure occurred on a day when the painter spent 45 percent of his time sandblasting and 20 percent painting. The lowest exposure occurred for the same painter on the following day when he spent 10 percent of his time sandblasting and 70 percent painting. The two other results (36 μg/m^3 and 890 μg/m^3) were obtained at the same shipyard on the same two days, but involve a second painter who spent 70 percent of the shift sandblasting and 15 percent of the time painting. On both days, the painters prepared for sand blasting during the remainder of the shift (NIOSH ECTB 233-110c, 1999). On the sampling dates both painters performed sandblasting outdoors within a screen enclosure intended to decrease the spread of silica dust to other areas. On other occasions these painters' job duties could include sand blasting inside the vessel.

The only other silica result that OSHA identified in the maritime industry was a partial-shift (202 minute) exposure for a painter at a custom fishing boat builder. OSHA obtained a result of 51 μg/m^3 (22 μg/m^3 as an 8-hour time-weighted average [TWA]) for this worker, who sprayed on and sanded paint that contained silica.[193] The worker utilized both hand and pneumatic sanding and wore a full-face airline respirator (OSHA SEP Inspection Report 300316627). In many cases sanding is not a full-shift activity and workers performing sanding likely spend an equivalent duration of their shifts engaged in painting and other activities not associated with silica exposure.

While the four exposure results in Table IV.C-44 for painters might not provide a representative sample (as noted previously), these are the only data currently available to OSHA. Furthermore, the exposure scenario represents abrasive blasting conditions available to shipyards of any size for any type

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[192] The U.S. Coast Guard estimates that 79,000 vessels could be engaged in fishing activities. Of these, 20,000 are 5 gross tons (GT) or more, and 59,000 are less than 5 GT (Kemerer, 2010).

[193] Because this was not a full-shift sample, the result was not included in the exposure profile.

of vessel. Therefore, in the absence of additional data, OSHA preliminarily concludes that the median of 463 µg/m^3 represents the baseline median for this job category.

Table IV.C-44
Respirable Crystalline Silica Exposure Range and Profile for Workers in Shipyards (Maritime Industry) Industry (NAICS 336611, 336612)

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean (µg/m³)**	**Median (µg/m³)**	**Min (µg/m³)**	**Max (µg/m³)**		**<25 (µg/m³)**	**≥25 and ≤50 (µg/m³)**	**>50 and ≤100 (µg/m³)**	**>100 and ≤250 (µg/m³)**	**>250 (µg/m³)**
Painter	4	1013	463	26	3100		0 0%	2 50%	0 0%	0 0%	2 50%
Painter’s Helper	3	175	160	85	280		0 0%	0 0%	1 33%	1 33%	1 33%
Totals	**7**	**654**	**160**	**26**	**3100**		**0** **0%**	**2** **29%**	**1** **14%**	**1** **14%**	**3** **43%**

Notes: All samples are PBZ results for durations of 360 minutes or more and represent 8-hour TWA exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Source: NIOSH ECTB 233-110c, 1999.

Baseline Conditions for Painters' Helpers

Based on descriptions of painters' helpers activities provided by NIOSH ECTB 233-110c (1999), OSHA preliminarily concludes that baseline conditions for this group of workers include dry sweeping and brushing to clean up between the painters' abrasive blasting and painting activities. These tasks are performed wherever painting will occur, including in confined spaces (e.g., vessel engine room) and outdoors on deck. For respiratory protection, painters' helpers wear filtering face-piece respirators while dry sweeping.

The painters' helpers evaluated in NIOSH ECTB 233-110c (1999) spent their entire shifts dry sweeping and using a hand brush; the three sampling results are summarized in Table IV.C-44. These values have a median of 160 µg/m^3, a mean of 175 µg/m^3, and a range from 85 µg/m^3 to 280 µg/m^3, with the lower level associated with the worker who swept the deck. The two higher values were obtained for two helpers who spent all or part of their shifts dry sweeping in the enclosed engine room.

The sampling results for painters' helpers in the maritime industry were obtained during the typical baseline conditions; therefore, OSHA preliminarily concludes that the median of 160 µg/m^3 represents the baseline median.

Additional Controls

OSHA recognizes that the data used to develop the exposure profile are sparse for determining additional controls for this activity. OSHA hopes to obtain additional information as part of the rulemaking process.

In the absence of additional information specific to silica in the maritime industry, OSHA has relied on details regarding additional controls available for abrasive blasting workers in the construction industry and other industries. As noted previously, maritime industry workers regularly perform abrasive blasting both in enclosed areas (e.g., ballast or bilge tanks, ship's holds) and on the ship exterior (decks and hull). OSHA considers examples for abrasive blasting in the construction industry to have some similar characteristics, particularly when construction workers perform abrasive blasting on large tanks (interiors and exteriors).

Additional Controls for Painters

Painters are potentially exposed to very high levels of silica. Since workers in this job category spend varying amounts of time performing blasting, exposures range from below 50 µg/m^3 to above 3,000 µg/m^3. Two of the four results (50 percent) for painters summarized in Table IV.C-44 are above 250 µg/m^3, and these workers will require additional controls. The remaining two of the four results (50 percent) are already less than 50 µg/m^3.

Controls are required not only to protect the painters performing blasting, but also the painters' helpers and any workers adjacent to the blasting operation. Workers who use silica-containing media to perform abrasive blasting in maritime industry facilities will benefit from the following exposure control options, some of which are outlined elsewhere in this technological feasibility analysis (e.g., Section IV.C.22 – Abrasive Blasters) and repeated here for convenience.

- Abrasive blasting with wet methods or other processes that reduce or eliminate dust generation.

- Automated and/or enclosed (shrouded) abrasive blasting equipment.
- Abrasive blasting cabinets for small and medium-sized parts.
- Low-silica and silica-free abrasive blasting media substitutes that are less toxic than silica sand.
- Enclosures, such as containment structures (which protect adjacent workers only).
- Local exhaust ventilation (LEV) of enclosures (with proper filtration to protect adjacent workers).

Wet Methods

Wet abrasive blasting methods will reduce the silica exposure levels of maritime workers who use silica sand. The exposure profile in Section IV.C.22 – Abrasive Blasters shows a median silica exposure of 230 µg/m^3 and a range of 12 µg/m^3 to 29,040 µg/m^3 for abrasive blasting operators performing dry, uncontrolled blasting without a booth or cabinet. In contrast, for abrasive blasting operators performing wet blasting without a booth or cabinet, the median silica exposure is 125 µg/m^3, and exposure levels range from 36 µg/m^3 to 407 µg/m^3. These values demonstrate the extent to which wet blasting can reduce exposure levels. It should be noted, however, that the construction industry data for both dry and wet abrasive blasting include samples collected under a variety of conditions, including some results obtained while workers used low-silica or silica-free abrasive blast media while blasting on silica-containing substrates, such as concrete.[194] The maritime exposure profile only includes sample results associated with dry silica-containing blast media, which OSHA considers more typical of shipyards and marinas. Although these differences exist between the two industries, the plentiful results from the construction industry offer valuable insight into aspects of abrasive blasting that also affect the maritime industry (e.g., benefits of wet abrasive blasting).

Wet Methods and Alternatives to Dry Abrasive Blasting with Silica Sand

Many of the alternative methods for dry abrasive blasting (listed in Table IV.C-45) have been tested in shipyards, where the large expanses of near-flat surfaces available on ship decks and hulls provide optimal surfaces for comparative trials. Many of these methods effectively remove paint and eliminate worker exposure to silica by completely enclosing or eliminating use of silica-containing blasting media or eliminating the process of abrasive blasting (substituting another process, such as grinding paint off the surface).

Some of the alternative abrasive blasting methods also offer some reduction in airborne exposure to other contaminants (e.g., metals) from the surface coating being removed. For example, Flynn and Susi (2004) also reviewed vacuum blasting and automated, robotic systems for paint removal. Vacuum blasting demonstrates the potential value of a well enclosed and well ventilated process. Using this technology, worker lead dust exposures were controlled to a considerable extent, from a geometric mean of 4,200 µg/m^3 during open blasting to 55 µg/m^3 during vacuum blasting (a 98.6 percent reduction). Although these lead results cannot be translated directly to silica exposure levels, they suggest that dusty air was captured to a large extent during the abrasive blasting. Exhaust ventilation systems do not discriminate between lead dust and silica dust.

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[194] The construction industry abrasive blasting data represent 8-hour TWA exposure levels, calculated with the assumption that no additional exposure occurred during any unsampled portion of the shift. Additional data would help OSHA better determine whether exposure times for maritime workers performing blasting are similar to construction industry patterns.

Furthermore, automated and semi-automated versions of hydroblasting, centrifugal wheel blasting, and vacuum blasting equipment offer quality cleaning of flat or gently curved surfaces (particularly beneficial for exterior hulls) while workers performing blasting stand at a distance from the surface being blasted. Each of these automated methods are challenged by corners, fittings, and sharp bends in the surface, where workers must still use mechanical stripping (needle gunning, grinding) or traditional abrasive blasting to finish the job. Additionally, these alternate methods result in different anchor patterns on the bare metal than traditional abrasive blasting, so workers require technical expertise to match alternate surface cleaning methods to the surface metal and paint system to be applied.

Table IV.C-45

Examples of Alternatives to Dry Abrasive Blasting

Name	**Description/Comments**
Wet Abrasive Blasting	Can be used in most instances where dry abrasive blasting is used. Includes: 1) compressed air blasting with the addition of water into the blast stream before the abrasive leaves the nozzle, and 2) water jetting with the addition of abrasive into the water stream at the nozzle. Additives and rust inhibitors might be used.
Hydroblasting	<u>High Pressure Water Jetting:</u> Uses pressure pump, large volume of water, and specialized lance and nozzle. Pressures range from 3,000 to 25,000 pounds per square inch (psi). Can remove loose paint and rust; will not efficiently remove tight paint, tight rust, or mill scale. Can be used in most instances where abrasive blasting is used. Primary application is for an older surface rusted in a saline environment rather than new steel. Rust inhibitors could be required to prevent flash rusting <u>Ultra-High-Pressure Water Jetting:</u> Similar to high-pressure water blasting. Uses pressurized water from 25,000 to 50,000 psi. Removes tight paint and rust, but not mill scale.
Centrifugal Wheel Blasting	Uses a rotating wheel assembly inside an enclosure equipped with a dust collector. Abrasive is propelled outward from the rotating wheel and removes rust, paint, and mill scale. Abrasives are recycled and include steel shot, steel grit, cut wire, and chilled iron grit. Generates no airborne dust or high velocity particles.
Vacuum Blasting	Uses standard blast nozzle inside a shroud (head) that forms a tight seal with the work surface. Vacuum is applied inside shroud during blasting to remove dust and debris. Abrasives are recycled and include aluminum oxide, garnet, steel shot, steel grit, and chilled iron grit. When used properly, cleans effectively with minimal dust.
Dry Ice Pellets	Dry ice blast cleaning with solid carbon dioxide. Waste is minimized and includes paint chips and rust. Storage and handling costs can be substantial.
Thermal Stripping	Uses a flame or stream of superheated air to soften paint, allowing for easy removal. Generates one waste stream (i.e., waste paint). Effective for small parts; not suitable for heat-sensitive surfaces. Very labor intensive.
Chemical Stripping	Uses hazardous chemical strippers such as methylene chloride-based or caustic solutions. Effective for small fiberglass, aluminum, and delicate steel parts. Requires adequate ventilation and other safety measures. Generates multiple waste streams (i.e., contaminated rinse water and waste strippers).

Table IV.C-45

Examples of Alternatives to Dry Abrasive Blasting

Name	**Description/Comments**
Mechanical Stripping	Involves chipping, grinding, sanding, or scraping the coating off small parts or surfaces through the use of needle guns, chipping hammers, sanders, and grinders. Generates paint waste and airborne dust. Some power tools are equipped with dust collection systems.

Sources: U.S. EPA, 1991; Kura et al., no date.

For shipboard use, low-silica substitutes and silica-free blasting media that are less toxic than silica sand offer another option for exposure control in areas where automated and semi-automated methods are impractical (most interior spaces and spaces with small surface areas, multiple fittings, or corners and angles) and most places where sand is used. As noted previously, some shipyards are already using this control method extensively to meet customer specifications. However, a NIOSH-sponsored study (described in more detail in the Section IV.C.22 – Abrasive Blasters) notes that even blasting operations using media with low silica content and nonsiliceous substrates can result in elevated airborne concentrations of silica. Silica exposure readings ranging from 240 μg/m^3 to 3,690 μg/m^3 were obtained for abrasive blasting operators during trials conducted by a consultant to NIOSH in an environmentally controlled laboratory with garnet and copper slag media, which both contain low amounts of quartz (KTA-Tator-Phase-1, 1998). Other investigators measured geometric mean silica concentrations of 5,000 μg/m^3 and 6,900 μg/m^3 in the breathing zone of abrasive blasters removing paint from foot bridges using recycled coal slag or steel grit (Meeker et al., 2006). Both studies also indicated the presence of other toxic substances, even in clean abrasives. Based on these studies, OSHA has determined that alternative blast media must be selected carefully.

NIOSH ECTB 233-110 (1999) notes that changing technology in the mid-1990s eliminated the need for some shipyard abrasive blasting by better preparing steel through automated shot blasting, reportedly 20 times faster than manual abrasive blasting, and anti-oxidant coatings. The resulting steel requires less abrasive blasting at the ship yard than it once did.

Another control method for workers who abrasively blast smaller, removable parts is the use of ventilated enclosures (e.g., ventilated abrasive blasting cabinet), which will isolate the abrasive blasting media and should limit (or eliminate) worker exposures to silica. In addition, proper work practices and housekeeping practices that reduce dust emissions are essential to controlling the exposures of painters and adjacent workers.

Maritime employers following 29 CFR 1915.34(c)(3)(i) protect painters from a wide range of hazards by equipping these workers with hoods and NIOSH-certified airline respirators or positive-pressure air helmets for abrasive blasting. In contrast, when maritime employers follow 29 CFR 1910.134 because they are using synthetic abrasive blasting media that contains less than 1 percent silica, they must determine the appropriate respirator by assessing the potential hazards to which painters will be exposed. For example, they will need to consider the proposed silica permissible exposure limit (PEL) of 50 μg/m^3

when selecting a respirator that offers adequate protection. For additional information regarding respiratory protection requirements for workers exposed to silica, see paragraph (g) of the proposed rule.

Additional Controls for Painters' Helpers

The three exposures for painters' helpers exceed 50 µg/m^3, as presented in the exposure profile in Table IV.C-44; therefore, additional controls are required to reduce the exposure of all these workers (100 percent) to levels of 50 µg/m^3 or less. The same controls for and alternatives to dry abrasive blasting with silica sand outlined for painters will benefit the helpers (regardless of the helpers' duties) to at least the same extent as those methods benefit the painters themselves. Automated, enclosed (e.g., isolating), or shrouded dry abrasive blasting methods, which employ some form of vacuum suction device to capture the media, will produce less dust and debris, which later will require less cleaning by the helpers. Wet methods such as wet abrasive blasting will limit the spread of dust and prevent silica dust from becoming airborne to the extent that the helpers can clean up the spent media while it is still damp. Low-silica substitutes and silica-free blasting media that are less toxic than silica sand will generate dust with lower silica content and reduce painters' helpers' exposures during cleaning.

Using vacuums, shovels, and scrapers to clean surfaces introduces less dust into the air than dry sweeping. Although these alternate methods have not been evaluated for abrasive blasting media and debris, Riala (1988) completed a study of Finnish construction site workers that compared the silica exposures for workers dry sweeping or using alternate cleaning methods. When compared with dry sweeping, exposures were approximately three times lower when the workers used squeegees to scrape surfaces, and approximately five times lower when workers used vacuums (Riala, 1988).

Based on the information presented here and in Section IV.C.22 – Abrasive Blasters, OSHA preliminarily concludes that the exposure levels of painters' helpers can be reduced by providing high-efficiency particulate air (HEPA)-filtered vacuums for cleaning. NIOSH recommends vacuuming with an approved HEPA-filtered vacuum (or the use of wet cleaning methods) as a method to minimize worker exposure to hazardous air contaminants such as asbestos, silica, and heavy metals during housekeeping activities in numerous industries (ERG-GI, 2008). Furthermore, when vacuum blasting was used for an abrasive blasting task, painter lead exposure levels were reduced by 98.6 percent (Flynn and Susi, 1999). A HEPA-filtered vacuum uses similar suction and filtration technology without an internal blasting component (an intense, high energy source of silica exposure), so will capture settled dust (very low energy) even more efficiently. Even if the HEPA vacuum is assumed to capture dust only 85 percent effectively, it would reduce the highest painters' helper silica exposure level from 280 µg/m^3 to 42 µg/m^3.

Feasibility Finding

Feasibility Finding for Painters

Based on information presented in Table IV.C-44, OSHA preliminarily concludes that among maritime industry painters that use sand as a blasting agent, 50 percent currently experience exposure levels of 50 µg/m^3 or less, primarily because they perform abrasive blasting in open air and only for a brief period of time during the shift.

OSHA also preliminarily concludes that the silica exposures of the remaining 50 percent of painters in this industry performing manual abrasive blasting using silica sand can be reduced somewhat by switching to wet abrasive blasting, but will not reach levels of 100 µg/m^3 or less even using wet methods. This determination is based on exposure results for abrasive blasting operators in the construction industry using wet abrasive blasting methods (see Section IV.C.22 – Abrasive Blasters).

Exposures for these operators show a median silica result of 125 µg/m^3 (range of 36 µg/m^3 to 407 µg/m^3) compared with a median exposure of 230 µg/m^3 (range of 12 µg/m^3 to 29,040 µg/m^3) for abrasive blasting operators performing dry, uncontrolled blasting.[195]

During open abrasive blasting using silica-containing media, engineering and work practice controls alone will not be sufficient to achieve painter exposure levels at or below the proposed PEL of 50 µg/m^3. In order to protect workers, employers will need to provide painters with respirators according to paragraph (g) of the proposed rule for silica.

OSHA also preliminarily concludes that some painters in this industry can use automated abrasive blasting methods that include vacuum suction and isolate the worker from the blast stream. To the extent that they are isolated from the abrasive blasting media, these workers will experience silica exposure levels that are lower than those achieved using wet abrasive blasting methods. However, OSHA acknowledges that these control methods are not universally practical for all surfaces.

Furthermore, as discussed previously, OSHA finds that some shipyards use, as another exposure control for abrasive blasting operations, alternative blasting media that are less toxic than silica sand. The OSHA maritime standard permits alternate respiratory protection for workers performing open-air blasting with synthetic media containing less than 1 percent silica. Strict compliance with the OSHA standards for maritime abrasive blasting (29 CFR 1915.34(c)) and respiratory protection (29 CFR 1915.154, or for general industry 29 CFR 1910.134) is essential for protecting workers performing abrasive blasting.

Feasibility Finding for Painters' Helpers

Based on the limited exposure data in Table IV.C-44 and the additional information included in this section, OSHA preliminarily concludes that all painters' helpers are currently exposed to silica at levels that exceed 50 µg/m^3, and additional controls will be required to reduce their exposures to or below the proposed PEL of 50 µg/m^3. To the extent that the helpers' exposures are related to painters' activities, OSHA finds that wet abrasive blasting and adherence to 29 CFR 1910.94 also would benefit painters' helpers. In addition, employers will need to ensure that they provide painters' helpers with the appropriate level of respiratory protection, as required by 29 CFR 1915.154 (or for general industry 29 CFR 1910.134).

Where painters' helpers' silica exposures are exclusively due to dust disturbed during cleaning, their exposures can be reduced by substituting HEPA-filtered vacuums instead of dry sweeping dust from surfaces to be painted. As noted above in the discussion of additional controls for painters' helpers, NIOSH recommends using HEPA-filtered vacuums. Vacuum blasting technology can reduce abrasive blaster lead dust exposure levels by 98.6 percent (from 4,200 µg/m^3 to 55 µg/m^3) (Flynn and Susi, 1999). Similarly filtered HEPA vacuums will reduce the exposure levels of painters' helpers at least as much when they clean up settled dust. Even if the HEPA vacuum offered just 85 percent reduction in exposure (compared to dry sweeping) the highest silica result for a painters' helper (280 µg/m^3) would be reduced to 42 µg/m^3.

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[195] As noted previously, under each condition the operators worked either in the open or in enclosed areas, but did not use booths or cabinets. Furthermore, some operators working under each condition used silica sand on a variety of surfaces, while others used alternate abrasive media to remove paint from silica-containing substrates, such as concrete.

Overall Feasibility Finding

Based on the available information, OSHA preliminarily concludes that the silica exposure of painters will be greatly reduced using wet abrasive blasting methods, but that the proposed PEL of 50 μg/m^3 will not be reliably achieved using these methods. Respiratory protection will continue to be required in accordance with 29 CFR 1915.34(c)(3)(i) and 1915.154 or, for general industry, 1910.94(a)(5) and 1910.134. These existing requirements currently protect painters who are routinely exposed to levels of other hazardous substances that exceed their PELs.

The adoption of wet methods by painters operating abrasive blasting equipment also will substantially reduce the exposure levels of painters' helpers by eliminating much of the dry dust that spreads and settles during dry abrasive blasting. Painters' helpers are responsible for cleaning up the residual dust, so reduced spread of dust translates directly to reduced exposure. The extent of the reduction will be sufficient to more reliably permit painters' helpers to wear a reduced level of respiratory protection, in the form of a half-facepiece respirator.

Painters' helpers who switch to cleaning using a HEPA-filtered vacuum instead of dry sweeping will experience substantial exposure reductions. If cleaning up after abrasive blasting is the helpers' only source of silica exposure, this control will be sufficient to reduce their exposures to 50 μg/m^3 or less. Even if the HEPA vacuum offered just 85 percent reduction in exposure (compared to dry sweeping) the highest silica result for a painters' helper (280 μg/m^3) would be reduced to 42 μg/m^3.

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Structural Clay

Description

Silica-containing materials are the primary ingredients in the manufacture of structural clay products, which include bricks, clay tiles, and ceramic tiles. Facilities manufacturing structural clay products are classified in six-digit North American Industry Classification System (NAICS) codes: 327121, Brick and Structural Clay Manufacturing; 327122, Ceramic Wall and Floor Tile Manufacturing; and 327123, Other Structural Clay Product Manufacturing. OSHA analyzed the facilities classified in NAICS codes 327121, 327122, and 327123 together, based on the similarity of materials, processes, and worker activities associated with potential exposure to silica throughout the majority of these facilities.

Structural clay products manufacturing typically begins with crushing, grinding, and screening silica-containing raw materials such as clay and shale. For one shape-forming method, the processed raw materials are mixed with water in a mill to form wet clay or slurry. Next, the wet clay is either pressed into a mold or, more commonly, extruded through a die and cut into shape with a wire-cutter. In contrast, an alternate method for forming high-density products (e.g., floor tiles) uses clay slurry that is spray-dried to a low-moisture compactable powder, then compressed in a mold. Regardless of the forming method, the resulting clay shapes can be coated with silica-containing coating mixtures at various stages in the shaping process. For example, a sand mixture is sometimes applied directly to the mold and is often sprayed or sprinkled on the formed product shape. The formed products are dried, fired in kilns, and then packaged. Structural clay products typically require no further processing after the forming, coating, and firing steps are complete. Workers do not normally cut, grind, sand, or saw the finished products, except perhaps to separate units cast as groups (ERG-GI, 2008).

Based on the available literature and exposure monitoring data presented in site visit reports, NIOSH reports, and OSHA Special Emphasis Program (SEP) reports, workers in all phases of structural clay products manufacture have potential for silica exposure. The primary job categories with potential for exposure are: material handler, grinding operator, and forming line operator. Certain workers regularly perform tasks associated with multiple job categories. To demonstrate certain trends in exposure, these job categories have been further broken down into subcategories. Material handlers are split into three categories—loader operator, production line handler, and post-production handler—depending on the type of material handled (raw material, shaped but unfired product, or fired product). Forming line operators are split by job activity into three categories as well: pug mill operators, coatings blenders, and formers. See Table IV.C-46 for a complete description of the job categories, major activities, and sources of silica exposure for workers in the structural clay products industry. For detailed process descriptions, refer to ERG-GI (2008).

Table IV.C-46

Job Categories, Major Activities, and Sources of Silica Exposure of Workers in the Structural Clay Industry (NAICS 327121, 327122, 327123)

Job Category	Major Activities and Sources of Exposure
Material Handler	
Loader Operator	Transferring raw materials (e.g., clay, shale) from storage piles to processing equipment or storage bins via front-end loader. • Dust from open transfer of silica-containing raw materials via front-end loader. • Dust re-suspended by passing traffic (e.g., spilled materials, settled dust). • Dust from conveyers and drop points.
Production Line Handler	Transferring unfired, shaped products within the production line (e.g., to dryers, kilns) using manual, power assisted, or automated processes. • Dust generated by spilled or broken product crushed under wheels. • Dust released from products during handling. • Dust from adjacent processes (e.g., forming line operators, sand coating application).
Post-Production Handler	Transferring finished, fired products through post-production inspection, packaging, and yard areas manually or using lifts and automated equipment. • Dust released during open transfer of products manually or by lift truck. • Dust disturbed by passing traffic (e.g., spilled materials, settled dust, yard dust).
Grinding Operator	Operating and maintaining raw material processing equipment, such as crushers, grinders, screens, and driers; performing housekeeping activities. • Dust generated during manual maintenance and operation of crushers, grinders, screens, and raw material driers. • Dust from housekeeping activities (e.g., dry sweeping, shoveling silica-containing materials).
Forming Line Operator	
Pug Mill Operator (including all raw clay-finishing processes)	Mixing dry clay with water to form wet clay to be extruded or molded; spray-drying clay slurry to create compactable clay powder. • Dust from transferring dry material into pug mills and related equipment. • Dust from spray-drying of clay and associated conveyers.

Table IV.C-46

Job Categories, Major Activities, and Sources of Silica Exposure of Workers in the Structural Clay Industry (NAICS 327121, 327122, 327123)

Job Category	Major Activities and Sources of Exposure
Coatings Blender	Preparing and transferring sand-based coatings to add pigment and texture to bricks. • Dust disbursed during open, manual emptying of bags of silica-containing materials into hoppers. • Dust generated by sand drying, mixing, and milling equipment used to create coatings.
Former	Forming product by hand or machine (molded or extruded products); applying coatings to products manually or monitoring automated application equipment. • Dust released during manual or automated application of silica-containing coatings (e.g., sand) to products. • Dust that becomes airborne while sand-coating bags are emptied and compacted for disposal.

Note: Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the facility.

Source: ERG-GI, 2008.

Baseline Conditions and Exposure Profile

To evaluate silica exposures of structural clay production workers, OSHA reviewed monitoring data on full-shift personal-breathing-zone (PBZ) respirable quartz exposure from five OSHA SEP inspection reports on brick manufacturing facilities (three of which, 300530805, 302005772, and 302547674, are all contained within OSHA SEP Inspection Report 300523396, the fifth is 301986345) and three NIOSH control technology and exposure assessment reports, also on brick manufacturing. These OSHA and NIOSH reports were previously described by ERG (ERG-GI, 2008). In addition, OSHA reviewed one report from a site visit to a ceramic tile manufacturing facility (ERG-ceramic-tile, 2001). Exposure monitoring data for each job category are discussed in detail in the following sections.[196]

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[196] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) derived from samples of 6-hours or longer, assuming the exposure concentration during any unsampled portion of the shift was the same as the concentration during the period sampled. Unless explicitly stated otherwise, all results discussed in the additional controls section meet the same criteria. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A–- Methodology.

Numerous activities at structural clay facilities produce silica dust, and the same dust often becomes resuspended. Dust arises while workers handle quantities of dry, dusty raw materials (clay, sand, and other minerals), use equipment for grinding raw materials and finishing clay (mills, mixers, spray driers), mix coatings and tend clay coating processes, and move unfinished and finished products through the plant.[197] Dust becomes airborne during production processes, and then settles on surfaces. When performed rigorously, housekeeping can either minimize silica exposure (when settled dust is effectively removed) or contribute to worker exposure by causing spilled or previously settled dust to become airborne.

Baseline Conditions for Material Handlers

As Table IV.C-47 indicates, the median full-shift PBZ exposure level for the 64 material handler results is 21 micrograms per cubic meter (μg/m^3), with a range of less than or equal to 10 μg/m^3 (the reported limit of detection [LOD]) to 258 μg/m^3.[198] Approximately 30 percent of material

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[197] NIOSH collected 38 samples at a brick manufacturing facility, 16 of which exceeded 50 μg/m3. Seven of these results also exceeded 100 μg/m3. NIOSH listed the primary sources of exposure as traffic passing over ground clay and shale in the grinding plant, loader dumping and spillage in the same area, conveyer spillage, dry broom sweeping of kiln cars, and various activities associated with the sand applied to bricks for texture and pigment. NIOSH described the strengths and weaknesses of housekeeping at this facility as follows: “Extensive efforts were made at housekeeping in this facility. The notable exception was in the C plant grinding area, which had significant accumulations of settled dust. [In the other areas] dry sweeping with brooms and shovels was common, with the powered sweeper used in some plant areas and the yard. Hi-Vac systems (Model 230) were installed in both the B and C plants for the cleaning of kiln cars. The vacuum systems were not equipped with [high-efficiency particulate air] HEPA filters. Workers used shovels to remove the largest pieces of brick, followed by dry sweeping, and then vacuuming of the cars” (NIOSH ECTB 233-126c, 2000). This facility had also installed a number of engineering controls.

[198] Results reported as “none detected” are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

Table IV.C-47
Respirable Crystalline Silica Exposure Range and Profile for Workers in the Structural Clay Industry (NAICS 327121, 327122, and 327123)

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean (µg/m^3)**	**Median (µg/m^3)**	**Min (µg/m^3)**	**Max (µg/m^3)**		**<25 (µg/m^3)**	**≥25 and ≤50 (µg/m^3)**	**>50 and ≤100 (µg/m^3)**	**>100 and ≤250 (µg/m^3)**	**>250 (µg/m^3)**
Material Handlers											
Loader Operators	7	61	58	10	157		3 42.9%	0 0.0%	2 28.6%	2 28.6%	0 0.0%
Production Line Handlers	20	72	51	12	258		6 30.0%	4 20.0%	6 30.0%	3 15.0%	1 5.0%
Post-Production Handlers (all types)	37	26	16	10	111		26 70.3%	6 16.2%	4 10.8%	1 2.7%	0 0.0%
Material Handlers - Total	64	44	21	10	258		35 54.7%	10 15.6%	12 18.8%	6 9.4%	1 1.6%
Grinding Operators	14	162	100	13	628		3 21.4%	1 7.1%	3 21.4%	4 28.6%	3 21.4%
Forming Line Operators											
Pug Mill Operators (including all raw clay-finishing processes)	7	312	226	41	1028		0 0.0%	1 14.3%	1 14.3%	2 28.6%	3 42.9%
Coatings Blenders	10	99	77	18	228		1 10.0%	1 10.0%	5 50.0%	3 30.0%	0 0.0%
Formers (all types)	37	124	73	12	794		10 27.0%	6 16.2%	6 16.2%	11 29.7%	4 10.8%

Table IV.C-47
Respirable Crystalline Silica Exposure Range and Profile for Workers in the Structural Clay Industry (NAICS 327121, 327122, and 327123)

Wet Clay Formers	10	28	20	13	78		6 60.0%	3 30.0%	1 10.0%	0 0.0%	0 0.0%
Clay Powder Formers	3	158	144	141	188		0 0.0%	0 0.0%	0 0.0%	3 100.0%	0 0.0%
Coatings Applicators (manual)	15	203	105	12	794		4 26.7%	1 6.7%	1 6.7%	5 33.3%	4 26.7%
Coatings Applicators (automated)	9	87	73	35	159		0 0.0%	2 22.2%	4 44.4%	3 33.3%	0 0.0%
Forming Line Operators - Total	54	144	78	12	1028		11 20.4%	8 14.8%	12 22.2%	16 29.6%	7 13.0%
Totals	**132**	**98**	**48**	**10**	**1028**		**49** **37.1%**	**19** **14.4%**	**27** **20.5%**	**26** **19.7%**	**11** **8.3%**

Notes: All samples are personal breathing zone (PBZ) results for durations of 360 minutes or more and represent 8-hour time-weighted average exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Sources: ERG-GI, 2008; ERG-ceramic-tile, 2001 handlers are exposed to silica at levels exceeding 50 μg/m^3, and 11 percent are exposed above 100 μg/m^3. Loader operators and material handlers working on the production line tend to have higher maximum and median exposure levels than material handlers working in post-production areas, handling finished goods. The three subcategories within the material handlers job category (loader operators, production line handlers, and post-production handlers) are discussed in the following sections. All three subcategories can be subject to silica exposure when passing vehicles crush spilled raw materials or broken product and disturb settled dust.

Baseline Conditions for the Loader Operators Subcategory

Among loader operators, the median exposure level is 58 μg/m^3 for 7 results ranging from 10 μg/m^3 (LOD) to 157 μg/m^3. Four results (57 percent) exceed 50 μg/m^3, and two results (29 percent) exceed 100 μg/m^3. The highest exposure, 157 μg/m^3, is associated with a loader operator in a ceramic tile facility who dumped dry materials into a hopper and monitored a partially enclosed and ventilated conveyer. Visible dust was released from the loader bucket, hopper, and conveyers, and the worker continued operations with the loader windows open for a portion of the sampling period (ERG-ceramic-tile, 2001). In contrast, exposures of 14 μg/m^3 and 10 μg/m^3 were obtained for loader operators at another facility moving crushed shale and schist from storage piles to hoppers. The floor was wet from the rain, and visible dust was not "particularly evident" (NIOSH ECTB 233-108c, 2000). ERG reported that typical work conditions for loader operators in this industry involve ventilated but poorly maintained or improperly used cab enclosures on all front-end loaders (ERG-GI, 2008). For example, at three facilities, workers operated cabs with ventilation systems turned off or windows left open, or allowed dust to accumulate in cabs. Loader operators also spend a portion of the shift outside the cab as they monitor raw material conveyer systems. These partially enclosed conveyers can emit silica dust when facilities have not enclosed and ventilated transition points, applied dust suppressant, or adjusted for optimal dust control. In addition, nearby raw material processing equipment (crushers, hammer mills, dry-pans, screens) is typically partially open, allowing silica dust to escape, despite some effort to provide exhaust ventilation for the equipment.

A loader operator working in an area where a dust suppressant foam system blanketed raw materials on conveyers had an exposure level of 56 μg/m^3 (NIOSH ECTB 233-124c, 2000). NIOSH noted an accumulation of dust on the loader cab interior, suggesting that results could be lower (e.g., at 50 μg/m^3 or less) if the cab interior had been kept clean.

Baseline Conditions for the Production Line Handlers Subcategory

The 20 results associated with production line handlers have a median of 51 μg/m^3 and a range of 12 μg/m^3 (LOD) to 258 μg/m^3. Ten results (50 percent) exceed 50 μg/m^3, and four results (20 percent) exceed 100 μg/m^3. The highest concentrations occurred when workers moved dry, unfired product. While transporting unfired product in the kiln area, the forklift (or squeeze lift) wheels crushed a mixture of high-silica gravel floor lining and spilled broken product, which became a source of exposure (258 μg/m^3 and 216 μg/m^3, respectively) (OSHA SEP Inspection Report 301986345). Workers with low exposures include those controlling the flow of bricks (presumably wet clay) from the molding machine (12 μg/m^3 and 21 μg/m^3) and transfer car operators moving bricks between the manufacturing area and the ovens (four exposures ranging from 17 μg/m^3 to 21 μg/m^3).

ERG (ERG-GI, 2008) reported that production line handlers typically work without task-specific exposure controls. Local exhaust ventilation (LEV) is sometimes associated with nearby processes, such as conveyer belts and coatings application; however, dust control is incomplete, and those processes still contribute to silica exposure of production line handlers. The extent to which handlers working in large forklifts utilize the isolation afforded by the equipment cab is unclear. In at least one case, after the facility purchased an air-conditioned cab for the lift as an exposure control measure, the ambient kiln environment caused the cab's air conditioning system to overheat, leading the worker to work with the windows open.

Baseline Conditions for the Post-Production Handlers Subcategory

Silica exposure levels tend to be lower for workers handling kiln-fired structural clay products than the other two material handler subcategories. After firing, the clay is substantially harder than in earlier parts of the manufacturing process, and thus handling creates less dust. The median exposure level for 37 post-production handler results is 16 µg/m^3; however, the associated exposure levels range from 10 µg/m^3 to 111 µg/m^3. Nine workers (24 percent) monitored automated unloading or packaging equipment. These workers had consistently low exposures, ranging from 11 µg/m^3 to 29 µg/m^3. Another 19 workers (51 percent) manually unloaded fired bricks. These workers generally had higher exposures, ranging from 10 µg/m^3 to 111 µg/m^3, with five results exceeding 50 µg/m^3. Finally, nine post-production workers (24 percent) operated forklifts or other heavy equipment to move stacks of fired and packaged bricks around the yard. Exposures for these forklift operators were all below 50 µg/m^3, ranging from 12 µg/m^3 to 44 µg/m^3.

ERG (ERG-GI, 2008) reported that most post-production handlers typically work with some type of task-specific engineering controls. One forklift operator using an enclosed, ventilated cab had an exposure of less than or equal to 12 µg/m^3 (LOD). Another facility that frequently sprayed water in the plant yard reduced all of its forklift operator exposures to below 50 µg/m^3 (four results less than or equal to the LOD [16 µg/m^3] and one result of 43 µg/m^3). Many facilities occasionally sprinkle water on heavily traveled routes through outdoor brickyards to suppress dust (ERG-GI, 2008). Some post-production handler results are associated with automated process control (including some obtained in areas where wet methods are also used). All results associated with automated processes are below 50 µg/m^3. Of the 19 results for workers manually unloading bricks, 13 (68 percent) are associated with some type of additional control (water spray nozzles, fans to remove dust on bricks prior to reaching the operator, or clean air supply blown in the worker's PBZ). Using these controls for manual operations was not always effective, however (e.g., an unloader supplied with clean air had an exposure of 111 µg/m^3).

Overall Baseline Conditions for All Material Handlers

While ERG-GI (2008) noted various trends in material handler work environments and suggested that some of those conditions are baseline controls, OSHA has determined that, across the industry, baseline conditions are best represented by the cross section of facilities reviewed for the exposure profile. Hence, OSHA preliminarily finds that the best description of current baseline exposures of loader operators includes all results summarized for this job category in Table IV.C-47; therefore, the median of 21 µg/m^3 for all material handlers represents their baseline exposure. OSHA acknowledges that this determination likely underestimates the baseline exposure levels for certain workers in some subcategories, but it still best represents the group as a whole.

Baseline Conditions for Grinding Operators

As Table IV.C-47 indicates, the median full-shift PBZ exposure level for grinding operators is 100 µg/m^3, with a range of 13 µg/m^3 to 628 µg/m^3. These values are based on 14 readings for grinding operators obtained from four OSHA SEP inspection reports (OSHA SEP Inspection Reports 301986345 and 300523396)[199] and three NIOSH reports (ERG-GI, 2008). Ten results (71 percent) exceed 50 µg/m^3,

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[199] OSHA SEP Inspection Report 300523396 also contains inspections 302005772 and 302547674, which were conducted at the same facility.

and seven (50 percent) exceed 100 µg/m^3. The three highest full-shift exposure levels (628 µg/m^3, 410 µg/m^3, and 362 µg/m^3) were all associated with a single production plant and remained high despite efforts on the part of the facility to enhance dust collection at the grinder and improve ventilation and housekeeping in the control room (OSHA SEP Inspection Report 300523396). The results might have been influenced, however, by newly installed milling equipment, which reportedly generated more dust and finer particles than had been evident before the installation (but OSHA does not have access to results from the period before the new mill was installed).

Typical conditions associated with this job category include the use of ventilated control rooms for the grinding operator for at least part of the shift (ERG-GI, 2008). Other typical conditions include opened conveyers and enclosed (in a room) and ventilated grinding equipment. The most substantial exposures occur when grinding operators exit control rooms and approach the grinder to clean and maintain equipment and perform housekeeping activities (e.g., manually remove rocks from grinder teeth, clean equipment, and sweep or shovel spilled debris from floors). Grinding operators at all five brick manufacturing facilities described in the OSHA SEP and NIOSH reports used for this exposure profile performed tasks within the grinder area. Although grinding operators perform these tasks intermittently (up to eight times per day), respirable quartz levels in the grinding area often are elevated to extreme levels and thus are the primary source of exposure for grinder operators. Poorly constructed control rooms can also become contaminated with silica, however, and contribute to worker silica exposures.

Based on the conditions described for this job category, OSHA has preliminarily determined that the baseline conditions for grinding operators across this industry are best represented by the range of results summarized in the exposure profile. Thus, their baseline exposure level is represented by the median exposure for this job category (100 µg/m^3).

Baseline Conditions for Forming Line Operators

As Table IV.C-47 indicates, the median full-shift PBZ respirable quartz exposure level for 54 readings for forming line operators is 78 µg/m^3 with a range of less than or equal to 12 µg/m^3 (LOD) to 1,028 µg/m^3. Thirty five results (65 percent) exceed 50 µg/m^3, and 23 results (43 percent) exceed 100 µg/m^3. Four of the 54 results (501 µg/m^3, 690 µg/m^3, 794 µg/m^3, and 1028 µg/m^3, all from the same facility) also exceed 500 µg/m^3. Silica exposures primarily occur when workers perform open transfer of clay and coatings ingredients into hoppers and mills, operate mixing and milling equipment, and apply sand-based coatings to products.

To better demonstrate trends within the diverse forming line operator job category, OSHA has described each separately in the following paragraphs.

Baseline Conditions for the Pug Mill Operators Subcategory

As shown in Table IV.C-47, the seven exposure results for pug mill operators (and workers controlling other clay-finishing equipment) range from 41 µg/m^3 to 1,028 µg/m^3, with a median of 226 µg/m^3. Five of the seven results (71 percent) exceed 100 µg/m^3. The highest value among the data available to OSHA for this industry (1,028 µg/m^3) was obtained for a forming line operator monitoring a pug mill equipped with a poorly maintained exhaust-ventilated enclosure (OSHA SEP Inspection Report 300523396). The report noted that the enclosure doors did not seal properly. After the inspection, the facility installed a second pug mill with a better-sealed exhaust-ventilated enclosure and added a greater quantity of water to the clay mix to reduce dust emissions. During a later inspection, a result of 214 µg/m^3 was obtained for an operator monitoring this second mill (an exposure 79 percent lower than the first reading). The operational status of the first pug mill during this later inspection is unclear (Inspection

300530805, contained in OSHA SEP Inspection Report 300523396). If the original mill was still present, it might have contributed to the worker's exposure on the second sampling date.

Two silica results (226 µg/m^3 and 337 µg/m^3) were obtained by ERG for the workers finishing clay at a ceramic tile manufacturing facility where a ball mill and spray drier prepared clay powder to be compressed into tiles (ERG-ceramic-tile, 2001). These two results are associated with workers working at adjacent workstations in the same room where visible dust reportedly was observed occasionally when the mill was charged with fired tile scrap and when the operator brushed spilled material away from the mill hatch. Furthermore, an automatic LEV system associated with the storage hoppers was functioning improperly, and the spray-drying equipment constantly emitted fine dust into the surrounding room as the clay powder was sized (in a cyclone-type separator), transferred, and conveyed through the process.[200] Dust release from vertical conveyors adjacent to the spray dryer was reduced with enclosures. Air samples obtained in other production processes suggested that dusty air leaking from this area (through doors and open conveyer passages through the walls) contributed to worker exposure further down the production line (e.g., material handlers and forming line operators). Although a control room was available, and the spray-drier operator spent 10 percent of the shift there, the door was frequently open and the room was unventilated. The floor, walls, windows, and equipment inside the control room were coated with a light layer of dust (ERG-ceramic-tile, 2001).

Detailed information is not available for the two lowest results (41 µg/m^3 and 70 µg/m^3) associated with the pug mill operator subcategory (OSHA SEP Inspection Report 301986345).

Baseline Conditions for the Coatings Blenders Subcategory

Exposures for 10 workers in the coatings blenders subcategory, which includes forming line operators who use mixing and milling equipment to prepare coatings (glazes) for a portion of their shift (typically working as formers for any remaining periods), range between 18 µg/m^3 and 228 µg/m^3, with a median of 77 µg/m^3. Eight results (80 percent) exceed 50 µg/m^3, and three results (30 percent) exceed 100 µg/m^3. The highest exposures (228 µg/m^3 and 190 µg/m^3) are associated with a worker operating a sand dryer and coatings mixer in a brick coatings preparation room. LEV was present at the dryer and at transition points between the particulate screen, bucket elevator, and weight bin; at the bag dumping station for the mixer; and at the transfer point between the mixer and skid tub; however, the dryer LEV operated at air velocities less than one-half of the 250 feet per minute recommended by the American Conference of Governmental Industrial Hygienists (ACGIH, 2010) for toxic materials and was poorly aligned with the hopper. Another worker dumping bags and mixing coatings for a different production line at the same plant had a much lower exposure, however: only 18 µg/m^3. Information on the controls associated with this other production line is not available (NIOSH ECTB 233-126c, 2000).

ERG reported that typical conditions for coatings blenders include the use of enclosed mixers and open transfer of silica-containing materials (ERG-GI, 2008). LEV is typically used to control dust generated by open, manual emptying of bags or boxes of silica-containing materials; however, this LEV is frequently inadequate.

Baseline Conditions for the Formers Subcategory

As Table IV.C-47 indicates, the 37 exposure results for formers, the subcategory of forming line operators who spend the entire shift at forming stations (without milling or mixing materials), range from

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[200] At times, the airborne dust was sufficient to reduce visibility. Furthermore, the facility provided information indicating that 30 percent of the particles in the milled clay processed through the drier were less than 4 µg in size, suggesting that a substantial portion of the clay particles were in the respirable size range.

12 µg/m^3 to 794 µg/m^3, with a median of 73 µg/m^3 and a mean of 124 µg/m^3. Twenty-one results (57 percent) exceed 50 µg/m^3, and 15 results (41 percent) exceed 100 µg/m^3.

The formers who primarily work with wet clay only (molding and extrusion processes, no coatings application) have the lowest range of exposures, from 13 µg/m^3 to 78 µg/m^3, with a median of 20 µg/m^3 (see Table IV.C-47). Only one of the 10 exposures exceeds 50 µg/m^3. In contrast, the three exposure results for formers dealing with pressing dry clay powder (pressing operations, no coatings application) are higher, ranging from 141 µg/m^3 to 188 µg/m^3. An automated air jet that blew residual clay powder from the molds several times per minute contributed to these workers' exposures (ERG-ceramic-tile, 2001). Data are not available to determine whether clay powder pressing operations have elevated exposures in the absence of air spray cleaning.

Coatings application operations (especially sand coating) are associated with some of the highest exposures in this industry (only pug mill operators have higher exposure levels). Fifteen formers who manually handled coatings (either during application or while refilling hoppers) had exposures ranging from 12 µg/m^3 to 794 µg/m^3, with a median of 105 µg/m^3. Nine of the 15 results (60 percent) exceed 100 µg/m^3. The lowest exposures for manual coatings application were associated with slurry application rather than dry mix coatings. Not surprisingly, higher exposures were reported for workers dumping bags of dry silica-containing materials, especially sand. Formers using automated coatings equipment experienced somewhat lower exposures, but seven of the nine results (78 percent) still exceeded 50 µg/m^3. Based on this information, OSHA preliminarily finds that, except for workers primarily handling (wet) clay slurry, all forming line workers routinely experience high exposure levels, principally from working with dry sand or dry clay.

ERG-GI (2008) found that formers typically work near local exhaust ventilation hoods, which are generally associated with the automated dry coatings application equipment (ERG-GI, 2008). Other engineering controls are not normally present on the forming line. For example, in contrast to coatings blending areas, the hoppers along the forming line into which workers dump dry coating materials are not fitted with exhaust ventilation. Additionally, ERG-GI (2008) noted that LEV is not normally available at the workstations where formers apply coatings by hand, either to molds or to product. Due to the warm conditions in facilities operating drying ovens and kilns, workers often use pedestal or ceiling fans for comfort, which can disturb settled dust and disrupt the function of ventilation systems. Workers also commonly (at least daily) clean the forming line floors by dry sweeping and using shovels to clean up spilled material as necessary.

Overall Baseline Conditions Forming Line Operators

As noted for material handlers, ERG-GI (2008) observed various trends in the work practices and control technology available (or not) for forming line operators, which might be considered baseline controls. OSHA has determined, however, that across the industry, baseline conditions are best represented by the cross section of facilities reviewed for the exposure profile. OSHA preliminarily finds that the best description of current baseline exposures of forming line operators includes the full dataset available to OSHA for this job category (summarized in Table IV.C-47). Therefore, the median of 78 µg/m^3 for all material handlers represents their baseline exposure. OSHA recognizes that this determination likely underestimates the baseline exposure level for workers who operate pug mills and other clay-finishing equipment.

Additional Controls

Additional Controls for Material Handlers

Information presented in the exposure profile (Table IV.C-47) indicates that the median exposure level for all material handlers is 21 μg/m^3, and these data range from 10 to 258 μg/m^3. The data summarized for material handlers are not distributed equally, however, across all three subcategories. Although Table IV.C-47 shows that 70 percent of material handlers in this industry already experience exposure levels less than 50 μg/m^3, 57 percent of loader operators and 50 percent of production line handlers currently have silica exposures exceeding 50 μg/m^3 and therefore require additional controls. Among data for post-production handlers (handling finished products), only 14 percent exceeded that level.

The following paragraphs describe additional controls suitable for material handlers.

Local Exhaust Ventilation

To obtain reductions in silica levels in raw material handling areas, the primary control methods target dust emissions from hoppers, conveyers, and transfer points associated with material handlers' duties. Such control methods include covering conveyers and augmenting ventilation at existing enclosed transfer points to meet the ACGIH recommended air velocity of 150 to 300 feet per minute across all openings in the enclosures (ACGIH, 2010).[201] NIOSH described an enclosed conveying system associated with grinding equipment, pug mills, silos, and mixers at a brick manufacturing facility (NIOSH ECTB 233-126c, 2000). This method has been used effectively in the foundry industry, in which sand systems operators and molders are routinely exposed to high levels of silica from sand and clay used for mold material in metal casting processes.

Some of the lowest results for these foundry industry job categories were associated with sand systems operators working in areas where sand transport systems were isolated (enclosed or pneumatic) and mullers (machines that process sand and clay, materials also used by the structural clay industry) were fitted with exhaust ventilation. For example, OSHA obtained a reading of 11 μg/m^3 (LOD) for a sand systems operator controlling a muller that had both the muller belts and sand elevator fully enclosed (OSHA SEP Inspection Report 108772377). Furthermore, NIOSH and OSHA evaluated pneumatic and enclosed systems to isolate the storage and transport of dry sand in two other foundries. The four results for the molder job category from these foundries include two results of 13 μg/m^3 (LOD) and one each of 20 μg/m^3 and 23 μg/m^3 (NIOSH ECTB 233-107c, 2000; OSHA SEP Inspection Report 122122534). At another foundry, OSHA reported a 65- to 70-percent reduction in exposures (from 140 μg/m^3 to 50 μg/m^3 and 42 μg/m^3) after the facility made improvements to sand delivery systems and exhaust ventilation systems throughout the facility (OSHA SEP Inspection Report 100494079). Further details on these improvements are not available.

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[201] ACGIH (2010, Chapter 13.50) recommends a minimum air flow of 150 feet per minute (fpm) across bin and hopper openings for manual loading operations; however, ACGIH also recommends air velocity of one-and-a-half to two times that rate (i.e., 225 fpm to 300 fpm) when conditions create conditions more dusty than during manual loading. The need for increased air velocity depends on the material flow rate (a front-end loader will add materials at a much greater material flow rate than manual transfers), dustiness (the material at this site was apparently very dusty), and the height the material falls (influenced both by hopper design and by material handler work practices). Furthermore, ACGIH recommends that the enclosure be "large enough to accommodate the 'splash' effect." For some dust controls, ACGIH suggests increasing the baseline air flow rate from 150 fpm to 250 fpm when the materials handled include toxic dusts.

If exposure levels remain elevated, another type of ventilation system is available for structural clay industry workers who spend a portion of the shift at a fixed location. A combination "push-pull" ventilation system—designed to exhaust contaminated air near the source, while supplying a similar amount of clean air behind or above the worker's head—has been demonstrated to be very effective for other types of dust. Heinonen et al. (1996) determined in an experimental study (using dusty flour) that compared with general ventilation alone, breathing zone total dust concentrations were reduced by 98 percent (from 42,000 µg/m^3 to 1,000 µg/m^3 or less) when the work surface was fitted with exhaust ventilation (at the front, side, or as a downdraft) in combination with local clean air supply above the worker's head. Although this study tested high concentrations of total dust, OSHA believes this type of "push-pull" ventilation system would be similarly effective for reducing levels of silica dust in the breathing zone of structural clay workers (in this case, to be considered "clean air," the air provided to the area around the worker would be free of silica). OSHA notes that for such a system to function, competing air from pedestal fans must be eliminated; however, the temperature of the provided air can be adjusted for worker comfort. A system similar to this was used on the packaging line (and also at a forming station) at a facility evaluated by NIOSH (NIOSH ECTB 233-126c, 2000).

Reduced Spillage and Adhesions Associated With Conveyers

Conveyer belts can be modified (e.g., using troughed belts or V-rollers) to reduce spilled material that also can contribute to silica exposure levels. NIOSH reported that the brick manufacturing facility that used LEV on various milling, mixing, and storage equipment (mentioned previously) also used alternative conveyers such as these to reduce the amount of raw materials lost from the conveyer belts associated with the raw material grinding equipment (NIOSH ECTB 233-126c, 2000). The same facility also uses conveyer belt cleaning (belt-scraping, rinsing) to limit the spread of silica dust from drying clay adhered to the belts. Although the benefit of this control method has not been quantified, it is part of the overall control package used by this facility to limit silica exposures, to the extent that just 1 of 32 samples (3 percent) exceeded 100 µg/m^3 in the plant (compared with 28 percent for the industry as a whole, as indicated by Table IV.C-47).

Housekeeping

Housekeeping that minimizes the amount of spilled materials and settled dust in areas of vehicular traffic reduces silica exposure that occurs when those sources are crushed or disturbed by passing traffic (including machinery operated by material handlers).

Thorough, professional-level cleaning in association with improved housekeeping procedures (to maintain cleanliness) can reduce exposures in facilities where dust has been allowed to accumulate. For example, professional cleaning in a brick manufacturing facility removed "several inches" of dust from floors, as well as from all structural and equipment surfaces (Brick Industry Consultant A, 2003). Post-cleaning air samples indicated a "dramatic" decrease in exposure levels (in some cases, a greater than 90-percent reduction, to levels less than 50 µg/m^3) for workers in areas where dusty materials were transported or handled. The cleaning also allowed the facility to identify and prioritize specific sources of dust for future control efforts.

Poor housekeeping can contribute substantially to worker exposure levels in all material handling areas.

Enclosed Cabs

For facilities where elevated exposures persist for material handlers using vehicular material handling equipment (e.g., loader operators), well-sealed, air conditioned cabs maintained under positive pressure with filtered air provide an effective control option. The information summarized in ERG-GI (2008) suggests that most (essentially all) front-end loaders used in this industry are equipped with cabs.

Although data documenting the effectiveness of such enclosures at structural clay manufacturing facilities are not available (most samples available to OSHA for operators using cabs were obtained with cab windows open), data from Hall et al. (2002) from the agricultural industry are helpful. The agricultural industry is interested in protection against respirable and total dust, including from pesticides, some of which can be more toxic than silica. The data from Hall et al. (2002) suggest that a 94- to 98.5-percent reduction in respirable dust[202] (inside, compared with outside the cab) can be achieved on tractors (a type of heavy equipment) fitted with well-sealed, air-conditioned, and filtered cabs.[203]

Operators working in heavy equipment cabs designed to meet the American Society of Agricultural Engineers' (ASAE)[204] standard (ASAE S525 –*Engineering Control of Environmental Air Quality*) should experience exposure reductions in the same general range as described by Hall et al. (2002), who tested cabs with specification similar to the ASAE standard. Lighter equipment, such as forklifts, might achieve lower exposure reduction, but a functional air conditioning system and careful maintenance should offer notable exposure reduction (e.g., 50 to 90 percent instead of 94 to 98.5 percent).[205]

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[202] Hall et al. (2002) tested two cabs manufactured or retrofit to a condition similar to the ASAE S525 standard criteria. The cabs were found to offer mean protection factors of 43 (manufacturer's cab) and 16 (retrofit cab) for particles smaller than 1.0 µm. These protection factors equate to exposure reductions of 98.5 percent (manufacture's cab) and 94 percent (retrofit cab). When tested against particles 3.0 µm and larger, the cabs were found to provide protection factors of 200 and greater. Although more than half of the mass of respirable particles is usually particles greater than 3 µm, a portion of respirable particles are usually smaller. Therefore, OSHA has used the protection factors for the smaller particles to ensure workers are fully protected, although this means that OSHA is underestimating the benefit these tractor cabs likely offer workers exposed to respirable particles.

[203] "At least three criteria must be met for a cab to fulfill properly its function: pressurization, minimum penetration with respect to the main pollutants, and cleaned airflow rate" (Bemer et al., 2009). The precise reduction depends on cab pressurization to exclude particles, particle penetration through filters, and clean airflow rate (Bemer et al., 2009).

[204] In 2005 the American Society of Agricultural Engineers (ASAE) changed its name to the American Society of Agricultural and Biological Engineers (ASABE).

[205] The Mine Safety and Health Administration (MSHA) found that for loaders, bulldozers, and trucks used by the surface and underground mining industry, where workers are also exposed to high levels of mineral dust that contains silica, sealed cabs can reduce (total) silica exposure levels by 42 percent to 99 percent (original equipment or retrofit). In most cases, when a loader or truck cab had a sufficiently filtered ventilation system which pressurized the cab by at least 0.04 inches of water (preferably 0.2 inches of water, or at least 25 cubic feet per minute (CFM) for a well-sealed cab), silica exposure reduction was 91 percent (MSHA, no date). Cabs offered less effective dust control (less than 80 percent reduction) when seals were poorly maintained or air filtration inadequate (e.g., metal mesh filters rather than higher efficiency paper filters). However, MSHA concluded that "a

Although these cabs require regular maintenance to function properly, and concerns exist regarding the construction standards of new heavy equipment, OSHA estimates that appropriately fitted and maintained cabs would offer an exposure reduction of at least 90 percent (the low end reported for larger equipment) for material handlers, including those using front-end loaders (ERG-GI, 2008).

Using Low-Silica Gravel on Floors

In the kiln area of one structural clay facility, the wheels on a lift that was transporting product crushed a mixture of high-silica gravel floor covering and spilled broken product. Plant personnel reported that the material on the floor contained up to 98 percent silica content, which became a source of exposure when dust from the crushed material became airborne. The highest result (258 $\mu g/m^3$) for material handlers is attributed to this exposure source (OSHA SEP Inspection Report 301986345). Another facility, described by NIOSH, used “washed limestone pea gravel”(a low-silica stone) on kiln floors, instead of the original brick chips and dust, as the wheels on mobile equipment tend to pulverize the material and were contributing to worker silica exposure in the enclosed kiln (NIOSH ECTB 233-124c, 2000). Workers covered the pea gravel with aluminum plates to provide thermal protection, improve forklift traction, and reduce dust. Results of 57 to 60 $\mu g/m^3$ were associated with material handlers who worked on the pea gravel surface but also performed dry sweeping and spent half the shift handling unfired dry clay (two additional sources of silica exposure). NIOSH commented that the potential for silica exposure remains, due to bricks that break during firing. OSHA notes that it might be necessary to replace the pea gravel frequently to avoid increasing amounts of broken product accumulating in the gravel where it will be crushed by passing in-plant vehicles

Wet Methods, Dust Suppressants, and Conducting Operations on Damp Clay

Wet methods are a particularly effective means of controlling silica, as water spray can help capture airborne dust, and damp surfaces release less dust than dry surfaces. NIOSH ECTB 233-108c (2000) reports six exposure results, all less than 30 $\mu g/m^3$ (ranging from 12 $\mu g/m^3$ to 29 $\mu g/m^3$) for post-production material handlers who operated *automated* product handling equipment equipped with spray nozzles. At the same facility, NIOSH also collected an additional six samples indicating similar exposure levels (ranging from 11 $\mu g/m^3$ to 36 $\mu g/m^3$) for material handlers working in an area where directional water-spray nozzles were used to reduce dust released from fired products before the products were *manually* unloaded (NIOSH ECTB 233-108c, 2000). At this facility, the spray heads could be triggered by the material handlers or set to operate automatically. An additional water hose with hand sprayers also was available for manual dust control. This report demonstrates how facilities can use both automatic and manual water sprays to optimize dust control and achieve modest exposure results to control dust from fired products.

Wet methods also can reduce exposure where silica-containing dust in the yard contributes to the overall exposure levels of material handlers. Dust suppressants or frequent wetting using a water spray truck can limit the amount of dust that becomes airborne. For example, a brick manufacturing facility described in NIOSH ECTB 233-124c (2000) sprayed the yard (product storage area) with water five times per day. Five of the six results obtained for material handlers operating in the area were below the LOD (16 $\mu g/m^3$ in this case), while one result was 43 $\mu g/m^3$ (NIOSH ECTB 233-124c, 2000).

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cab without additional controls provides some additional protection to the worker, because it protects the worker from peak concentrations” (MSHA, no date). Furthermore, MSHA also concluded that housekeeping practices should include vacuuming or wet wiping the cab interior daily. Some loaders tested by MSHA (Caterpillar models 992G, 992C and 980F) were similar to the model used by a structural clay facility evaluated by NIOSH (Caterpillar model 950F) (NIOSH ECTB 233-126c, 2000).

Dust suppressants, such as foam sprays, can also be applied to conveyers to prevent silica dust from becoming airborne as raw materials are transferred between work areas. As noted earlier (under baseline conditions for material handler – loader operator subcategory), this method is in use at a structural clay facility visited by NIOSH and is associated with a silica result of 56 µg/m^3, despite visible dust accumulation in the loader cab (NIOSH ECTB 233-124c, 2000).[206] OSHA has preliminarily determined that more frequent cleaning of the loader cab would minimize dust and reduce the operator's silica exposure to a level of 50 µg/m^3 or less (a reduction of at least 6 µg/m^3, or 12 percent). NIOSH has identified dust from floors and surfaces in cabs as a source of operator exposure.

Another way to reduce exposures to silica dust while transporting unfired clay is to transport or manipulate the clay objects while they are still slightly damp rather than fully dried. For example, if bricks are handled (to transfer or further process them) while still slightly damp, they will be less dusty, and material handlers (and other production workers) will experience less silica exposure. An informal review of the data available to OSHA shows that airborne silica concentrations for damp clay operations range from less than or equal to 12 µg/m^3 (LOD) to 91 µg/m^3, with a median exposure of 28 µg/m^3. In contrast, manual operations of dried clay are associated with exposures ranging from 61 µg/m^3 to 216 µg/m^3, with a median exposure of 103 µg/m^3. These results support the intuitive conclusion that work involving dried clay is dustier than work involving damp clay. OSHA acknowledges, however, that even when workers can perform manual operations on damp clay, the clay eventually must be allowed to dry (e.g., prior to kiln firing). Furthermore, spilled damp clay must be cleaned up before it dries and becomes an ongoing source of exposure.

Automation

Automated material handling and transfer equipment offers another opportunity to reduce worker exposures. Another informal review of the exposure data available to OSHA (see Table IV.C-47) shows that post-production material handlers performing the tasks of unloading kilns and stacking finished structural clay products had lower exposure levels when they used automated material handling equipment (all nine results less than 50 µg/m^3, with eight of those results also less than 25 µg/m^3) than did workers performing this work by hand (NIOSH ECTB 233-124c, 2000). For manual work, 25 percent of 19 total results exceeded 50 µg/m^3 and one exceeded 100 µg/m^3. Automatic material handling tools include kiln unloading equipment, automated transfer, and stacking and bundling or strapping equipment.

Summary of Controls for Material Handlers

Although most exposure control methods for material handlers are universally beneficial for all workers in this job category, some of the controls discussed previously are more appropriate for certain material handler subcategories than others. The following paragraphs summarize the control methods suitable for workers in the material handler subcategories.

Loader Operators Subcategory: The primary controls for loader operators are LEV and suitable enclosures at receiving hoppers, conveyers (including conveyers designed to limit spillage), and transfer points. Other controls include rigorous housekeeping and well-sealed enclosed cabs with air conditioning and air filtration systems.

Production Line Handlers Subcategory: Exposure control methods for this subcategory of material handlers include using low-silica stone (e.g., limestone) in place of high-silica gravel on kiln

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[206] The foam application system consisted of "a drum of citrus-based surfactant, a control panel, hoses, a manifold, and 4 spray heads. This system worked by blanketing the surface of the conveyed material with foam, preventing the generation of silica containing aerosols" (NIOSH ECTB 233-124c, 2000).

floors (where it can be crushed). Workers can also handle formed clay products in a slightly damp, rather than fully dried, state, which is less dusty. These workers will also experience a reduction in exposure when housekeeping is improved and the exposure levels of other workers in the immediate area are better controlled (e.g., forming line operators and the associated sand application processes).

Post-Production Line Handlers Subcategory: The primary controls for this group of workers include wet methods (water spray on fired product and in the yard) and automation.

Additional Controls for Grinding Operators

The data summarized in Table IV.C-47 show that 29 percent of grinding operators' exposures are already below 50 µg/m^3. OSHA finds that additional controls are needed to reduce the exposures of 71 percent of grinding operators in the structural clay products industry.

Combination Engineering Controls

A combination of engineering controls led to reduced worker exposure during grinding operations at one structural clay products facility (NIOSH ECTB 233-108c, 2000). This facility uses troughed conveyors to reduce spillage of raw materials as they are transferred to the grinding equipment, enclosed grinding machinery to minimize dust release during the grinding process, a covered conveyor to reduce dust release from ground materials as they are transferred to storage silos, and sealed bins to reduce dust release from storage units. This facility also uses raw materials with higher water content (20 percent) than the facilities described in other NIOSH reports (9 percent to 13 percent). NIOSH obtained exposure readings of 67 µg/m^3 and 13 µg/m^3 for the grinding operator at this facility. These values are substantially lower than the median of 100 µg/m^3 for this job category (see Table IV.C-47). Although the report does not indicate conditions that would explain the difference between the two readings, it does suggest that compressed air is used for cleaning and contributes to worker silica exposures. Based on information presented in the following section regarding the use of compressed air, OSHA preliminarily finds that both these levels would likely have been lower (e.g., both less than 50 µg/m^3) if the workers had not used compressed air for cleaning.

Eliminating Use of Compressed Air for Cleaning

As noted previously, compressed air for cleaning remains an ongoing source of silica exposure for grinder operators. OSHA has preliminarily determined that facilities eliminating the use of compressed air for cleaning can reduce the exposure levels of grinder operators in the structural clay industry.

NIOSH consistently cites the elimination of compressed air for cleaning when recommending methods to reduce silica exposures in this and other industries, such as the concrete products, refractory products, and foundry industries, which also use substantial quantities of sand, and clay- and concrete-based materials (NIOSH ECTB 233-109c, 1999; NIOSH ECTB 233-127c, 2000; NIOSH ECTB 233-128c, 2000; NIOSH HETA 97-0004-2642, 1997).

ERG-GI (2008) discusses the impact that compressed air use has on worker silica exposure levels in foundries. In that document, ERG describes an informal review of 26 results for cleaning/finishing operators working at five foundries where NIOSH or OSHA had observed use of compressed air to blow sand and clay molding material (similar to the silica-containing mineral dust found in structural clay facilities) off metal castings or equipment. The associated exposure levels were extremely high, as indicated by the median of 487 µg/m^3 for those 26 results. Furthermore, all 26 results (100 percent) were 230 µg/m^3 and higher. This median is more than twice as high as the overall median of 196 µg/m^3 for all

213 cleaning/finishing operator results shown in the exposure profile for cleaning/finishing operators in Section IV.C.8 – Foundries.[207] Among this larger general group, a lower proportion (23 percent) exceeded 250 µg/m^3 and more than one-third (37 percent) were 50 µg/m^3 or less. OSHA notes that the exposure profile median includes some values associated with compressed air use (i.e., 26 results described above) and might include some results for which compressed air usage occurred but was not documented. Even so, the group of results linked to overt use of compressed air is markedly higher than the overall group, of which the 26 results are a subset, suggesting a relationship between use of compressed air and higher exposures.

As alternatives to cleaning with compressed air, preferable practices include vacuuming using appropriately filtered vacuums and wet cleaning methods.

Operator Control Booth

Operator control booths (or rooms) can limit silica exposures to low levels (often below the LOD) during the time that the operator spends in the booth. ERG-GI (2008) noted that control booths are widely used for grinder operators in the structural clay industry; however, these booths are not necessarily maintained optimally to limit worker silica exposure levels. To provide a low-exposure environment, a control booth must be well-sealed, supplied with clean air, under slight positive pressure to help keep dusty air out, and regularly cleaned to remove any dust that is tracked in.

At a structural clay facility visited twice by OSHA, an area sample collected inside a ventilated control room used by the grinder operator resulted in an average silica concentration of 111 µg/m^3 (OSHA SEP Inspection Report 300523396). Before OSHA's next visit, the facility sealed gaps around the main entrance door to the control room, which reduced airborne silica levels inside the room to one-tenth the original level. A 6-hour area sample taken on the second visit showed an average respirable quartz concentration of 11 µg/m^3 inside the control room, suggesting that the room provided a substantial level of protection for any worker inside.

During the two visits, OSHA also collected personal samples for the grinder operator. The silica exposure level of the grinder operator was 362 µg/m^3 during OSHA's initial visit and fell to 101 µg/m^3 during OSHA's second visit, a 72-percent reduction.[208] Although the report does not indicate the relative amount of time the operator spent in the control room on the two sampling dates, the report attributes this reduction in the grinder operator exposure level to the improvements in the control booth.

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[207] These 213 values used in the exposure profile include the 26 documented as associated with compressed air use (i.e., compressed air was used to the extent that NIOSH and OSHA commented on it in the sampling notes). Compressed air might also have been used incidentally while some of the other results were being collected, but not to the extent that it attracted attention sufficient attention to be recorded and was noted in the sampling notes. If the 26 results had not been included in the exposure profile for cleaning/finishing operators, the difference between the medians would have been even greater.

[208] On the first sampling date the grinder operator exposure is assumed to have been concurrent with the area sample in the control room. The second grinder operator sample is known to have been obtained concurrently with the second area sample collected in the control room (OSHA SEP Inspection Report 300523396).

Exhaust Ventilation

The use of effective exhaust ventilation systems for clay grinding machines is another option for reducing worker exposures. Although no information specific to the structural clay industry is available, ERG-GI (2008) identified two studies that evaluated exhaust ventilation systems for activities analogous to grinding operations (i.e., rock crushing, which often involves a similar action to this type of grinding, and raw clay processing, which is equally as dusty as structural clay). An LEV system installed at a rock crushing plant (processing rock containing as much as 60 percent silica) was associated with reductions of silica ranging from 20 to 79 percent. In another study, a total mill ventilation system (TMVS) for a clay processing facility that performed crushing and screening operations was associated with an average respirable dust reduction of 40 percent throughout the facility. OSHA estimates that similar reductions in respirable dust levels in structural clay products facilities would result in reduced silica exposures for grinding operators (ERG-GI, 2008).

Housekeeping

Another potential control is diligent housekeeping with HEPA-filtered vacuums and dust suppressants to prevent settled dust from accumulating in grinding areas and control rooms. The use of HEPA-filtered vacuums and dust suppressants to clean grinding areas rather than dry sweeping and shoveling also can reduce re-suspension of silica-containing dust. Although the effectiveness of HEPA-filtered vacuums and dust suppressants for reducing exposures of grinding operators has not been quantified, a NIOSH report indicates that dry sweeping and shoveling of “fine material” in the grinding area is a notable exposure source that can be eliminated by using a vacuum cleaner equipped with an appropriate filter (NIOSH ECTB 233-124c, 2000). Additionally, as previously mentioned under additional controls for material handlers, dramatic exposure reduction was associated with professional-level cleaning in areas where raw materials were handled (Brick Industry Consultant A, 2003). At that facility, the exposure level of most workers was reduced dramatically, in some cases by over 90 percent, to levels of 50 μg/m^3 or less.

Additional Controls for Forming Line Operators

The Table IV.C-47 exposure profile indicates that 65 percent of forming line operators currently experience exposure levels above 50 μg/m^3. As is the case for material handlers, the data for this job category are not equally distributed across all three subcategories: only 14 percent of pug mill operators and 20 percent of coatings blenders, but 43 percent of formers, experience exposures below 50 μg/m^3. Additional controls are needed to reduce the exposures of the remaining workers in this job category.

The following paragraphs outline additional controls for forming line operators.

Combination Engineering Controls

Pug mill operators and formers on the forming line are exposed to silica dust released as dry materials fall into the hopper and mill. Mixers with doors that seal well and enclosed, ventilated mixer hoppers can limit this dust release. For example the installation of a mixer equipped with a ventilated enclosure and improved water feed system is associated with a 79-percent reduction in respirable quartz exposure readings (OSHA SEP Inspection Report 300523396). This exposure reduction was achieved after an initial reading of 1,028 μg/m^3 (the highest among the data available to OSHA for this industry) was obtained for a forming line operator who monitored a mixer equipped with LEV and a partial enclosure (OSHA SEP Inspection Report 300523396). The enclosure had several openings, and its doors did not seal properly, allowing dust to escape. Later, the facility installed another mixer with an improved enclosure and a water-feed system to wet the materials during mixing. A reading of 214 μg/m^3 was obtained for an operator who monitored the second mixer (OSHA SEP Inspection Report 300523396). The operational status of the first pug mill at the time of this later reading is unclear. Although this level still exceeds allowable limits, it represents a notable decrease in worker exposure level. Improved ventilation of the mixer hopper—for example, to levels recommended by ACGIH (2010)—might further reduce operator exposure.

Local Exhaust Ventilation

Bag dumping stations capture silica dust during coatings preparation activities performed by some forming line operators (coating preparers and formers). To be effective, the stations require properly ventilated enclosures, which capture dust release during both bag emptying and bag disposal. OSHA has not identified any structural clay products facilities using bag dumping stations that effectively controlled dust generated by bag emptying and disposal. Comparable respirable quartz exposure monitoring data exist, however, for workers using bag dumping stations to empty similar 50-pound bags of silica-containing materials at a paint manufacturing facility (ERG-paint-fac-A, 1999). A bag dumping station with fully functioning LEV was found to reduce silica exposure by at least 95 percent (from 363 μg/m^3 to 12 μg/m^3). The stations consist of hoppers topped with grates enclosed by LEV hoods. After each bag is emptied, the worker releases it, and suction automatically pulls the bag into the ventilation system and transfers it to an enclosed storage area. Bag dumping stations with other types of ventilated bag disposal equipment should be equally effective as long as they capture dust as bags are compressed. Ventilated bag dumping and bag disposal stations are readily available from commercial sources (Whirl-air, 2003; Carolina Conveying, 2010; Chicago Conveyor, 2004; Flexicon, 2009; Vac-U-Max, 2006a).

Automated Coatings Transfer System

Automated material transfer equipment can also help reduce dust released as hoppers are filled (e.g., hoppers that hold sand coatings distributed onto bricks along forming lines). For example, at a facility inspected by OSHA, an 86-percent reduction in respirable quartz exposure readings occurred after management installed an enclosed, automated sand transfer system (OSHA SEP Inspection Report 300523396). Initially, a reading of 501 μg/m^3 had been obtained for a forming line operator who manually cut open and emptied 120 50-pound bags of silica sand into a hopper at an unventilated sand charging station (OSHA SEP Inspection Report 300523396). After the inspection, the facility installed an automated system with enclosed conveyors to transfer sand to the hopper from a storage silo. During a subsequent inspection, a reading of 70 μg/m^3 was obtained for an operator who monitored the automated transfer system (OSHA SEP Inspection Report 300523396). The inspection report observed that sand leaked from the conveyor leading to the hopper because the conveyor was not the correct size. OSHA notes that with tightly sealed correctly-sized components, it is possible that exposures could be reduced further using this type of equipment.

Housekeeping

As discussed previously (see the discussion of additional controls for material handlers in this industry), considerable exposure reduction was associated with professional-level cleaning in areas where raw materials were handled. OSHA preliminarily finds that thorough cleaning and rigorous housekeeping offers the same benefit (exposure reductions of 90 percent, in many cases to less than 50 μg/m^3) in other plant areas that have accumulated dust. Much of the dust is of similar origin, so it can be expected to behave similarly. Once emissions from grinding and conveying equipment have been reduced, eliminating this source of exposure is as effective in the grinding area as in other material handling areas.

Summary of Controls for Forming Line Operators

Although most exposure-control methods for forming line operators are effective for all workers in this job category, some of the controls discussed previously are more appropriate for certain subcategories than others. The following paragraphs summarize the control methods suitable for workers in the individual forming line operators subcategories.

Pug Mill Operators Subcategory: The primary controls for this group of workers include improved enclosures for clay finishing equipment (mills, spray driers, conveyers), LEV fitted to the equipment enclosures, and water-feed systems that help reduce dust by wetting the dry clay. In work areas where dust has accumulated, improved housekeeping also helps reduce silica exposure levels.

Coatings Blenders Subcategory: For this subcategory, which prepares coatings mixtures for structural clay products, the primary control is LEV (particularly in the form of bag dumping stations, bag disposal equipment, and LEV for mixing equipment).

Formers Subcategory: Workers in this subcategory tend equipment that shapes bricks and applies sand coatings for tint or texture. Where the sand hopper is at the production line, these worker will also benefit from LEV in the form of a ventilated bag dumping station or batch-receiving hopper and bag disposal units. Where sand-based coatings are delivered from the coatings blending area by conveyer, enclosed and ventilated conveyers will be required. In both cases, formers will require coating sand application zones with LEV that enclose the coating process and capture silica dust before it spreads through the work area.

Feasibility Finding

Feasibility Finding for Material Handlers

Based on Table IV.C-47, OSHA preliminarily concludes that 70 percent of material handlers already experience exposure levels of 50 µg/m^3 or less. The same level of 50 µg/m^3 or less can be achieved for the remaining 30 percent of workers in this job category most of the time by using a variety of situation-specific controls. Based on the information presented earlier in this section, OSHA has preliminarily determined that the controls necessary for this job category include covering, ventilating, and modifying conveyers; augmenting ventilation at transfer points; using well-maintained environmental cabs (for loader operators); installing push-pull ventilation (for workers performing manual transfers); using water sprays where practical (storage yards, roads, in areas where workers handle kiln-fired finished product); and performing professional cleaning. A summary of the control methods suitable for workers in the individual material handler subcategories was presented at the end of the discussion on additional controls for material handlers in this industry.

LEV is needed at hoppers, conveyers, and screens to reduce dust during material transfer and processing. In the foundry industry, where workers also move dry mixtures of sand and clay, silica exposures were reduced from a 140 µg/m^3, a level similar to that found in the structural clay industry, to 50 µg/m^3 and 42 µg/m^3 by making improvements to the sand handling equipment and exhaust ventilation systems (OSHA SEP Inspection Report 100494079).

Where additional dust control is necessary (e.g., in crushing areas), process equipment can be further isolated in an enclosed work room and foam dust suppressants applied. A loader operator at a brick manufacturing facility using this type of system had a silica exposure level of 56 µg/m^3 (NIOSH ECTB 233-124c, 2000). NIOSH noted an accumulation of dust on the loader cab interior, suggesting that results could be lower (i.e., below 50 µg/m^3) if the cab interior were kept clean.

OSHA has determined that those material handlers who are able to spend the entire shift in an environmental loader cab can maintain silica exposures at or below 25 µg/m^3. This finding is based on a conservative estimate of respirable dust reduction of 90 percent,. This estimate is lower than the reductions of at least 94 percent and 91 percent reported by Hall et al. (2002) and MSHA (no date), respectively, for well-maintained, efficiently filtered, and ventilated environmental cabs used in other industries that also generate substantial mineral dust (agriculture, mining). This 90-percent reduction would reduce a silica result of 157 µg/m^3 (the highest level among the data available to OSHA for a front-end loader operator in this industry) to less than 16 µg/m^3 (the LOD for an 8-hour sample). Although some loader operators must spend a portion of the shift working in dusty environments outside loader cabs, these workers will decrease their average daily silica exposure in proportion to the amount of time they are able to spend in a controlled cab.

In kiln areas where high-quartz aggregate covers the floor, material handler silica exposures from this source can be all but eliminated by switching to an alternate low-silica stone (e.g., low-silica limestone pea gravel), but it is necessary to also replace the gravel frequently so broken bricks are not incorporated into the mix crushed under wheels. Results of 57 µg/m^3 to 60 µg/m^3 were associated with workers operating close to kiln-area gravel with low silica content at a brick manufacturer (NIOSH ECTB 233-124c, 2000). Based on the other work also performed by these workers (dry sweeping and handling unfired dry clay products), OSHA preliminarily concludes that their exposure level might have been lower if other sources of silica had also been better controlled. In contrast, a material handler at a brick manufacturer using high-silica gravel on the kiln floor (reportedly 98-percent silica) experienced a silica result of 258 µg/m^3, attributed to gravel pulverized under vehicle wheels (OSHA SEP Inspection Report 301986345). Assuming all other conditions were equal, the low-silica aggregate reduced average worker exposure levels by at least 77 percent.

For workers who handle kiln-fired or unfired structural clay products at fixed locations (e.g., load and unload kiln carts), an alternate type of LEV reduces exposures to acceptable levels. In an experimental study using dusty flour, Heinonen et al. (1996) demonstrated that push/pull ventilation reduced total dust concentrations by 98 percent compared to general ventilation alone (from 42,000 µg/m^3 to 1,000 µg/m^3 as total dust).[209] OSHA acknowledges that this control might not reduce exposures to the same extent in a workplace where other ventilation systems and heat currents competed with the ventilation; OSHA judges that a 90-percent reduction is more realistic. Among the results for production line handlers available to OSHA, the highest value of 258 µg/m^3 would be reduced to 26 µg/m^3 by a ventilation system control that offered a 90-percent reduction.

Additionally, many material handler exposures (including those of production line and post-production handlers) will be further reduced when silica levels associated with other adjacent job categories are also reduced below the proposed permissible exposure limit (PEL) of 50 µg/m^3. If material handler exposures in a structural clay facility continue to be elevated, rigorous housekeeping will also be

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[209] In most dusty workplaces, the level of total dust is considerably higher than the respirable dust. In turn, silica levels are a fraction of the respirable dust levels. This ratio is demonstrated in research by Foreland et al. (2008), who measured total dust, respirable dust, and silica concentrations in the Norwegian silicon carbide industry and found the average (arithmetic mean) of two values for samples obtained for one job category in one facility were 22,000 µg/m3 total dust, 1,300 µg/m3 respirable dust, and 23 µg/m3 respirable quartz. OSHA preliminarily finds that a ventilation system that reduces total dust levels from 42,000 µg/m3 to 1,000 µg/m3 (regardless of whether the dust is flour or clay) can reasonably be expected to reduce silica levels dramatically too. Even if real-world performance of the exhaust ventilation system for controlling respirable quartz offers an exposure reduction of just 90 percent, then the ventilation will still reduce the maximum silica value for this job category (258 µg/m3) to a level of 26 µg/m3.

necessary, beginning with a professional-level cleaning. Post-cleaning air sampling indicated a dramatic reduction decrease in exposure levels (in some cases greater than 90 percent) for workers in areas where dusty materials were transported or handled. Most worker exposures were reduced to levels less than 50 µg/m^3 (Brick Industry Consultant A, 2003).

Based on the information presented here, OSHA preliminarily concludes that the control methods listed above will reduce the exposures of most material handlers to levels of 50 µg/m^3 or less most of the time.

Wet methods and automation also remain options for controlling dust released during some material handler functions. Among the data available to OHSA, all nine results associated with automated material handling in structural clay plants were less than 50 µg/m^3 and eight of the nine results were less than 25 µg/m^3. Many of these results were also associated with wet methods. For material handlers who operated automated product handling equipment equipped with spray nozzles, four of six exposures were less than or equal to 12 µg/m^3 (LOD), and the remaining two were 30 µg/m^3 or less (NIOSH ECTB 233-108c, 2000).

Feasibility Finding for Grinding Operators

Based Table IV.C-47, OSHA preliminarily concludes that exposure levels of 50 µg/m^3 or less have already been achieved for 29 percent of grinding operators. The silica exposures of most of the remaining 71 percent of grinding operators can be controlled to the same level by using a combination of controls, including well-enclosed grinding equipment, conveyor enclosures, dust suppressants or water spray on raw materials, covered or troughed conveyors, tightly sealed storage units, and professional-level cleaning. A facility that used a combination of troughed conveyors, enclosed grinding machinery, covered conveyors, sealed bins, and raw materials with higher water content achieved exposures of 67 µg/m^3 and 13 µg/m^3 for a grinding operator (NIOSH ECTB 233-108c, 2000). No information is available on exposure levels at this plant without these controls in place; however, OSHA notes that most of the highest exposure levels for this job category are associated with poorly sealed, leaking equipment. In contrast, completely enclosed equipment with exhaust ventilation can be expected to nearly completely control the source of dust emissions regardless of how severely the original equipment leaked dust; therefore, results of 67 µg/m^3 and 13 µg/m^3 can be expected by any plant that takes these steps. In plants with older equipment, implementing these steps might mean replacing grinders and conveying equipment not originally designed to be fully enclosed. Furthermore, although the NIOSH report does not identify reasons for the difference between the two exposures (67 µg/m^3 and 13 µg/m^3), it does indicate that compressed air was used for cleaning.

OSHA also preliminarily concludes that, in addition to the controls listed previously, by switching from the use of compressed air to HEPA-filtered vacuums for cleaning and by using a well-sealed control booth during at least one-third of the shift, most grinder operator exposures will be reduced to levels of 50 µg/m^3 or less most of the time.[210] OSHA bases this conclusion on information outlined in the section on additional controls for grinder operators. Specifically, the use of compressed air for cleaning is associated with markedly elevated exposure levels (e.g., in the foundry industry, where workers also manipulate sand and clay), and the median exposure level for 26 cleaning/finishing operators using compressed air was 487 µg/m^3, more than twice the median for all cleaning finishing

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[210] Approximately one-third of an 8-hour shift (i.e., 160 minutes) is the amount of time during which OSHA estimates a 67 µg/m3 exposure would need to be reduced to a typical limit of detection (12 µg/m3) in order to achieve an exposure of 50 µg/m3 or less.

operators in that industry (ERG-GI, 2008). Furthermore, a structural clay industry grinding operator control room with an average respirable quartz concentration of 11 µg/m^3 inside the control room provides a substantial level of protection for any worker inside. A foundry with elevated operator exposure levels repaired an existing control room to create such a space (OSHA SEP Inspection Report 300523396). If the operator described in the previous paragraph (i.e., silica exposure level of 67 µg/m^3 with a combination of controls in place) had also used a control room (e.g., 12 µg/m^3)[211] for one-third (33 percent) of the shift, the exposure level of that operator would have been reduced to 50 µg/m^3. By also eliminating the use of compressed air for cleaning (which is a prohibited practice under paragraph (f)(3)(ii) of the proposed rule when it could contribute to exposures above the PEL), OSHA estimates that such a worker can experience silica exposure levels well below 50 µg/m^3.

Elevated exposures can still occur during discrete activities, such as opening the grinder housing doors. In cases where a grinder must inspect the area inside the sealed doors enclosing the grinder, the operator must deactivate the grinder and let the LEV evacuate dusty air before opening the doors. If this is not possible, the operator must wear respiratory protection to inspect the grinder. If the ventilation system is running and the grinder is turned off (but not evacuated), a respirator that provides an applied protection factor (APF) of 10 (e.g., a half-facepiece respirator) should offer adequate protection under the proposed PEL of 50 µg/m^3.[212] The maximum use concentration (MUC) for such a respirator is 500 µg/m^3.

Feasibility Finding for Forming Line Operators

Based on the data shown in Table IV.C-47, OSHA preliminarily concludes that 35 percent of forming line operators already experience results of 50 µg/m^3 or less. Employers of the remaining 65 percent of forming line operators can achieve exposure levels below 50 µg/m^3 for most of these workers by a combination of control measures. These controls include rigorous housekeeping, starting with thorough professional cleaning; well-ventilated and enclosed mills, mixers, hoppers, and conveyers; tightly-sealed storage units; enclosed, automated sand transfer systems or bag dumping stations with LEV; exhaust-supply ventilation at workstations, and elimination of compressed air for cleaning. Wet-clay formers will also experience reduced silica exposure when the silica exposures associated with other adjacent activities (e.g., pug mill operators and sand coating activities) are also reduced to levels of 50 µg/m^3 or less. A summary of the control methods suitable for workers in the individual forming line operator subcategories appears at the end of the discussion on additional controls for forming line operators in this industry.

Samples collected during two visits by OSHA to a structural clay plant with a leaking pug mill showed that the facility reduced airborne respirable quartz from 1,028 µg/m^3, the highest value in Table IV.C-47, to 214 µg/m^3 when it installed another mixer equipped with a ventilated enclosure and improved water feed system (OSHA SEP Inspection Report 300523396). Because the operational status of the first pug mill is unclear, this 79-percent reduction might include that first mill as an ongoing source of exposure. OSHA notes that, as shown previously in the discussion of additional controls for grinder operators, it is reasonable to expect that well-sealed enclosed equipment with sufficient exhaust ventilation will not emit excessive dust during normal operations; however, other sources of respirable dust must also be controlled (e.g., hoppers, conveyers). Because all these types of equipment use aggressive action on dusty raw materials (with grinders being the most aggressive), and each type of equipment can be encased in ventilated housing, it is reasonable to expect that pug mills and related clay

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[211] In this example 12 µg/m3 is used instead of the reported value of 11µg/m3 because 12 µg/m3 is the typical LOD for an 8-hour sample.

[212] If the grinder remains running, a higher level of respiratory protection will likely be required (e.g., a full-facepiece respirator with an APF of 50).

finishing equipment can be controlled to at least the same extent as grinding equipment (67 μg/m^3 and 13 μg/m^3) by using similar equipment modifications (or replacement with newer, more tightly sealed models). As described previously in the feasibility finding for the grinder operator job category in this industry, additional measures—such as using control booths or eliminating the use of compressed air for cleaning—also will further reduce most operator exposures to levels of 50 μg/m^3 or less.

Forming line operators mixing coatings, applying coatings, or working where coatings are applied will require ventilated mixing equipment, ventilated bag dumping stations, and enclosed conveyers between bulk raw material storage and mixers, or between the coatings hoppers and the coatings application points to reduce exposures to 50 μg/m^3 or less. At a structural clay facility inspected by OSHA, an 86-percent reduction in respirable quartz exposure readings (from 501 μg/m^3 to 70 μg/m^3) occurred after management installed an enclosed, automated sand transfer system, despite having an incorrectly sized conveyer (OSHA SEP Inspection Report 300523396). As an example of the extent of exposure reduction achieved when a ventilation system (with bag disposal option) is functioning, ERG-paint-fac-A (1999) obtained respirable quartz data for workers in the paint manufacturing industry, in which workers empty 50-pound sacks of materials with high-silica content into hoppers and mixers in a manner similar to that used by structural clay workers. Results for five paint industry workers using a ventilated bag dumping station were all less than or equal to 12 μg/m^3, and a result for a worker who used a bag dumping station with an LEV system that was not operating for 2 hours was 263 μg/m^3. Hence, a bag dumping station that reduces exposure by 95 percent would reduce the highest coatings blender exposure from 228 μg/m^3 to 11 μg/m^3.

Although the controls described previously will reduce silica levels of nearly all production line operators to levels between 12 μg/m^3 and 67 μg/m^3, further reductions are possible. The type of supply-exhaust ventilation system described as a control option for material handlers working near the production area will also control exposure levels for production line operators who work at fixed locations in the production area. As noted previously, such a system might reduce exposure levels by 90 percent under real-world conditions (higher levels have been show experimentally). This reduction would limit exposures on the production line to levels less than the typical LOD for an 8-hour sample (12 μg/m^3).

Using these combinations of controls, OSHA preliminarily finds that the silica exposures of all forming line operators, except operators of pug mills and related clay finishing equipment, can be reduced to levels of 50 μg/m^3 or less. Most pug mills and related clay finishing equipment operators will experience exposure levels of 50 μg/m^3 most of the time, but might not be able to do so consistently, particularly if they cannot spend at least a third of the shift in a control booth.

Additionally, most forming line operator exposures will further decline when silica levels associated with other worker activities (such as the operators of grinders and pug mill or other clay finishing equipment) are reduced below the proposed PEL of 50 μg/m^3. ERG-ceramic-tile (2001) found that dust emitted from a ball mill and spray drier influenced exposure levels downstream along the forming line.

In the event that the exposure levels of production line operators continue to be elevated, rigorous housekeeping will also be necessary, beginning with professional-level cleaning. At a brick manufacturing plant, post-cleaning air sampling indicated a dramatic decrease in exposure levels (in some cases greater than 90 percent) for workers in areas where dusty materials were transported or handled. Most worker exposures were reduced to levels less than 50 μg/m^3 (Brick Industry Consultant A, 2003).

As mentioned previously, this level might not be consistently achieved for some operators of pug mills and related clay finishing equipment if they cannot spend at least 33 percent of the shift in a well-sealed control room. In order to consistently protect these workers under the proposed PEL of 50 μg/m^3, respirator protection might be required. Based on the exposure levels that can be expected for most of the shift (67 μg/m^3 or less), a half-facepiece respirator that provides an assigned protection factor of 10 will protect workers under the proposed PEL of 50 μg/m^3.

Overall Feasibility Finding

Based on the information just described, OSHA preliminarily concludes that the exposures of all material handlers and all production line operators (except operators of pug mills and related clay finishing equipment) can be controlled to levels of 50 μg/m^3 or less most of the time. Exposures of most grinder operators and most production line handlers working with pug mills and related equipment also can be controlled to levels of 50 μg/m^3 or less most of the time, but these workers will likely require respiratory protection for certain activities, such as equipment inspections. Provided the controls described above are in place, a half-facepiece respirator will likely offer sufficient protection under the proposed PEL of 50 μg/m^3.

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Abrasive Blasters

Description

This section addresses miscellaneous abrasive blasting operations that occur in construction. Workers use portable abrasive blasting equipment to deliver a high-pressure stream of abrasive media to a surface. According to a review of the OSHA Special Emphasis Program (SEP) inspection reports (1990–1997), construction companies use abrasive blasting mainly to remove surface coatings or clean the surfaces of structures and equipment, such as oil tanks, water tanks, gasoline tanks, bridges, and steel beams. Workers in this industry perform abrasive blasting as part of their job or assist an abrasive blaster by refilling the abrasive blasting machine's reservoir or helping to maneuver the hoses.

Abrasive blasting workers also are employed in general industry, in which blasting is not a sector itself, but rather encompasses a cross section of related activities in numerous industries. The general industry abrasive blasters with potential exposure to silica work in a diverse range of manufacturing and service industries. Their work occurs mainly in the following sectors and is addressed in those sections of this technological feasibility analysis: IV.C.3 – Concrete Products, IV.C.4 – Cut Stone, IV.C.6 – Dental Laboratories, IV.C.8 – Foundries, IV.C.10 – Jewelry, and IV.C.20 – Shipyards (Maritime Industry).

Typically, abrasive blasting related to construction differs from industrial abrasive blasting in that construction workers perform these activities at temporary worksites without the use of a fixed-position abrasive blasting booth or cabinet fitted with exhaust ventilation. Abrasive blasting operations similar to those found on construction sites also occur on the premises of some manufacturing and nonmanufacturing general industry establishments, where the abrasive blasting operation is not a normal part of the establishments' main business (e.g., food manufacturing, retail stores). For these establishments, it is difficult to distinguish whether the blasting is performed as part of construction activities or facility maintenance. At these locations, the baseline conditions, exposure profile, and additional controls presented here apply equally, regardless of whether the abrasive blasting is for the purpose of construction or maintenance. OSHA's existing requirement that abrasive blasting workers wear respiratory protection also applies equally.[213]

Construction workers who perform abrasive blasting at least occasionally are associated with numerous construction industry North American Industry Classification System (NAICS) codes, including: 236210, Industrial Building Construction; 236220, Commercial and Institutional Building Construction; 237110, Water and Sewer Line and Related Structures Construction; 237120, Oil and Gas Pipeline and Related Structures Construction; 237130, Power and Communication Line and Related Structures Construction; 237310, Highway, Street, and Bridge Construction; 237320, Paint and Wall Covering Contractors; 237990, Other Heavy and Civil Engineering Construction; 238190, Other Foundation, Structure, and Building Exterior Contractors; and 238990, All Other Specialty Trade Contractors. This section presents information from these segments of the construction industry and is representative of most construction abrasive blasting operations and conditions.

Table IV.C-48 summarizes the job categories, major activities, and primary sources of silica exposure of workers in the construction industry.

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[213] For OSHA's requirements for respirators and exhaust ventilation for abrasive blasting, see 29 CFR 1926.57 – Ventilation (or 1910.94 – Ventilation for general industry) and 1910.134 – Respiratory Protection.

Table IV.C-48

Job Categories, Major Activities, and Sources of Exposure of Abrasive Blasters

Job Category*	Major Activities and Sources of Exposure
Abrasive Blasting Operator	Uses abrasive blasting equipment to clean a variety of surfaces. • Dust generated from the use of silica-containing abrasive blast media. • Dust generated from the abrasive blasting on concrete substrates. • Dust raised by sweeping or shoveling spent abrasive material (housekeeping).
Abrasive Blaster's Helper (Pot Tender)	Tends blasting equipment. • Dust raised by filling abrasive blasting reservoir (e.g., emptying bags of grit). • Dust generated by abrasive blasting operations carried out by the Abrasive Blasting Operator. • Dust raised by sweeping or shoveling spent abrasive material (housekeeping).

*Job categories are intended to represent job functions; actual job titles may differ and responsibilities may be allocated differently, depending on the construction site.

Source: ERG-C, 2008.

Baseline Conditions and Exposure Profile

The following paragraphs describe baseline conditions for the job categories abrasive blasting operator and abrasive blaster's helper, based on OSHA SEP inspection reports and NIOSH reports. These reports present information on abrasive blasting (identified by standard industrial classification number) as performed for construction purposes at building sites, steel and concrete tanks (inside and outside), swimming pools, highway/bridges, and an oilfield construction site. Together these sources provide the best data available to OSHA for workers performing miscellaneous abrasive blasting operations in construction.

For this profile, OSHA reviewed exposure data contained in OSHA SEP reports (mainly from 1990 to 1997), NIOSH studies (mainly from 1999 to 2009), New York Department of Transportation memos (NYDOT 1998, 2003), and published articles. The exposure profile summarizes the results of 59 silica samples for abrasive blasting workers at 20 commercial, storage tank, and highway construction sites, including bridge locations.[214]

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[214] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) calculated assuming no additional exposure during any unsampled portion of the shift. Unless explicitly stated otherwise, all results discussed in the additional controls section are also 8-hour TWAs calculated the same way. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

Table IV.C-49 presents the exposure profile and summarizes the data available to OSHA for workers involved with abrasive blasting operations in the construction industry.

Baseline Conditions for Abrasive Blasting Operator

Based on descriptions of abrasive blasting operators' activities and equipment in those sources mentioned above, OSHA concludes that baseline conditions for this group of workers include the use of a portable abrasive blasting machine with dry silica-containing abrasive blast media. Abrasive blasting operators also wear respiratory protection in the form of supplied-air abrasive blasting hoods. These baseline conditions are represented in Table IV.C-49 by the data summarized for workers performing "dry blasting, uncontrolled, with no blasting booth or cabinet."

The highest silica exposure levels are associated with abrasive blasting operators dry sandblasting in unventilated enclosed spaces. For instance, a silica reading of 29,040 micrograms per cubic meter (μg/m^3) was obtained by OSHA for a worker blasting inside a city water tower (Barker, 2002). NIOSH surveys also found high readings associated with dry sandblasting in unventilated enclosures. An abrasive blasting operator[215] working inside an enclosure had a respirable quartz exposure of 19,000 μg/m^3. In this case, sandblasting operations were performed inside a steel-plate water tank (NIOSH HETA 93-1037-2541, 1993).

Significant silica exposure can occur during the use of alternative nonsilica abrasives, mainly when the work surface contains silica. For example, NIOSH obtained a 90-minute short-term reading of 440 μg/m^3 (83 μg/m^3 as an 8-hour TWA) for a worker using an abrasive containing less than 1-percent quartz to remove paint from the steel understructure of a bridge. The worker blasted inside an enclosure; silica was thought to come from concrete adjacent to the steel being cleaned (NIOSH-WV-Route 1, 1992).

A result of 73 μg/m^3 was collected for an operator who also used a nonsilica abrasive to blast a swimming pool (OSHA SEP Inspection Report 300219854). The specific source of the silica was not indicated; however, OSHA notes that swimming pools are typically lined with painted concrete and tile, both of which contain silica. Although this reading is markedly lower than results for workers performing abrasive blasting using sand, it nonetheless indicates the potential for exposure from abrasive blasting on materials that contain silica, even when the worker uses a nonsilica alternative blasting media. These media are a safer alternative to silica sand, but do not necessarily eliminate exposure under all conditions.

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[215] According to NIOSH, workers typically spend the same proportion of their entire shift performing abrasive blasting as they spent performing abrasive blasting during the 4-hour sampling period. Thus silica concentrations measured during the sampling period are also representative of the workers' 8-hour exposures. Specifically, in this study NIOSH collected half-shift samples with durations of 240 minutes to reduce the chance of filter overloading. NIOSH stated that "at this operation, half-shift sample concentrations are reasonable approximations of full-shift concentrations (2 hours of sandblasting per 4-hour half-shift is similar to 4 hours of sandblasting per 8-hour full-shift). Therefore, half-shift, 4-hour time-weighted average (TWA) exposures are believed to be reasonable approximations of full-shift, 8-hour TWA exposures" (NIOSH HETA 93-1037-2541, 1993).

Table IV.C-49
Respirable Crystalline Silica Exposure Range and Profile for Abrasive Blasters

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean (μg/m^3)**	**Median (μg/m^3)**	**Min (μg/m^3)**	**Max (μg/m^3)**		**<25 (μg/m^3)**	**≥25 and ≤50 (μg/m^3)**	**>50 and ≤100 (μg/m^3)**	**>100 and ≤250 (μg/m^3)**	**>250 (μg/m^3)**
Abrasive Blasting Operator Dry blasting, uncontrolled, no blasting booth or cabinet	27	3,582	230	12	29,040		7 25.9%	1 3.7%	3 11.1%	3 11.1%	13 48.1%
Same as baseline, with wet methods attempted	17	161	125	36	407		0 0.0%	3 17.6%	3 17.6%	7 41.2%	4 23.5%
Abrasive Blasting Operator Subtotals	**44**	**2,260**	**170**	**12**	**29,040**		**7** **25.9%**	**4** **9.1%**	**6** **13.6%**	**10** **22.7%**	**17** **38.6%**
Abrasive Blaster's Helper Assisting with dry blasting, uncontrolled, no blasting booth or cabinet	7	926	41	10	4,700		2 28.6%	2 28.6%	0 0.0%	1 14.3%	2 28.6%
Same as baseline, with wet methods attempted	8	60	68	12	104		2 25.0%	1 12.5%	4 0.0%	1 12.5%	0 0.0%
Abrasive Blaster's Helper Subtotals	**15**	**464**	**65**	**10**	**4,700**		**4** **26.7%**	**3** **20.0%**	**4** **26.7%**	**2** **13.3%**	**2** **13.3%**
Totals for Abrasive Blasting Operator and Abrasive Blaster's Helper	**59**	**1,804**	**111**	**10**	**29,040**		**11** **18.6%**	**7** **11.9%**	**10** **16.9%**	**12** **20.3%**	**19** **32.2%**

Notes: All samples are personal breathing zone (PBZ) results and represent 8-hour time-weighted average exposures with the assumption that no additional exposure occurred during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Although most construction work involving abrasive blasting is conducted outdoors, some portions of the same abrasive blasting jobs might occur inside enclosed spaces (e.g., tanks or tarp enclosures); however, from the available descriptions supporting the data, it is often not possible to tell where the samples were obtained relative to the enclosures.

Sources: Barker, 2002; ERG-C, 2008; Linch, 2002; NIOSH HETA 93-1037-2541, 1993; NIOSH ECTB-247-11c, 1999; NIOSH-WV-Route 1, 1992; NYDOT, 1998; NYDOT, 2003; OSHA SEP Inspection Reports 107092223, 107094641, 108863093, 109305631, 116160821, 300190147, 300191079, 300206133, 300219854, 300390176, 300477189, 300544350, 302391594.

NIOSH evaluated a wet blasting operation in which abrasive blasting operators blasted exterior concrete surfaces of a parking garage with a wet blasting system that projected a mixture of water and silica sand (NIOSH ECTB 247-11c, 1999). Fourteen exposure readings, ranging from 36 µg/m^3 to 395 µg/m^3, were obtained for these abrasive blasting operators. These results are markedly lower than values typically associated with uncontrolled dry blasting.

Table IV.C-49 presents the exposure profile for workers using abrasive blasting equipment. This table summarizes the best exposure data available to OSHA for these workers. Of the 59 respirable quartz readings summarized in the exposure profile, 44 represent abrasive blasting operators and 15 are associated with abrasive blasters' helpers. Of the 44 abrasive blasting operator results, 27 were obtained while workers performed dry abrasive blasting, with 8-hour TWA exposure levels ranging from 12 µg/m^3 to 29,040 µg/m^3. The median for this group is 230 µg/m^3 and the mean is 3,582 µg/m^3. The remaining 17 of the 44 abrasive blasting operator results represent workers using wet blasting methods, ranging from 36 µg/m^3 to 407 µg/m^3, with a median of 125 µg/m^3 and a mean of 161 µg/m^3. Although the silica exposure levels for abrasive blasting operators routinely exceed OSHA's permissible exposure limit (PEL), OSHA already requires that employers provide these workers with respiratory protection and, when the work is in an abrasive blasting booth, ensure that these workers have the benefit of exhaust ventilation. For more information on these requirements, see 29 CFR 1926.57–Ventilation (for general industry 1910.94–Ventilation) and 1910.134–Respiratory Protection.

Baseline Conditions for Abrasive Blasters' Helpers

Baseline conditions for abrasive blasters' helpers are nearly identical to those of abrasive blasting operators except that they spend less time in close proximity to blasting operations. The helpers typically use particulate-filtering respirators. In Table IV.C-49, typical exposure levels representing these baseline conditions are summarized with the data for abrasive blasters' helpers "assisting with dry blasting, uncontrolled, with no blasting booth or cabinet."

Fifteen results in the Table IV.C-49 exposure profile represent abrasive blasters' helpers, with seven of those results associated with dry abrasive blasting. These exposures have a median of 41 µg/m^3, a mean of 926 µg/m^3, and ranged from 10 µg/m^3 to 4,700 µg/m^3 (the highest results are discussed in more detail in the next paragraph). Of the 15 results for helpers, the remaining eight, all from one concrete parking garage construction site described in NIOSH ECTB-247-11c (1999), represent exposures to abrasive blasters' helpers during abrasive blasting workers' attempts at wet dust control methods. When wet dust control methods are used the helpers have a median of 68 µg/m^3 and a mean of 60 µg/m^3, and the highest result is 104 µg/m^3. While these data imply that wet methods have the greatest impact on helpers who would otherwise be exposed at the high end of the range (their exposures are much lower than they would have been), OSHA notes that additional information from other blasting sites is needed to confirm this effect.

Exposures for abrasive blasters' helpers can vary widely depending on the activities required of the helper (e.g., refilling media reservoirs, maintaining air compressors, maneuvering hoses), the helper's proximity to the point where abrasive blasting occurs, and the amount of time spent there. As with abrasive blasting operators, some of the highest exposure levels for abrasive blasters' helpers were associated with dry blasting in unventilated enclosed spaces. For instance, NIOSH reported an 84-minute short-term exposure of 27,000 µg/m^3 (4,700 µg/m^3 as an 8-hour TWA) during an evaluation of dry sandblasting operations on the interior of a 750,000-gallon steel-plate water tank sandblasting (NIOSH HETA 93-1037-2541, 1993). The worker shoveled sand from an elevated ledge to the bottom of the inside of the tank. OSHA also obtained an exposure reading of 1,466 µg/m^3 for a helper while sandblasting was performed inside a city water tower, a job that lasted 8 hours (Barker, 2002). Additionally, NIOSH measured a 72-minute short-term silica reading of 1,470 µg/m^3 (221 µg/m^3 as an 8-

hour TWA) during paint removal from the steel understructure of a bridge using a dry coal-slag blasting grit (an alternative to silica sand) (NIOSH-WV-Route 1, 1992). The abrasive blaster's helper spent the majority of the sampling period in the enclosure. OSHA notes that when helpers must work inside enclosed spaces during dry abrasive blasting, their exposure levels are dramatically higher than when their activities are limited to tending equipment and loading sand into the grit pot outside the enclosed space (all results less than 41 µg/m^3).

Additional Controls

As the exposure profile indicates, abrasive blasting workers are potentially exposed to levels of silica hundreds of times higher than the current PELs. Controls are required not only to protect the abrasive blasting operator, but also the abrasive blaster's helper and any workers adjacent to the blasting operation.

Additional Controls for Abrasive Blasting Operators

Exposure control options for abrasive blasting operators include:

- Blasting with wet methods or other processes that reduce or eliminate dust generation.
- Local exhaust ventilation of enclosures (with proper filtration to protect adjacent workers).
- Enclosures, such as containment structures (protect adjacent workers only).
- Use of low-silica and silica-free blasting media substitutes.
- Respiratory protection.

The effectiveness of these options in controlling silica exposures is discussed in the following sections. Given the high levels of hazardous dust generated during abrasive blasting, OSHA anticipates that respiratory protection will continue to be necessary to reduce silica exposure to acceptable levels, even with these controls in place. Respiratory protection is also discussed further below. In addition, strict adherence to proper work practices and housekeeping practices that reduce dust emissions are essential to controlling the exposures of abrasive blasting workers and adjacent workers. Also, in all cases, employers must comply with the applicable requirements of 29 CFR 1926.57–Ventilation (for general industry 1910.94–Ventilation) and 1910.134–Respiratory Protection to protect abrasive blasting workers adequately.

Wet Methods and Alternatives to Dry Abrasive Blasting

Alternative techniques to dry abrasive blasting can be used to reduce the silica exposure levels of abrasive blasting workers and adjacent workers, although the effectiveness of these methods in reducing silica exposures has not been extensively documented. These techniques, summarized in Table IV.C-50, include wet abrasive blasting, hydroblasting, centrifugal wheel blasting, vacuum blasting, and blasting with dry ice pellets. Cleaning techniques that do not use abrasive blasting and are suitable for smaller jobs include thermal, chemical, and mechanical stripping methods. Other removal techniques that could reduce or eliminate silica dust levels during surface preparation include blast cleaning with baking soda (sodium bicarbonate), reusable sponge abrasives, or plastic media blasting (PMB); cryogenic stripping (immersing small parts into liquid nitrogen, followed by gentle abrasion or PMB); and laser paint stripping (generates no waste and uses a pulsed carbon dioxide laser as the stripping agent).

Table IV.C-50

Examples of Alternatives to Dry Abrasive Blasting

Name	**Description/Comments**
Wet Abrasive Blasting	Can be used in most instances where dry abrasive blasting is used. Includes: 1) compressed air blasting with the addition of water into the blast stream before the abrasive leaves the nozzle, and 2) water jetting with the addition of abrasive into the water stream at the nozzle. Additives and rust inhibitors may be used.
Hydroblasting	High Pressure Water Jetting: Uses pressure pump, large volume of water, and specialized lance and nozzle. Pressures range from 3,000 to 25,000 pounds per square inch (psi). Can remove loose paint and rust; will not efficiently remove tight paint, tight rust, or mill scale. Can be used in most instances where abrasive blasting is used. Primary application is for an older surface rusted in a saline environment rather than new steel. Rust inhibitors could be required to prevent flash rusting. Ultra High Pressure Water Jetting: Similar to high pressure water blasting. Uses pressurized water from 25,000 to 50,000 psi. Removes tight paint and rust, but not mill scale.
Centrifugal Wheel Blasting	Uses a rotating wheel assembly inside an enclosure equipped with a dust collector. Abrasive is propelled outward from the rotating wheel and removes rust, paint, and mill scale. Abrasives are recycled and include steel shot, steel grit, cut wire, and chilled iron grit. The operator has no contact with airborne dust or high velocity particles.
Vacuum Blasting	Uses standard blast nozzle inside a shroud (head) that forms a tight seal with the work surface. Vacuum is applied inside shroud during blasting to remove dust and debris. Abrasives are recycled and include aluminum oxide, garnet, steel shot, steel grit, and chilled iron grit. When used properly, cleans effectively with minimal dust.
Dry Ice Pellets	Dry ice blast cleaning with solid carbon dioxide. Waste is minimized and includes paint chips and rust. Storage and handling costs can be significant.
Thermal Stripping	Uses a flame or stream of superheated air to soften paint, allowing for easy removal. Generates one waste stream (i.e., waste paint). Effective for small parts; not suitable for heat-sensitive surfaces. Very labor intensive.
Chemical Stripping	Uses hazardous chemical strippers such as methylene chloride-based or caustic solutions. Effective for small fiberglass, aluminum, and delicate steel parts. Requires adequate ventilation and other safety measures. Generates multiple waste streams (i.e., contaminated rinse water and waste strippers).
Mechanical Stripping	Involves chipping, grinding, sanding, or scraping the coating off small parts or surfaces through the use of needle guns, chipping hammers, sanders, and grinders. Generates paint waste and airborne dust. Some power tools are equipped with dust collection systems.

Sources: U.S. EPA, 1991; Kura et al., no date.

Wet methods can be used to reduce or eliminate the amount of dust generated during surface preparation. All wet blasting techniques (such as wet abrasive blasting and hydroblasting) produce substantially lower dust emissions compared with dry abrasive blasting. For example, after reviewing other published and unpublished work, Lahiri et al. (2005) estimated that silica exposure associated with sandblasting can be eliminated by using hydroblasting (which involves no abrasive grit), even when the surface being hydroblasted contains silica (e.g., concrete). OSHA recognizes that although this method effectively cleans many surfaces with minimal silica release, it cannot replace abrasive media blasting under all circumstances.

A 2008 report from Germany's Institute for Occupational Safety and Health of the German Social Accident Insurance[216] indicates that silica exposures are reduced by wet methods, but that "dust emissions are influenced substantially by the type and quantity of the water feed." The German report indicates that compared with dry abrasive blasting, modest amounts of water result in some exposure reduction, but the silica levels can still be extremely high. As an extreme example, during laboratory tests using quartz-free blasting media moistened with 10 percent water to abrasively blast concrete,[217] airborne quartz concentrations were still up to 6,000 µg/m^3. If silica sand had been used in this test, the quartz concentration would likely have been doubled, or higher. BGIA reports that "if materials containing quartz, such as concrete, are dry-blasted with quartz sand, over half the quartz dust exposure is attributable to the blasting agent" (BGIA, 2008).

This German report also indicates that increasing the water content to form a slurry improves dust control. A provided example involved replacing the conventional pneumatic blast unit with an ultra-high-pressure slurry blasting unit (29,000 psi) to work on a concrete silo. Under these conditions, investigators measured an average quartz concentration of 500 µg/m^3. They consider it possible that average results could be lower still, but concluded that use of such equipment is unlikely to reduce concentrations below 150 µg/m^3 (BGIA, 2008).

An intermediate amount of water added to the blasting media offers intermediate results. As mentioned in the exposure profile, NIOSH evaluated a wet blasting operation in which workers blasted exterior concrete surfaces of a parking garage (NIOSH ECTB 247-11c, 1999). Their system used a mixture of 80 percent silica sand and 20 percent water. NIOSH reported that this method appeared to reduce the silica exposures associated with abrasive blasting, but the extent of the reduction was not determined, and operators' exposures remained as high as 395 µg/m^3. The same study is published as Mazzuckelli et al. (2004). NIOSH did conclude that the exposure readings obtained for this evaluation were lower than readings obtained for other abrasive blasting operations. Most of the other values for abrasive blasting operators described here support NIOSH's conclusion. Exposure readings obtained inside enclosed spaces tend to be particularly high. For example, OSHA obtained an exposure reading of 7,016 µg/m^3 for an abrasive blasting operator who performed dry blasting of hardened concrete from a cement truck using silica sand media (OSHA SEP Inspection Report 300190147).

Heitbrink (2007) conducted a field study of a wet abrasive blasting technique and obtained significantly lowered silica exposures compared with silica exposure data reported in the literature. The tested device was a water induction nozzle described as a venturi nozzle in which water is added to the abrasive-air mixture to reduce dust during blasting. Workers were monitored while blasting outdoors in

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[216] At the time of the report, Germany's Institute for Occupational Safety and Health of the German Social Accident Insurance was known as BGIA, but this organization is now called by the German acronym IFA.

[217] The pneumatic abrasive blasting unit operated at a pressure of 102 to 116 psi (BGIA, 2008).

open areas on concrete panels using silica sand abrasive from which the fines had been removed.[218] In 10 samples, the geometric mean silica was 60 μg/m^3, and the range was 20 μg/m^3 to 130 μg/m^3. The author found that restricting the fines content of the sand in combination with wet blasting was effective in reducing silica exposures, but noted that in this study the individual effects of the two controls were confounded (i.e., they could not be identified separately). Also, although excessive water application rates were not a problem at this site, Heitbrink noted that such water application rates could present a problem at other work sites.[219] This data also appears as a study by Old and Heitbrink (2007).

The amount of water required for effective dust control during blasting depends on the device and the application, and the relation between water flow rates and dust emissions has not been widely studied to date. In some cases, a volume of water is mixed directly with a volume of abrasive. For instance, Heitbrink describes a wet abrasive blasting device that mixes water and abrasive in a pressurized tank, with a ratio of about 80 percent abrasive and 20 percent water (Heitbrink, 2007). In other devices, the water is supplied continuously at a given flow rate. The patent for a water induction nozzle tested by Heitbrink reported that visual dust was reduced as water flow rate increased from 1 to 5 liters per minute (Heitbrink, 2007). Heitbrink points to the need for controlled laboratory testing to develop recommended water application rates for wet blasting.

Subfreezing conditions could present an additional challenge to the use of wet methods for dust suppression. As discussed in the introductory section of this chapter, however, most workers will be able to use wet methods most of the time.

Enclosures and Local Exhaust Ventilation

Enclosures in which workers perform blasting keep silica contained, providing a measure of exposure control for other workers performing activities outside the enclosure. Unless properly ventilated, however, such enclosures concentrate the levels of silica in a small area and thus can present a significant hazard to the person performing abrasive blasting. For example, NIOSH found elevated short-term results of 820 μg/m^3, 1,730 μg/m^3, and 2,960 μg/m^3 (sample durations of 93, 96, and 93 minutes, respectively) for area samples collected inside an unventilated enclosure used to confine dust generated during the blasting process (NIOSH-WV-Route 1, 1992).

Strict compliance with the OSHA ventilation standard for abrasive blasting in construction (29 CFR 1926.57) is essential for controlling the exposures of abrasive blasting workers working in enclosures. According to that standard, all blast-cleaning enclosures must be adequately ventilated, whether silica or an alternative abrasive agent is used. Portable blast-cleaning equipment and temporary containment structures must have sufficient exhaust ventilation to: 1) prevent a build-up of dust-laden air and reduce the concentrations of hazardous air contaminants, 2) prevent any leakage of dust to the outside, and 3) provide prompt clearance of dust-laden air from the enclosure when blasting has ceased. Exhaust ventilation systems must be constructed, installed, inspected, and maintained according to the OSHA construction ventilation standard. The exhaust air from blast-cleaning equipment must be discharged to the outside through an appropriate dust collector to protect the workplace, the environment,

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[218] The abrasive media had been screened through a 100-mesh sieve so that particles passing through the sieve comprised less than 3 percent of the media (Heitbrink, 2007).

[219] During Heitbrink's (2007) study, water was applied at rates ranging from 3.2 kilograms per minute (kg/min) to 8.6 kg/min (equal to 0.8 gallons/minute to 2.2 gallons/minute). The author noted that water puddles did occur at these water application rates.

and the surrounding community from hazardous air contaminants. The dust collector should be set up so that the accumulated dust can be emptied and removed without contaminating work areas.

Thus, local exhaust ventilation (LEV) alone is not expected to completely control the silica exposures of workers below acceptable levels. OSHA finds, nonetheless, that LEV installed in accordance with 1926.57 is essential in protecting abrasive blasting workers in enclosures. Operators working inside ventilated enclosures must also be protected by hoods and airline respirators, or by positive-pressure air helmets.

Respiratory Protection

The OSHA ventilation standard for construction, at 29 CFR 1926.57(f)(5)(ii)(A-C), requires that employers provide abrasive-blasting respirators for their workers to wear when using silica sand in manual blasting operations where the nozzle and blast are not physically separated from the operator in an exhaust-ventilated enclosure and/or where concentrations of toxic dust dispersed by the abrasive blasting might exceed the limits set in 29 CFR 1926.55 or other pertinent regulations.[220]

During dry blasting with silica sand inside unventilated enclosures or spaces, workers might be exposed to extremely high levels of silica, as high as 29,040 µg/m^3 (Barker, 2002). A continuous-flow supplied-air respirator with an assigned protection factor (APF) of 1,000 would ideally protect a worker in these conditions, reducing the in-hood silica concentration to at least 29 µg/m^3. Another elevated silica exposure level, 19,000 µg/m^3, was reported for a worker blasting with sand in an unventilated steel-plate water tank (NIOSH HETA 93-1037-2541, 1993). At this exposure level, if properly used, the same respirator would also protect the worker by providing an in-hood silica concentration below 19 µg/m^3. Exposures in the hood could be much higher if the respirator malfunctions or if the operator fails to adhere strictly to proper work practices.

Respirators require a high degree of worker knowledge in the proper selection, use, fitting, and maintenance of such equipment, as well as worker vigilance in following work practices to prevent contamination of the respirator. For instance, high area concentrations of silica outside the respirator could result in elevated exposures if the airflow to the respirator is reduced or if the operator removes the respirator while still inside the blasting enclosure. Also, contamination of respirators can result in elevated worker exposure, as illustrated by sample results found in general industry indicating levels of respirable quartz as high as 2,567 µg/m^3 obtained under the blasting hood (OSHA SEP Inspection Report 300235389). Another reading, 1,282 µg/m^3, was collected inside the hood, while a worker blasted outdoors with silica sand on a silica substrate (concrete panels) (OSHA SEP Inspection Report 301322095). At the same site and under the same conditions, a reading of 705 µg/m^3 was collected inside a worker's blasting hood.

In a somewhat dated NIOSH study, readings of 490 µg/m^3, 690 µg/m^3, and 250 µg/m^3 (sample durations of 215, 430, and 495 minutes, respectively) were obtained for samples collected under sandblasting hoods (NIOSH HETA 80-153-881, 1980). Another NIOSH study found silica readings of 85 µg/m^3 and 87 µg/m^3 in sampling conducted inside airline respirators (NIOSH HETA 82-186-1203, 1982). The source of exposure was undetermined but was assumed to be due to contamination of the airlines.

Moreover, respirators protect only the workers wearing them. Depending on their proximity to the blasting operation, abrasive blasters' helpers and adjacent workers might have significant exposures and thus require the same level of respiratory protection as blasting operators. For example, OSHA obtained an exposure of 1,466 µg/m^3 for a helper at a site that used silica sand to remove paint from

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[220] Similar requirements apply to general industry under the ventilation standard at 29 CFR 1910.94.

inside a city water tower (Barker, 2002). Wearing an N-95 particulate-filtering facepiece with an APF of 10, the worker was protected to a level of 147 µg/m^3, which was still in excess of the PEL.

Despite the disadvantages associated with respirator use, OSHA expects that respirators will be required to control the silica exposures of abrasive blasting workers, given the high levels of silica generated by abrasive blasting. Respirators likely will be required even when individual controls or combinations of them (for example LEV and substitution) are in place because of the extremely high levels of silica typically generated during blasting.

Housekeeping

Dry sweeping of spent abrasive blasting media and debris can be a sizeable source of silica exposure to workers. For example, a NIOSH study of abrasive blasting in a shipyard found exposure levels of 85 µg/m^3, 160 µg/m^3, and 280 µg/m^3 for workers who spent the entire sampling period dry sweeping material from surfaces, using a hand broom or a whiskbroom (NIOSH ECTB 233-110c, 1999). Using vacuums, shovels, and scrapers to clean surfaces introduces less dust in to the air than dry sweeping. Although these alternate methods have not been evaluated for abrasive blasting media and debris, Riala (1988) completed a study of Finnish construction site workers that compared the silica exposures for workers dry sweeping and using alternate cleaning methods. When compared with dry sweeping, exposures were approximately three times lower when the workers used squeegees to scrape surfaces and approximately five times lower when workers used vacuums (Riala, 1988). During wet abrasive blasting, moisture in the abrasive media will continue to suppress dust as long as workers dispose of or recover the abrasive before it dries.

Use of Alternative Abrasive Media and Dust Suppressant Additives

Although the sand used in abrasive blasting contains as much as 96 percent silica, it has become popular as an abrasive blasting material because of its low cost, effectiveness, and availability. However, in recent years the amount of silica sand used or sold for abrasive blasting has been declining, and, in some applications, other abrasive blasting media have replaced sand. The most recent design standard developed by the American National Standards Institute (ANSI) on exhaust systems for abrasive blasting operations at fixed location enclosures prohibits the use of silica sand as an abrasive blasting agent in such operations (ANSI/American Industrial Hygiene Association [AIHA] Z9.4-1997).

To eliminate the hazards posed by using silica sand as the abrasive media, employers can select safer blasting agents. Since 1974, NIOSH has recommended the use of less hazardous abrasive blasting media containing less than 1-percent silica to control the exposures of abrasive blasting workers (NIOSH HEW Publication No. 75-120, 1974).

The choice of substitutes, however, is critical in controlling the silica exposures of blasting workers as well as preventing elevated exposure to other hazardous substances. Nonsand abrasive materials containing small amounts of silica (1 percent or less) could result in elevated respirable quartz exposure levels, even when used in ventilated enclosures. For instance, the use of blasting media containing less than 1-percent quartz resulted in an area respirable quartz level of 1,580 µg/m^3 (369-minute sample duration) inside a ventilated containment structure erected around two steel tanks (NIOSH ECTB 183-13a, 1993). NIOSH concluded that the high levels of abrasive overwhelmed the LEV.

Alternative abrasive media containing less than 1-percent silica include garnet, steel grit, aluminum oxide, and slags of copper, coal, or nickel (MSU, 1999). Employers will need to consider the possible hazards of substitutes if switching from silica. For example, depending on the abrasive, alternative media can result in elevated levels of other hazardous air contaminants such as heavy metals.

A NIOSH-sponsored study evaluating several types of abrasive media indicates that the silica exposures of abrasive blasting operators can be reduced with the use of certain media (KTA-Tator-Phase-1, 1998; KTA-Tator-Phase-2, 1998; KTA-Tator-Phase-3, 1999). Phase I of the study involved collecting exposure monitoring data during test trials, in which the abrasive blasting operator used different media to blast a steel surface inside a ventilated enclosure. Exposures ranging from 2,930 µg/m^3 to 22,030 µg/m^3 were obtained during trial runs in which silica sand media was used. No respirable quartz was detected in samples collected during trial runs in which the operator used coal slag, specular hematite, or steel grit. The study shows, however, that even blasting operations using media with low silica content and nonsiliceous substrates can result in elevated airborne concentrations of silica. Exposure readings ranging from 240 µg/m^3 to 3,690 µg/m^3 were obtained during trial runs with garnet and copper slag media, which both contain low amounts of quartz. The study also indicates that the potential presence of other toxic substances requires that alternative blast media be selected carefully (KTA-Tator-Phase-1, 1998).

In a study of exposures among painters using three alternative blasting abrasives during a New Jersey highway footbridge repainting project, Meeker et al. (2005 and 2006) reported that steel grit, specular hematite, and coal slag all resulted in elevated silica exposures, ranging from 420 µg/m^3 to 90,100 µg/m^3, likely due to the very high silica content in the paint. High variability in silica exposures during the 2- to 3-hour task-based sampling periods, however, made it difficult for researchers to detect statistical differences in exposures associated with the different abrasives. Sources of the high level of variability are unknown; however, they could be related to harsh environmental conditions during abrasive blasting as well as the small sample size. This study also supports the conclusion that workers might potentially be exposed to other hazardous substances such as beryllium, cadmium, chromium, manganese, and nickel during the use of these alternative blasting abrasives (Meeker et al. 2006).

Additional literature suggests use of various more benign abrasive media substitutes. For example, based on a review of engineering control technology for abrasive blasting, Flynn and Susi (2004) report that dolomite (i.e., calcium magnesium carbonate) might be a good, nontoxic alternative to silica-containing abrasive blasting media. The authors also comment on the apparent potential for good results with crushed glass.

Use of dust suppressant additives provide a limited amount of dust control during blasting with silica sand. For instance, during Phase II of the study, silica sand abrasive was used to blast the side of a coal barge. Silica exposures ranged from 9,910 µg/m^3 to 50,522 µg/m^3, with a geometric mean of 27,959 µg/m^3. When a dust suppressant was used with the silica sand abrasive, silica levels in four readings had a geometric mean of 19,040 µg/m^3 (ranging from 9,180 µg/m^3 to 28,200 µg/m^3), about 68 percent of the mean for untreated silica sand (KTA-Tator-Phase-2, 1998). Although these levels are still excessive, dust suppressant methods may be used in combination with other measures, such as ventilation and work practices, to reduce silica exposures when silica sand must be used as the blasting agent. Effective dust suppressant additives will also help reduce silica exposures when workers (e.g., abrasive blasters' helpers) handle abrasives before and after the actual abrasive blasting.

Additional Controls for Abrasive Blasters' Helpers

The exposure levels associated with abrasive blaster's helpers are routinely lower than abrasive blasting operator exposures, but slightly more than half of the helpers (53 percent) still exceed 50 µg/m^3, as indicated by the exposure profile for helpers presented in Table IV.C-49. OSHA preliminarily concludes that the same controls that benefit abrasive blasting operators will also benefit abrasive blasters' helpers. In fact, to the extent that helpers' exposures are due to the actions of abrasive blasting operators (including the highest helper exposures, which occurred when helpers worked inside enclosures during uncontrolled or poorly controlled abrasive blasting), control measures that reduce operator exposure will also reduce the silica concentrations to which helpers are exposed. Furthermore, wet abrasive blasting will directly benefit helpers by reducing exposures associated with sweeping or shoveling spent media during cleaning and media recovery tasks, if the helper performs these tasks while the media is still damp. Although not evaluated, OSHA assumes that other dust suppressants added to the media before abrasive blasting will also help reduce the silica exposure levels of helpers during these housekeeping activities, as well as while they empty bags of media into the grit pot.

Feasibility Finding

Feasibility Finding for Abrasive Blasting Operators

Based on the information described above, OSHA preliminarily concludes that the exposure levels for most workers performing abrasive blasting will not be reduced to below 100 µg/m^3 even with the use of exposure controls such as wet methods and LEV. This conclusion is based on the median 8-hour TWA reading of 125 µg/m^3 for workers who used wet abrasive blasting. As indicated in Table IV.C-49, 82 percent of this group has exposure levels that exceed the proposed PEL of 50 µg/m^3 even when employing wet abrasive blasting methods. Thus, the use of appropriate respiratory protection and proper ventilation, especially within enclosures, will still be needed to protect workers from hazardous levels of contaminants that may be generated during abrasive blasting, from either the abrasive, the substrate, or both. To ensure protection, respiratory protection and ventilation must meet the requirements of 29 CFR 1926.57 and 1910.134, respectively.

Feasibility Finding for Abrasive Blasters' Helpers

Based on information presented in this analysis, including Table IV.C-49, OSHA preliminarily concludes that nearly half (46 percent) of all abrasive blasters' helpers currently experience exposure levels less than the proposed PEL of 50 µg/m^3; however, even when the abrasive blasting operator uses wet blasting methods, slightly more than half (54 percent) of the abrasive blasters' helpers continue to have exposure levels that exceed this level. Until the exposures of abrasive blasters are controlled, OSHA anticipates that the assistants who help them also remain at risk of exposures above 50 µg/m^3, and these workers will require respiratory protection whenever they are required to work in the vicinity of the blasting activity. When wet methods are used, however, the exposure level of most abrasive blasters' helpers will be controlled to the point where a NIOSH-approved half-facepiece respirator, with an APF of 10, can provide sufficient protection.

Overall Feasibility Finding for Abrasive Blasting Workers

Based on the available information, OSHA preliminarily concludes that the silica exposure of abrasive blasting operators will be greatly reduced using wet abrasive blasting methods, but that the proposed PEL of 50 µg/m^3 will not be reliably achieved using these methods. Respiratory protection will continue to be required in accordance with the ventilation provision of 29 CFR 1926.57(f)(5)(ii)(A-C) (or, for general industry, 1910.94[a][5]) and 1910.134–Respiratory Protection. These existing requirements currently protect abrasive blasting operators who are routinely exposed to levels that exceed PELs.

The exposure levels of abrasive blaster's helpers will also be substantially reduced when abrasive blasting operators adopt wet methods. The extent of the reduction will be sufficient to permit abrasive blaster's helpers to wear a reduce level of respiratory protection, in the form of a half-facepiece respirator.

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Drywall Finishers

Description

After segments of drywall have been installed, drywall workers use a joint compound paste to seal the cracks between segments and to cover divots from nails. Once the joint compound is dried, workers sand the surface by hand to create a smooth finish. The drywall installer might perform the finishing, or a specialized trades worker might perform this work. Sanding dried joint compound containing silica is believed to be the primary source of silica exposure in this job category. Industries that engage in drywall work are classified in the 238310 North American Industry Classification System (NAICS) code.

The drywall itself contains little or no silica (U.S. Gypsum, 1999). Although silica-free joint compounds have become widely available in recent years, some products continue to contain silica. For example, NIOSH (NIOSH ECTB 208-11a, 1995) found that bulk samples of a commercially available joint compound contained up to 6 percent quartz, although silica was not listed on the material safety data sheet for the product. In another study, NIOSH (NIOSH HETA 94-0078-2660, 1997) determined that three of six drywall compounds purchased at a retail store contained trace amounts of silica. Epling et al. (1999) found that four of six joint compounds tested contained between 1.1 and 3.7 percent silica. Drywall finishing jobs monitored by NIOSH (NIOSH HETA 94-0078-2660, 1997) lasted from 1.5 hours to more than 8 hours per shift.

Table IV.C-51 summarizes the single job category, drywall finisher, and its major activities and sources of exposure.

Table IV.C-51

Job Category, Major Activities, and Sources of Exposures of Drywall Finishers

Job Category	Major Activities and Sources of Exposure
Drywall Finisher	Applying joint compound to sections of drywall and sanding dried joint compound to create a smooth finish. • Dust generated while sanding dried, silica-containing joint compound.

Source: ERG-C, 2008.

Baseline Conditions and Exposure Profile

Fifteen sample results obtained by NIOSH (NIOSH HETA 94-0078-2660, 1997) form the basis of this exposure profile (Table IV.C-52).[221] NIOSH, in collaboration with the Center to Protect Workers'

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[221] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) calculated assuming no additional exposure during any unsampled portion of the shift. Unless explicitly stated otherwise, all results discussed in the additional controls section are also 8-hour TWAs calculated the same way. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A –

Rights, obtained these results for 10 drywall sanders working at two work sites (an office renovation job and a project renovating a low-income public housing apartment complex) (NIOSH HETA 94-0078-2660, 1997). Workers in this study used silica-free joint compounds or compounds with very low silica content and performed sanding by hand or with a pole sander. No work practices were identified.

As Table IV.C-52 indicates, the median 8-hour time-weighted average (TWA) personal breathing zone (PBZ) respirable quartz concentration for drywall finishers is 12 micrograms per cubic meter (μg/m^3). Seven of the 15 results are at or below the limit of detection (LOD), and the mean concentration is 17 μg/m^3. The highest respirable quartz result among drywall finishers is 72 μg/m^3, obtained for a worker performing overhead sanding (NIOSH HETA 94-0078-2660, 1997); this is the only reading greater than 50 μg/m^3. A single result from a worker in Canada, also below the LOD, demonstrates comparable exposure levels elsewhere in North America (Verma et al., 2003).[222]

The past potential for drywall workers to be exposed to higher levels of silica, however, is indicated in the Rozanowski (1997) review of OSHA Integrated Management Information System (IMIS) data. The summary information presented in that review shows that 22 percent of samples collected during OSHA inspections in the 1980s through the early 1990s in Standard Industrial Classification (SIC) 1742 (plastering, drywall, insulation) exceeded the PEL. In that case the PEL was based on OSHA's general industry formula for respirable dust containing silica.[223] Individual exposure results were not provided in the review, and as a result these samples were not included in the exposure profile.

Baseline conditions for drywall finishers include using low-silica or silica-free joint compounds and manual sanding without specific work practices or other controls. All of the results in the exposure profile are associated with these baseline conditions.

Methodology.

[222] Results reported as “none detected” are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

[223] In this case, although evaluating a construction industry activity, the investigator elected to compare silica exposure results with OSHA’s gravimetric general industry PEL for silica. This might be due to the fact that the construction industry PEL for silica is based on the units millions of particles per cubic foot (mppcf), requiring an obsolete analytical method not available through most analytical laboratories. Instead, laboratories typically report silica air sampling results as mass-based gravimetric values (e.g., mg/m^3) for respirable dust, along with the percent silica, which are also used in the gravimetric general industry PEL for silica. Investigators compare these results with the gravimetric general industry PEL because the units are compatible. An alternative has been available since 2008, when OSHA published a compliance directive, National Emphasis Program (NEP)–Crystalline Silica CPL 03-00-007 (Appendix E), providing a conversion factor to convert air sampling results between mppcf and mg/m^3 or μg/m^3. However, some investigators continue to use the more familiar gravimetric units and compare construction industry air monitoring results with the gravimetric general industry PEL for silica.

Table IV.C-52
Respirable Crystalline Silica Exposure Range and Profile for Drywall Finishers

	Exposure Summary			Exposure Range			Exposure Profile				
Job Category	**Number of Samples**	**Mean (µg/m^3)**	**Median (µg/m^3)**	**Min (µg/m^3)**	**Max (µg/m^3)**		**<25 (µg/m^3)**	**≥25 and ≤50 (µg/m^3)**	**>50 and ≤100 (µg/m^3)**	**>100 and ≤250 (µg/m^3)**	**>250 (µg/m^3)**
Drywall Finisher											
Baseline Conditions	15	17	12	8	72		13	1	1	0	0
							86.7%	6.7%	6.7%	0.0%	0.0%

Notes: All samples are personal breathing zone (PBZ) results and represent 8-hour time-weighted average exposures with the assumption that no additional exposure occurred during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Source: ERG-C, 2008.

Additional Controls

Substitution

The primary source of exposure for drywall workers is the use of silica-containing joint compounds. In cases of elevated exposure, the best control mechanism is substitution: changing to a joint compound that does not contain silica. NIOSH has indicated that there are a number of commercially available compounds that do not contain silica, and OSHA believes that substitution in new construction is possible most of the time. However, some joint compounds that do not list silica as an ingredient might still contain small amounts of silica (NIOSH HETA 94-0078-2660, 1997), and during remodeling projects drywall finishers might be exposed while refinishing existing drywall surfaces that had used silica-containing joint compound.[224] When working with silica-containing joint compound, ventilated (or vacuum) sanders, wet methods, and pole sanders are all options for dust control.

Ventilated Sanders

NIOSH tested the effectiveness of five off-the-shelf ventilated sanding systems during drywall finishing: three designed to control dust during pole sanding and two to control dust during hand sanding. Total dust area sample results revealed that all five systems were effective for reducing total airborne dust by at least 80 percent, ranging up to 97 percent (NIOSH ECTB 208-11a, 1995). The effectiveness of ventilated sanders was confirmed in a study by Young-Corbett and Nussbaum (2009a), which found that using a ventilated sander during drywall sanding reduced respirable dust in the PBZ by 88 percent compared with a block sander (no controls). Although ventilated sanders are the most effective control option after substitution and offer indirect benefits to workers and managers (NIOSH Appl Occup Environ Hyg 15, 2000), there are many perceived barriers to their adoption in the workplace. Workers and managers are concerned about: 1) maneuverability in small spaces, 2) reliance on a nearby power source, 3) product cost, 4) delays in learning the new equipment, and 5) maintenance (NIOSH ECTB 208-11a, 1995; Young-Corbett and Nussbaum, 2009b). Furthermore, some models of ventilated sanders require a water source for their use (NIOSH ECTB 208-11a, 1995).

Wet Methods

Young-Corbett and Nussbaum (2009a) found that a wet sponge sander reduces respirable dust in the PBZ by 60 percent compared with a block sander (no controls). A wet sponge sander, literally a sponge with an abrasive surface, is one type of wet method. Other wet methods include wiping a clean, damp sponge over the still damp joint compound to smooth the seam and rinsing the sponge in a bucket of water as it becomes loaded with compound, or wetting dried joint compound with a spray bottle and sanding with sandpaper (NIOSH ECTB 208-11a, 1995). Although wet methods are technologically simple and can be used wherever a water source is available, less than 10 percent of firms report using them regularly (Young-Corbett and Nussbaum, 2009b). Workers and managers have concerns about the finished texture, increased work time, mess, and adding moisture to the product (which could harm the product and delays painting) (Flanagan, 2001; NIOSH 99-113, 1999; NIOSH ECTB 208-11a, 1995; Ventura, 2001; Young-Corbett and Nussbaum, 2009b). OSHA suggests that the use of a heat gun can expedite the drying process if necessary.

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[224] OSHA expects that drywall finishers usually sand only new joint compound, but might briefly encounter older joint compound occasionally while smoothing the junction where a new drywall segment meets a pre-existing joint.

Pole Sanders

Finally, the use of a pole sander—which creates distance between the worker and the point at which dust is generated—is a simple way to reduce exposure (NIOSH Appl Occup Environ Hyg 15, 2000). Data suggest that it is almost as effective as a wet method, reducing total respirable dust by 58 percent compared with a block sander (no controls) (Young-Corbett, 2009a).

Although silica levels were not specifically measured in the studies cited here, OSHA estimates that these controls could reduce silica concentrations by similar amounts (ERG-C, 2008).

Feasibility Finding

Based on the data described above, OSHA preliminarily concludes that most workers who finish drywall are currently exposed to silica at levels less than 50 µg/m^3. Ninety-three percent of the results summarized in Table IV.C-52 are below this level. Furthermore, OSHA preliminarily concludes that a value of 25 µg/m^3 can be achieved for all drywall finishers who are provided with drywall compound that does not contain silica.

In the event that substitution is not possible and during renovation work where silica-containing joint compound might be present, ventilated sanders, pole sanders, and wet methods are other options. Based on studies quantifying reductions in total dust levels when using ventilated sanders (Mead et al, 2000; NIOSH ECTB 208-11a, 1995; Young-Corbett and Nussbaum, 2009a), OSHA estimates that the silica exposure of all drywall finishers can be reduced to levels below 25 µg/m^3. OSHA determined this conservative estimate by reducing the highest drywall finisher reading summarized in Table IV.C-52 (72 µg/m^3) by 80 percent, the minimum amount by which ventilated sanding equipment reduced respirable dust (NIOSH ECTB 208-11a, 1995). OSHA also estimates that the use of pole sanders and wet methods can reduce the silica exposure of all drywall finishers to levels below the proposed permissible exposure limit (PEL) of 50 µg/m^3 under circumstances when these offer a more convenient form of dust control. OSHA determined this estimate by reducing the highest drywall finisher reading (72 µg/m^3) by 58 and 60 percent, the amounts by which pole sanding and wet methods, respectively, reduced total respirable dust (NIOSH ECTB 208-11a, 1995).

OSHA preliminarily concludes that exposures of less than 50 µg/m^3 can be achieved for all drywall finishers by using additional controls on the rare occasions when silica might be encountered.

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Heavy Equipment Operators

Description

Workers in this job category drive crawlers or rubber-tired tractors and maneuver large attached construction tools. Attachments include (but are not limited to) augers, backhoes, buckets, cranes, hammers, dozer blades, draglines, forklifts, graders, rippers, rollers, scrapers, shovels, and trenchers (Russell, 1985). The category also includes dump-truck drivers, as well as operators of other heavy construction equipment (e.g., power cranes and power shovels). OSHA is analyzing these workers together, based on: 1) the similarity in worker position relative to the point of tool action (operators' seat is usually 5 to 20 or more feet from the point of action); 2) the potential for enclosing (in a cab) the workers who operate this type of equipment; and 3) the large percentage of the shift that these operators typically spend in the operator's seat, rather than at a point closer to the point of tool action. Equipment reviewed here does not include, however, rock or concrete drilling rigs, rock crushers, milling machines, or tunnel boring machines. Activities associated with these types of equipment are reviewed in other sections of the feasibility analysis.

Table IV.C-53 provides an overview of tasks performed by heavy equipment operators, which include demolition; displacement (excavation); loading; and dumping of rock, soil, concrete, and other construction materials and debris. When these materials contain silica, dust generated during these activities is the primary source of exposure. Heavy equipment operators might or might not work in an enclosed cab. Unlike other construction workers, heavy equipment operators usually perform the same activity (operating their equipment) nearly constantly for more than 7 hours per shift (ERG-C, 2008).

Table IV.C-53

Job Categories, Major Activities, and Sources of Exposure of Heavy Equipment Operators

Job Category*	Major Activities and Sources of Exposure
Heavy Equipment Operator	From an operator's seat, manipulating tractor or vehicle-based implements (e.g., backhoe, crane, power shovel, excavator, hammer, dump truck) to perform demolition; excavation; loading; and dumping of rock, concrete, soil, and other construction materials and debris. • Dust from breaking down construction materials. • Dust from disturbing, transporting, or dumping soil or construction materials.

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the work site.

Sources: Russell, 1985; ERG-C, 2008.

Baseline Conditions and Exposure Profile

The exposure profile (Table IV.C-54) is based on 24 8-hour time-weighted average (TWA) personal breathing zone (PBZ) respirable quartz readings.[225] These results were obtained from four NIOSH reports; five OSHA Special Emphasis Program (SEP) inspection reports; and one journal article, previously described in ERG-C (2008). Two results were obtained from an additional NIOSH report (NIOSH EPHB-247-15b, 2002), which describes two operators participating in the demolition of a plaster ceiling. A track-hoe operator was responsible for pulling down the ceiling (87 micrograms per cubic meter (μg/m^3), one of the three highest results for this job category), and a skid-steer loader operator removed construction debris from the area (49 μg/m^3). Cabs were unenclosed, and both operators were paired with laborers who sprayed water specifically to suppress dust generation.

In contrast, results from a road demolition site were among the lowest available to OSHA. At this site, over the sampling period of 6 to 8 hours the operators of a crane, a backhoe, and two excavators all had 8-hour TWA results of 12 μg/m^3 (the limit of detection [LOD]) while breaking and removing pieces of asphalt and concrete road and the underlying sand bed (NIOSH ECTB 233-120c, 1999).[226] At a third work site, where OSHA visited a tunnel construction site, a tractor operator removing dirt at the mouth of the tunnel experienced a result of 41 μg/m^3 (OSHA SEP Inspection Report 116179359). This result is similar to the mean (32 μg/m^3) and range (8 μg/m^3 to 59 μg/m^3) of exposure values published by Blute et al. (1999) for five operating engineers involved in the “cut and cover” and tunnel finishing phases of a major highway tunnel construction project.

As Table IV.C-54 shows, exposures range from less than or equal to 11 μg/m^3 (the LOD reported by the investigator) to 170 μg/m^3; the median is 12 μg/m^3; and the mean is 27 μg/m^3. Sixteen results (67 percent) are less than or equal to 12 μg/m^3. Three results (13 percent) exceed 50 μg/m^3, and only one of those results exceeds 100 μg/m^3. Of the 19 results for which the status of the cab was established, 17 (89 percent) operated in unenclosed cabs (includes enclosed cabs where the windows and/or door were opened).

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[225] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) calculated assuming no additional exposure during any unsampled portion of the shift. Unless explicitly stated otherwise, all results discussed in the additional controls section are also 8-hour TWAs calculated the same way. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

[226] Results reported as “none detected” are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

Table IV.C-54
Respirable Crystalline Silica Exposure Range and Profile for Heavy Equipment Operators

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**N**	**Mean (μg/m^3)**	**Median (μg/m^3)**	**Min (μg/m^3)**	**Max (μg/m^3)**		**<25 (μg/m^3)**	**≥25 and ≤50 (μg/m^3)**	**>50 and ≤100 (μg/m^3)**	**>100 and ≤250 (μg/m^3)**	**>250 (μg/m^3)**
Heavy Equipment Operator											
Unenclosed cab	17	21.7	12.0	11.0	87.0		14 82.0%	1 6.0%	2 12.0%	0 0.0%	0 0.0%
Enclosed cab	2	12.3	12.3	12.3	12.3		2 100.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Various conditions (Inadequate information)	5	51.2	22.0	11.0	170.0		3 60.0%	1 20.0%	0 0.0%	1 20.0%	0 0.0%
Totals	**24**	**27.0**	**12.0**	**11.0**	**170.0**		**19** **79.2%**	**2** **8.3%**	**2** **8.3%**	**1** **4.2%**	**0** **0.0%**

Notes: All samples are PBZ results and represent 8-hour TWA exposures with the assumption that no additional exposure occurred during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Source: ERG-C, 2008.

Other investigators, drawing on data from a variety of sources, report slightly higher exposure levels for heavy equipment operators; however, their data sets included operators of particularly dusty equipment that OSHA instead addresses in other sections of this technological feasibility analysis (see Sections IV.C.29 – Millers Using Portable or Mobile Machines, IV.C.30 – Rock and Concrete Drillers, and IV.C.31 – Rock-Crushing Machine Operators and Tenders). Working with a large set of construction data from academic, government, construction, and consultant organizations, Flanagan et al. (2006) reported a geometric mean silica result of 50 μg/m^3 for 102 workers operating all types of heavy equipment (not defined). For a subset of this data (i.e., the 45 results associated with the specific task of heavy equipment demolition), the geometric mean was lower at 30 μg/m^3. The 30 results for workers specifically operating backhoes, excavators, bulldozers and bobcats tended to be even lower, with a geometric mean of 10 μg/m^3 (as reported by the author), which was the lowest mean silica result among the various construction tool categories evaluated by Flanagan et al. (2006). The investigators did not provide information about controls or sample durations associated with these data; however, they did report the median sample time for the entire construction database (219 minutes). OSHA notes that these results, which were not adjusted for 8 hours, indicate that many heavy equipment operators already experience silica exposure levels of 50 μg/m^3 or less.

Rappaport et al. (2003) reported a median exposure of 75 μg/m^3 for 46 heavy equipment operators involved primarily with highway construction. However, this value includes some high-exposure activities treated separately by OSHA in this analysis (e.g., earth, rock, and dowel drilling; stone crushing; concrete and asphalt milling) and is thus not representative of heavy equipment operators as defined here. Overall, the data available to OSHA for heavy equipment operators are generally lower than those for other construction workers who also spend time in an operator's cab or booth, but do so less consistently during the shift and might operate equipment that generate greater levels of airborne silica close to the operator's position (e.g., rock and concrete drilling rigs and rock crushers). As noted previously, these workers are covered by other sections of this technological feasibility analysis.

A review of OSHA, NIOSH, and other published reports conducted by ERG (ERG-C, 2008) indicates that construction workers who drive or otherwise operate tractors or other heavy construction equipment typically work outdoors without using engineering controls or specific work practice controls. When workers operated equipment from inside cabs, windows were typically open, diminishing the effectiveness of the isolation provided by the cabs. ERG determined that this typical situation represented the baseline condition for heavy equipment operators. OSHA, however, notes that the exposure profile shows some heavy equipment operators do keep windows closed under dusty conditions and that the range of conditions represented in the exposure profile also represent the baseline conditions for all heavy equipment operators in the United States. Consistent with the methods OSHA is using to calculate baseline exposure levels for other construction tasks, OSHA has preliminarily determined that the median exposure level presented in Table IV.C-54 also represents the baseline exposure level for heavy equipment operators.

Additional Controls

Where heavy equipment operators' respirable quartz exposures are elevated, properly ventilated enclosed cabs and dust suppressants are options for reducing exposure levels. OSHA believes that using a properly sealed and ventilated enclosed cab under positive pressure with filtered air is the primary additional control for reducing exposure. This finding is based on field studies reviewed in ERG-C (2008), and field and research data presented here. Rappaport et al. (2003) report an 85 percent reduction in the geometric mean silica exposure for heavy equipment operators in ventilated versus open cabs performing highway construction activities (10 μg/m^3 versus 65 μg/m^3). There is no information about whether the ventilated cabs are pressurized and/or filtered.

Pannell and Grogin (2000) find that pressurized, enclosed cabs without high-efficiency filtration can still provide a high degree of protection for operators under field conditions (e.g., performing excavation work). For 44 samples associated with workers operating a water wagon and a scraper, which were both outfitted in this way, the investigators reported mean respirable dust results of 72 µg/m^3 during approximately 4- to 5-hour sampling periods. These respirable dust values were 80 to 90 percent lower than the results experienced for operators of open-cab equipment, who had mean respirable dust exposures of 426 µg/m^3 (four results for grader operators), 672 µg/m^3 (40 results for dozer operators), and 837 µg/m^3 (10 results for workers operating a second dozer). Respirable dust samples collected inside and outside the scraper showed that this equipment reduced the operators' exposure by nearly 90 percent (Pannell and Grogin, 2000).[227,228,229]

Based on published research, ERG-C (2008) found that effective enclosed cabs are generally air conditioned, tightly sealed, and positively pressurized, and that they use a high-efficiency filter on outdoor intake air. NIOSH recommends several additional features for an optimally dust-reducing cab design:

1. Cabs should be equipped with a recirculation filter which continuously filters the air circulating within the cab (Cecala et al., 2005; NIOSH 528, 2007). This is the only way to eliminate dust that has entered the cab (e.g., on shoes, or through an open door).

2. Cabs should avoid the use of floor heaters or any discharge of clean air low in the cab, which entrains dust from the floor and dirty work clothes before entering the worker's breathing zone (Cecala et al., 2005; NIOSH 486, 2001). Ideally, air flow would circulate from the top of the cab to the bottom, and recirculation pick-up would occur low in the cab.

3. The inlet for intake air should be strategically located so that it avoids, as much as possible, the equipment's major dust sources. Typically, this means high above ground level (NIOSH 485, 2001).

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[227] In this case, the work site was atypical: to construct a solid low-level radioactive waste disposal facility, workers in a semi-arid environment excavated 64,000 cubic meters (m^3) (more than 2 million cubic feet [ft^3]) of soil containing up to 65 percent silica. Using OSHA's general industry equation, the authors calculated a permissible exposure limit (PEL) of 182 µg/m^3 for respirable dust containing silica (Pannell and Grogin, 2000).

[228] In this case, although evaluating a construction industry activity, the investigator elected to compare silica exposure results with OSHA's gravimetric general industry PEL for silica. This might be due to the fact that the construction industry PEL for silica is based on the units millions of particles per cubic foot (mppcf), requiring an obsolete analytical method not available through most analytical laboratories. Instead, laboratories typically report silica air sampling results as mass-based gravimetric values (e.g., mg/m^3) for respirable dust, along with the percent silica, which are also used in the gravimetric general industry PEL for silica. Investigators compare these results with the gravimetric general industry PEL because the units are compatible. An alternative has been available since 2008, when OSHA published a compliance directive, National Emphasis Program (NEP)–Crystalline Silica CPL 03-00-007 (Appendix E), providing a conversion factor to convert air sampling results between mppcf and mg/m^3 or µg/m^3. However, some investigators continue to use the more familiar gravimetric units and compare construction industry air monitoring results with the gravimetric general industry PEL for silica.

[229] Pannell and Gorgin (2000) reported summary data rather than individual results.

4. Cabs must be well maintained and kept clean (Cecala et al., 2005; NIOSH 487, 2001). Filters must be changed regularly so that they do not become overloaded with dust, and seals must be maintained to preserve pressurization inside the cab. A gritless, natural base sweeping compound should be applied to the floor of the cab to bind dirt and dust tracked in during normal work activities. The compound should also be used for regular housekeeping activities.

These recommendations, and others, are summarized in NIOSH (NIOSH 2009-123, 2009). Cabs employing several of these recommendations achieve efficiencies exceeding 90 percent (Cecala et al., 2005; NIOSH 528, 2007).

Feasibility Finding

Based on the data presented in Table IV.C-54, OSHA preliminarily concludes that the respirable quartz exposure of most (87 percent) heavy equipment operators is already at a level of 50 µg/m^3 or less, with no specific work practices or engineering controls in place. The median full-shift PBZ result of less than or equal to 12 µg/m^3 supports this assertion.

For the 13 percent of workers who require additional controls, OSHA estimates that employers who provide properly ventilated enclosed cabs can reduce the exposure of all equipment operators to levels below 50 µg/m^3. This conclusion is based on reducing the highest exposure presented in the exposure profile, 170 µg/m^3, by 90 percent, a reasonable estimate for a well-maintained, enclosed, pressurized, and ventilated cab (Cecala et al., 2005). This yields an exposure of 17 µg/m^3. Furthermore, for most heavy equipment operators who primarily experience silica exposure from intermittent activities (e.g., loading, dumping), results of 50 µg/m^3 can be achieved if the operators ensure cab windows are completely closed during these activities.

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Hole Drillers Using Hand-Held Drills

Description

This section includes workers in the construction industry who use hand-held drills to create holes for anchors, bolts, and other means of attachment in concrete and other silica-containing construction materials. Workers use common electric drills, pneumatic drills, rotary hammers, or percussion hammer drills to drill holes. The portability and light weight of hand-held drills allow the worker to operate them at any angle. For practical reasons, drillers often must remove the dust and debris that build up in the bottom of the hole. Occasionally, hole drillers use compressed air to blow dust from holes (Hallin, 1983). Workers also often sweep the work area. A worker operating a common drill and a rotary bit may employ a technique known as pecking, in which the operator removes the drill briefly from the hole and continues to run the drill to allow the accumulated chips and dust to fly off the rotating bit (White, 1977). At least one gas-powered drill includes a self-cleaning design to clear the hole of dust by continuously forcing air through the chuck and drill shank (NIOSH HETA 2003-0275-2926, 2004). Drilling may be performed only briefly or intermittently or might be done continuously during the work shift; see ERG-C (2008) for an example. This section does not discuss concrete coring, involving stabilized equipment used with copious amounts of water to produce a large hole or opening.

Table IV.C-55 summarizes the job categories, major activities, and primary sources of silica exposure of workers in this industry.

Table IV.C-55

Job Categories, Major Activities, and Sources of Exposure of Hole Drillers Using Hand-Held Drills

Job Category*	Major Activities and Sources of Exposure
Hole Driller	Create pilot holes, holes for anchors, bolts, and other means of attachment, or assist in lifting slabs. • Dust from action of drill bit. • Dust raised by sweeping, brushing, and/or using compressed air to clear holes (including housekeeping).

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the work site.

Sources: ERG-C, 2008; NIOSH HETA 2003-0275-2926, 2004.

Baseline Conditions and Exposure Profile

Based on the available information, OSHA concludes that construction workers performing hole drilling most commonly work indoors on concrete and use no engineering controls or dust-suppressing work practices. Of the fourteen 8-hour TWA PBZ respirable quartz readings summarized in the exposure profile, 7 represent hole drilling under these conditions (Lofgren, 1993; OSHA SEP Inspection Report 103011359; McKernan et al., 2002).[230] These situations are considered baseline conditions. Both ordinary drills and, more routinely, percussion or rotary drills are used for drilling holes into concrete and other substrates containing silica. Dry sweeping, brushing, the use of compressed air, and pecking are also baseline practices related to increased exposure.

ERG-C (2008) summarizes nine respirable quartz samples for hole drilling using hand-held equipment in multilevel structures and on a bridge. ERG extracted these results from one NIOSH report, an OSHA Special Emphasis Program (SEP) inspection report, and a published article (Lofgren, 1993; NIOSH ECTB 233-123c, 1999; OSHA SEP Inspection Reports 103011359, 300035557). In this report, the lowest exposure readings were obtained for two workers who spent an entire 8-hour shift alternately drilling 2-inch holes through brick and steel and installing masonry anchors in exterior and courtyard walls (NIOSH ECTB 233-123c, 1999). Two other readings at the limit of detection (LOD), reported at less than or equal to 67 μg/m^3 and 69 μg/m^3, were obtained for workers drilling a concrete floor indoors with pneumatic drills to make holes to help lift out floor sections (OSHA SEP Inspection Report 103011359).[231] The highest result (286 μg/m^3) was recorded for a worker drilling holes in the floor of a concrete parking garage where air circulation was poor (Lofgren, 1993). The remaining values are all less than 75 μg/m^3.

As discussed in the following paragraphs, OSHA identified several additional results to add to the exposure profile in two reports from McKernan et al. (2002) and NIOSH (HETA 2003-0275-2926, 2004). Although limited, the results incorporated into the exposure profile represent the best data available to OSHA for workers involved in hole-drilling activities using hand-held equipment.

McKernan et al. (2002) presented one sample result of 58 micrograms per cubic meter (μg/m^3) for a worker drilling concrete and brick without controls to install rebar at an indoor construction site.

The NIOSH investigators collected four samples during outdoor rock drilling operations while workers operated by hand 75-pound or 30-pound gas-powered drills (NIOSH HETA 2003-0275-2926, 2004). As part of motor function, the larger drill was designed to generate compressed air (20 to 30 pounds per square inch [psi]) that it forced through the shank to clear the hole. This drill was considerably faster but resulted in higher 8-hour time-weighted average (TWA) exposures (120 μg/m^3 and 130 μg/m^3) than did use of the smaller, slower drill that did not include a forced air feature. Two 8-hour TWA exposure results associated with the smaller drill were obtained from original measurements that were both less than or equal to 30 μg/m^3 (LOD). The sampling method was not sensitive enough to determine whether water poured down the drilling holes during one of the small-drill sampling periods reduced worker exposure compared with dry drilling with the same equipment. NIOSH noted that the workers rarely operated either size drill more than 3 hours a day because they are heavy and difficult to control;

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[230] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) calculated assuming no additional exposure during any unsampled portion of the shift. Unless explicitly stated otherwise, all results discussed in the additional controls section are also 8-hour TWAs calculated the same way. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

[231] Results reported as “none detected” are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

therefore, the 8-hour TWAs that OSHA uses in the exposure profile assume that the workers did not drill beyond the sampling period and had no additional silica exposure for the remainder of the day (NIOSH HETA 2003-0275-2926, 2004).

Table IV.C-56 presents the exposure profile and summarizes the best exposure data available to OSHA for hole drillers using hand-held equipment. Of the 14 respirable quartz readings summarized in the exposure profile, seven represent hole drilling *indoors* under uncontrolled conditions. The median (8-hour TWA) exposure for this group is 60 µg/m^3. The highest reading obtained for workers in this job category, 286 µg/m^3, was recorded for a worker drilling holes in the floor of a concrete parking garage where air circulation was poor (Lofgren, 1993).

The other seven results, most of which were collected during *outdoor* drilling of brick and rock, are also spread over a wide range, but tend to be lower than the indoor values. These outdoor samples are represented by a median result of 30 µg/m^3 and maximum of 130 µg/m^3. The maximum and the next highest outdoor value (120 µg/m^3) are both associated with the large rock drill with a forced air feature (which blows dust into the operator's breathing zone) evaluated by NIOSH HETA 2003-0275-2926 (2004). Based on these values and the results of area samples collected downwind of the larger, faster drill, NIOSH went on to recommend that workers operating this drill continue to wear the powered air-purifying respirator (PAPR) respirator hoods provided by the employer and that other workers should stay 20 feet back to minimize their exposure. In contrast, four of the other five results obtained at three outdoor construction sites are less than 50 µg/m^3. Although limited, these data suggest outdoor drilling most often results in worker exposure levels below the proposed permissible exposure limit (PEL) of 50, and results do not usually exceed 100 unless contributing factors, such as forced air combined with large, aggressive drill size, make the job particularly dusty.

Table IV.C-56
Respirable Crystalline Silica Exposure Range and Profile for Hole Drillers Using Hand-Held Drills

	Exposure Summary			Exposure Range			Exposure Profile				
Job Category*	**Number of Samples**	**Mean (μg/m^3)**	**Median (μg/m^3)**	**Min (μg/m^3)**	**Max (μg/m^3)**		**<25 (μg/m^3)**	**≥25 and ≤50 (μg/m^3)**	**>50 and ≤100 (μg/m^3)**	**>100 and ≤250 (μg/m^3)**	**>250 (μg/m^3)**
Hole Driller Using Hand-Held Drill											
Indoors, concrete substrate, no controls	7	90	60	41	286		0 0.0%	2 28.6%	4 57.1%	0 0.0%	1 14.3%
Other mixed conditions (primarily outdoors, various drills, substrates, and work practices)	7	58	30	12	130		2 28.6%	2 28.6%	1 14.3%	2 28.6%	0 0.0%
Totals	**14**	**74**	**59**	**12**	**286**		**2** **14.3%**	**4** **28.6%**	**5** **35.7%**	**2** **14.3%**	**1** **7.1%**

Notes: All samples are PBZ results for durations of 360 minutes or more and represent 8-hour time-weighted average (TWA) exposures with the assumption that exposure continued at the same level during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Source: ERG-C, 2008; McKernan, 2002; NIOSH HETA 2003-0275-2926, 2004.

Additional Controls

As indicates in the discussion of the exposure profile for hole drillers, the median exposure reading for hole drillers is 60 µg/m^3 when dry drilling indoors on concrete, but just 30 µg/m^3 outdoors. Therefore, additional controls are not normally required for hole drillers working outdoors except in exceptionally dusty circumstances. Construction sites where workers drill extensively indoors, however, will require additional controls to reduce worker exposures. Local exhaust ventilation (LEV) is the primary option available for reducing the exposure level of hole drillers both indoors and outdoors.

Local Exhaust Ventilation

Shepherd et al. (2009) found that, compared with uncontrolled drilling, using dust collection cowls connected to portable vacuums reduced silica exposure by 91 to 98 percent. The researchers tested four combinations of two cowls and two vacuums (all commercially available, including a bellows-style cowl and a telescoping ring cowl) in multiple 1-hour trials. For each trial, the worker-subjects used a 6.9 amp hammer drill with a 3/8 inch bit to continuously drill a series of 3-inch holes between shoulder and waist height in a vertical concrete wall.[232] Average respirable quartz levels varied among the different cowl/vacuum combinations, but all combinations resulted in personal breathing zone (PBZ) exposures of 28 µg/m^3 or less during these periods of constant drilling. In contrast, periods of uncontrolled drilling resulted in a geometric mean exposure level of 308 µg/m^3. Although the investigators note that results may vary for different drill types and drill bit sizes, OSHA estimates that even moderately effective ventilated dust collection cowls would still result in silica exposure levels that are 50 µg/m^3 or less during periods of intense drilling and that 8-hour TWA values would be lower still.

In an earlier study of vacuum suction dust control devices conducted in Sweden, Hallin (1983) evaluated rotary and percussion hammers equipped with various LEV systems and various drill bit sizes.[233] During the study, the tools were operated indoors, usually in a test room designed to mimic a small enclosed construction area with poor air circulation (one air change per hour). Under these conditions, the study showed that the use of LEV resulted in a 57-percent reduction in the median estimated respirable quartz exposure level for workers drilling 50-millimeter-deep holes in concrete with 6-millimeter drill bits (from a median of 140 µg/m^3 without LEV to a median of 60 µg/m^3 with LEV-equipped tools). Hallin found an 85-percent reduction in the median respirable quartz exposure level for workers drilling 80-millimeter-deep holes in concrete with 10-millimeter drill bits (295 µg/m^3 without LEV compared with 45 µg/m^3 with LEV).

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[232] The test wall was located indoors in a large enclosed space (100 feet by 60 feet by 30 feet, similar to a warehouse) for half the randomized trials with several operators each using the four combinations of equipment. The wall was moved outdoors for the other half of the trials. In this case, the investigators found no statistical difference between indoor and outdoor trials for the various equipment combinations.

[233] In this study, each LEV system consisted of a suction-type connection and a dust extractor. Hallin's (1983) test readings represent actual sampling times (rather than calculated 8-hour TWAs), and were based on short sample durations (ranging from 60 to 180 minutes of intensive drilling). Additionally, silica levels were estimated from a composite of several respirable dust samples collected at the test site and using individual respirable dust samples (area samples) obtained near, but not in, the workers' breathing zones. The workers did not use compressed air to clean the holes during these tests, which took place in a room approximately 15 feet by 18 feet by 8 feet.

This same study also indicates a greater potential for overexposure during overhead drilling performed indoors. Drilling for 120 minutes in a concrete ceiling with a percussion drill and a hammer drill gave respirable quartz exposures of 1,740 μg/m^3 and 720 μg/m^3, respectively (Hallin, 1983). When the same model of percussion drill was fitted with a dust collector, however, the respirable quartz reading for a 180 minute sample was only 80 μg/m^3. The authors note that because of the ergonomically stressful nature of this activity, overhead drilling should not be performed consistently for a full shift.

OSHA estimates results from drilling (including overhead drilling) in well-ventilated work areas will be lower than those reported by Hallin. The median and maximum exposure levels in Table IV.C-56 for workers drilling indoors are at least twice as high as those associated with outdoor work, where dust can dissipate more rapidly. Furthermore, NIOSH studies of exposure controls for lead-based paint removal showed that adding dilution ventilation to enclosed work areas reduced airborne lead fume concentrations by nearly half (45 percent, from 22 μg/m^3 to 12 μg/m^3 of lead) during lead paint removal by the heat gun method (NIOSH 98-112, 1997).[234] NIOSH notes that in very dusty areas, increasing dilution ventilation can actually increase exposure if the additional air movement causes quantities of settled dust to be re-suspended in air, so housekeeping is an important component of dust control.

Several manufacturers produce LEV dust removal systems for a variety of tool types, including most models of drills (Bosch, 2010; DeWalt, 2010; Hilti-dust-removal, 2009). When the LEV cowl is supplied with its own dust collection bag, both Hallin (1983) and Shepherd et al. (2009) suggest that better dust capture is achieved by removing the bag and attaching a vacuum hose in its place. An adaptor obtained from the local hardware store might be required (Shepherd et al., 2009). The vacuums described in detail by Shepherd et al. (2009) are also commercially available.[235]

Work Practices

The practice of sweeping or brushing debris from the hole appears to contribute to the exposure of workers drilling in concrete. The use of compressed air to clean the holes also increases exposure, regardless of whether the air is blown by the drill (a design feature of some drills) or by a worker using a compressed air nozzle. A pilot study indicated that respirable dust concentrations were cut to 50 percent of the original level when the worker stopped sweeping the wall after each hole was drilled (Shepherd and Woskie, 2003). A high-efficiency particulate air (HEPA)-filtered vacuum can be used instead of dry sweeping, brushing, and cleaning with compressed air.

Feasibility Finding

Considering the data described above, OSHA preliminarily concludes that all hole-driller exposures can be reduced to levels of 50 μg/m^3 or less. The exposure profile shows that among workers who perform drilling with hand-held equipment, approximately 40 percent already experience exposure levels less than the proposed PEL of 50 μg/m^3. No additional controls are necessary for workers drilling occasional holes outdoors.

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[234] Fumes are very small particles, the largest of which (1 micrometer) are in the lower end of the respirable size range (DiNardi, 2003). Like silica particles, fumes remain airborne rather than settling out of the air during a workshift.

[235] The two vacuums used by Shepherd et al. (2009) were rated by the vacuum manufacturers to pull 114 or 188 cubic feet per minute at 94 to 118 inches-water gauge. One of the models incorporated a cyclonic pre-separator to minimize the amount of dust reaching the filter.

Furthermore, data from Shepherd and Woskie (2003) suggest that simply decreasing workers' reliance on blowing or dry sweeping drilling debris from the work surface can reduce exposures by approximately 50 percent. Portable HEPA-filtered vacuums with extension wands can be used instead. This 50 percent reduction would bring exposure levels below 50 µg/m^3 for all the drill operators who are currently exposed to silica at levels of 100 µg/m^3 or less (78 percent of those represented in the Table IV.C-56 exposure profile). OSHA estimates that reducing reliance on drills that blow air down the hole will offer drillers the same degree of exposure control as reducing use of other forms of compressed air to clean holes.

Additional controls, such as fitting an LEV cowl and vacuum suction to the drill described by Shepherd et al. (2009), will be required for the remaining workers (the 22 percent currently exposed to silica levels greater than 100 µg/m^3 according to Table IV.C-56). Based on evidence provided by Shephard et al. (2009), several combinations of drill cowls and portable vacuums can reduce driller silica exposures by at least 90 percent, to levels of 28 µg/m^3 or less. In contrast, the mean uncontrolled level in that study was 308 µg/m^3 during continuous drilling, leading OSHA to estimate that the commercially available test equipment could reduce even the highest value in the exposure profile to a level well below the proposed PEL of 50 µg/m^3.

OSHA also preliminarily concludes that, in addition to the controls described above (i.e., HEPA-filtered vacuum hole cleaning and LEV cowl with vacuum attachment), the activities of some workers will require improved air circulation in indoor work areas. Among these workers will be those who drill for extended periods indoors or with particularly large, aggressive drills, or who repeatedly drill overhead. Hallin (1983) showed that even workers drilling overhead benefitted from suction devices; however, silica exposures remained in the range of 80 µg/m^3 during periods of intensive overhead drilling in a small, poorly ventilated, enclosed area. To achieve the proposed PEL of 50 µg/m^3 for these workers, OSHA estimates that construction sites will also need to ensure the work site is kept clean (free of dust piles) and that fresh air exchange is provided to enclosed areas (e.g., temporary ducting or fans set in windows to improve air circulation and permit the free exchange of fresh air). NIOSH 89-112 (1997) reported that improving general dilution ventilation reduced lead fume particulate levels by 45 percent at lead abatement construction sites. OSHA estimates that a 45 percent reduction in the exposure level of 80 µg/m^3, reported by Hallin (1983) for overhead drillers using a cowl with vacuum attachment, will result in exposures of 36 µg/m^3 even during periods of intensive overhead drilling indoors.

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Jackhammer and Impact Drillers

Description

Hand-operated breaking and chipping equipment (commonly known as jackhammers, breaker hammers, drill hammers, rotary hammers, percussion hammers, impact drills, needle guns, and related tools) are used for demolition, renovation, and excavation. These tools deliver rapid repetitive blows to fracture rock, concrete, or masonry. Workers use these tools with the point of impact within 1 to 5 feet of the breathing zone and can hold the equipment at any angle, including overhead, depending on the weight of the tool (a limitation in some cases) and the configuration of the structure being chipped.

Workers can use chipping and breaking equipment for as little as a couple of hours or for as long as 7 hours or more (ERG-C, 2008). At some job sites where a large volume of concrete must be removed (e.g., bridge deck renovation), several jackhammer operators might perform pavement breaking simultaneously in the same general area, increasing the dust concentration in the area. Impact drillers frequently use dry sweeping to clear larger chipping debris from the work area and use hand-held blowers or compressed air to remove fine dust from the chipped surface (ERG-C, 2008).

Construction workers who use impact drills for drilling small holes are covered in Section IV.C.25 – Hole Drillers Using Hand-Held Drills.

Table IV.C-57 summarizes the job categories, major activities, and primary sources of silica exposure of workers in this industry.

Table IV.C-57

Job Categories, Major Activities, and Sources of Exposure of Workers Using Jackhammers or Other Impact Drills

Job Category	Major Activities and Sources of Exposure
Jackhammer Operator or Impact Driller	Chipping and breaking concrete, stone, and masonry during demolition, renovation, and excavation. • Dust from chipping or breaking action of the tool. • Dust raised by sweeping, brushing, and/or using compressed air to clear the work surface (housekeeping).

Source: ERG-C, 2008.

Baseline Conditions and Exposure Profile

ERG (ERG-C, 2008) summarized 99 respirable quartz samples for jackhammering and impact drilling at multiple commercial and highway construction sites, including a bridge. These results were extracted from seven NIOSH reports, numerous OSHA Special Emphasis Program (SEP) inspection reports, a published article, and a New Jersey state construction partnership report. OSHA has identified 10 additional results, summarized below[236].

OSHA determined that two samples from OSHA SEP Inspection Report 300033461, previously excluded from the ERG-C (2008) exposure profile, were acceptable for inclusion, noting that a worker notification letter indicates that the results represent silica in respirable dust (rather than in total dust as previously thought based on related documents). These 10-hour samples, which were obtained for workers operating jackhammers on bridge expansion joints, resulted in concentrations of 18 micrograms per cubic meter (µg/m^3) and 23 µg/m^3.

McKernan et al. (2002) reported two sample results (also included in the exposure profile) as nondetectable (ND), with sample periods of 278 and 428 minutes for workers chipping concrete and brick without controls at an indoor construction site.

OSHA also added to the exposure profile two results that NIOSH (NIOSH EPHB 247-15a, 2001) obtained for two demolition workers intermittently using 15- and 40-pound chipping hammers. Although working side by side, the silica results reported for these two workers varied greatly: 120 µg/m^3 and a result below the limit of detection (LOD) (33 µg/m^3 in this case). NIOSH did not explain the difference, but OSHA judges that it could be due to a combination of factors including work practices, ventilation, and other adjacent activities.

An additional four results were added to the exposure profile based on samples collected by NIOSH during maintenance and repair activities on a waterway lock system (NIOSH HETA 2002-0014-2958, 2005). Workers used drills, operated jackhammers, or were near other workers using chipping equipment. Of the five 4-hour samples collected, four resulted in concentrations below the LOD of 24 µg/m^3 and were included in the exposure profile. One short-term sample result fell between the LOD and limit of quantitation (LOQ) (in this case 71 µg/m^3) and was excluded from the exposure profile because of the considerable range to which the result could belong (NIOSH HETA 2002-0014-2958, 2005).

Table IV.C-58 presents the exposure profile for workers using chipping and breaking tools. This table summarizes the best exposure data available to OSHA for these workers. Of the 109 respirable quartz readings summarized in the exposure profile, 44 results (40 percent) represent jackhammering outdoors under uncontrolled conditions. These results range from less than or equal to the LOD (12 µg/m^3) to 566 µg/m^3 and have a median of 73 µg/m^3 and a mean of 139 µg/m^3.

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[236] Note that all exposure profile values, and, unless otherwise explicitly stated, all results discussed in the additional controls sections are considered full-shift samples. The relationship between these samples and 8-hr TWA calculations is discussed in Section IV.A – Methodology.

Table IV.C-58
Respirable Crystalline Silica Exposure Range and Profile for Workers Using Jackhammers and Other Impact Drills

	Exposure Summary			Exposure Range			Exposure Profile				
Job Category	**Number of Samples**	**Mean (µg/m^3)**	**Median (µg/m^3)**	**Min (µg/m^3)**	**Max (µg/m^3)**		**<=25 (µg/m^3)**	**>25 and ≤50 (µg/m^3)**	**>50 and ≤100 (µg/m^3)**	**>100 and ≤250 (µg/m^3)**	**>250 (µg/m^3)**
Jackhammer Operator or Impact Driller											
Baseline conditions (outdoors, concrete substrate, no controls)	44	139	73	12	566		11 25.0%	6 13.6%	8 18.2%	10 22.7%	9 20.5%
Same as baseline, with wet methods attempted	5	229	140	26	639		0 0.0%	1 20.0%	0 0.0%	3 60.0%	1 20.0%
Other conditions (various environments, equipment, substrates, and work practices)	60	419	194	12	3,059		9 15.0%	2 3.3%	9 15.0%	14 23.3%	26 43.3%
Totals	**109**	**297**	**140**	**12**	**3,059**		**20** **18.3%**	**9** **8.3%**	**17** **15.6%**	**27** **24.8%**	**36** **33.0%**

Notes: All samples are personal breathing zone (PBZ) results and represent 8-hour time-weighted average (TWA) exposures with the assumption that no additional exposure occurred during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Sources: ERG-C, 2008; McKernan et al., 2002; NIOSH HETA 2002-0014-2958, 2005; OSHA SEP Inspection Report 300033461.

Five of the results in the exposure profile (5 percent) represent jackhammering outdoors attempting wet dust control methods. Under these condition, exposures range from 26 µg/m^3 to 639 µg/m^3, with a median of 140 µg/m^3 and a mean of 229 µg/m^3. There is not enough information available to OSHA to determine how the wet method control was applied in four of these five trials (the lowest exposure indicates that water was applied continuously at the point of operation). Sample durations and silica concentration in the raw material in these four trials are comparable to outdoor trials with no engineering controls. Additionally, four of five of these “wet” operations resulted in higher exposures than some “dry” operations with similar parameters, with the amount of respirable dust created in each of these four wet operations being higher than that created from comparable dry runs. Based on this information, OSHA has reason to believe that the water dust suppression control was not applied optimally.

The 60 remaining results (55 percent) were collected during chipping and breaking activities performed under a variety of “other conditions” (e.g., various tools, degrees of enclosure, attempted controls, numbers of jackhammers operating side by side, uses of compressed air or other construction equipment) (ERG-C, 2008). This group also includes results for which no information is available regarding controls or working conditions. These exposures tend to be higher, ranging from the LOD (12 µg/m^3) to 3,059 µg/m^3, with a median of 194 µg/m^3 and mean of 419 µg/m^3.

Several of the highest results in the “Other Conditions” category, including the maximum value, were obtained for workers using pneumatic-powered needle guns equipped with a contractor-built water-spray system to remove epoxy surfacer from an indoor concrete block wall (NIOSH HETA 83-132-1508, 1983). Other extremely elevated results in this category were also associated with indoor work, including results ranging from 340 µg/m^3 to 2,350 µg/m^3 associated with workers using an air hammer to chip concrete in a parking garage. However, indoor exposures were not uniformly elevated to these extreme levels. Some indoor results were more moderate, including three results between 58 µg/m^3 and 111 µg/m^3 that were obtained for workers operating jackhammers in another parking garage (NIOSH ECTB 233-105c, 1999). In addition, the “Other Conditions” category includes 20 outdoor results, 12 of which exceeded 250 µg/m^3, from bridge deck job sites (NJDHSS, 2000). These unusually elevated results might result from having multiple jackhammers working side by side, using compressed air as a cleaning technique, and cross exposure from other highway equipment.[237]

OSHA also reviewed four more reports not addressed in ERG’s analysis (ERG-C, 2008) of chipper and jackhammer operators. These include Flanagan et al. (2006), Blute et al. (1999), and Valiante et al. (2004), none of which report individual silica exposure concentrations, and Nij et al. (2004), which summarizes silica results for construction workers in the Netherlands. Although individual results from the four studies do not appear in the exposure profile, as discussed in the following paragraphs, these reports do offer additional insight into the silica exposure of construction workers using chipping and breaking equipment.

In a review of data from a variety of published and private sources, Flanagan et al. (2006) analyzed multiple tools and tasks used in construction activities. Flanagan reviewed 178 respirable quartz samples associated with the use of jackhammers or chipping guns in construction and found a geometric

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[237] Twenty-two samples obtained from the New Jersey Silica Partnership identified outdoor jackhammer work on concrete as the predominate activity contributing to silica exposure at highway construction sites (NJDHSS, 2000). Median jackhammer exposures were almost three and a half times greater among the New Jersey exposure data than among the other, principally industrial/commercial construction exposure data reviewed in ERG-C (2008). ERG noted that the use of compressed air for cleaning, the tendency to have two or more adjacent jackhammers operating simultaneously, and dust generated or disturbed by other highway construction equipment likely contributed to these higher exposure levels (ERG-C, 2008).

mean of 150 µg/m^3 for those samples. This is not inconsistent with the exposure profile provided in Table IV.C-58, which indicates that a large percentage (more than half) of all workers using chipping and breaking equipment are exposed above 100 µg/m^3. OSHA's and Flanagan's data sources likely overlap substantially because they draw from much of the same published literature and some of the same unpublished sources.

A report addressing silica exposures during underground tunnel construction, reviewed in ERG-C (2008) in the Underground Construction section of that report, also summarized respirable quartz concentrations for workers using chipping equipment in the tunnel. Over the periods monitored, the mean exposure level for 10 workers operating chipping guns was 280 µg/m^3, with a range of 9 µg/m^3 to 1,640 µg/m^3 (Blute et al., 1999). These samples contained mean quartz content of approximately 12 to 16 percent. The exposures of the tunnel chipping gun operators are comparable to those compiled in the exposure profile for all workers using chipping and breaking equipment, supporting OSHA's estimate that, in general, underground construction worker exposure levels are typically similar to the levels experienced by workers performing the same task above ground. Although underground construction sites are enclosed (similar to an indoor construction site), the improved ventilation used in many tunnels mitigates the elevated exposures often found in poorly ventilated enclosed spaces.

Valiante et al. (2004) summarized results for 25 workers operating jackhammers at highway projects conducted by the New Jersey Department of Transportation. Silica exposures ranged from 30 µg/m^3 to 630 µg/m^3, with a mean of 276 µg/m^3. The majority of the data from this study were previously identified in ERG-C (2008) as results associated with the New Jersey silica partnership (NJDHSS, 2000) and are included in OSHA's exposure profile.

Finally, an international study conducted by Nij et al. (2004) collected samples from construction workers in the Netherlands (i.e., concrete drillers, tuckpointers, and demolition workers) whose tasks involved the use of jackhammers and other dust-generating tools. Silica results for 21 samples from 10 demolition workers ranged from the LOD of 38 µg/m^3 to 1,300 µg/m^3, with a mean exposure of 250 µg/m^3. These results provide some support for those documented in OSHA's exposure profile (Table IV.C-58), but it is important to note that, in addition to jackhammering, the workers evaluated in this study performed activities excluded from OSHA's exposure profile for jackhammers and impact drills (such as using grinding equipment and excavators fitted with breaking tools).

Based on the best available exposure information and ERG-C (2008), OSHA finds that most construction workers who use jackhammers and impact drills work outdoors on concrete structures and do not use engineering controls or dust-suppressing work practices. However, when impact drillers work indoors, they often attempt various methods of dust control, but no single method is used consistently or effectively. Other workplace conditions might be typical in the highway construction environment where silica exposures tend to be higher than in outdoor commercial or industrial construction. Specifically, in that environment multiple jackhammer operators often work in the same area and use compressed air for cleaning dust from freshly chipped surfaces.

The results included in the exposure profile represent the range of conditions under which workers use jackhammers and impact drills. Therefore, OSHA has preliminarily determined that the overall median result of 140 µg/m^3 for the job category represents the baseline median.

Additional Controls

Wet drilling and using tools equipped with local exhaust ventilation (LEV) are the primary controls available to reduce the respirable quartz exposures of jackhammers and impact drillers. The effectiveness and availability of these measures are discussed in the following paragraphs.

Wet Methods

An OSHA SEP inspection report contains silica results for five samples, all less than 19 µg/m^3, obtained by a consultant while workers chipped concrete with 90-pound pavement breakers and used a 2-inch water hose and pump to wet the area (OSHA SEP Inspection Report 106719750). Because the consultant did not provide supporting details (e.g., sample duration needed to calculate an 8-hour TWA), these results are not included in OSHA's exposure profile; however, they do demonstrate the potential for water-based dust suppression methods to minimize exposure.

Although OSHA was not able to identify a commercial source of jackhammers and impact drills equipped with water supply systems, individual employers, NIOSH, and an informal consortium of New Jersey organizations interested in controlling silica during road construction activities have all tested wet dust suppression methods with chipping and breaking equipment. One method is to apply water by using a garden and/or hydraulic hose taped to the tool's bit. In one instance, a continuous stream of water directed at the concrete breaking point during a 345-minute period resulted in a respirable quartz exposure level below the LOD of approximately 17 µg/m^3. This reading was obtained by OSHA for a jackhammer operator breaking concrete outdoors (OSHA SEP Inspection Report 106719750), and represents a 77-percent reduction from the median exposure level for uncontrolled outdoor work of 73 µg/m^3.

NIOSH completed several studies evaluating water spray devices to suppress dust created while workers use chipping and breaking equipment. These devices use a directed mist, which suppresses dust while conserving water compared with direct application from the mouth of a hose. NIOSH (NIOSH EPHB 282-11a, 2003) investigated water spray dust control used by workers breaking concrete with 60- and 90-pound jackhammers. Using both a direct reading instrument and a high-flow cyclone and filter, NIOSH collected 10-minute respirable dust readings with and without the spray activated. Compared with concentrations during uncontrolled pavement breaking, respirable dust results were between 72 and 90 percent lower when the water spray was used. The flow rate of 350 milliliters per minute (ml/min) reportedly dried quickly, without adding a substantial amount of water to the work site (NIOSH EPHB 282-11a, 2003; Echt et al., 2003). A follow-up NIOSH study reported a similar 77 percent reduction in silica concentration during 60-minute trials with a solid cone nozzle producing water mist at a rate of 300 mL/min (NIOSH EPHB 282-11c-2, 2004). In this case, silica levels were reduced from 320 µg/m^3 and 430 µg/m^3 during uncontrolled trials to less than 40 µg/m^3 and 130 µg/m^3 when water spray was used.[238] The NIOSH findings suggest that the water mist is able to reduce dust considerably, but that work practices are necessary if construction sites want to keep results below 50 µg/m^3 for all workers using chipping and breaking equipment. Employers will need to train workers to observe dust release and conscientiously adjust the flow rate or spray direction to maximize visible dust control. Additionally, workers must be trained to observe the spray quality (its effect on visible dust) and stop work to clean or replace a nozzle that becomes clogged.

Williams and Sam (1999) also evaluated a shop-built water spray nozzle mounted on a hand-held pneumatic chipper used by a worker removing hardened concrete from inside concrete mixing truck drums. Although this was not a construction worker, the task was performed in a mobile, confined space comparable to a worst-case environment for construction concrete chipping and breaking jobs. Under

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[238] In this NIOSH study, one worker used an 80-degree nozzle supplying water at 300 milliliters per min (mL/min), and another worker used a 60-degree nozzle that delivered water at a rate of 250 mL/min. The 80-degree nozzle reduced silica exposure 77 percent, while the 60-degree nozzle provided a silica reduction of 39 percent, about half as much as the 80-degree nozzle. The nozzle with the higher flow rate and wider spray pattern reduced silica levels to a greater extent than the other nozzle. When a nozzle became clogged after striking concrete, the silica concentrations rose, which demonstrates the importance of careful maintenance and consistent use of water spray for dust control (NIOSH EPHB 282-11c-2, 2004).

those conditions, the water spray decreased respirable dust approximately 70 percent in the worker's breathing zone compared with uncontrolled chipping in the same environment.

Although not currently commercially available, simple instructions for developing this type of spray equipment for jackhammers are readily available, published by the New Jersey Laborers Health and Safety Fund (Hoffer, 2007), NIOSH (NIOSH 2008-127, 2008), and the New Jersey Department of Health and Senior Services (NJDHSS, no date). An improved design tested in New Jersey involving a double water spray (one on each side of the breaker blade) reduced peak dust concentrations by approximately 90 percent compared with the peak concentration measured for uncontrolled pavement breaking (NJDHSS, no date).

OSHA finds (from the reports described above) that wet methods can reduce exposure levels substantially when optimized, but that until properly adjusted, results can still exceed 100 µg/m^3. This is consistent with the information in Table IV.C-58 showing a median result of 229 µg/m^3 for workers at sites attempting wet methods of one type or another. To be effective, water spray must: 1) provide sufficient water mist (flow rate optimized), 2) provide a suitable droplet size and pattern (the right nozzle), and 3) be appropriately directed. NJDHSS (no date) suggests that a double spray nozzle, described above, improves dust suppression beyond the reported levels.

Considering the provided information on water spray controls, OSHA estimates that under normal working conditions, properly adjusted water mist spray controls can reduce typical breathing zone silica concentrations by approximately 77 percent. This percentage of reduction, reported in NIOSH EPHB 282-11c-2 (2004), is the median amount by which respirable dust or silica was reduced by wet methods evaluated in the reports described above (range of 70 to 90 percent reduction). In practice, this means that water spray controls can be expected to reduce median silica exposure level for workers using chipping and breaking equipment outdoors from the Table IV.C-58 median of 73 µg/m^3 to 17 µg/m^3. In fact, a 77-percent reduction due to installing an effective water spray will reduce baseline exposure levels that are currently up to 200 µg/m^3 (between 57 and 80 percent of all jackhammer operators currently working outdoors under uncontrolled conditions, as indicated in Table IV.C-58) to levels of 50 µg/m^3 or less. Therefore, OSHA conservatively estimates that on outdoor construction sites using water mist spray systems, but otherwise representing baseline conditions, at least 57 percent of the chipping and breaking equipment operators will experience exposure levels of 50 µg/m^3 or less.

OSHA also examined the effect that wet method controls might have on workers whose current exposure is well above the median level. OSHA used as an example two construction workers whose measured 8-hour TWA exposures were 297 µg/m^3 and 449 µg/m^3 (with 19 and 21 percent silica in the samples) over the approximately 450-minute periods monitored, putting them well within the top 20 percent highest values reported in the exposure profile (see Table IV.C-58) for outdoor uncontrolled chipping and breaking work. These impact drillers spent the entire shift chipping concrete, but otherwise worked under typical baseline conditions (i.e., outdoors, with no controls). For these two workers, exposure levels would be reduced (to 68 µg/m^3 and 103 µg/m^3) by the same water mist spray dust control method described above and reported in NIOSH EPHB 282-11c-2 (2004) as offering 77-percent reduction in silica exposures; however, results below 50 µg/m^3 would not necessarily be achieved for these highly exposed workers (in the upper 20 percent of exposed workers in Table IV.C-58) if they operated chipping and breaking equipment for their entire shift.

Flanagan et al. (2003) recorded worker activities in addition to worker exposure during a wide range of construction activities. During more than 16 hours of direct observation (combined time over at least six periods of evaluation), workers performing "demolition with handheld power tools" spent half (51 percent) of the observed time directly performing the target activity (in this case defined as using a handheld power tool, such as a jackhammer).[239] For the workers discussed in the paragraph above, daily silica exposure levels would be lower if the workers only used jackhammers or other chipping tools for half their shift (e.g., 4 hours or less) as did the workers reviewed by Flannagan et al. (2003) and as is common for many in the construction industry. In this case, OSHA calculates that 8-hour TWA exposure levels would be approximately half of the average daily concentrations produced by a whole shift of chipping and breaking using the water spray dust control. Again, as an example, consider the two workers whose exposures were in the upper 20 percent (Table IV.C-58). Suppose that this time they worked half a shift of work in a low-dust environment and used the NIOSH water spray controls. Instead of encountering exposure levels of 68 µg/m^3 and 103 µg/m^3 (estimated above) for a full day of chipping and breaking with water spray controls, the resulting daily exposure levels associated with a half shift of this work would be 34 µg/m^3 and 52 µg/m^3. Thus, OSHA estimates that even some of the most highly exposed workers (upper 20 percent in Table IV.C-58) would experience levels in the range of 50 µg/m^3 or less on days when they used jackhammers for less than 4 hours.

OSHA acknowledges that a large portion of construction workers operate chipping equipment under complex conditions (ERG-C, 2008). These workers often have much higher levels of exposure than workers operating strictly under more typical outdoor conditions, simply because workplace factors create or concentrate more airborne silica dust in their breathing zones. These workers perform their jobs outdoors but use compressed air to remove dust and debris from the chipping site, or they operate impact drills and jackhammers indoors or in enclosures (to prevent the spread of dust off the work site), or they are part of teams using pavement breakers in close proximity to each other. Based on the findings of NIOSH (EPHB 282-11a, 2003; EPHB 282-11c-2, 2004) and Williams and Sam (1999), OSHA believes that using carefully adjusted wet methods combined with low-dust cleaning methods can control the respirable quartz exposures of most impact drillers to a level equal to or less than 100 µg/m^3. The 42 percent of these workers for whom results are already less than 100 µg/m^3 will experience exposure reductions to 30 µg/m^3, but not all will be able to do so consistently with the equipment evaluated. Improvements to spray systems, such as the double spray nozzle system tested in New Jersey, might bring a larger portion of worker exposure levels (e.g., those with current exposures less than 250 µg/m^3) to levels of 50 µg/m^3 or less.

Local Exhaust Ventilation

LEV systems present an additional control option for reducing the respirable quartz exposures of impact drillers. The available information on LEV dust control systems for chipping and breaking equipment suggests that some systems might be nearly as effective as certain wet methods. In a study described above, NIOSH also tested two tool-mounted LEV shrouds: one custom built, the other a commercially available model during work with chipping hammers (intended for chipping vertical concrete surfaces). Comparing multiple short–term samples, NIOSH found that the shrouds reduced respirable dust by 48 to 60 percent (Echt et al., 2003; NIOSH EPHB 282-11a, 2003). In a separate evaluation, NIOSH showed that this type of LEV system controls dust equally well for smaller chipping equipment. That evaluation involved short-term samples taken while workers used 25- or 30-pound jackhammers to chip concrete from inside concrete mixer truck drums. During 90- to 120-minute periods of active chipping, mean silica levels decreased 69 percent (from 970 µg/m^3 to 300 µg/m^3) when the workers used a tool-mounted LEV shroud in these enclosed spaces (NIOSH EPHB 247-19, 2001). In this

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[239] Because other tools were also considered part of the hand demolition activity, actual time using a jackhammer would have been less than 51 percent if the worker changed tools during the period of evaluation. The other tools listed under this activity included: chipping guns, rivet busters, sledgehammers, shovels, brooms and vacuum cleaners (Flanagan et al., 2003).

study, a combination of LEV and general exhaust ventilation provided additional dust control, resulting in a 78 percent decrease in silica readings.[240]

During a separate manufacturer-sponsored test at an indoor demolition site, an LEV shroud mounted to a breaker hammer reduced the number of near-respirable 5-micron-sized particles by 26 percent. A company representative noted that this result could have been improved if the trial had involved the optimal airflow rate recommended for shrouds (120 cubic feet per minute [cfm]) (ESS-engineer, 2009; ESS-test, 2008). For this test, the investigators used an electric breaker hammer and a bag-style vacuum fitted with a high-efficiency particulate air (HEPA) filter, which could have affected the results. Another vacuum type might have offered greater and more consistent air flow to improve dust capture.

Relevant to all studies of LEV for chipping and breaking tools, OSHA notes that recent information on vacuum suction devices used for construction dust control indicates that some LEV methods are likely to be more effective than previously reported when paired with vacuums that consistently provide adequate air flow. Additionally, vacuum cleaners that use bags (plus HEPA filters) for dust capture might not function as consistently as vacuums that include cyclonic pre-separators to capture most of the dust (see discussion in Section IV.C.32 – Tuckpointers and Grinders in this technological feasibility analysis for the construction industry).

Several impact drill manufacturers currently offer LEV options (Atlas-Copco, 2001; Krenzer, 2000; Shave-Away, Europe, 2001; Trelawny, 2001). Other companies specialize in manufacturing after-market ventilation systems for various hand-held tools such as jackhammers and chipping equipment (Alto International A/S, 2001; DustControl AB, 1999; ESS-boot, 2008).

Combination Wet Methods and Local Exhaust Ventilation

A combination of LEV and water is another control option, although OSHA has not been able to quantify its effectiveness. Information obtained for workers operating hand-held grinders suggests that combining wet methods and LEV might reduce exposure further, in the range of 7 percent, beyond using wet methods alone (NIOSH-construction-site-16, 1998; NIOSH ECTB 247-12, 2000). OSHA has preliminarily determined that adding LEV to wet methods can provide at least as great an exposure reduction for jackhammers as for hand-held grinders.[241] As noted above in the discussion of wet method

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[240] Decreased silica content in the second respirable dust sample was responsible for about one-fourth of the difference between results obtained during uncontrolled chipping and while using a combination of LEV and general exhaust ventilation (NIOSH EPHB 247-19, 2001).

[241] While both are high energy operations, respirable size particles are produced rapidly by crushing action, but are not accelerated by jackhammers to the extent that they are by grinding tools, resulting in a greater ease of capture by LEV, provided that the LEV volume is sufficient. For jackhammers, the challenge is capturing a large volume of respirable dust that disburses rapidly in highly (but nondirectionally) disturbed air. In contrast, grinding wheels, release large volumes of respirable dust from a small, discrete point, but at extremely high velocity. A very high capture air velocity is required to overcome the particle speed. To achieve the high air velocity, a large air volume and strong vacuum suction are required. Collingwood and Heitbrink (2007) note that a 4.5-inch diameter (1.18 foot circumference) tuckpointing grinding wheel operates at 10,000 to 12,000 rotations per minute (rpm). At that rotation rate, OSHA estimates that the cutting edge of the blade is moving at a speed of nearly 200 feet per second (1.18 feet times 10,000 rotations per minute, divided by 60 seconds per minute),

controls alone, OSHA finds that appropriate water sprays might reduce jackhammer operator exposures by 77 percent. By adding the two (at least 7 percent and 77 percent), OSHA estimates that the combined benefit could offer an exposure reduction of at least 84 percent compared with uncontrolled impact drilling. Using the previous example of the two impact drillers, a combination of LEV and wet methods might have decreased the results of 297μg/m^3 and 449 μg/m^3 by at least 84 percent to 48 μg/m^3 and 72 μg/m^3, respectively.

As noted above in the discussion of wet method controls alone, OSHA finds that appropriate water sprays might reduce jackhammer operator exposures by 77 percent. By adding the two (at least 7 percent and 77 percent), OSHA estimates that the combined benefit could offer an exposure reduction of at least 84 percent compared with uncontrolled impact drilling. Using the previous example of the two impact drillers, a combination of LEV and wet methods might have decreased the results of 297μg/m^3 and 449 μg/m^3 by at least 84 percent to 48 μg/m^3 and 72 μg/m^3, respectively.

Work Practices

OSHA expects that many impact drillers provided vacuums rather than compressed air to clean work surfaces could experience reduced exposures. Vacuuming collects dust particles before they become airborne while using compressed air causes them to become airborne (increasing the potential for greater exposures). In particular, if either water spray or LEV were used to reduce exposures on highway construction jobs and vacuums replaced compressed air for cleaning any residual dust on those sites, ERG estimated that most workers using chipping and breaking equipment would routinely experience silica exposure levels less than 100 μg/m^3. OSHA concurs, estimating that this combination of controls would reduce the exposure limits of even the most highly exposed workers during outdoor work to 100 μg/m^3. When vacuum cleaning is used in combination with improved water spray systems (i.e., adequate flow rate, appropriately directed spray, suitable nozzle), the exposures of most of these workers could be brought down to 50 μg/m^3. OSHA does not possess individual studies that show the cumulative benefit of using vacuuming in combination with wet methods or LEV systems. However, the Agency knows that vacuuming will prevent dust accumulation and re-suspension which may be an additional source of exposure when the settled dust dries. Additionally, the benefits offered by wet methods and LEV systems will remain the same, and according to the percent reductions reported for both controls, most of these workers will be able to experience levels below the proposed PEL. Furthermore, the use of compressed air for cleaning will be a prohibited practice under the proposed rule.

Feasibility Finding

Based on the information described above, OSHA preliminarily concludes that the exposure levels for most workers using jackhammers and chipping equipment outdoors will be reduced to less than 100 μg/m^3 as an 8-hour TWA by using either wet methods (i.e., appropriate water sprays) or LEV systems paired with suitable vacuums (e.g., sufficient volume, cyclonic pre-separator). Furthermore, up to 80 percent of workers operating under baseline conditions and using wet methods or LEV systems will experience exposures less than the proposed PEL of 50 μg/m^3 if their job duties include using chipping or breaking equipment for less than 4 hours per day (as is typical for when they use these large, heavy tools). Thus exposure levels of 50 μg/m^3 or less can be achieved for most of these workers most of the time.

For the majority of jackhammer operators who work under more complex conditions (e.g., indoors/enclosures, multiple jackhammers), and so might currently experience exposure levels greater than those associated with baseline conditions, a combination of methods will be necessary to achieve the same results. An adequate combination of controls, including a water spray system supplemented by low-

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entraining the particles it releases from the surface it is grinding.

dust cleaning techniques, will reduce the exposures of these workers to 100 µg/m^3. Improved water spray dust suppression includes direct spray at dust source, spray nozzles that offer droplet size similar to the dust size, and a sufficient spray rate to visibly reduce dust. NIOSH showed that jackhammers fitted with an 80-degree nozzle supplying water at 300 mL/min reduced silica exposure by 77 percent (NIOSH EPHB 282-11c-2, 2004). Low-dust cleaning involves vacuuming or wet sweeping excess dust (as a substitute for blowing with compressed air). During a manufacturer-sponsored test, an LEV shroud mounted to a breaker hammer reduced the number of near-respirable 5-micron-sized particles by 26 percent, a result that could have been improved if the trial had involved the optimal airflow rate of 120 cfm recommended for shrouds (ESS-engineer, 2009; ESS-test, 2008).OSHA anticipates that similar exposure reductions reported by wet methods and LEV systems during outdoor work can be applied to indoor work, as long as arrangements are made to provide adequate fresh air circulation in order to prevent the accumulation of respirable dust in a worker's vicinity. As such, the Agency estimates that most workers performing indoor work may achieve levels of 50 µg/m^3 or less if the appropriate control strategy is implemented.

Under the above circumstances, when workers use jackhammers for less than 4 hours of their shifts, which is typical of most work performed, OSHA preliminarily concludes that levels of 50 µg/m^3 or less can be achieved for most workers most of the time.

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Masonry Cutters Using Portable Saws

Description

Workers in the construction industry use a variety of portable and mobile saws to perform a wide range of cutting activities. Activities include resizing bricks and blocks, cutting segments out of existing masonry structures or pavement, making straight cuts (e.g., to straighten an edge or to weaken a structure in preparation for demolition), and cutting grooves for utility installation. Exposures to silica occur when the masonry worker is cutting silica-containing material, especially concrete, asphalt, and brick.

For this analysis, OSHA divides portable and mobile saws into three primary categories: 1) hand-held saws, 2) walk-behind saws, and 3) drivable saws. A brief description of each type of saw follows; see ERG-C (2008) for more detailed descriptions of each type of saw.

Hand-held saws: The hand-held saw operator (cutter) holds the saw with both hands and leans over the work, which is typically between ground level and waist height. The cutter's breathing zone is often within an arm's length of the point of dust generation. Operators typically use hand-held saws for brief, intermittent periods; however, the process might be repeated numerous times over the course of a shift (ERG-C, 2008). Some workers use a hand-held saw as an alternative to a stationary masonry saw for cutting concrete block and brick close to where the block or brick will be installed.

Walk-behind saws: Construction workers use walk-behind saws to cut expansion joints or slabs out of existing pavement. Workers maneuver the equipment from behind using a control bar or handle(s) so that their breathing zone is typically 5 to 10 feet from cutting action. Masonry cutters using walk-behind saws most commonly work outdoors cutting concrete roadways (ERG-C, 2008).

Drivable saw: A drivable saw operator typically sits in an open cab, about 15 feet away from the pavement cut point, guiding the saw to make long cuts such as are common for utility installation along roadways. The blade housed by this vehicle can be large (e.g., 8 feet in diameter and 2 inches thick) and is typically equipped with a water-fed system to cool the blade. Because of their size, drivable saws are typically used outdoors (ERG-C, 2008).

Table IV.C-59 summarizes the job categories, major activities, and primary sources of silica exposure of workers in this industry.

Table IV.C-59

Job Categories, Major Activities, and Sources of Exposure of Masonry Cutters Using Portable Saws

Job Category*	**Major Activities and Sources of Exposure**
Job Category*	
Masonry Cutters Using Portable Saws	
Hand-Held (Cut-off/Chop) Saw	Using hand-held power saw to cut bricks, concrete blocks, tiles (i.e., wall, floor, roofing), and small sections of concrete structures (e.g., pavement, curbs, walls). • Dust generated by cutting action of the abrasive blade in concrete or masonry.
Operator Walk-Behind Saw (Flat Saw) Operator	Manipulating wheeled saw using handles. Cutting existing pavement, typically to form expansion joints, slabs, or margins of pavement sections to be removed by other tools. • Dust generated by cutting action of the abrasive blade in concrete or asphalt.
Drivable Saw Operator	Controlling saw from an open cab to make long cuts in existing pavement (e.g., to install underground utilities). • Dust generated by cutting action of the abrasive blade in concrete or asphalt.

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the facility.

Source: ERG-C, 2008.

Baseline Conditions and Exposure Profile

ERG-C (2008) summarized a total of 74 8-hour time-weighted average (TWA) personal breathing zone (PBZ) respirable quartz results for construction workers using portable and mobile saws.[242] The results were compiled from NIOSH reports, information on state and federal OSHA inspections (published and unpublished), and published journal articles. Subsequently, ERG determined that nine of those samples did not meet the criteria for this analysis, so they were withdrawn.[243] OSHA has since identified an additional 26 adequately documented respirable quartz results from three NIOSH health hazard evaluation reports related to construction workers using hand-held saws while installing cement

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[242] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) calculated assuming no additional exposure during any unsampled portion of the shift. Unless explicitly stated otherwise, all results discussed in the additional controls section are also 8-hour TWAs calculated the same way. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

roof tiles (NIOSH HETA 2003-0209-3015, 2006; NIOSH HETA 2005-0030-2968, 2008; NIOSH HETA 2005-0031-3055, 2008). Together, the 91 respirable quartz results represent the best exposure monitoring data available to OSHA for workers operating portable and mobile saws.

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[243] Sample duration was not published for nine values presented in Flanagan et al. (2001). As a result, ERG deemed the supporting detail insufficient under current exposure profile criteria. Other more fully-documented results from this study are included in the exposure profile, and all the values contribute information to the additional controls portion of this analysis.

Table IV.C-60 provides silica exposure data for all saw operators and for each category of saw operators. Exposures for all saw operators range from 11 micrograms per cubic meter (μg/m^3) to 10,318 μg/m^3, with a median of 110 μg/m^3 and a mean of 275 μg/m^3. The baseline conditions for workers operating hand-held saws, walk-behind saws, and drivable saws will be discussed separately.

Baseline Conditions and Exposure Profile for Hand-Held (Cut-off/Chop) Saw Operators

Workers who use hand-held saws are the largest category of portable and mobile saw operators. Meeker et al. (2009) note that portable hand-held saws are increasingly used as a direct substitute for water-fed stationary saws.[244] OSHA reviewed 68 results from over a dozen construction sites where workers used cut-off, chop-style, and various other hand-held saws. Silica exposures for this group range from 12 μg/m^3 to 10,318 μg/m^3, with a mean of 334 μg/m^3 and a median of 130 μg/m^3. Fifty results (73 percent) exceed 50 μg/m^3, and 42 results (62 percent) exceed 100 μg/m^3. Ten of the 68 results (15 percent) were very high, exceeding 250 μg/m^3, while 13 results (19 percent) were 25 μg/m^3 or lower.[245] Seven of the 13 lowest results were associated with workers who used wet methods. The highest 8-hour TWA result, based on a 350-minute sample at 14,150 μg/m^3 silica concentration, was reported for a plumber who used a hand-held saw to dry-cut slabs out of concrete bathroom floors indoors on each level of a 16-story building. A floor-stand fan aimed at an open window was the only attempt at dust control (NIOSH-WV-Route 6, 1992).

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[244] According to Meeker et al. (2009), "Historically, stationary wet saws served as the primary tool bricklayers used to cut masonry units such as brick. However, contractors have increasingly used portable masonry abrasive cutters, often referred to as 'chop saws,' in lieu of the stationary wet saw. Stationary wet saws require the user to be on the ground to make cuts. Some contractors, therefore, view the use of portable masonry saws as a productivity gain because they can be used without getting down from scaffolding. However, gasoline-powered equipment is prohibited on suspended scaffolding [reference 29 CFR 1926.451(d)(14) – Scaffolds]. In addition, portable abrasive cutters are heavy, generate high dust levels, and pose an increased safety risk for accidental cuts and amputations if not used correctly. The stationary wet saw also offers many ergonomic advantages compared with the portable saw." Meeker et al. (2009) go on to explain that with a stationary saw the operator is able to work in an upright position and does not have to bear any of the saw's weight. In contrast, operators using hand-held saws often adopt a bent posture and must support the full weight of the saw while cutting objects at ground level.

[245] Many of the readings below 25 μg/m3 also were below the LOD and were obtained for workers performing actual cutting operations for significantly less than 8 hours. For example, an 8-hour TWA result of 12 μg/m3 is calculated from an LOD reading of 40 μg/m3 or less for a hand-held saw operator dry-cutting concrete pavement for 140 minutes (the period sampled) (Shields, 2000). The calculated 8-hour TWA value is based on the assumption that the worker had no additional exposure during the unsampled portion of the shift (ERG-C, 2008).

Table IV.C-60
Respirable Crystalline Silica Exposure Range and Profile for Masonry Cutters Using Portable Saws

	Exposure Summary			Exposure Range			Exposure Profile				
Job Category	**Number of Samples**	**Mean (µg/m^3)**	**Median (µg/m^3)**	**Min (µg/m^3)**	**Max (µg/m^3)**		**<25 (µg/m^3)**	**≥25 and ≤50 (µg/m^3)**	**>50 and ≤100 (µg/m^3)**	**>100 and ≤250 (µg/m^3)**	**>250 (µg/m^3)**
Hand-Held Saw Operator											
Sawing concrete or masonry outdoors, no dust control (baseline conditions)	48	200	150	12	1,472		4 8.3%	3 6.3%	6 12.5%	28 58.3%	7 14.6%
Sawing concrete or masonry outdoors, wet methods (presumed sufficient)	8	38	24	12	101		5 62.5%	1 12.5%	1 12.5%	1 12.5%	0 0%
Indoors or location unspecified*	8	1,574	119	12	10,317		2 25.0%	1 12.5%	0 0.0%	2 25.0%	3 37.5%
Indoors or location unspecified, wet methods*	4	64.2	42	19	154		2 50.0%	0 0.0%	1 25.0%	1 25.0%	0 0.0%
Hand-Held Saw Subtotals	**68**	**334**	**130**	**12**	**10,318**		**13** **19.1%**	**5** **7.4%**	**8** **11.8%**	**32** **47.1%**	**10** **14.7%**
Walk-Behind Saw Operator											
Sawing concrete outdoors, sufficient wet methods (baseline conditions)	12	22	12	11	61		8 66.7%	3 25.0%	1 8.3%	0 0.0%	0 0.0%
Other conditions	8	237	236	65	461		0 0%	0 0%	1 12.5%	3 37.5%	4 50%
Walk-Behind Saw Subtotals	**20**	**108**	**39**	**11**	**461**		**8** **40%**	**3** **15%**	**2** **10%**	**3** **15%**	**4** **20%**
Drivable (Vehicular) Saw Operator											
Sawing concrete outdoors, wet methods (baseline conditions)	2	23	23	12	33		1 50%	1 50%	0 0%	0 0%	0 0%
Other conditions (clogged water discharge)	1	88	88	88	88		0 0%	0 0%	1 100%	0 0%	0 0%
Drivable Saw Subtotals	**3**	**45**	**33**	**12**	**88**		**1** **33.3%**	**1** **33.3%**	**1** **33.3%**	**0** **0%**	**0** **0%**
Totals	**91**	**275**	**110**	**11**	**10,318**		**22** **24.2%**	**9** **9.9%**	**11** **12.1%**	**35** **38.5%**	**14** **15.4%**

Notes: All samples are PBZ results and represent 8-hour TWA exposures with the assumption that no additional exposure occurred during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

* Might include hand-held saws that are not chop saws (e.g., extension saws, hand-guided saws temporarily mounted on a wall to make repeated and progressively deeper cuts in a thick concrete wall). Additionally, the location (i.e., outdoor/indoor) was either unspecified or ambiguous for three results associated with dry cutting and one result associated with wet methods.

Sources: ERG-C, 2008; NIOSH HETA 2003-0209-3015, 2006; NIOSH HETA 2005-0030-2968, 2008; NIOSH HETA 2005-0031-3055, 2008.

Forty-eight measurements were obtained for workers using hand-held saws while the worker cut concrete or masonry *outdoors*, with no dust controls. For this subgroup, the median silica result was 150 μg/m^3. This is substantially greater than the median of 24 μg/m^3 obtained for the eight results from other outdoor workers who used similar saws with wet methods. Table IV.C-60 shows a similar relationship between the median exposure levels associated with dry and water-fed sawing for sawyers primarily working *indoors* (or where location was unspecified). Wet dust control methods have a marked beneficial effect on silica exposures of workers operating hand-held saws both indoors and outdoors.

In addition to the documents that contributed individual results to the exposure profile, OSHA reviewed a study by Flanagan et al. (2006) that summarized 65 results for workers using hand-held saws. The authors reported a geometric mean quartz concentration of 130 μg/m^3 for this data set, which generally supports the information OSHA has summarized for this job category in Table IV.C-60.[246]

Based on these sources, OSHA preliminarily concludes that baseline conditions for construction workers using hand-held saws typically involve outdoors work on concrete or masonry units, with no engineering or work practice dust controls in place. The median exposure level for masonry cutters working under these conditions is 150 μg/m^3. Although the same type of dry cutting using hand-held equipment is occasionally performed indoors, other equipment (e.g., a stationary or hand-operated water-fed masonry saw) is often selected for indoor cutting. The median exposure for workers (indoors or outdoors) using wet methods to control dust is substantially lower; however, some exposures remain over the proposed permissible exposure limit (PEL) of 50 μg/m^3 because wet methods are not necessarily adjusted for optimal dust control.

Overall, the exposure profile indicates that 26 percent of construction workers using hand-held saws currently experience exposure levels of 50 μg/m^3 or less.

Baseline Conditions and Exposure Profile for Walk-Behind Saw Operators

OSHA reviewed 20 silica results for workers operating walk-behind saws ranging from 11 μg/m^3 to 461 μg/m^3 (Table IV.C-60). The mean for this group is 108 μg/m^3, and the median is 39 μg/m^3. Nine results (45 percent) exceed 50 μg/m^3, and seven results (35 percent) exceed 100 μg/m^3.

Construction workers cutting concrete outdoors and using wet methods to cool the blade or suppress dust are represented by a subset of 12 results from at least six construction sites visited by OSHA and NIOSH.[247] At three of these sites, workers used a single wet method: spraying water at the point where the saw blade cut pavement. In addition to spraying water, workers at a fourth site cut into

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[246] Flanagan et al. (2006) reported a geometric mean quartz exposure level of 70 μg/m3 for sawyers using table saws (stationary saws), compared with a geometric mean of 130 μg/m3 for portable saws. Although the authors did not describe the working conditions associated with each result, it is likely that practices associated with reduced exposures (e.g., wet cutting) were more prevalent with the use of stationary saws than portable saws, a trend also seen among the silica exposure data available to OSHA for workers using the two types of saws (see also Section IV.C.28 – Masonry Cutters Using Stationary Saws in this technological feasibility analysis). These practices greatly reduce both the median and the highest exposure levels (which influence the mean). Flanagan et al. (2006) do not report median exposure values for these data.

[247] Some information sources contain results representing multiple sites.

"fresh" concrete, which had been poured within 6 hours of cutting and therefore had not set completely (ERG-C, 2008).[248] These methods were generally effective in maintaining worker silica exposure levels below 50 μg/m^3: as summarized in Table IV.C-60, 8 of the 12 sample results (67 percent) were below 25 μg/m^3, and only one result (61 μg/m^3) exceeded 50 μg/m^3. The median value was 12 μg/m^3. These data suggest that the standard wet methods typically used with walk-behind saws effectively control operators' 8-hour TWA silica exposure levels most of the time. However, concentrations might exceed 100 μg/m^3 during short-term sampling activity, presumably covering periods of intensive sawing, even when wet methods are used. For example, a silica concentration of 230 μg/m^3 was reported for an 85-minute period during which an operator used a water-fed walk-behind saw to cut a road surface. This sample, which contained 21 percent respirable quartz on the filter (higher than typical), resulted in an 8-hour TWA of 41 μg/m^3 (Shields, 2000). The example demonstrates that elevated silica concentrations can occur during active wet sawing; however, the available documentation does not indicate whether the water-fed system was adjusted to provide optimal dust control.

The remaining eight results for walk-behind saw operators were collected under various other conditions (i.e., other than confirmed wet cutting outdoors). The median value of 236 μg/m^3 is almost 20 times higher than the median of 12 μg/m^3 just described for workers using wet methods outdoors. Flanagan et al. (2001) obtained four of the eight results (ranging from 65 μg/m^3 to 350 μg/m^3) over 4 to 7 hours of indoor work involving wet sawing. The authors attributed at least one of the elevated exposures to the work practices common among inexperienced workers, who closely watch the progress of the blade, "…so their breathing zone was in the particle spray zone." More experienced workers tended to stand back out of the spray (particularly when cutting walls with hand-guided saws on tracks). The authors also indicate that to represent "worst case" conditions, they elected to monitor only indoor work sites where jobs with long task durations were scheduled (Flanagan et al., 2001).[249] The remaining four results in the "Other Conditions" group are only partially described. Working conditions are less clearly documented, and the results are somewhat higher (140 μg/m^3 to 461 μg/m^3, also over 4 to 7 hours) for these four workers, who appear to have used dry or ineffective wet sawing methods (NJDHSS, 2000; OSHA SEP Inspection Reports MN-302502505 and 300219979). The highest of these results is associated with a sawyer cutting repair boundaries on a bridge deck, probably under dry working conditions (NJDHSS, 2000). The difference between these groups of results points to a strong link between lower worker silica exposure levels, effective wet dust suppression, and site conditions that minimize the extent to which airborne particles linger near workers' breathing zones (e.g., outdoors).

Drawing from a variety of sources, Flanagan et al. (2006) compiled a data set of 33 results for workers using walk-behind saws. The authors reported a geometric mean quartz concentration of 90 μg/m^3 for these workers. This is generally consistent with the mean (arithmetic) of 108 μg/m^3 (median 39 μg/m^3) reported in Table IV.C-60 for the 20 results for walk-behind saw operators, which includes workers cutting under a variety of conditions. Although Flanagan et al. (2006) did not describe individual exposures or the working conditions associated with each result, OSHA notes that the data likely represent a range of conditions similar to the conditions described in ERG-C (2008).

On the basis of site visits by OSHA and NIOSH, and other published and unpublished reports, OSHA finds that typical conditions for masonry cutters using walk-behind saws vary considerably;

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[248] Reports on the remaining sites indicated that workers used other or unspecified wet methods.

[249] This strategy of selecting only work sites with long-duration ("full-shift") sawing jobs both allowed the investigators to evaluate "worst-case" conditions and also helped ensure that silica exposure results were above the limit of detection (LOD). The authors note that "many jobs do not involve such extensive periods of cutting, with workers often working at two or three job sites per day. Time spent commuting between sites and cleanup for each job provided periods of minimal or no exposure" (Flanagan et al., 2001).

however, use of the saws outdoors with wet cutting methods is the most frequent situation and can be considered the baseline condition. Table IV.C-60 indicates that this baseline condition is represented by a median of 12 μg/m^3. Because higher exposures can be expected with various dry or indoor cutting conditions (including indoor wet cutting), OSHA finds that additional controls will be required for the 40 percent of workers operating under those conditions, which are represented by a median of silica value of 236 μg/m^3. Overall, the exposure profile suggests that over half (55 percent) of walk-behind saw operators currently experience exposure levels of 50 μg/m^3 or less and that most, if not all, of these workers are using wet methods.

Baseline Conditions and Exposure Profile for Drivable Saw Operators

Three silica results are available for workers operating water-fed drivable saws. The three samples were obtained over relatively short sampling periods, but are presented as 8-hour TWAs based on the assumption that the worker had no additional exposure during the unsampled portion of the shift. One of the results was less than or equal to 12 μg/m^3 (limit of detection [LOD]), because of low respirable dust loading on the filter during the 70-minute sample period.[250] Another result of 33 μg/m^3 was based on a 125-minute sample that recorded a respirable quartz concentration of 128 μg/m^3. A third result of 88 μg/m^3 is based on a respirable quartz concentration of 530 μg/m^3 measured over the 80-minute sampling period. Sampling notes for this highest value indicate that the water discharge onto the saw was clogged, suggesting that the wet methods controls were not operating appropriately (Shields, 2000).

These short-term results indicate the potential for elevated exposure if the worker were to operate the drivable saw continuously for the entire 8-hour shift. Although only short-term operation of these mobile saws was observed at any one location, OSHA anticipates that some workers might continue cutting after moving the saw to another work site. Consequently, these results might under-represent operators' actual silica exposures (ERG-C, 2008). Based on the information presented here, OSHA preliminarily finds that baseline conditions for drivable saw operators involve cutting pavement outdoors using water-fed equipment, although the water feed might not always function as intended. These are the conditions associated with all three results (median of 33 μg/m^3) summarized in Table IV.C-60.

Additional Controls

The primary exposure controls available for masonry sawyers using any of the three categories of portable and mobile saws are wet cutting methods or local exhaust ventilation (LEV)-equipped saws (e.g., vacuum dust collection systems).

Additional Controls for Hand-Held Saws

Wet Methods

Wet cutting methods are a highly effective dust control option for masonry saws. The worker exposure data available to OSHA (presented in Table IV.C-60) show that most (75 percent) 8-hour TWA worker exposure results are 50 μg/m^3 or less when workers use water-fed saws outdoors. This also is true for operators of stationary saws working in similar conditions (see Section IV.C.28 – Masonry Cutters Using Stationary Saws). Additionally, when construction sites reduce related or contributing sources of exposure (e.g., dust from adjacent activities, dust-laden water, dried slurry, shop vacuums) workers (both

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[250] Results reported as "none detected" are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

saw types) experience further reductions in silica exposure. In contrast, when construction workers use hand-held or stationary masonry saws without dust controls, peak exposure can reach hundreds or even thousands of micrograms per cubic meter and are often the greatest source of silica dust in the area. These parallels between the two saw types are not coincidental, as both kinds of saws function similarly and workers' distance to the cutting point is generally the same for both types. As noted before, workers increasingly use hand-held saws as an alternative to a stationary saw.

However, the ease with which wet methods can be applied differs between hand-held and stationary saws. Stationary saws are typically fitted with a recirculating water basin. In contrast, water applied to the saw blade on a hand-held saw is not recirculated and generally ends up as a slurry of masonry dust and water on the ground, as described by Flanagan et al. (2001). Additional silica exposure can occur if the slurry is not captured properly (e.g., dried dust is re-suspended or released with inadequately filtered or ducted shop vacuum exhaust). Silica dust that is not effectively controlled or is re-suspended during indoor sawing can accumulate in the workspace and contribute to worker exposure levels (Flanagan et al., 2001).

Investigators have evaluated water-based dust control options specifically for hand-held saws and report worker silica exposure level reductions ranging from 90 to 96 percent with various water application methods and cutting conditions. Thorpe et al. (1999) evaluated the effectiveness of two types of water supplies commonly used with hand-held saws: 1) a pressurized portable water supply and 2) a constant water supply. During this evaluation, 15-minute PBZ samples were collected during uncontrolled and controlled (i.e., water-fed) cutting of concrete slab containing 20 percent to 40 percent silica (i.e., worst-case conditions). This short sampling duration is appropriate, because, as previously noted, hand-held saws are typically used intermittently to make short cuts. The uncontrolled mean respirable crystalline silica concentration during multiple 15-minute trials of intensive cutting ranged from 1,700 µg/m^3 to 4,800 µg/m^3, similar to other respirable silica results reported for brief periods of intensive cutting with hand-held saws (NIOSH 96-112, 1996; NIOSH-WV-Route 6, 1992; NJDHSS, 2000; OSHA SEP Inspection Report 302003694; Shields, 2000). With wet dust controls, respirable dust levels were reduced by up to 94 percent using pressurized portable water supply systems, somewhat less than the 96 percent reduction found using constant supplying water sources, which offer more constant pressure and water flow (Thorpe et al., 1999). All but three of the 48 exposure results presented in Table IV.C-60 for workers dry cutting outdoors are below 500 µg/m^3. The most modest exposure reduction reported for wet methods (a 90-percent reduction) will bring all but those three maximum exposures (or 93 percent of all the hand-held saw operators currently cutting outdoors with no controls) to levels of 50 µg/m^3 or less.

Wet cutting methods also can be used indoors. OSHA identified a respirable silica measurement that was less than or equal to 21 µg/m^3 (the LOD) for a worker using a hand-held saw indoors with wet methods. In this case, the worker spent 40 percent of a 401-minute monitoring period cutting a concrete floor (ERG-C, 2008).

However, the benefits of wet cutting *indoors* are not demonstrated as consistently as wet cutting outdoors. The indoor exposure levels of saw operators are influenced by several factors, including decreased air circulation, which prevents dust from dispersing; other workers' activities that generate airborne silica; and indoor discharge from inadequately filtered shop vacuums used with the saws.

One investigator observed several of these factors contributing to exposure levels simultaneously. Flanagan et al. (2001) reported 8-hour TWA respirable quartz levels of 240 µg/m^3 and 260 µg/m^3 for a hand-held saw operator who used wet methods indoors under worst-case conditions (e.g., longer than normal period of sawing, multiple saws being used in one area). An assistant used a wet shop vacuum to control the spread of slurry. In this case, lack of ventilation in the indoor environment might have accounted for a substantial portion of these exposure levels. The authors suggest that, "Since area and helper exposures are similar to the operator's exposure, the primary exposure might be due to a buildup of respirable aerosol within the enclosed space, rather than direct exposure to slurry spray. Judicious use of dilution ventilation with box fans and open doors and windows might reduce the exposure." Additionally, vacuums, including the wet vacuum used here, can produce airborne dust through "reentrainment of already collected particles" (Flanagan et al., 2001). Other factors such as decreasing airflow rates can also diminish a vacuum's ability to capture dust (ERG-C, 2008).

All of these factors can contribute to elevated silica exposure levels, but exposure levels also can be controlled using methods such as attentive work scheduling, rigorous housekeeping, increased general ventilation, sufficient and more reliable vacuum suction, and proper routing or filtration of air discharged from vacuums. OSHA expects that when these related sources of dust are properly managed, the exposure levels of sawyers using hand-held saws with wet methods indoors and outdoors will be similar to those of sawyers using stationary saws with wet methods indoors and outdoors (median of 33 μg/m^3, from Section IV.C.28 – Masonry Cutters Using Stationary Saws).

In addition to the studies reviewed in ERG-C (2008), OSHA has identified additional reports that further support the use of wet methods for construction workers who use hand-held saws. NIOSH EPHB 282-13 (2007) evaluated the performance of a commercially available water spray attachment, pre-set by the attachment manufacturer to provide 1.4 liters per minute (0.36 gallons per minute), for hand-held saws during concrete-block cutting. The hand-held electric abrasive cutter was used outdoors to make cuts through concrete blocks laid lengthwise on a plank 17 inches above the ground. Although results indicate that respirable silica levels were extremely high (1,620 μg/m^3) during the 5- to 10-minute trials with water-fed saws, the water-spray attachment did reduce quartz exposures by an average of 90 percent from uncontrolled levels of up to 38,000 μg/m^3 (38 mg/m^3) (NIOSH EPHB 282-13, 2007).

Evaluating different water application methods for stationary masonry saws, Beamer et al. (2005) found that freely flowing water resulted in dust reduction of about 93 percent. The authors extrapolated the results from trials in which they applied mist instead of free-flowing water and found that the results suggested that a misting flow rate between 35 and 40 gallons per hour (about 0.6 to 0.7 gallons per minute) would be essentially as effective as freely flowing water (48 gallons per hour in this case) in controlling dust. The authors saw an important benefit to misting, noting that, as an aerosol, mist tends to dry much more quickly than freely flowing water used to control dust. Because of the similarities in saw function, OSHA preliminarily concludes that these findings for stationary saws apply equally to hand-held saws. Rapid drying is considered a benefit because sawyers using brick or block sometimes prefer to work with dry surfaces; however, OSHA notes that rapid drying can contribute to increased exposure from re-suspension of previously wetted dust.

Water-fed hand-held saws are commercially available from a variety of sources (CS Unitec, 2009; Hilti-water-fed, 2009). In some cases the operator simply connects a hose to a factory-installed port. In other cases an adaptor kit is required and is pre-packaged with certain models of the saw.

Water-fed stationary saws offer an effective alternative to hand-held saws for cutting brick, concrete block, tile, and other movable construction materials. As noted previously, these saws are already being used interchangeably at many construction sites. The recirculating water pump and collection basin minimize the amount of water needed for cutting and eliminate the need for additional helpers and equipment to capture slurry on the floor. Furthermore, by using these saws as intended (clean water appropriately directed to the blade), exposure levels less than 50 μg/m^3 can be achieved for most workers most of the time. For additional information, see Section IV.C.28 – Masonry Cutters Using Stationary Saws in this technological feasibility analysis.

Dust Extraction (Vacuum Suction, Local Exhaust Ventilation)

Hand-held saws can be equipped with LEV air extraction systems. OSHA was not able to obtain extended-period exposure monitoring data indicating the effectiveness of LEV-equipped saws under workplace conditions. However, experimental data indicate that such saws might be somewhat effective in controlling respirable silica exposure. In some tests LEV-equipped saws offered as much (or more) dust control as wet methods.

Thorpe et al. (1999) found that an LEV system on a hand-held saw reduced mean respirable dust concentrations by 88 percent (from 8,000 µg/m^3 to 700 µg/m^3) during periods of active cutting of concrete. A more recent experimental study by Meeker et al. (2009) evaluated a commercially available LEV engineering control used with a hand-held electric abrasive saw while cutting block or brick. Breathing zone measurements collected over brief periods (5 to 25 minutes) of controlled and uncontrolled sawing showed a 91 percent to 96 percent reduction in quartz concentrations (for example, a mean of 110 µg/m^3 when using LEV versus 2,830 µg/m^3 for no control). The results from this study show that saw-based LEV extraction equipment can reduce respirable silica exposures to levels near 100 µg/m^3 during short-term periods of active cutting. Since most workers cut intermittently even during times of active cutting (e.g., 10 or 20 seconds using the saw followed by a longer period—up to several minutes—of measuring and moving materials or equipment), 8-hour TWA values are likely to be considerably lower (Flanagan, et al., 2001). For example, based on the highest result obtained by Meeker et al. (2009) during concentrated cutting with LEV (170 µg/m^3), OSHA estimates that an outdoor worker who cut for 1 minute out of every 5 minutes for the entire shift (i.e., 20 percent of the shift was spent cutting) would experience an 8-hour TWA of 34 µg/m^3. However, OSHA has not been able to confirm that these saw ventilation methods offer the same degree of exposure reduction to workers currently experiencing more modest, but still elevated, exposure (for example, in the range of 250 µg/m^3 with no controls). Additionally, extended periods of intensive cutting and cutting indoors were not evaluated in the Meeker et al. (2009) study. Substantially higher 8-hour TWA exposures might result in areas where residual airborne dust cannot dissipate. In those cases, OSHA notes that supplemental ventilation would be required to maintain sufficient air circulation.

The NIOSH EPHB 282-13 (2007) study described earlier also evaluated the performance of a commercially available LEV system for hand-held saws during concrete-block cutting. The hand-held electric abrasive cutter was equipped with an LEV shroud connected via 3 meters of 35-millimeter (mm) (1.4-inch) diameter hose to a wet/dry high-efficiency particulate (HEPA) vacuum cleaner with filter “pulse clean.”[251] With new bags installed, this vacuum cleaner pulled 56 cubic feet per minute (cfm) through the shroud while the abrasive cutting saw was operating. This relatively modest air flow rate reduced both silica and respirable dust exposures by 95 percent—slightly better results than the water-spray attachment (90 percent reduction) (NIOSH EPHB 282-13, 2007). Despite this substantial exposure reduction, respirable silica concentrations in the worker’s breathing zone remained elevated at levels of 790 µg/m^3 to 1,100 µg/m^3 during the five 10-minute trials of intensive cutting. This is consistent with the findings described elsewhere in this technological feasibility analysis. Section IV.C.32 – Tuckpointers and Grinders notes that the choice of vacuum suction has a dramatic effect on dust control efficiency. Although not tested, OSHA believes that it is reasonable to expect improved dust capture with a vacuum suction device that consistently offers greater air flow than the one tested by NIOSH.

LEV-equipped saws do not appear to offer a reliable level of dust reduction under all circumstances. ERG (ERG-C, 2008) reviewed experiments conducted by Croteau et al. (2002) on a hand-held saw equipped with an LEV system exhausted at 70 cfm. This LEV set-up did not reduce respirable silica exposure relative to the same saw without LEV. The authors concluded that the shape of the dust

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[251] A self-cleaning feature involving a reverse air pulse that knocks dust from the filter.

collection shroud opening allowed the rotating blade to push dust away from the shroud (i.e., the blade rotated in the opposite direction than that for which the shroud was designed). To be effective, some saw and LEV combinations might require the rotation of the blade to be reversed to better direct dust into the shroud.

NIOSH also evaluated an LEV-equipped hand-held gas-powered saw to assess its potential for reducing respirable silica in the breathing zone at two residential building construction sites during a 2004 health hazard evaluation. The results of the evaluation do not indicate a significant benefit of using the LEV-equipped saw compared with the non-LEV-equipped saw. Overall, the LEV-equipped saw did not consistently reduce exposures to respirable silica. However, the authors noted that the limited amount of data precluded a complete assessment of this type of control (NIOSH HETA 2005-0030-2968, 2008).

A ventilated booth, used with or without wet-methods, offers another control option for hand-held saws. Flanagan (1997) evaluated a booth-style enclosure used with an abrasive cut-off saw, which reduced worker exposure to silica by 85 percent during brief periods of intensive dry cutting. The same saw also was tested with a combination of controls (booth plus wet cutting), which at first reduced respirable silica concentrations by more than 99 percent. During this test, the author reported a silica concentration of 30 µg/m^3 in the operator's breathing zone. However, the filter bags became saturated with water over time, and in a subsequent test the respirable dust capture deteriorated until the silica concentration reached 2,540 µg/m^3, half the concentration observed during uncontrolled cutting (5,030 µg/m^3). The author suggests several design changes that would improve dust capture during dry cutting and extend effective dust capture during wet cutting. Specifically, she suggests using a different booth design that would reduce the booth face area, provide greater capture velocity, and provide a different style of vacuum suction device (for example, one with a cyclone dust separator).

Additional Controls for Walk-Behind Saws

Wet Methods

Wet methods are the primary dust control option for walk-behind saws, and most manufacturers offer water-fed models.[252] Most of these saws, however, are designed to provide water to cool certain types of blades, rather than specifically for dust control.

The available data, summarized in the exposure profile for construction workers using walk-behind saws, provide strong evidence that workers using wet methods usually experience lower silica exposure levels. Table IV.C-60 shows that, of the 12 respirable silica results associated with wet cutting concrete *outdoors* using walk-behind saws, only one measurement exceeded 50 µg/m^3. This single elevated reading, 61 µg/m^3 (the limit of quantification), was obtained by NIOSH for a worker cutting with water supplied to the saw tip during a 231-minute sampling period (NIOSH-Concrete-Coring, 1995). Furthermore, 8 of the results obtained for this group of walk-behind saw operators were reported as less than or equal to the LOD of 12 µg/m^3. These results suggest that, in the manner most typically used (i.e., *outdoors*), water-fed walk-behind saws are generally associated with 8-hour TWA silica exposures below the proposed PEL of 50 µg/m^3.

Although the data are limited, water-fed walk-behind saws used while *indoors* might result in exposures that are considerably higher than those measured outdoors. Flanagan et al. (2001) reported

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[252] Water-fed walk-behind saws (manual and self-propelled) are widely available from many manufacturers and construction tool distributors (Grainger-cat-Husqvarna-concrete saw, 2001; EDCO-E-MPS-I-1007, 2007; Toolfetch-MK-diamond-walkbehind-saw, 2010; EDCO-self-propelled-saws, no date; CS-Unitec-catalog, 2009).

higher 8-hour TWA respirable silica levels for operators and their assistants who used water-fed walk-behind saws indoors for most of their shift (worst-case conditions, resulting in four 8-hour TWA values between 130 $\mu g/m^3$ and 710 $\mu g/m^3$) compared with workers using similar water-fed saws outdoors (two results of 50 $\mu g/m^3$). As noted in the previous discussion of this study regarding hand-held saws, the author suggests that factors such as inadequate ventilation or poor wet vacuum capture efficiency likely contributed to higher indoor respirable silica levels.

Flanagan et al. (2001) also demonstrated the importance of water flow rates in dust suppression. These investigators reported 8-hour TWA respirable quartz levels as high as 350 $\mu g/m^3$ for a worker and assistant who spent 4 hours cutting concrete using a water-fed walk-behind saw and wet shop vacuum (to collect the slurry) at an indoor construction site. Water was supplied to the cutting blade at 0.5 gallons per minute. When similar work was performed with a water-feed rate of 2 gallons per minute, the 8-hour TWA dropped to 110 $\mu g/m^3$, one-third of the original value.[253] As previously noted, the authors suspected that the exposure remained somewhat elevated because of a buildup of respirable aerosol within the enclosed space rather than direct exposure to slurry spray. OSHA preliminarily concludes that results lower than 110 $\mu g/m^3$ are possible for operators of walk-behind saws working *indoors* if they use sufficient water and ensure that other sources do not contribute exposure (including those related to managing slurry from water-fed saws).

When elevated exposures occur during the use of wet methods, especially indoors, additional efforts need to be taken to ensure that sufficient amounts of water are reaching the cutting point and that water-fed systems are working correctly. In some cases, the water supply or water pump might need to be upgraded to ensure optimal water flow, if the original equipment is insufficient. Construction sites also might need to put in place administrative controls and equipment to ensure that workers capture all slurry (including that on clothing) before it dries and that vacuums do not emit respirable particulates in the work area (ERG-C, 2008).

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[253] The manufacturer of a walk-behind saw with an original-equipment water port also recommends connecting a hose providing 2 gallons per minute (EDCO-E-MPS-I-1007, 2007).

Dust Extraction (Vacuum Suction, Local Exhaust Ventilation)

Although some manufacturers offer an LEV option for walk-behind saws,[254] OSHA could not obtain exposure monitoring data on the effectiveness of LEV under either actual working conditions or experimental conditions (ERG-C, 2008).

Based on the information reported here for hand-held and drivable saws, OSHA preliminarily concludes that LEV for walk-behind saws should perform equally well, provided a shroud or blade housing and sufficient vacuum suction are available. For most walk-behind saws, OSHA expects that adequate performance will require a relatively large vacuum cleaner. For example, the instruction manual for one relatively small walk-behind saw indicates that the vacuum hood over the blade is intended to be used with a high-volume vacuum that provides more than 200 cfm of suction (EDCO-E-C10-I-0209, 2009).[255] Larger walk-behind saws are likely to require even larger vacuums. As discussed elsewhere in this technological feasibility analysis (see Section IV.C.32 – Tuckpointers and Grinders), insufficient vacuum suction (regardless of the cause) severely limits the effectiveness of vacuum-based dust controls. Industry literature suggests that, as with other types of saws, LEV for walk-behind saws might not reliably achieve silica exposure levels below the current general industry PEL (100 µg/m^3) for the workers who use the saws.[256] For example, a manufacturer of walk-behind saws instructs owners to provide a respirator in addition to connecting the saw to a dust control system during dry cutting. In contrast, the instructions do not mention respiratory protection for wet cutting with a minimum water flow (EDCO-E-MPS-I-1007, 2007). Thus, OSHA preliminarily concludes that the LEV systems that have been tested to date are unlikely to consistently control exposures below the proposed PEL of 50 µg/m^3 in typical work environments.

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[254] Examples of walk-behind saws that have an LEV option are described in the following: CS-Unitec-CSR-150 (2009), EDCO-accessories-walk-behind-saw (2010), EDCO-E-C10-I-0209 (2009), and EDCO-E-MPS-I-1007 (2007). In some cases the saw is factory equipped with vacuum ports; in other cases the manufacturer offers an optional vacuum-compatible blade guard.

[255] This walk-behind saw is a "crack-chaser" style for use with 7- to 10-inch blades and a blade housing (hood) that encloses the blade nearly to ground level, which provides more complete enclosure than the guards used on many walk-behind saws. The manufacturer also recommends several other features that a vacuum for this saw might include, such as a self-purging system and filtration designed to capture "submicron" silica particles (EDCO-E-C10-I-0209, 2009).

[256] Although evaluating a construction industry activity, investigators generally elect to compare silica exposure results with OSHA's gravimetric general industry PEL for silica. This might be due to the fact that the construction industry PEL for silica is based on the units millions of particles per cubic foot (mppcf), requiring an obsolete analytical method not available through most analytical laboratories. Instead, laboratories typically report silica air sampling results as mass-based gravimetric values (e.g., mg/m^3) for respirable dust, along with the percent silica, which are also used in the gravimetric general industry PEL for silica. Investigators compare these results with the gravimetric general industry PEL because the units are compatible. An alternative has been available since 2008, when OSHA published a compliance directive, National Emphasis Program (NEP)-Crystalline Silica CPL 03-00-007 (Appendix E), providing a conversion factor to convert air sampling results between mppcf and mg/m^3 or µg/m^3. However, some investigators have continued in their studies to use the more familiar gravimetric units and compare construction industry air monitoring results with the gravimetric general industry PEL for silica.

Combination of Controls

Exposure reductions for these workers can also be achieved using a combination of controls that both suppress dust and prevent dust from accumulating in the air. An appropriate combination of control methods includes use of sufficient wet methods; meticulous maintenance of the water-fed system; rigorous control of slurry; an efficient system for discharging the slurry vacuum exhaust air outside the work space (or HEPA-filtering it); and arrangements to improve fresh air exchange in enclosed areas (e.g., via exhaust trunks). Although OSHA could not obtain data on the effectiveness of the above controls combined for walk-behind saws, each control has independently been shown to reduce airborne respirable dust concentrations. Furthermore, a similar combination of controls has proven highly effective for reducing silica exposures of sawyers in the stone and stone products industry (described in Section IV.C.4 – Cut Stone). In the stone products industry, saws are typically water fed and produce a substantial quantity of stone dust slurry that contains silica (granite can be up to 45 percent quartz). This slurry can be a continuing source of exposure if not carefully managed. ERG (ERG-GI, 2008) reviewed full-shift silica exposure results[257] and identified a median exposure level of 30 μg/m^3 for eight sawyers working indoors at four stone fabricating facilities that used a combination of dust control measures:

- Using water-fed saws.
- Using vacuum suction ducted outdoors from saw enclosure.
- Using pre-washed stone (to wet and remove dust).
- Managing slurry by removing it from the work area before it dried.
- Reducing dust from adjacent activities.
- Performing general housekeeping to prevent dust from building up where it could be disturbed.

Although the saws in these cases were stationary saws (not walk-behind), the water was sometimes permitted to run across the floor, creating a condition similar to that of walk-behind saw operators working indoors. The median of 30 μg/m^3 is 44 percent lower than the median of 54 μg/m^3 for all sawyers in that industry (see the exposure profile for Section IV.C.4 – Cut Stone in this technological feasibility analysis).

Additional Controls for Drivable Saws

Wet Methods

Drivable saws are typically factory equipped with water-fed systems that apply water directly to the cutting blade. Two of the three samples in the exposure profile were collected for saw operators using sufficient wet-cutting methods. One 8-hour TWA result was reported as less than or equal to the LOD of 12 μg/m^3 (actual sample duration 70 minutes), and the other 8-hour TWA result was reported as 33 μg/m^3 (actual sample duration 125 minutes) (ERG-C, 2008). These levels could potentially be reduced further by adjusting the water spray to optimize dust capture.

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[257] In this case, full-shift is defined as greater than 360 minutes sample duration, with the 8-hour TWA value calculated assuming exposure continued at the same level for any unsampled portion of the shift.

In contrast, the highest result in the drivable saw group was obtained for a saw operator who cut pavement while the water nozzle at the saw blade was clogged. The 8-hour TWA measurement of 88 µg/m^3 was based on an 80-minute sample with an actual respirable quartz reading of 530 µg/m^3 during the period monitored. This high reading demonstrates the benefit of using sufficient amounts of water to reduce silica exposures and highlights the importance of ensuring that water-fed equipment works properly. In this case, unclogging the water nozzle would almost certainly have resulted in a lower exposure level, although follow-up sampling was not performed (ERG-C, 2008). Based on these limited data, OSHA preliminarily concludes that water-spray optimized for dust suppression can control worker silica exposure below 50 µg/m^3.

Dust Extraction (Vacuum Suction, Local Exhaust Ventilation)

Another approach that should be considered for controlling the exposures of drivable saw operators is to equip the saws with LEV. But, as is the case with walk-behind saws, OSHA could not obtain exposure monitoring data indicating the effectiveness of LEV under either actual working conditions or experimental conditions (ERG-C, 2008). However, the benefits that such an approach might offer have been demonstrated by an LEV system for drivable asphalt road milling machines developed by a team from the Netherlands. Asphalt milling machines aggressively remove more road surface material (greater volume per minute) than a saw, suggesting that LEV sufficient to control dust from a milling machine also would be sufficient to control dust from a drivable saw. Silica exposure levels were reduced from a range of 20 µg/m^3 to 290 µg/m^3 (uncontrolled) to a range of 1.9 µg/m^3 (as reported) to 17 µg/m^3 when the milling machine was fitted with an LEV system. Tests of different control methods demonstrated that for this road milling machine model (also available in the United States), the LEV approach to dust management offered more effective control of respirable silica than wet methods (OSHA-Europa, 2004). The Netherlands group reported that the key to successful dust control is to enclose the milling drum (road-grating tool) and provide sufficient vacuum suction to keep the drum area under constant negative air pressure (which prevents dust from escaping). OSHA believes that this strategy could be equally effective for drivable saws, should an alternative to wet dust control methods become necessary; however, OSHA knows of no examples of commercially available drivable saws fitted with vacuum suction for dust control.

Feasibility Finding

Feasibility Finding—Hand-Held Saws

Based on the evidence presented in the exposure profile for hand-held saws (Table IV.C-60), OSHA preliminarily concludes that wet methods can control the silica exposure of most workers using hand-held saws to levels of 50 µg/m^3 or less. The profile indicates that currently, when wet methods are used by workers using hand-held saws, 75 percent of those working outdoors and 50 percent of those working indoors experience exposure levels of 50 µg/m^3 or less. Table IV.C-60 also shows a median silica reading of 24 µg/m^3 for hand-held saw operators using wet methods outdoors.

Additional controls will be required to reach this level for the remaining operators. For workers who currently perform dry cutting with hand-held saws (comprising the vast majority of all workers using any type of portable or mobile saw), the additional controls involve switching to water-fed saws. Where workers currently experience exposure levels above 50 µg/m^3 while using wet sawing methods, additional controls include increasing attention to the rate and application position of water used for wet dust suppression, carefully managing slurry (for example, adding an assistant to help capture slurry before it dries and routing vacuum exhaust outdoors or adding HEPA filtration to the vacuum), using work practices that limit the amount of slurry spray (coming off the saw blade) that directly contacts the worker, and controlling silica exposure from adjacent sources (including other saws). Indoors, in addition to the controls just mentioned, increased general or exhaust ventilation (fans, exhaust trunks, or fresh air ducts) also will be required to minimize accumulation of airborne dust in the work area. These sources of silica exposure (slurry, dust from adjacent activities) and the absence of effective ventilation are implicated in the elevated concentrations measured for workers who spent particularly long portions of the shift working with hand-held water-fed saws indoors (Flanagan et al., 2001). OSHA believes that to a large extent silica exposure can be controlled using the methods just described.

Where it proves particularly difficult to control exposures below 50 µg/m^3 for workers who currently use hand-held saws to cut block, brick, and tile, switching to water-fed stationary (tabletop) masonry saws is an alternative that will offer the benefits of wet sawing while simultaneously reducing the challenges of controlling slurry in the work area and other safety concerns associated with hand-held portable saws (e.g., cuts, increased risk of amputations, ergonomic stressors) (Meeker et al., 2009). In Section IV.C.28 – Masonry Cutters Using Stationary Saws, OSHA preliminarily concludes that most construction workers using stationary masonry saws will experience exposure levels of 50 µg/m^3 or less most of the time when they operate water-fed saws in a manner that optimizes dust control.

When wet methods are not possible, LEV-equipped hand-held saws might reduce silica exposures to levels of 100 µg/m^3 when saws are used outdoors. However, the available data are not adequate to determine whether all workers using such saws can reliably and consistently achieve the proposed PEL of 50 µg/m^3. The LEV option provides sufficient dust control that the use of a half-facepiece respirator outdoors and indoors (a full facepiece respirator may be needed on occasions during indoor work) will offer workers adequate protection under the proposed PEL of 50 µg/m^3 until the reliability of LEV can be confirmed over extended work periods.

Feasibility Finding—Walk-Behind Saws

Based on OSHA’s review of available data summarized in Table IV.C-60, the silica exposures of most (92 percent) walk-behind saw operators who work *outdoors* using water-fed machines are already controlled to a level less than or equal to 50 µg/m^3. Most workers who use walk-behind saws typically operate under these conditions (i.e., wet methods, outdoors). The median result for 12 workers cutting (mainly concrete) under these operating conditions is less than or equal to 12 µg/m^3. It is reasonable to expect that the small percentage of walk-behind saw operators who are exposed at levels above 50 µg/m^3 can reduce their exposures through frequent, meticulous maintenance of water-fed systems (e.g., ensuring nozzles are cleaned or replaced as often as necessary to keep them functioning as intended) and sufficient use of water (e.g., according to the saw manufacturer’s directions). In some cases this might require adding a supplemental water source or pump.

Walk-behind saw operators working *indoors* generally experience higher respirable silica concentrations. However, OSHA estimates that levels of 50 µg/m^3 or less can be achieved for most of these workers by using a combination of controls that both suppress dust and prevent dust from accumulating in the air. The necessary control methods include use of sufficient wet methods; meticulous maintenance of the water-fed system; rigorous control of slurry, an efficient system for discharging the slurry vacuum exhaust air outside the work space (or HEPA filtering it); and arrangements to improve fresh air exchange in enclosed areas (e.g., via exhaust trunks). A similar combination of controls has proven highly effective for reducing silica exposures of sawyers in the stone and stone products industry where workers cut granite (up to 45 percent quartz) indoors using water-fed saws that sometimes permit stone slurry to run across the floor. Using the combination of controls, sawyer exposures were reduced by more than 40 percent to a median full-shift silica level of 30 µg/m^3 (ERG-GI, 2008). A combination of controls will be particularly important when workers use walk-behind saws for unusually long periods (e.g., more than half of the shift).

Vacuum suction systems for walk-behind saws are available, but OSHA requires additional information to confirm that these saws can consistently control worker exposures below the proposed PEL of 50 µg/m^3.

Feasibility Finding—Drivable Saws

Based on a very small number of respirable silica measurements summarized in Table IV.C-60, OSHA preliminarily finds exposure levels of 50 µg/m^3 or less have already been achieved for 67 percent of drivable saw operators. The same level can be achieved for the remaining 33 percent of operators by improving maintenance of water-fed systems (for example, by implementing a maintenance program for the dust control equipment). However, as discussed above, drivable saw operators might visit more than one site per day and thus might be subject to respirable silica exposure levels higher than those reported in the limited partial-shift data available. To ensure that all drivable saw operator exposures remain below the proposed PEL of 50 µg/m^3 even when they cut at more than one job site per shift, an additional 33 percent of the operators (those in Table IV.C-60 with exposures between 25 µg/m^3 and 50 µg/m^3) will need to operate equipment covered by a maintenance program for the water-fed/dust control equipment.

Overall Feasibility Finding for Portable and Mobile Saws

Based on the information presented above, OSHA preliminarily concludes that silica exposure levels of 50 µg/m^3 or less can be achieved for most workers using portable and mobile saws most of the time by increasing the number of these construction workers who use wet sawing methods optimized to provide dust control. Among workers already using wet methods outdoors, the data suggest that silica exposures of 50 µg/m^3 or less are already experienced by 75 percent of those who use hand-held saws, 91 percent of the workers using walk-behind saws, and 67 percent of drivable saw operators. This exposure level can be achieved for most of the remaining workers by switching from dry to wet sawing or improving the way existing wet methods apply water (e.g., by cleaning/replacing nozzles or increasing water flow rate). For workers sawing indoors, controls also will need to include work practices and equipment to carefully control slurry before dried particles become reentrained (e.g., suitably filtered or ducted wet/dry shop vacuums) and to improve work area air circulation (e.g., fans, fresh air trunks). In the event that wet methods cannot be used for a particular job, saws fitted with LEV remain an option. While the available data are not adequate to show that workers using hand-held saws can reliably and consistently achieve the proposed PEL of 50 µg/m^3 using this method, the LEV option provides sufficient dust control that the use of a half-facepiece respirator outdoors and indoors (a full-facepiece respirator may be required on occasions during indoor work) will offer workers adequate protection under the proposed PEL of 50 µg/m^3 until the reliability of LEV can be confirmed over extended work periods.

Vacuum suction options are available for hand-held and walk-behind saws, but information is insufficient to confirm that these will reliably control worker exposures to the proposed PEL of 50 µg/m^3.

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Masonry Cutters Using Stationary Saws

Description

Workers in the construction industry use stationary saws to cut silica-containing masonry materials, such as bricks, concrete blocks, stone, and tile. These table-top or stand-mounted saws include a flat platform where the work piece (e.g., a brick) sits. To form a cut, the worker brings a rotating circular abrasive blade into contact with the work piece, either by pressing a swing arm-mounted blade down onto the piece, or by moving the piece on a sliding platform into contact with a fixed-position blade (depending on the saw design). In either configuration, the masonry is brought to the saw, and the saw's orientation is fixed. The cutting surface is generally about waist-high and little more than arm's length from the worker's breathing zone. Most stationary masonry saws are designed for use with wet dust control methods. The necessary pump and basin equipment are widely available for nearly all stationary masonry saw models; however, workers often cut brick and block dry, particularly when working outdoors.

Many saw operators alternate cutting with laying masonry and/or mixing mortar, and thus might cut for only a short portion of the shift. Some saw operators, however, cut masonry nearly continuously throughout the shift (ERG-C, 2008). Table IV.C-61 summarizes the job categories, major activities, and primary sources of silica exposure of workers in this industry.

Table IV.C-61

Job Categories, Major Activities, and Sources of Exposure of Masonry Cutters Using Stationary Saws

Job Category*	Major Activities and Sources of Exposure

Table IV.C-61

Job Categories, Major Activities, and Sources of Exposure of Masonry Cutters Using Stationary Saws

Masonry Cutter Using Stationary Saw	Cutting block, brick, or stone. • Dust generated by abrasive cutting wheel during dry cutting. • Re-suspended dust particles released when dust-laden water or slurry from wet cutting dries and becomes airborne (particularly under extremely hot or dry conditions).

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the facility.

Source: ERG-C, 2008.

Baseline Conditions and Exposure Profile

ERG-C (2008) summarizes the best exposure monitoring data available to OSHA, which include 28 sampling results for typical masonry cutting conditions indoors and outdoors from 13 construction sites.[258] These results were reported in eight OSHA Special Emphasis Program (SEP) reports, two NIOSH visits, a Minnesota OSHA inspection report, an ERG site visit, and one independent investigation.

Of these 28 measurements, 12 readings were for workers dry cutting outdoors with no controls. The mean 8-hour time-weighted average (TWA) silica concentration for the 12 results is equal to 354 micrograms per cubic meter ($\mu g/m^3$), although the median notably lower at 50 $\mu g/m^3$. The two lowest results, 21 $\mu g/m^3$ and a result at or below the limit of detection (LOD) of 12 $\mu g/m^3$, were obtained for a worker dry-cutting concrete block for approximately 45 minutes during each of two 8-hour sampling periods (NIOSH ECTB 233-118c, 1999).[259] The concrete block being cut during these sampling periods contained 4 percent and less than 3 percent silica, respectively. The maximum silica concentration reported in this 12-sample subset was 2,005 $\mu g/m^3$ (an 8-hour TWA obtained over a 350-minute work period), associated with a sawyer dry-cutting concrete blocks containing 15 percent silica (OSHA SEP Inspection Report 122316805).

Exposure levels were considerably lower when workers used wet methods. Among the seven results for workers using water-fed masonry saws to cut brick and block, the highest 8-hour TWA was 93

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[258] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) calculated assuming no additional exposure during any unsampled portion of the shift. Unless explicitly stated otherwise, all results discussed in the additional controls section are also 8-hour TWAs calculated the same way. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

[259] Results reported as “none detected” are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

μg/m^3, with a median of 33 μg/m^3 and a mean of 42 μg/m^3 (ERG-C, 2008). The median percentage of silica in these samples was 9 percent. An additional nine results for workers dry cutting using various administrative and engineering controls resulted in a mean of 210 μg/m^3 and median of 90 μg/m^3. Table IV.C-62 summarizes the exposure profile for masonry cutters using stationary saws under various conditions, including dry cutting, dry cutting with administrative or engineering controls, and wet cutting.

Flanagan et al. (2006) compiled a dataset of 51 results for workers using table (i.e., stationary) saws from a variety of sources (likely including some of the data used in OSHA's exposure profile). The authors reported a geometric mean quartz concentration of 70 μg/m^3, suggesting that stationary saws generate lower exposure levels than most other tools and equipment used by construction workers. Among the 12 types of equipment evaluated, lower geometric mean exposures were reported only for workers in three groups: those operating cement mixers, heavy equipment (e.g., backhoe, bulldozer), or brooms and shovels. Because the authors did not describe individual exposures or the working conditions associated with each result, the utility of the dataset is limited; however, these results likely represent a mixture of wet methods and uncontrolled dry cutting, as have been reported for the data available to OSHA.

On the basis of the NIOSH and other published and unpublished reports described here, OSHA determined that typical conditions for masonry cutters using stationary saws vary widely, with common conditions including wet cutting methods (any location) and dry cutting outdoors with no engineering controls. Although most masonry saws can be operated using wet methods, the data available to ERG suggest that these saws are often operated without active water flow (ERG-C, 2008). The option of dry cutting with administrative or engineering controls (e.g., local exhaust ventilation [LEV]) is increasingly available, but not used widely.

Overall, the exposure profile suggests that nearly half (46 percent) of masonry cutters using stationary saws currently experience exposure levels of 50 μg/m^3 or less.

Table IV.C-62
Respirable Crystalline Silica Exposure Range and Profile for Masonry Cutters Using Stationary Saws

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean (µg/m^3)**	**Median (µg/m^3)**	**Min (µg/m^3)**	**Max (µg/m^3)**		**<25 (µg/m^3)**	**≥25 and ≤50 (µg/m^3)**	**>50 and ≤100 (µg/m^3)**	**>100 and ≤250 (µg/m^3)**	**>250 (µg/m^3)**
Masonry Cutter Using Stationary Saw											
Dry cutting methods (no engineering controls)	12	354	50	12	2,005		2 16.7%	4 33.3%	1 8.3%	1 8.3%	4 33.3%
Dry cutting methods (mix of administrative or engineering controls)	9	210	90	12	824		2 22.2%	0 0.0%	4 44.4%	0 0.0%	3 33.3%
Wet cutting methods	7	42	33	11	93		2 28.6%	3 42.9%	2 28.6%	0 0.0%	0 0.0%
Totals	**28**	**230**	**63.2**	**11**	**2,005**		**6** **21.4%**	**7** **25.0%**	**7** **25.0%**	**1** **3.6%**	**7** **25.0%**

Notes: All samples are personal breathing zone (PBZ) results and represent 8-hour time-weighted average exposures with the assumption that no additional exposure occurred during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Source: ERG-C, 2008.

Additional Controls

Based on ERG-C (2008), OSHA has determined that the primary exposure controls available for masonry cutters using stationary saws are wet sawing methods, LEV-equipped saws (e.g., vacuum dust collection systems), ventilated booths, and administrative controls.

Wet Methods

The most reliable data in the literature providing evidence of substantial reductions in silica exposures involve wet sawing methods. As noted previously, ERG identified seven respirable quartz samples for masonry sawyers using wet methods (ERG-C, 2008). The mean of 42 µg/m^3 associated with wet cutting is substantially lower than the mean of 354 µg/m^3 for dry cutting operations. The available exposure monitoring data, however, include examples of concentrations higher than the proposed permissible exposure limit (PEL) of 50 µg/m^3 even when wet cutting methods are used. These exposure levels can result when wet methods are used improperly or when housekeeping is inadequate. For example, a reading of 80 µg/m^3 was obtained for a sawyer wet-cutting concrete brick and block for only 20 percent of a shift (about 96 minutes) (NIOSH ECTB 233-118c, 1999). NIOSH observed that a significant dust cloud was generated during cutting, suggesting that the wetting was not sufficient to provide optimal exposure control. No details are available for the other elevated result (93 µg/m^3) associated with wet cutting methods (Shields, 2000).

In addition to the studies reviewed in ERG-C (2008), OSHA has identified additional reports that further support the use of wet methods. NIOSH investigators collected silica samples during dry cutting and wet cutting of brick and block at a masonry construction site. Silica exposure measured over a short duration (10 minutes) ranged from 3,385 to 15, 913 µg/m^3 (dry cutting of block using portable saws), compared with a range from below the LOD to 87.5 µg/m^3 for two samples taken during wet cutting of block with stationary saws. The investigators report that the average respirable dust concentration during wet cutting is 154 times lower than during dry cutting, a reduction of 99.3 percent (NIOSH HETA 2000-0226-2890, 2001). These findings are supported by a review performed by OSHA and NIOSH, which indicates that wet masonry saw operators' exposures are routinely below 100 µg/m^3 and usually below 50 µg/m^3, not only when averaged over an 8-hour shift, but also during just the sampled portion of the shift (OSHA 3362-04, 2009).

In a recent study under experimental conditions, Meeker et al. (2009) ran trials of intensive masonry cutting for 5 minutes (uncontrolled) or 25 minutes (using exposure controls). Because of the short sample durations, these results are not included in OSHA's exposure profile. The investigators separated results associated with stationary wet sawing into groups obtained while a worker cut either block (mean of 260 µg/m^3 for the duration sampled) or brick (mean of 90 µg/m^3 for the duration sampled). Not surprisingly, these mean respirable quartz concentrations measured during short periods of intensive cutting were somewhat higher than the silica concentrations obtained for workers using wet methods on construction sites, as reported in ERG-C (2008).[260] On construction sites, even workers cutting "continuously" will pause to move materials, measure upcoming cuts, adjust the saw, and take breaks, resulting in less intensive cutting (and lower exposures) than occurs during brief experimental trials.

Differences have also been observed in the various wet cutting methods used. Beamer et al. (2005) conducted experiments using a stationary saw to cut bricks in order to compare respirable dust suppression through water misting using three different flow rates—low (4.8 gallons per hour), medium (8.6 gallons per hour), and high (17.3 gallons per hour)—and free-flowing water application. The results

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[260] Meeker et al. (2009) did not test stationary saws using dry cutting methods.

showed that low-misting nozzles reduced the respirable mass fraction of dust by about 63 percent, medium-misting nozzles by about 67 percent, and high-misting nozzles by about 79 percent. The greatest impact occurred with freely flowing water, resulting in dust reduction of about 93 percent and confirming the benefits of water flowing over the stationary saw cutting blade, the most common configuration used for these saws. Because the misting data showed a generally linear relationship between misting rate and dust reduction, the authors extrapolated the results to suggest that a misting flow rate between 35 and 40 gallons per hour (about 0.6 to 0.7 gallons per minute) would be essentially as effective in controlling dust as freely flowing water (48 gallons per hour in this case). Nevertheless, the authors saw an important benefit to misting, noting that, as an aerosol, mist tends to dry much more quickly than freely flowing water used to control dust (Beamer et al., 2005). Rapid drying is considered a benefit because sawyers using brick or block often prefer to work with dry surfaces; however, OSHA notes that rapid drying can contribute to increased exposure from re-suspension of previously wetted dust. Rigorous housekeeping with a high-efficiency particulate [HEPA]-filtered vacuum can limit exposure from re-suspended dust.

On the basis of the available literature, OSHA finds that wet cutting substantially reduces, but does not entirely eliminate, worker exposure to respirable silica.

Local Exhaust Ventilation

ERG-C (2008) reviewed literature suggesting that additional controls for workers could include the use of LEV-equipped stationary masonry saws or stationary saws set into ventilated enclosures (e.g., a ventilation booth that permits the operator to stand outside the enclosure). There is evidence that workers who cut blocks using saws located in site-built ventilation booths throughout their shifts can consistently reduce silica exposures to levels below 100 µg/m^3 (ERG-C, 2008). For example, a 78-percent reduction in respirable quartz exposures (to a mean of 66 µg/m^3) was observed when workers used a site-built ventilated booth outdoors compared with cutting outdoors with no booth (mean of 354 µg/m^3 from Table IV.C-62) (ERG-C, 2008).[261] OSHA concurs that ventilated booths can decrease worker exposure and might provide additional benefit if used together with wet methods (e.g., water-fed saw set in a booth).

Although OSHA estimates that controlling silica exposure is best achieved by cutting brick and block wet, some construction methods specify dry cutting to avoid discoloration or because dry brick is desirable for subsequent processes (NIOSH EPHB 247-18, 2001). NIOSH evaluated dry-cutting methods with and without the use of LEV using a commercially available masonry saw factory-equipped with two exhaust take-offs (one below the blade and one surrounding the blade guard).[262] After enclosing the masonry saw in a test cell, a worker operated the saw to dry cut bricks with and without the saw LEV activated. NIOSH designed the test cell's independent exhaust system to pull air at a steady rate (2800 cubic feet per minute [cfm]) from the cell, and this air was evaluated with a dust analyzer to determine the extent to which the LEV system connected to the saw captured dust (i.e., prevented it from dispersing in the test cell). With the saw LEV turned off, the respirable dust concentration in air drawn from the cell was 13,000 µg/m^3 (13 mg/m^3). However, when the saw LEV was activated, the measured respirable dust concentration was notably lower at 50 µg/m^3 (0.05 mg/m^3) (NIOSH EPHB 247-18, 2001). Although these concentrations do not relate directly to worker exposure levels, they do indicate that the LEV system

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[261] OSHA obtained four 8-hour TWA results for workers using the masonry saw in a ventilated booth: 15 µg/m^3, 70 µg/m^3, 86 µg/m^3, and 93 µg/m^3 (OSHA SEP Inspection Report 302007034). The mean of these values is 66 µg/m^3, and the median is 78 µg/m^3.

[262] As standard features, this EDCO GMS-10 masonry saw is designed for use with both LEV and wet dust control methods (EDCO-GMS-10, 2008).

captured dust well during the tests. NIOSH concluded that exhaust ventilation can be used to reduce respirable dust emissions by at least 99 percent when LEV air flow rates are sufficient (206 cfm in this case, with suction divided between two vacuum cleaners).[263] However, NIOSH also recommended enlarging the exhaust take-off below the blade to minimize airflow restrictions (to reduce the static pressure loss from greater than 30 inches of water), increase the transport velocity (to 4500 feet per minute [fpm]), and prevent captured dust from settling where it could block air flow (NIOSH EPHB 247-18, 2001).

Administrative Controls

A review of the literature also finds that worker exposures to airborne silica could be reduced by employing specific administrative controls. For example, locating the worker downwind of a stationary saw caused a four- to five-fold higher respirable dust exposure compared with locating the worker upwind of the saw (NIOSH HETA 2000-0226-2890). OSHA recognizes that administrative controls such as this are beneficial, but not always practical (particularly because workers cannot always adjust their orientation to stationary equipment to step out of a dust plume). These methods are helpful, but should be used in conjunction with other exposure controls.

Saw dust controls work best when construction managers ensure workers know how to use the equipment to its best advantage (e.g., how to adjust water flow to minimize dust, when to empty vacuums and clean filters), and choose equipment that is appropriate to their needs (e.g., appropriately sized vacuums that will consistently provide sufficient suction) (OSHA 3362-04, 2009). Additionally, saws with either water filtration or LEV systems require regular maintenance and servicing to limit clogging of hoses and filters (ERG-C, 2008). Furthermore, Yereb (2003) noted that worn saw blades should be replaced to minimize the amount of fine particles produced.

Feasibility Finding

Based on the information presented in this section, OSHA preliminarily concludes that when wet sawing methods are employed, most respirable quartz exposures can be reduced below 50 µg/m^3. This conclusion is based on the median 8-hour TWA reading of 33 µg/m^3 for workers who used wet methods to cut masonry with stationary saws. Based on the exposure profile (Table IV.C-62), OSHA estimates that wet cutting methods across the construction industry will need to be employed, or employed more rigorously than at present, for just over half (54 percent) of masonry cutters. OSHA anticipates that those workers who are already using wet methods but experiencing exposure levels above 50 µg/m^3 (29 percent of the workers now using wet cutting methods) will need further instruction to achieve optimal dust control with these methods (e.g., what level of water flow to use, how water flow should be directed on the blade, and/or when to change dust-laden water in the tank). NIOSH ECTB 233-118c (1999) described a sawyer wet-cutting concrete brick and block for part of the shift and generating a significant dust cloud in the process. The result of 80 µg/m^3 confirmed that the wetting was not sufficient to provide optimal exposure control for this worker and further adjustments or administrative actions were needed.

Other administrative actions supplement water flow adjustments. In order to consistently reduce exposures to workers using stationary saws to below 50 µg/m^3, OSHA expects construction employers will need to replace saw blades when worn, maintain LEV systems in good working condition, and ensure

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[263] By attaching hoses from two powerful vacuums to the two saw exhaust ports, the investigators prepared the LEV system to exhaust 93 cfm from below the blade and an additional 113 cfm from the guard surrounding the blade. This configuration resulted in a 99 percent reduction in respirable dust emissions. In the same study, but using lower air flow rates, NIOSH found that the LEV system reduced respirable dust emissions to a smaller extent (NIOSH EPHB 247-18, 2001).

that workers accompany wet methods with rigorous housekeeping to prevent dust particles from becoming airborne when dust-laden water dries.

Although most masonry cutters can use wet methods with good results, wet methods might be less effective for a small portion of the workforce (ERG-C, 2008). For example, extremely hot, dry atmospheric conditions can cause dust-laden mist particles from the saw to dry while still airborne. In small or enclosed spaces this condition will permit silica to accumulate in the air. Similarly, if spilled water/slurry is permitted to dry, silica-containing dust particles can become re-suspended if disturbed. Or, wet methods might simply be inappropriate for certain construction techniques. For these alternative working environments OSHA estimates that the use of LEV will be necessary to reduce exposures to levels below 50 µg/m^3. When possible, a combination of controls (exhaust ventilation and wet methods) should be employed. For example, positioning a water-fed saw in a site-built ventilated booth would provide significant additional protection. This combined approach would also make it possible to use wet methods in indoor locations where mist might otherwise complicate their use.

In summary, OSHA preliminarily concludes that most construction workers using stationary masonry saws will experience exposure levels of 50 µg/m^3 or less most of the time when they operate water-fed saws in a manner that optimizes dust control. Construction managers will also need to develop programs to ensure that equipment is well-maintained to maximize dust control benefits. Specifically, administrative policies must encourage workers to change dust-laden water routinely, replace worn saw blades, and maintain LEV systems to ensure consistent suction.

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Millers Using Portable or Mobile Machines

Description

Millers are workers who use milling equipment to grate or grind solid surfaces, such as concrete floors, masonry walls, sidewalks, and asphalt roads. OSHA has divided this job category into three subcategories to describe baseline conditions and control options:

- Workers who operate large driven (or road) milling machines from seats on top of the equipment.
- Workers who tend the large milling machines by walking beside the equipment.
- Workers who operate walk-behind milling machines.

Milling machinery often uses a rapidly rotating drum or a bit covered with nibs to abrade surfaces, although other mechanisms are also common (e.g., systems based on impact, shot-blast, or rotating abrasive cups). The operator can drive larger models from above (e.g., road milling equipment used in recycling/resurfacing operations) or guide smaller milling equipment by hand (e.g., walk-behind equipment used for small pavement areas and floor work). Laborers or construction workers operate the smaller machines during specialty tasks such as resurfacing floors, repairing pavement, or installing electrical systems (i.e., creating grooves for conduit).

While some smaller milling equipment is operated dry, all road milling equipment is designed with a water feed at the milling drum to cool the blades. Regardless of the equipment size, the operator is often responsible for sweeping and disposing of debris after milling is complete, although for larger equipment an assistant might also be involved. For example, a NIOSH report described a laborer working with a shovel who walked beside a large road mill driven by another worker (NIOSH-Swank, 1995). On road milling sites, a vehicular street sweeper is also usually present.

As in other construction job categories, the duration of milling activities might vary substantially from shift to shift. For example, at a site evaluated by NIOSH, workers milled a road for more than 8 hours the first day but only 3.5 hours the next day because the job was finished (NIOSH-Swank, 1995). Duration varies even more—from 1 to 8 hours—for smaller milling equipment.

Table IV.C-63 summarizes the job categories, major activities, and primary sources of silica exposure of millers.

Table IV.C-63

Job Categories, Major Activities, and Sources of Exposure of Millers Using Portable or Mobile Machines

Job Category	Major Activities and Sources of Exposure
Large Driven Milling Machine Operator	Grating or grinding solid surfaces such as asphalt roads; operator often seated on top. • Dust from action of cutting blades.
Large Milling Machine Tender	Assisting operation of large milling machines while walking beside the machines. • Dust from action of cutting blades. • Dust from related activities, such as sweeping or shoveling debris.
Walk-Behind Milling Machine Operator	Grating or grinding solid surfaces such as concrete floors, masonry walls, and sidewalks; operator often guides from behind. • Dust from action of cutting blades. • Dust disturbed during cleanup/housekeeping tasks.

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the construction site.

Source: ERG-C, 2008.

Baseline Conditions and Exposure Profile

The following sections describe baseline conditions for each affected job category based on an ERG site visit report, OSHA SEP inspection reports, and NIOSH reports. Table IV.C-64 presents the exposure profile and summarizes exposure results for workers in each job category.[264] Although limited, these results represent the best data available to OSHA for workers using milling equipment. ERG initially obtained six results for workers in this job category (ERG-C, 2008). OSHA subsequently identified additional results in five NIOSH reports (NIOSH EPHB 282-11b, 2004; NIOSH EPHB 282-12a, 2007; NIOSH EPHB 282-14a, 2009; NIOSH EPHB 282-15a, 2009; NIOSH EPHB 282-16a, 2009). Furthermore, several results for workers using gas-powered routers on pavement (OSHA SEP Inspection Report 300442977) were added to the exposure profile when they were re-categorized as more closely associated with milling equipment than with hand-held grinding tools, which are described in a different section of this analysis.

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[264] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) calculated assuming no additional exposure during any unsampled portion of the shift. Unless explicitly stated otherwise, all results discussed in the additional controls section are also 8-hour TWAs calculated the same way. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

OSHA also identified two recent reports by Flanagan et al. (2003, 2006) that provide summary data for milling equipment operators and two studies on pavement milling machine dust controls used in the Netherlands (TNO Bouw, 2002; Van Rooij and Klaase, 2007). Although these studies do not provide individual results suitable for the exposure profile, as discussed in the following paragraphs, these reports do offer additional insight into the silica exposure of construction workers involved with milling equipment.

Baseline Conditions and Exposure Profile for Large Driven Milling Machine Operators

As indicated in Table IV.C-64, 14 exposure results were obtained for large driven milling machine operators. The median exposure level is 17 micrograms per cubic meter (μg/m^3), with a mean of 40 μg/m^3 and a range from 5 μg/m^3 to 181 μg/m^3. Three of the fourteen results (21 percent) exceed 50 μg/m^3, and only one result (7 percent) exceeds 100 μg/m^3. Construction workers operating large driven milling machines most commonly perform their duties from the tops of the machines. A typical asphalt milling machine has a built-in reservoir from which water is applied to the cutting drum (NJDHSS, 2000). The operators use the same water-fed equipment (with different teeth) for concrete milling, but since the vast majority of U.S. roadways are paved with asphalt, concrete milling is performed less frequently (Wirtgen, 2010). The machines are available with or without cabs, although sources suggest that cabs are uncommon because of concerns about visibility and safety (Burstyn et al., 2000; Wirtgen, 2010).

The contractor report (ERG-C, 2008) originally identified two readings, both less than or equal to the limit of detection (LOD) of 12 μg/m^3, for asphalt milling machine drivers performing wet milling (NIOSH-Swank, 1995).[265] All of the additional data in the current exposure profile comes from more recent research in which NIOSH conducted a series of five studies in association with the National Asphalt Paving Association investigating wet methods of dust control during asphalt milling (summarized in Table IV.C-65). All of these studies had an experimental component in which some aspect of the water spray was systematically varied. Thus, 8-hour time-weighted averages (TWAs) were calculated from two to four consecutive samples (the majority being 2 hours or shorter) during which various water treatments were applied (e.g., high- and low-flow). The total duration of sampling for each operator was at least 4 hours for the majority of samples and only incorporated periods of active milling. Zero exposure was assumed for the unsampled portion of the shift. The results of these studies were included in the exposure profile because working conditions reflect those actually experienced by milling operators on the job (contracted road work was performed during these studies), although on some dates the amount of time spent milling might have been on the low end of the normal range for milling machine operators.

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[265] Results reported as “none detected” are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

Table IV.C-64
Respirable Crystalline Silica Exposure Range and Profile for Millers Using Portable or Mobile Machines

	Exposure Summary			Exposure Range			Exposure Profile				
Job Category	**Number of Samples**	**Mean (μg/m³)**	**Median (μg/m³)**	**Min (μg/m³)**	**Max (μg/m³)**		**<25 (μg/m³)**	**≥25 and ≤50 (μg/m³)**	**>50 and ≤100 (μg/m³)**	**>100 and ≤250 (μg/m³)**	**>250 (μg/m³)**
Large Driven Milling Machine Operator	14	39	17	5	181		10	1	2	1	0
							71.4%	7.1%	14.3%	7.1%	0.0%
Large Milling Machine Tender	15	58	27	13	340		6	4	4	0	1
							40.0%	26.7%	26.7%	0.0%	6.7%
Walk-Behind Milling Machine Operator	6	32	20	12	80		3	2	1	0	0
							50.0%	33.3%	16.7%	0.0%	0.0%
Totals	35	46	20	5	340		19	7	7	1	1
							54.3%	20.0%	20.0%	2.9%	2.9%

Notes: All samples are personal breathing zone (PBZ) results and represent 8-hour TWA exposures with the assumption that no additional exposure occurred during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Sources: ERG-C, 2008; NIOSH EPHB 282-11b, 2004; NIOSH EPHB 282-12a, 2007; OSHA SEP Inspection Report 300442977; NIOSH EPHB 282-14a, 2009; NIOSH EPHB 282-15a, 2009; NIOSH EPHB 282-16a, 2009.

Table IV.C-65

Overview of Five NIOSH Asphalt Milling Machine Studies Conducted 2003 Through 2006

Study Date	Type of Milling	Average Water Spray	8-hour TWA PBZ Silica Results[A]	Percent Silica	Important Findings and Conclusions	Report No. (Year)
Oct 2003	Road demolition (12-inch removal)	Cutter drum: 6 to 9 gpm Conveyor:[B] 4 to 3.7 gpm	Operator: 14 to 100 µg/m^3 Tender: 27 to 66 µg/m^3	4 to 9 percent silica on filters. 12 to 28 percent quartz in bulk samples.	The deep cut created more dust than typical jobs because of the large gap it created between the bottom of machine and the milled surface (allowing more dust to escape) and the greater quantity of material removed. This is not a typical job.	NIOSH EPHB 282-11b (2004)
Jul 2004	Typical “mill and fill” (1 to 4-inch removal)	Cutter drum: 5 to 9 gpm Conveyor: 2 to 3 gpm	Operator: 22 to 91 µg/m^3 Tender: 15 to 25 µg/m^3	10 percent silica on filters.	Increased water application rate resulted in 50 percent overall reductions in dust emissions.	NIOSH EPHB 282-12a (2007)
Jun 2006	Typical “mill and fill” (1 to 4-inch removal	Cutter drum: 16 to 18.5 gpm Conveyor: Not available	Operator: 5 to 8 µg/m^3 Tender: 13 to 28 µg/m^3	5 percent silica on the filters.	No substantial difference in dust control was found between the two relatively similar flow rates.	NIOSH EPHB 282-15a (2009)

Aug 2006	Typical “mill and fill” (1 to 4-inch removal	Cutter drum: 7 to 12 gpm Conveyor: 5 to 6.5 gpm	Operator: 15 to 20 µg/m^3 Tender: 15 to 20 µg/m^3	ND to 4 percent silica on filters.	Dust levels were reduced when water flow rate increased. The hot weather caused the asphalt to become sticky, which might have helped suppress dust.	NIOSH EPHB 282-14a (2009)
Sep 2006	Typical “mill and fill” (1 to 4-inch removal	Cutter drum and conveyor (total):[C] 12.5 to 20 gpm	Operator: 39 to 181 µg/m^3 Tender: 60 to 82 µg/m^3	14 to 17 percent silica on filters.	There was no correlation between water flow rates and dust levels. Pressure spray at higher flow rate might have stirred dust into the air. The cold weather might have caused the asphalt to become brittle, contributing to particularly high levels of dust.	NIOSH EPHB 282-16a (2009)

Notes: gpm = gallons per minute; ND = none detected.

[A] Eight-hour TWAs were calculated from two to four consecutive samples (the majority being 2 hours or shorter) during which various water treatments were applied (e.g., high- and low-flow). The total duration of sampling for each operator was at least 4 hours for the majority of samples and only incorporated periods of active milling. Zero exposure was assumed for the unsampled portion of the shift.

[B] When water flow to the cutter drum increased, water flow to the conveyor decreased.

[C] Separate values for cutter drum and conveyor are not available.

Sources: Blade, 2010; NIOSH EPHB 282-11b, 2004; NIOSH EPHB 282-12a, 2007; NIOSH EPHB 282-14a, 2009; NIOSH EPHB 282-15a, 2009; NIOSH EPHB 282-16a, 2009.

In the first study (October 2003), NIOSH investigators collected air samples while evaluating an asphalt-milling machine water spray dust suppression system using two different types of nozzles, high-flow and low-flow (NIOSH EPHB 282-11b, 2004). NIOSH obtained an exposure result of 14 µg/m^3 for the milling machine operator on the first day, which was a typical day of wet-milling (although water flow rate was not evaluated). A higher result of 100 µg/m^3 was obtained for the operator on the day that investigators evaluated nozzle types (average flow rates between 10 and 12.7 gpm). NIOSH noted that the effect of wind speed and direction is uncertain. At this site, workers removed 12 inches of pavement all at once. This is a highly unusual operation, essentially a specialized form of road demolition, and reportedly does not represent typical "mill and fill" repaving activity (Blade, 2010). During mill-and-fill type jobs, only the top layer(s) (usually 1 to 4 inches) of pavement is removed prior to resurfacing. In this first NIOSH study, the removal of excess pavement during milling machine demolition-type work created a large gap between the road and the milling machine drum enclosure, allowing more dust to escape than during typical milling conditions. Milling operators will rarely encounter these "worst case" conditions during their careers (Blade, 2010).

Subsequently (in July 2004), NIOSH completed a similar study to determine if the engineering controls supplied with new asphalt milling machines and operated according to the manufacturer's recommendations were adequate to control worker exposures. Two results of 91 µg/m^3 and 22 µg/m^3 were obtained for the milling machine operator during this typical "mill and fill" job, while water spray flow rate averages ranged from 5 gpm to 9 gpm at the cutting drum (NIOSH EPHB 282-12a, 2007). The system tested provided additional spray at the conveyor. The next study in this series (June 2006) compared several new milling machines equipped with the manufacturer's spray system, which were tested at 80 percent and 100 percent of their respective maximum flow rates. Two of three operator quartz exposure levels were below the LOD (less than or equal to 5 µg/m^3), and the third result of 8 µg/m^3 also was very low (NIOSH EPHB 282-15a, 2009). Similarly low results were observed in the fourth study (August 2006), which tested a late-model mill retrofitted with the newest manufacturer spray system with average total (cutter drum and conveyor) water spray flow rates between 12 gpm and 19 gpm. The three operator quartz exposures were below the LOD (two results of less than or equal to 20 µg/m^3 and one result less than or equal to 15 µg/m^3) (NIOSH EPHB 282-14a, 2009). Although percent silica in the asphalt was relatively low (containing an average of 14 percent quartz), respirable dust also was well controlled. NIOSH suggested that the high summer temperatures (85° to 100° Fahrenheit [F]) caused the asphalt to become sticky, which helped limit respirable dust emissions.

The final study in this series (September 2006) again tested a late-model milling machine retrofitted with the newest manufacturer spray system; average total water spray flow rates ranged between 12 gpm and 20 gpm. Quartz exposures obtained at this site, 39 µg/m^3 and 181 µg/m^3, were higher than those at the previous site (NIOSH EPHB 282-16a, 2009). As previously noted, the PBZ exposure levels are composites of samples taken during both high- and low-flow trials, so they do not correlate with specific flow rates. Milling was conducted at nighttime when temperatures were very cool (in the 40s°F). NIOSH noted that it is unclear whether this influenced the silica results, although it is possible that the tendency of asphalt to fracture when cold contributed to the difference in results from this and the warm weather trial of August 2006.

In a separate review of construction data from a variety of sources, Flanagan et al. (2006) summarized 48 respirable quartz samples associated with the use of road milling machines in construction and found a geometric mean of 11 µg/m^3. Flanagan's dataset was drawn from a variety of published and private data (not all of which are available to OSHA), and likely overlaps substantially with OSHA's. The results in the larger Flanagan dataset support the results in OSHA's exposure profile, which show that most milling machine operator exposures are below the proposed permissible exposure limit (PEL) of 50 µg/m^3.

OSHA also examined differences between asphalt and concrete milling and believes that the exposure of operators milling concrete roads might be somewhat higher than the exposure during milling of asphalt, but not necessarily to the extent shown by the concrete milling data available to OSHA. The New Jersey Department of Health and Senior Services (NJDHSS, 2000) reported that, while none of the eight asphalt road millers it evaluated were exposed to silica above the current PEL (average level was one-half the calculated PEL for respirable dust containing silica), the average of the results for two concrete road millers was more than 12 times the PEL.[266,267] In these cases, the asphalt milling was performed as a wet process while the concrete milling was a dry operation (NJDHSS, 2000). A milling machine manufacturer notes that the manufacturer's recommended operating procedures include wet processes for all road milling to protect the equipment; because dry milling quickly results in costly equipment damage, it is not an accepted normal practice for asphalt or concrete (Wirtgen, 2010).

Wirtgen (2010) also indicates that there are no practical contraindications to using water sprays during concrete milling, although with equivalent water spray, silica emissions could still be higher during concrete milling than asphalt milling. This difference is due to the potential for higher silica content in concrete compared with some asphalts and also due to the softness and "stickiness" of asphalt milled warm, which likely helps reduce separation of the pavement components and perhaps limits dust release in hot weather (NIOSH EPHB 282-14a, 2009; Wirtgen, 2010). Because the same milling machines (fitted with different models of interchangeable teeth on the milling drum) can be used to mill asphalt and concrete roads (Wirtgen, 2005), OSHA expects that operators use these machines on both materials.

Based on information described above, OSHA preliminarily concludes that the baseline conditions for road milling machine operators consist of no cabs or open cabs (which would not provide

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[266] NJDHSS (2000) calculated the PEL using OSHA's general industry silica PEL equation based on the percent of quartz in a respirable dust sample. The percent silica in the respirable dust samples varied, so the value of the PEL (as a concentration of respirable dust) ranged from 630 µg/m^3 to 5,000 µg/m^3 (0.63 mg/m^3 to 5.00 mg/m^3) for samples obtained during asphalt milling using wet methods. Note that when the percent silica in a material is non-detectable a value of zero is given to the "% SiO_2" variable, and the equation yields a PEL of 5,000 µg/m^3 for respirable dust. This is also the same PEL value in table Z-1 in OSHA's Air Contaminant Standard (29 CFR 1910.1000) for all particulates not regulated by the table. The value of the silica PEL (again as a concentration of respirable dust) was 670 µg/m^3 (0.67 mg/m^3) during the dry concrete milling, while the measured 8-hour TWA respirable dust level was 7,620 µg/m^3 (7.62 mg/m^3), approaching 12 times the calculated PEL.

[267] In this case, although evaluating a construction industry activity, the investigator elected to compare silica exposure results with OSHA's gravimetric general industry PEL for silica. This might be due to the fact that the construction industry PEL for silica is based on the units millions of particles per cubic foot (mppcf), requiring an obsolete analytical method not available through most analytical laboratories. Instead, laboratories typically report silica air sampling results as mass-based gravimetric values (e.g., mg/m^3) for respirable dust, along with the percent silica, which are also used in the gravimetric general industry PEL for silica. Investigators compare these results with the gravimetric general industry PEL because the units are compatible. An alternative has been available since 2008, when OSHA published a compliance directive, National Emphasis Program (NEP)–Crystalline Silica CPL 03-00-007 (Appendix E), providing a conversion factor to convert air sampling results between mppcf and mg/m^3 or µg/m^3. However, some investigators have continued in their studies to use the more familiar gravimetric units and compare construction industry air monitoring results with the gravimetric general industry PEL for silica.

substantial isolation from the outdoor environment) and use of wet milling methods (with varying degrees of attention to water flow). Furthermore, baseline conditions include primarily “mill and fill” asphalt replacement, with only occasional road demolition jobs (i.e., deeper milling action). Because the results included in the exposure profile represent a similar range of conditions, OSHA preliminarily concludes that the exposure profile for driven milling machine operators represents the normal baseline exposure for these workers (median of 17 μg/m^3, mean of 40 μg/m^3, and range of 5 μg/m^3 to 181 μg/m^3). Operators of road milling machines typically experience silica exposure levels less than 50 μg/m^3, but airborne concentrations can be higher, particularly when workers mill concrete road surfaces, but also depending on environmental conditions, status and design of the water feed system, and depth of milling.

Baseline Conditions and Exposure Profile for Large Milling Machine Tenders

Table IV.C-64 describes the 15 results for tenders of large milling machines. This job category has a median silica exposure of 27 μg/m^3, a mean of 58 μg/m^3, and range of 13 μg/m^3 to 340 μg/m^3. Five results (33 percent) exceed 50 μg/m^3, and one result (7 percent) exceeds 100 μg/m^3. Construction workers tending large milling machines most commonly perform their duties while walking beside the machines. These duties can include operating the ground-based rear controls of the milling machine, which require the worker to walk beside the milling machine.

The two highest exposure results in this job category (97 μg/m^3 and 340 μg/m^3) were obtained at a site where minimal water spray was used to cool the equipment. This was the job site where the highest milling machine operator exposures also were obtained, and where NIOSH had strongly suggested that the water spray volume and position needed to be improved (NIOSH-Swank, 1995).

The series of five NIOSH studies investigating water spray dust suppression described above also measured exposures of milling machine tenders. During the first study, two 8-hour TWA exposure results of 66 μg/m^3 and 27 μg/m^3 were obtained for the foreman and a skid steer loader operator, respectively. NIOSH noted that both of these workers spent half of the first (most typical) day working at ground level while operating the rear controls of the milling machine, which were located on the side of the machine. They spent the remainder of the shift on tasks elsewhere at the construction site. A result of 44 μg/m^3 was obtained on the second day of sampling for another crewmember, who operated the rear controls for the entire day (NIOSH EPHB 282-11b, 2004). At another construction site, NIOSH investigators obtained two exposure results of less than or equal to 15 μg/m^3 and 25 μg/m^3 for a foreman who operated the ground-based rear controls of a milling machine (NIOSH EPHB 282-12a, 2007). A ground man performing these same duties during the third study had exposures of 28 μg/m^3, 18 μg/m^3, and 13 μg/m^3 on three consecutive days (NIOSH EPHB 282-15a, 2009). At the fourth site, the foreman divided his time between operating the controls alongside the mill and driving the water truck. The exposures for this worker were below the LOD (two results of less than or equal to 20 μg/m^3 and one result of less than or equal to 15 μg/m^3) (NIOSH EPHB 282-14a, 2009). Finally, the ground man at the last study site, who operated controls alongside the mills, had elevated exposures of 82 μg/m^3 and 60 μg/m^3 (NIOSH EPHB 282-16a, 2009). These reports from NIOSH suggest that water spray design, environmental conditions, and depth of milling can affect the exposures of ground-based construction workers near asphalt milling machines and operators of such machines to a similar degree.

Based on information described earlier in this section OSHA preliminarily concludes that the baseline conditions for road milling machine tenders consist of operating controls alongside the milling machine where wet milling methods are in use (with varying degrees of attention to water flow). Furthermore, baseline conditions include primarily “mill and fill” asphalt replacement, with only occasional road demolition jobs (i.e., deeper milling action). OSHA preliminarily concludes that the exposure profile for milling machine tenders represents the baseline exposure for these workers. Tenders of road milling machines typically experience silica exposure levels less than 50 μg/m^3, but airborne concentrations can be higher, particularly when workers mill concrete road surfaces, but also depending on environmental conditions, status and design of the water feed system, and depth of milling.

Baseline Conditions and Exposure Profile for Walk-Behind Machine Operators

Table IV.C-64 presents the exposure profile for walk-behind milling machine operators. The six results have a median of 20 μg/m^3, a mean of 32 μg/m^3, and a range of 12 μg/m^3 to 80 μg/m^3. The 80 μg/m^3 exposure reading is the only one exceeding 50 μg/m^3. Millers in this third job category operate walk-behind machines.

ERG (ERG-C, 2008) summarized two results (both below the LOD of 12 μg/m^3) obtained by ERG for workers using water-fed walk-behind milling machines indoors while producing a terrazzo floor. For the present exposure profile, OSHA has added four more results that represent operator exposures under baseline conditions. OSHA collected two of the results (14 μg/m^3 and 80 μg/m^3) while visiting a work site at which workers used a gas-powered walk-behind router-style milling machine as part of asphalt road pavement repair.[268] Two additional follow-up monitoring results of 26 μg/m^3 and 48 μg/m^3 were obtained while workers of the same company used similar equipment on pavement at an airport (OSHA SEP Inspection Report 300442977). During the sampling period, another worker also used compressed air to clean the dust from the grooves. Dust controls were not mentioned on either occasion.

OSHA reviewed an additional study designed to evaluate exposure to silica during common dust-producing construction activities. Flanagan et al. (2003) summarized nine sample results for concrete floor sanding activities and reported a geometric mean of 70 μg/m^3. However, because the study did not provide the individual sample results, OSHA was unable to include them in the exposure profile. Based on worker position and abrasive action of the tool, OSHA has grouped floor sanding activities (described as a concrete finishing process using a sandpaper disk attached to equipment operated from a standing position) with walk-behind milling machine operations for the purpose of this analysis.

In a separate study, short-term experimental silica results for operator exposure associated with a walk-behind scabbler used on a covered[269] (semi-enclosed) concrete parking garage floor were as high as 2,100 μg/m^3 over an 8-minute test period evaluating dry milling (at during other test periods, intense use of wet methods controlled the exposure) (NIOSH EPHB 247-15d, 2002). Based on the available information, OSHA preliminarily concludes that the results in the Table IV.C-64 exposure profile represent the baseline exposure levels for walk-behind milling machine operators. However, OSHA acknowledges that the experimental results of NIOSH EPHB 247-15d (2002) suggest that when using certain types of particularly aggressive equipment indoors, some workers likely encounter higher airborne silica concentrations during short periods of intensive milling without dust controls.

Vacuums can be connected to walk-behind milling machines to exhaust dust generated during milling. Although most walk-behind milling machines are currently manufactured with vacuum ports (to which a vacuum can be connected), older equipment might not include this feature (ERG-C, 2008).

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[268] A variety of equipment is available for “chasing cracks,” which was the type of road repair being performed at this work site. Some walk-behind equipment models are similar to masonry saws. In this case, the OSHA representative called the machine a router, suggesting it was more closely related to milling equipment (OSHA SEP Inspection Report 300442977).

[269] The semi-enclosed configuration of the parking garage is inferred from photos of the milling trials that show support columns in the area being milled (NIOSH-EPHB 247-15d, 2002).

Moreover, even when a port is available, workers might not connect an appropriate vacuum to the machine (ERG-C, 2008). None of the results in the exposure profile were collected with local exhaust ventilation (LEV); thus OSHA preliminarily concludes that baseline conditions for walk-behind milling machine operators do not include appropriate use of vacuums to control dust. In contrast, wet methods appear to be used more commonly with certain types of walk-behind milling equipment, including the terrazzo-milling equipment for which results are included in Table IV.C-64; thus, OSHA preliminarily concludes that use of wet methods is within the range of normal baseline conditions for this diverse group of equipment as a whole, but is not universally used (e.g., wet methods were associated with one-third of the results summarized in Table IV.C-64).

Additional Controls

Additional Controls for Large Driven Milling Machine Operators

Water spray and LEV are the primary dust controls for this job category. These methods are described in detail in the following paragraphs.

Wet Dust Control Methods

Cooling water applied to the cutting drum helps reduce the dust exposure of milling machine operators. All of the results in Table IV.C-64 for road milling machine operators are associated with the use of wet dust suppression, and 79 percent of the results were 50 μg/m^3 or less. Purpose-built systems for wet dust suppression can be even more effective at reducing silica exposure.

In a study conducted in the Netherlands, a novel wet dust emission suppression system reduced the PBZ respirable quartz exposure of asphalt milling machine drivers to a mean of 20 μg/m^3 (n = 4), with a range of 9 μg/m^3 to 30 μg/m^3 (Van Rooij and Klaasse, 2007). The system consists of 24 spray nozzles (located at the picks drum, collection conveyer, and loading conveyer), which spray aerosolized water containing an additive (likely a foam, based on the product name) onto the milled asphalt material (Van Rooij and Klaasse, no date, 2007). The additive foam causes the dust to become tacky and aggregate, and expands rapidly to encompass small particles generated by the tool's aggressive action. This technology can offer more effective dust suppression than plain water.[270] Milling machine tenders benefitted equally from the system, having a mean PBZ respirable quartz exposure of 8 μg/m^3 (n = 4) with a range of 4 μg/m^3 to 12 μg/m^3. Compared with a standard milling machine, which uses only cooling water (not aerosolized) on the blade, the use of the aerosolized water and foam system reduced the mean exposure for drivers and tenders combined by 97 percent. Without the added controls (i.e., cooling water only), mean exposure was 418 μg/m^3 (n = 2) for drivers and 509 μg/m^3 (n = 1) for tenders.

Investigators Van Rooij and Klaasse (2007) also reported results for the use of aerosolized water without the additive foam. Aerosolized water alone provided a substantial benefit, giving PBZ respirable quartz exposures of 42 μg/m^3 and 57 μg/m^3 for drivers, and 56 μg/m^3 and 104 μg/m^3 for tenders. Aerosolized water reduced the mean exposure for drivers and tenders combined by 86 percent compared with cooling water only; however, three of four exposures remained above the proposed PEL of 50 μg/m^3. The authors did not report individual sample durations, but the average sampling time for all 15 results was 254 minutes (range: 60 to 388 minutes). The investigators concluded that exposure results were lower when the additive was used in the spray water.

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[270] Although more costly than a simple water spray, foams are more effective (by volume applied) than water spray. Foam can be adapted to control dust from most tasks, including applications that require a rugged design (Midwest-Edwards, 1999).

The series of five NIOSH studies (described previously and summarized in Table IV.C-65) on water spray controls (without added dust suppressants) on cold milling machines compared the effectiveness of varying water flow rates on silica concentrations using the standard cooling water system available in milling machines. Taken as a body of work, the results of these studies are inconclusive and highlight the need for wet methods purposefully adjusted to control dust (as has been found effective for other construction tasks). Based on the descriptions, the spray used in these NIOSH studies is possibly a larger droplet spray than the mist described in the Netherlands study. Even so, many of the results are suggestive of the potential for wet methods to control silica. However, outlying results indicate the need for continuing research to optimize the use of manufacturer water-alone spray systems as an effective dust control under all milling conditions.

Since the NIOSH studies were conducted (2003 through 2006), improved dust control has been a topic of interest to milling machine manufacturers, some of which have begun installing modified, or separate, water sprays intended to reduce dust emissions (Wirtgen, 2010; Blade, 2010). One of these systems, available in the United States since 2009, reportedly reduces machine maintenance requirements and improves visibility (by reducing emitted dust) on and around the milling machine. The design provides the operator with more options for controlling a second, separate spray system, applying more spray where needed, and conserving water where it is not needed.

Milling concrete can pose additional challenges for controlling silica exposure compared with milling asphalt.[271] Additionally, the smaller teeth on concrete milling drums produce more fine dust (Schill, 2000). Despite these differences, some of the same milling machines (high-power equipment) can readily be adapted to mill concrete (Wirtgen, 2005). Thus, OSHA believes that water spray nozzles applied to asphalt milling machines will function similarly when the same machine is used for concrete. Although the available data are not enough to conclude with certainty that workers milling concrete roads would achieve the same exposure level as seen for asphalt millers, there is evidence suggesting wet methods work well for managing concrete dust. For example, in a study of tunnel construction workers, Blute et al. (1999) reported silica results of 10 µg/m^3, 49 µg/m^3, and 79 µg/m^3 for workers removing concrete with heavy equipment (e.g., forklifts, backhoes) having grinder or scabbler attachments (analogous action and worker positioning to large milling machines). The authors posited that these relatively low exposures (not exceeding the current silica standard)[272] resulted from the use of hoses to wet down the concrete and the distance between the source of the silica dust and the worker. Therefore, OSHA preliminarily concludes that work on open concrete roadways using wet methods may result in exposure levels similar to those reported during asphalt milling using wet methods. The use of dust suppressants (e.g., foams that offer binding and surfactant properties, such as used in studies by Van Rooij and Klaasse [2007]) should further reduce exposures.

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[271] In one evaluation, the percentage of silica on respirable dust sample filters was higher with concrete milling (15 percent) than with asphalt milling (7 percent) (NJDHSS, 2000). However, in the series of five NIOSH asphalt milling machine studies summarized in Table IV.C-65, the amount of silica in respirable dust on the sample varied to an even greater extent just among asphalt milling jobs (NIOSH found samples from 4 to 17 percent silica on the filters). These findings suggest that the amount of sand and the type of aggregate contained in the road surface are more important factors influencing the amount of silica in the sample than whether the substance milled is asphalt or concrete.

[272] Blute et al. (1999) used the general industry equation to calculate the PEL for respirable dust containing silica.

Based on the information reviewed here, OSHA concludes that wet methods for large milling machines are most effective when flow rate, direction, and droplet size are optimized for dust suppression rather than drum cooling, and when chemical suppressants are added to the water. Spray nozzles should be directed at all dusty locations, which include the conveyers in addition to the drum blades. Water spray should be misted (i.e., aerosolized) to enhance dust capture. Larger water droplets create an air slipstream as they move, which prevents capture of small dust particles (Raring Corporation, 2009). In addition, higher flow rates than are typical for milling equipment can sometimes improve dust suppression. Finally, the addition of a tackifying agent, foaming agent, or surfactant to the water can substantially enhance dust suppression. Several U.S. manufacturers produce a wide variety of foaming and tackifying agents and surfactants, which serve the same function as the foam employed in the Van Rooij and Klaasse (2007) study.

Spray systems for dust control have only recently become available as original equipment on road milling machines (supplemental to cooling water applied to the cutting blades) (Wirtgen, 2010). One design was described as a two-part system that permits fine-tuning of where and how much water spray is applied (Wirtgen, 2010). Spray systems purpose-designed for dust suppression also can be retrofit to older models of milling machines as custom shop installations.

Local Exhaust Ventilation

An additional control option for driven milling machine operators involves LEV to minimize release of dust from the machine. A cooperative effort between a road construction company, a road milling machine manufacturer, labor organizations, and a governmental group in the Netherlands resulted in the development of a prototype LEV system for road milling machines after attempts at using wet methods did not provide the desired results (OSHA-Europa, 2004). A study by TNO Bouw (2002) measured TWA exposure levels for a milling machine operator over a 5-day period with the exhaust system fitted on the machine; exposures ranged from less than 4 µg/m^3 to 28 µg/m^3.[273] The study found similar exposure results for workers on the ground (rear control operator) ranging from less than 3 µg/m^3 to 29 µg/m^3. A street sweeper cleaned up loose debris behind the milling machine when milling involved less than the full road surface depth.

Initially, the construction company in the Netherlands started with an asphalt milling machine with a 2-meter (approximately 79-inch) drum. Modifications to the milling machine included improvements to make the milling drum compartment airtight and addition of an air exhaust system that kept the drum compartment under negative pressure. Ductwork carried the dusty exhaust air from the milling drum to the long conveyer extending out from the front of the milling machine (used to transfer milled material to a dump truck or reprocessing equipment). The conveyer was covered, so dusty air followed the path of the conveyer to its terminal transfer point, adding distance and elevation between the point of road milling and the point where dusty air was released to the environment. The TNO Bouw

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[273] The multi-day test period covered by this report encompassed work on wet and dry pavement (due to rainy and clear weather); still and breezy days; highway, residential, and bicycle path pavements; and asphalt road grinding to several depths, ranging from 2 centimeters (top layer of about three-quarters of an inch removed) up to 25 centimeters deep (nearly 10 inches, involving total demolition/removal of the road surface and some of the supporting layers). Actual road milling occurred over 35 to 67 percent of each monitoring session, which lasted 3 to 4 hours per morning session and 2 to 3 hours per afternoon session (8-hour TWA calculated based on both sessions for the day, typically a total of 6 to 7 hours). In most samples, 6 to 13 percent of respirable dust on the sample filter was quartz, although values as low as 2 percent and as high as 28 percent quartz were recorded on occasion.

(2002) report suggests that certain wind conditions could blow dusty air back to the milling machine, increasing operator exposure to respirable dust and silica. The report further suggests that this blow-back was the reason that the highest 8-hour TWA result (29 µg/m^3) was greater than the other results obtained for the milling machine operator during the test period (TNO Bouw, 2002). However, even this result is below OSHA's proposed PEL.

A follow-up article on the same construction company in the Netherlands indicated that the firm subsequently retrofit all of its front-loader milling machines (various models) with LEV to improve dust control company-wide. The article states: "Using unmodified machines, exposure measurements were between 0.02 and 0.290 mg/m^3 [20 and 290 µg/m^3]. This has been reduced to between 0.0019 and 0.017 mg/m^3 [1.9 and 17 µg/m^3] for machines fitted with the exhaust system" (OSHA-Europa, 2004).[274] The exhaust system resulted in a 94 percent reduction in the highest reported exposure levels, and OSHA anticipates that comparable results could be achieved by milling machines in the United States fitted with a similar dust extraction system. In fact, such systems are, as of 2010, being commercially offered on several models of front-loading milling machines in the United States (Wirtgen, 2010).[275] Furthermore, the model of road milling machine that the construction company in the Netherlands initially retrofit with LEV is commercially available in the United States, and the company is able to similarly modify other models of milling machines (OSHA-Europa, 2004; WirtgenAmerica, no date).

TNO Bouw (2002) suggests that other improvements could further reduce exposure by minimizing airborne dust blow-back. These improvements include: 1) redesigning the exhaust duct outlet over the conveyer so released exhaust air does not create turbulence that kicks up more dust from material on the conveyer and 2) adding water spray nozzles to the exhaust discharge to suppress dust (TNO Bouw, 2002).[276] Additionally, the construction company was reportedly testing filtration systems to capture dust in exhaust air to minimize blow-back on operators even in a head-on wind (OSHA-Europa, 2004). However, no further information is available to date regarding the implementation or effectiveness of these additional controls.

Additional Controls for Large Milling Machine Tenders

OSHA believes that drum-level dust control methods can reduce airborne silica concentrations for milling machine tenders to a similar extent as they can for machine operators. When milling machines are fitted with LEV or appropriate wet dust suppression systems at the grinding drum, dust release is controlled at the source (i.e., at ground level). During intermittent periods when they work immediately adjacent to the drum the tenders can experience greater exposures during uncontrolled milling than do operators seated on top of the machine. This means that controls on the milling drum that reduce

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[274] Low value of 0.0019 [1.9 µg/m^3] is as reported by the authors (OSHA-Europa, 2004). The article does not specify whether these exposure levels are time weighted for 8-hour shifts.

[275] The exhaust system is not promoted as a silica exposure control, but rather as a means to reduce dust for the purpose of enhancing visibility (WirtgenAmerica, 2009). A German organization that certifies exposure controls acknowledged good dust capture efforts in this equipment, but requested additional testing (Wirtgen, 2010).

[276] Based on previous experience with a modified sandstone milling machine, the report suggests a water application rate of 5 liters per 2 hours, equal to a little more than one half-gallon per hour (TNO Bouw, 2002).

exposures from that source can particularly benefit tenders, by reducing these peak exposures. Effective control measures of this type benefit workers in both job categories, but operators on top of the machines might continue to experience exposures from more diffuse sources, while the primary source of exposure for tenders is minimized by drum-level controls. The studies by Van Rooij and Klaasse (2007) and TNO Bouw (2002), described in the discussion of additional controls for milling machine operators, both found comparably low results for both machine operators and tenders (exposures below 50 µg/m^3).

Additional Controls for Walk-Behind Milling Machine Operators

Additional controls for walk-behind milling machine operators include LEV and improved water application. These classes of controls function effectively for large milling machines, as described in the previous sections, and can likely be adapted for walk-behind milling machines. Control measures used with large milling machines (wet methods and LEV) can be scaled down and should provide similar results for smaller equipment performing analogous activities (e.g., grating, grinding) under comparable working conditions (e.g., generally flat surface permitting minimal gap between surface and machine). Tenders of large vehicular milling machines often stand or walk adjacent to the milling drum box (as a walk-behind milling operator would). The milling drum on a vehicular milling machine is frequently 10 or more times wider than the milling drum on a walk-behind model and removes correspondingly more material. Therefore, OSHA anticipates that controls for vehicular milling machines will work at least as well for walk-behind machines, and, in fact, dust from the smaller walk-behind equipment might be easier to control.

Wet Methods

Wet methods are widely used to protect equipment on most types of milling machines, such as drivable milling machines, walk-behind machines used for grinding and polishing terrazzo, and some types of stationary stone milling equipment used in cut stone fabricating shops (ERG-C, 2008; see also Section IV.C.4 – Cut Stone in this technological feasibility analysis). In tests of road milling equipment, NIOSH has shown that water spray on the cutting drum can offer effective dust control under some working conditions. Water spray adjusted specifically for dust suppression on milling machines results in better dust control than water applied simply to wet surfaces. Water attachments for walk-behind milling machines can be a standard or optional feature, depending on the equipment (Allen Engineering, 2003; EDCO-scarifiers-CPM-8, 2010).

As described in the earlier discussion of wet method controls for vehicular milling machines, adding a dust suppressant to the water improves the results. Compared with a standard milling machine, which uses cooling water on the blade only (no spray aerosol), the use of the aerosolized water and foam system reduced the mean exposure for drivers and tenders combined by 97 percent (Van Rooij and Klaasse, 2007).

ERG (ERG MTF-A, 2000) measured exposure levels below the LOD (12 µg/m^3) for workers using wet methods while milling a newly installed terrazzo floor indoors. Echt et al. (2002)[277] tested a custom-built water-fed system that provided a copious amount of water (15 gpm) to the concrete work surface (not the cutting teeth) milled by a scabbler with an 8-inch cutting width. The investigators compared results from alternating 5-minute periods of milling with and without the water-feed activated. The water reduced average respirable dust levels by at least 80 percent. Because of low filter loading, respirable dust was often below the LOD in samples associated with the water control, and none of these samples could be analyzed for silica. However, one measurable PBZ respirable dust level of 400 µg/m^3 was obtained during the wet process, and OSHA estimates that the silica concentration in that sample

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[277] This same study also is published as NIOSH EPHB 247-15d (2002).

would be substantially lower (likely 52 µg/m^3 or less, based on the maximum of 13 percent silica measured in respirable dust on the filters during dry milling at this test site). Measurements taken during similar brief periods of intensive dry milling found respirable dust levels of 13,000 µg/m^3 and 17,000 µg/m^3 (13 mg/m^3 and 17 mg/m^3), with silica values of 1,700 µg/m^3 and 2,100 µg/m^3. Work practices also contributed to the operator's exposure during the scabbler study because the worker generated the most airborne dust when passing the machine over a previously milled area.

OSHA notes that, although an effective control, the copious water flow of 15 gpm (equal to 1.9 gpm per inch of cutting width) used by the investigators is impractical and probably more than is necessary for walk-behind milling machines. The investigators acknowledge, and OSHA concurs, that in general carefully directed spray nozzles that deliver an optimally sized water mist can achieve better dust suppression with substantially less water. Recent experience with vehicular milling machines demonstrates this point. NIOSH EPHB 282-14a (2009) reports that under common road milling conditions, water spray provided to the cutting drum area at 12 gpm is capable of suppressing dust generated by a 7-foot wide (84 inches) vehicular milling machine cutting drum (an application rate of just 0.14 gpm per inch of cutting width). OSHA preliminarily concludes that, with careful adjustment, water spray methods using a fraction of the water used in the Echt et al. (2002) scabbler study should prove at least as effective in reducing silica dust exposures generated by scabblers. As a simple example, if the same "gpm per inch of cutting width" ratio holds for both the vehicular and walk-behind milling machines, then an estimated water mist application rate of 1.1 gpm (0.14 gpm x 8 inches cutting width) would be appropriate for the walk-behind 8-inch scabbler as used in the Echt et al. (2002) study. OSHA recognizes that differences in the way these machines function and other environmental factors (e.g., indoors, outdoors) might mean that this model for estimating water flow is too simplistic. However, even if the water application rate is doubled to compensate for these uncertainties, the resulting estimated flow rate needed for the 8-inch scabbler is 2.2 gpm.

As discussed previously in conjunction with driven milling machines, Blute et al. (1999) evaluated the silica exposure of workers using wet dust control methods for scabbling and large-scale grinding tasks at an underground construction site. In this case, rather than being walk-behind equipment, the scabblers and grinders were attached to the articulated arm of heavy equipment. Although these workers are classified here as heavy equipment operators (addressed in Section IV.C.24 – Heavy Equipment Operators) and they used drivable machines (removing more material than the typical walk-behind milling machine), their work scabbling and grinding excess concrete from tunnel walls demonstrates the value of wet methods when these activities are performed in enclosed spaces. This is particularly relevant to walk-behind milling machines that are used indoors to mill concrete surfaces. In the underground work environment, all three workers experienced task-based silica concentrations below the current PEL.[278] The authors suggested that this was "most likely due to the use of hoses to wet down the concrete and the greater distance from the source of silica dust to the worker."[279] Although one of the results (79 µg/m^3) exceeds the proposed PEL of 50 µg/m^3, these values are substantially lower than results available for workers performing dry milling of any type, even aboveground. As discussed below, adding LEV near the scabbling and grinding attachments or increasing general dilution ventilation would likely have further reduced all three values.

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[278] The PEL was calculated using OSHA's general industry PEL equation for silica in respirable dust (Blute et al., 1999).

[279] Blute et al. (1999) did not mention the presence of equipment cabs as a control, and so these might not have been available or did not influence exposure because windows were open.

Local Exhaust Ventilation

The similarity between vehicular and walk-behind milling machines also supports use of vacuum dust collection (exhaust suction) methods for the smaller form of milling equipment. As discussed previously, the TNO Bouw (2002) study found that when exhaust suction methods were applied to the milling drum area of vehicular milling machines, exposure levels for operators obtained over a 5-day period ranged from less than 4 μg/m^3 to 28 μg/m^3. The study also found similar exposure results for machine tenders, who walk next to the machine, ranging from less than 3 μg/m^3 to 29 μg/m^3. Additional exposure sources for tenders include conveyers and transfer points, neither of which are components of walk-behind milling machines; instead, on these smaller milling machines the vacuum suction immediately carries all dust and small debris into the vacuum cleaner where the air is filtered before release. However, operators of walk-behind milling machines can experience additional exposure when they empty the vacuum cleaner and clean or change the dust filter. Accepted emptying and disposal methods limit exposure during these activities.

In a European study of control equipment (Hallin, 1983), walk-behind milling machines equipped with dust extractors (i.e., LEV) were tested indoors. The study estimated a median concentration of 280 μg/m^3 for short-term samples ranging from 10 to 60 minutes. Noting that the machine still released a substantial amount of dust into the surrounding environment, Hallin recommended redesigning the exhaust train to release dust outside the work space. Using a vacuum fitted with a high-efficiency particulate air (HEPA) filter would minimize this concern by filtering out airborne particles prior to releasing the air back into the work environment, thus eliminating the need to exhaust the vacuum air outside the workplace. In addition, recent research suggests that studies such as this one might not have used vacuum suction equipment that provided an adequate or consistent level of exhaust ventilation. As discussed in more detail in Section IV.C.32 – Tuckpointers and Grinders, construction sites that use LEV must choose a portable vacuum with the capacity and design to offer consistent vacuum suction. Many of the challenges associated with tuckpointing also must be addressed for construction sites where workers perform aggressive floor milling with walk-behind machines. Specifically, both of these construction activities generate a quantity of debris that can rapidly reduce vacuum suction. To prevent this, vacuum cleaner design should protect filters from rapid dust loading (e.g., cyclonic pre-separation) and offer sufficient suction (measured in inches of water gauge) to move air even when filters begin to load.

One milling machine manufacturer that produces walk-behind scabblers specifically for removing layers of contaminated concrete from floor surfaces recommends the use of a vacuum source that provides at least 75 to 90 cubic feet per minute (cfm) suction for a 6-inch wide scabbler. The contaminants mentioned by the equipment manufacturer (e.g., lead paint and radioactive materials) generally have occupational exposure limits similar to the proposed PEL for silica, suggesting that this rate of exhaust would also be protective of silica (Pentek-Squirrel-III, 1997).[280] Proportionally greater exhaust rates would be required for larger walk-behind milling equipment. For example, another manufacturer of commercially available scabblers recommends specific vacuums for use with specific scabblers: a 160 cfm vacuum with a smaller scabbler and a 500 cfm vacuum with a larger scabbler, for which an industrial dust control vacuum system is recommended as an alternative (EDCO-E-CD3,5-I-0809, 2009). Some scarifiers, particularly those intended for indoor use, are available with both a vacuum port (for connecting a portable industrial vacuum system) and water mist system as standard equipment (EDCO-scarifiers-CPM-8, 2010).

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[280] The same company produces a remote control option for their milling equipment, allowing the operator to work a greater distance from the abrasive action or even stand in another room (Pentek-Squirrel-III, 1997).

However, several limitations to the use of LEV-equipped walk-behind milling machines exist. First, the vacuum suction device needs to be emptied frequently. Workers might need to empty the dust extractor as frequently as every 30 minutes in some work environments, which requires shutting down the vacuum (Concrete Grinding Company, 2000). A vacuum with a pressure gauge can alert workers when the vacuum needs to be emptied and filters cleaned. Second, a vacuum powerful enough to support most common walk-behind milling machines will be large and heavy. A vacuum with a cyclonic pre-separator that achieves sufficient airflow to support a scabbler can weigh 100 to 200 pounds when full. Furthermore, the dust collector generally needs a generator for power, and workers might need to transport the generator with an additional truck or heavy handcart. Although gasoline and propane powered models are available, in general, the need for an electrical power source makes the use of LEV outdoors uncommon.

Another limitation is that the effectiveness of vacuum suction depends on minimizing the gap between the bottom of the machine and the surface being milled (as discussed for drivable milling machines and tuckpointing equipment). To achieve acceptable dust control, milling must proceed in a manner that limits the gap between the bottom of the walk-behind milling machine and the surface being milled (e.g., the floor). As has been shown for road milling equipment, construction sites will find it difficult to control dust emissions if walk-behind milling machines remove excessive depth in one pass. The resulting drop between milled and unmilled surfaces prevents the milling machine from sealing properly against the surface, allowing dust to escape. Workers can achieve better dust control during deep removals by milling to the final desired depth in several incremental phases. However, milling a previously milled surface has been shown to create high levels of airborne dust, and so care must be taken to clean areas with a HEPA-filtered vacuum prior to making a second pass.

Finally, unlike vehicular milling machines, walk-behind machines can be used indoors where natural ventilation is poor and the surface being milled is likely to be concrete. Under these circumstances, special precautions will be needed to prevent airborne silica dust from accumulating. Supplemental general exhaust ventilation (in addition to vacuum exhaust or wet methods), in the form of large fans set in open windows or exhaust trunks creating air exchange similar to an outdoor environment, will help prevent silica dust from collecting in the space.

To date OSHA has not been able to quantify the effectiveness of currently available LEV in controlling respirable quartz levels associated with walk-behind milling operations; however, OSHA believes that evidence from similar construction tasks supports its value for workers performing milling. Although walk-behind milling machines are larger than tuckpointing grinders, the grinding blades operate at lower speeds[281] (dust particles are released at lower energy), and the worker's breathing zone is a greater distance from the point of dust release. Thus OSHA believes that the LEV dust control option might work at least as effectively (and likely more effective) for milling machines as for tuckpointing grinders. Collingwood and Heitbrink (2007) report a 95-percent reduction in silica exposure compared with the geometric mean of 1,140 µg/m^3 for a group of uncontrolled tuckpointing exposure levels. Although the tuckpointers using LEV still experienced a geometric mean result of 60 µg/m^3, walk-behind milling machine operators have the advantages of lower uncontrolled exposure levels, greater distance between the tool and their breathing zone, and equipment that is self-supporting (the milling drum enclosure more easily kept sealed against the floor), rather than hand-held. Therefore, an LEV system with an appropriately sized vacuum will likely reduce most walk-behind milling machine operator exposures to levels lower than those experienced by tuckpointers. For example, even a hypothetical 80 percent reduction in exposure (well below the 95 percent demonstrated for tuckpointers) would reduce the highest walk-behind milling machine operator exposure (80 µg/m^3) to 16 µg/m^3.

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[281] As an example, one type of walk-behind scabbler drum rotates at 1,700 rotations per minute (rpm) (SPE USA, 2006) compared with 11,000 rpm for a tuckpointing grinder blade (Boschtools-rpm, no date).

Housekeeping

Cleanup is critical for both LEV and wet method controls for walk-behind milling machines. Echt et al. (2002) reported that airborne dust increased when the scabbler described above passed over previously milled areas. Milling debris must be cleaned up using a HEPA-filtered vacuum prior to making a second pass over an area, regardless of whether the miller uses wet or dry dust controls. This step prevents the milling debris from interfering with the seal between machine and floor and minimizes the gap. Additionally, it prevents debris from being re-suspended and acting as another source of contamination.

Feasibility Finding

Feasibility Finding for Large Driven Milling Machine Operators

Results presented in the exposure profile indicate that 79 percent of all large driven asphalt milling machine operators already experience silica levels less than 50 µg/m^3 as a result of using water spray adjusted to cool the cutting drum. Considering information presented by NIOSH EPHB 282-14a (2009) and NIOSH EPHB 282-15a (2009) demonstrating low silica exposure (12 8-hour TWA results below 50 µg/m^3) for both operators and tenders across varying flow rates, OSHA preliminarily concludes that improved water spray intended to reduce dust will help reduce exposure levels of the remaining 21 percent of large driven milling machine operators who currently experience exposures above 50 µg/m^3. However, information is insufficient to confirm that this method alone will reliably control most workers' exposures. Until water spray can be adjusted in a manner that consistently maintains exposures to levels of 50 µg/m^3 or less, this control method will need to be paired with either additional spray on the conveyer and a dust suppressant, as described by Van Rooij and Klaasse (2007), or a vacuum suction system, as described by TNO Bouw (2002).

Van Rooij and Klaasse (2007) tested a novel wet dust emission suppression system and found that it reduced the PBZ respirable quartz exposure of asphalt milling machine drivers to a mean of 20 µg/m^3 (n = 4) with a range of 9 µg/m^3 to 30 µg/m^3. TNO Bouw (2002) reported that, after retrofitting milling machines to add exhaust ventilation and make modifications to the grinding drum box so that it can be held under negative pressure by the ventilation system, driven milling machine operators in Europe experienced exposure levels of 29 µg/m^3 or less. OSHA preliminarily concludes that these methods, combined with water spray systems purposefully designed to control dust at the cutting drum, transfer points, and conveyers, will control vehicular milling machine operators' silica below 50 µg/m^3 during "mill and fill" operations under the typical range of conditions (e.g., day and night, warm and cool weather, asphalt and concrete road surfaces).

However, these control measures, even in combination, might not be sufficient to maintain exposure levels below the proposed PEL of 50 µg/m^3 during road demolition activities, such as full-depth removals or removals greater than 4 inches deep. For these rare occurrences, respiratory protection will be required to protect the milling machine operators until additional controls can be developed.

Feasibility Finding for Large Milling Machine Tenders

Based on the information presented in this section, OSHA preliminarily concludes that the exposure levels for most tenders of large milling machines can be reduced to 50 µg/m^3 or below most of the time using the same methods described for the operators of large milling machines. As presented in Table IV.C-64, the exposure levels for 66 percent of large milling machine tenders are already 50 µg/m^3 or less. Workers on the ground near driven milling machines in the Netherlands experienced results in the same range as the operators (from less than 3 μg/m^3 up to 29 μg/m^3) regardless of whether or not a mechanical sweeper followed the milling machine (TNO Bouw, 2002). With LEV and wet method control options, both of which prevent dust release from the bottom of the machine, tenders on the ground had exposures similar to those reported for the operators at the top of the machine.

As is the case for milling machine operators, these control measures, even in combination, might not be sufficient to maintain milling machine tenders exposure levels below the proposed PEL of 50 μg/m^3 during full-depth removals or removals greater than 4 inches deep. For these rare occurrences, respiratory protection will be required to protect the milling machine tenders until additional controls can be developed.

Feasibility Finding for Walk-Behind Milling Machine Operators

Based on the data described above, OSHA preliminarily concludes that construction sites can achieve an exposure level of 50 μg/m^3 or below for most workers operating small, walk-behind milling machines most of the time by providing vacuum suction dust collection or wet methods with added dust suppressant (or both). OSHA draws this conclusion from success with dust controls for larger milling machines and for tuckpointing and grinding equipment. As discussed previously, similar control measures (wet methods and LEV) can be adapted to walk-behind milling machines and should provide similar results during grating activities in comparable work environments. OSHA finds compelling evidence that controls effective for vehicular milling machines are adaptable to the smaller (and thus potentially easier to control) walk-behind milling machines.

Even in indoor environments, results below 50 μg/m^3 can be achieved for most walk-behind milling machine operators most of the time through vigorous use of controls, conscientious housekeeping (including cleaning up debris between passes of the machine) and general ventilation that promotes good air circulation in the space. ERG (ERG MTF-A, 2000) measured exposure levels below the LOD (12 μg/m^3) for two milling machine operators using wet methods indoors.

Overall Feasibility Finding

OSHA preliminarily concludes that silica exposure levels of 50 μg/m^3 or lower can be achieved for most milling machine operators and tenders most of the time using wet dust controls or vacuum suction methods. In situations where wet methods alone do not adequately capture dust, foam additives will help bring exposure to an acceptable level. Workers milling concrete or milling in enclosed indoor or tunnel environments for extended periods will likely require both wet methods and some form of exhaust ventilation.

If, on a rare occasion, a milling job calls for milling equipment to cut deep into a surface, operators and tenders of large driven milling machines will require respiratory protection. Operators of walk-behind milling machines will require administrative controls to ensure that workers remove the material incrementally and perform housekeeping after each pass, particularly in indoor work areas. Making several passes with moderate cut depth minimizes large depth changes between milled and un-milled surfaces. These controls will protect both the milling machine operators (vehicular and walk-behind) and the tenders who assist them.

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Rock And Concrete Drillers

Description

This section covers workers who use vehicle-mounted drilling rigs to produce deep holes in the ground or in concrete. The holes typically range from 1 inch to more than 6 inches in diameter and can reach a few inches to more than 100 feet deep. The workers typically guide and activate drill bits from control panels mounted on their vehicles and remove a substantial volume of rock or concrete over the course of a shift. This section also includes roof bolters who work at construction sites and use rig-based drills to produce holes in tunnels, both overhead and in wall surfaces.[282] Although the equipment used for each type of drilling varies, OSHA concludes that workers using drilling rigs of all types for rock, earth, and concrete can be addressed together in this section because the worker activities have much in common and the general methods of silica control are also similar. Specifically, these workers control the vehicle-mounted or rig-based drills from more than an arm's length from the drill bit(s). They also perform certain intermittent tasks near the drilling point, such as fine-tuning the bit position, moving debris away from the drill hole, and working directly or indirectly with compressed air to blow debris from deep within the holes.

When drilling rock, workers typically use rigs that are vertically oriented and equipped to produce a deep hole through the addition of bit extensions, often for purposes such as inserting explosives in rock formations or creating hydrogeological wells. Drill bits can be solid or hollow. These track-, truck-, or trailer-mounted rigs are frequently equipped with compressed bailing air, which is continuously forced through a bit's hollow core (when available) to "bail" rock or concrete dust and debris from the bottom of the deep hole (ERG-C, 2008).

To drill concrete, workers often use rigs that consist of an array of one or many drills fixed to the maneuverable arm of a construction vehicle (e.g., backhoe, bulldozer, forklift) or purpose-built mobile machine, which permits the operator to produce a series of precisely spaced mid-size holes, typically a pre-set depth of a few inches to 4 feet, at any orientation. The holes might be used as part of demolition work (as anchor points for lifting gear or to insert explosives), but commonly are intended to receive rebar and dowel-pin reinforcements in concrete repair work (e.g., when replacing part of a concrete bridge deck). As with rock drilling, the drill bits can be solid or have a hollow core through which compressed air or water is forced to clear the hole (Minnich, 2009a). Workers who use these rigs routinely use hand-held compressed air nozzles to blow debris from completed holes (NIOSH EPHB 334-11a, 2008). As a standard practice, some types of rock or concrete drill bits (e.g., diamond tip) are water fed to improve function and extend the useful life of the bit.

Table IV.C-66 presents job categories, major activities, and sources of silica exposure for workers using drilling rigs. Although rig-based drilling is often a one-person job, some of the associated activities, such as fine-tuning the drill position and clearing debris from in or around the holes, can be performed by a second worker (ERG-C, 2008).

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[282] Most roof bolters work in the mining industry, but are sometimes employed in construction tunnels. Only roof bolters who work at construction sites are covered in this analysis.

IV.C-66

Job Categories, Major Activities, and Sources of Exposure of Workers Using Rock and Concrete Drilling Rigs

Job Category*	Major Activities and Sources of Exposure
Worker Using Drilling Rigs	Position and operate drill rigs from control panel mounted on vehicle or rig. • Dust from action of drill bit. Adjust bit position. • Dust from action of drill bit and bailing air or compressed air nozzle. Clear tailings and dust from in or around the hole, during or after drilling. • Dust raised by bailing air or compressed air nozzle.

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the operation.

Sources: ERG-C, 2008; ACPA, 1995; FHWA, 2006; NIOSH EPHB 334-11a, 2008.

Baseline Conditions

Baseline Conditions for Workers Using Drilling Rigs

ERG-C (2008) summarizes the best exposure monitoring data available to OSHA for drilling rig operators, which include 39 sampling results for various drilling rig configurations including track-mounted rigs drilling holes 80 feet deep through granite and multi-drill sets (dowel packs) drilling a few inches into concrete.[283] The various sites range from a concrete highway repair construction site to a 10-acre rock excavation site where drilling rig operators produced blast holes during the demolition phase prior to building a parking lot and below-ground theaters. These data were reported in four OSHA Special Emphasis Program (SEP) reports, four NIOSH investigations, unpublished data from a state health department, and a published article (Lynch, 2002; NIOSH-Breckenridge, 1992; NIOSH ECTB 233-120c, 1999; NIOSH ECTB 233-122c, 1999; NIOSH-Shelly, 1995; NJDHSS, 2000; and OSHA SEP Inspection Reports 200458362, 300035557, 300340908, and 301459095).

ERG reviewed working conditions for construction workers (drillers as well as laborers) using drilling rigs and found that the exposures and controls vary from job to job (ERG-C, 2008). Significant sources of variability include:

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[283] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) calculated assuming no additional exposure during any unsampled portion of the shift. Unless explicitly stated otherwise, all results discussed in the additional controls section are also 8-hour TWAs calculated the same way. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

- The substrate being drilled (rock or concrete).
- The silica content of the substrate (silica levels often vary by 20 to 50 percent from site to site, with the greatest range occurring between different types of rock).
- The type of hole being drilled, which influences the type of bit used (water-fed diamond/coring bits cut more slowly but are preferred when workers need to minimize chips and fractures in the substrate [“spalling”]).
- The work location and proximity of other activities (including whether the location requires dust emissions control and if these controls are used effectively).
- Whether the rig has an enclosed cab.

Based on ERG’s report (ERG-C, 2008) and the exposure profile presented in Table IV.C-67, OSHA concludes that baseline conditions for workers using drilling rigs include a range of conditions, from no controls to systems that integrate one or more of the following: dust extraction (in the form of local exhaust ventilation [LEV]), wet methods at the drill hole, and dust management techniques (such as enclosure and wet methods) at the point where the system ultimately dumps extracted dust. Information from industry sales representatives serving the construction industry suggests that water-fed bits are used frequently for many types of drilling, but dust extraction systems and augmented water pumps are less common (Minnich, 2009a; Drilling Rig Manufacturer A, 2009).[284] This information suggests that the industry profile underestimates the proportion of workers using drilling rigs that might require controls.

Using the best available data, OSHA reviewed 17 exposure results associated with a group of workers using drilling rigs with no controls, described previously in ERG-C (2008). These results, summarized in Table IV.C-67, include 8-hour time-weighted average (TWA) exposure levels obtained at six worksites for 16 workers using concrete drilling equipment and one worker using a rock drilling rig. These data indicate that in the absence of controls, nearly 20 percent of these workers have silica exposure levels of 50 micrograms per cubic meter (µg/m^3) or less, and approximately 60 percent are exposed to levels above 100 µg/m^3 (including workers drilling either rock or concrete). Substantially lower exposures have been reported for a second group (workers who routinely use drilling rigs fitted with one or more features that reduce exposure, such as some form of wet methods, air exhausted from the bit entry point, or an enclosed cab). Among the data that are available to OSHA for this second group, more than 80 percent of the results were less than 50 µg/m^3, and just one of the 22 workers experienced

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[284] Conversations with drilling rig manufacturers indicate that it is rare for new rigs to be ordered with the upgraded water pumps that permit optimal water flow for dust control (the water pumps provided as standard equipment support only water-fed bits, but not other uses, such as water mist spray in dusty areas above ground, for which a pump upgrade is helpful). In contrast, hollow-core bits are relatively common in certain sectors of the rock drilling industry, such as for core drilling in granite, and when diamond-tipped bits are used, some water is added to the bailing air to protect the bit. Rock-drilling rig customers, however, rarely purchase the more versatile pumps that permit more than a minimal amount of cooling water to be added (Drilling Rig Manufacturer A, 2009). Water-feed kits for concrete drilling rigs are also purchased infrequently, in part because the process requires considerable water (often 1 to 3 gallons per minute). Minnich (2009a) indicates that these water-fed systems are used primarily in underground construction operations. Furthermore, although diamond-tipped bits are more likely to be hollow, the slower action of these bits reduces their popularity. A diamond-tipped bit can take four to 10 times as long to produce a hole of the same size, compared with other bit styles (Minnich, 2009a). Finally, among employers purchasing concrete drilling rigs, water-fed systems are being phased out in favor of dust collecting equipment.

an exposure exceeding 100 µg/m^3. Overall, the exposure profile shows that 21 of the 39 workers (54 percent) who use drilling rigs, with or without any controls, have exposure levels of 50 µg/m^3 or less.

The highest exposure for this job category (1,190 µg/m^3, based on an 8.5 hour sample) is associated with a drilling assistant who stood at the back of the rig to help position the drill during a highway construction project (NIOSH-Shelly, 1995). Other results for this job category are substantially lower, but still often exceed 100 µg/m^3 when dust controls are ineffective or not used. For example, an 8-hour TWA value of 540 µg/m^3 was reported for a drill operator dry drilling with the dust collection system out of operation, to produce holes in rock that contained 17 to 42 percent quartz (NIOSH-Breckenridge, 1992). This 8-hour TWA was based on a result of 800 µg/m^3 collected over 324 minutes. Not unexpectedly, some of the lowest concentrations were associated with dust controls at the drill hole. Results of 12, 31, 35, and 54 µg/m^3 were reported for workers who spent the whole shift operating or assisting with drilling rigs fitted with water feeds or vacuum dust collection (or both) (SEP Inspection Report 300340908; NIOSH ECTB 233-122c, 1999).

OSHA was not able to obtain information on exposures of roof bolters (a type of drilling rig operator) at U.S. construction sites; however, mining data reviewed by NIOSH showed that in coal mines 70 percent of respirable dust samples for roof bolters in the United States contain more than 5 percent silica, and 25 percent of those (or 17.5 percent of the total) exceed 100 µg/m^3. NIOSH considers exposure from adjacent sources of silica dust a primary cause of the elevated exposures (Goodman and Organiscak, 2002). Although roof bolters work underground and most other drilling rig operators work above ground, this percentage of operators exposed to silica at levels above 100 µg/m^3 is similar to, but slightly less than, the exposure profile for rock and concrete drillers presented in Table IV.C-67, which indicates that 28 percent of these workers experience exposure levels greater than 100 µg/m^3. Among the results available to OSHA, dust in drilling rig operator samples also routinely exceeds 5 percent silica. International information published by Bakke at al. (2002) suggests that roof bolters at a Norwegian tunnel construction site would experience a geometric mean quartz concentration of roughly 100 µg/m^3 during drilling; however, the tunnel construction site workers spent no more than a quarter of the shift on this activity. In the absence of other information, these studies from the U.S. mining and Norwegian construction industries demonstrate that, although underground, roof bolter exposure levels may be generally comparable to the exposure of other drilling rig operators. This is likely due to ventilation routinely installed at tunnel construction sites and rock bolters' current regular use of engineering controls, such as vacuum suction collector boxes described later in this section.[285]

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[285] See Section IV.C.33 – Underground Construction Workers for further details regarding other in-tunnel sources of silica exposure, as well as current requirements and recommendations for tunnel ventilation.

IV.C-67

Respirable Crystalline Silica Exposure Range and Profile for Workers (Drillers and Laborers) Using Rock and Concrete Drilling Rigs

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean (µg/m³)**	**Median (µg/m³)**	**Min (µg/m³)**	**Max (µg/m³)**		**<25 (µg/m³)**	**≥25 and ≤50 (µg/m³)**	**>50 and ≤100 (µg/m³)**	**>100 and ≤250 (µg/m³)**	**>250 (µg/m³)**
Worker Using Drilling Rigs											
No Controls	17	219	125	12	1,190		1 5.9%	2 11.8%	4 23.5%	6 35.3%	4 23.5%
One or More Controls	22	30	19	10	110		13 59.1%	5 22.7%	3 13.6%	1 4.5%	0 0.0%
Totals	**39**	**112**	**50**	**10**	**1,190**		**14** **35.9%**	**7** **17.9%**	**7** **17.9%**	**7** **17.9%**	**4** **10.3%**

Notes: All samples are personal breathing zone (PBZ) results and represent 8-hour time-weighted average exposures with the assumption that no additional exposure occurred during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Sources: Lynch, 2002; NIOSH-Breckenridge, 1992; NIOSH ECTB 233-120c, 1999; NIOSH ECTB 233-122c, 1999; NIOSH-Shelly, 1995; NJDHSS, 2000; and OSHA SEP Inspection Reports 200458362, 300035557, 300340908, and 301459095.

Additional Controls

Additional Controls for Workers Using Drilling Rigs

ERG (ERG-C, 2008) reviewed literature suggesting that additional controls for workers using drilling rigs could include environmentally controlled cabs for operators; more consistent use of wet methods specifically adjusted to maximize dust control; optimized dust collection systems involving adequate exhaust air, effective shrouds and shroud placement, and appropriate filtration (when used); and worker position (out of the dust plume). OSHA concurs that these factors affect worker exposure levels and finds that, when used together, wet methods and dust collection systems benefit workers as they perform all activities associated with drilling rigs. Reducing workers' reliance on compressed air for cleaning holes will minimize another notable source of silica exposure. Worker exposures will be further reduced by supplemental controls on dust collector discharge points and use of remote control devices that give operators the freedom to adjust their positions within the local work area.

Construction and mining investigators have long known that routine use of wet dust suppression methods substantially reduces worker exposure to dust. Historically, investigators have reported dust control efficiencies of 96 to 98 percent, depending on the methods used; however, adequate water flow for dust control created problems under certain working conditions (e.g., moisture shortening life of tricone roller bits, high-pressure water causing spalling of the drill hole wall). Advances in recent decades have produced equipment that permits workers to use wet methods in a wider range of circumstances. New "water separator sub" designs extend bit life beyond the previous norm and reduce spalling in a variety of rock types (NIOSH EPHB 334-11a, 2008).

Consistent use of dust extraction shrouds or hoods reduce worker exposures at both rock and concrete drilling sites. NIOSH showed that dust collector efficiency is optimal when workers use an appropriate suction rate, maintain the shroud (surrounding a bit) in good condition, and keep the shroud positioned to fully enclose the bit as it enters the hole. NIOSH reviewed dust control research conducted from the 1920s through the early 2000s and found that when used properly, modern shroud designs now help achieve this objective more consistently for rock drilling rigs than they once did (Reed et al., 2008). Dust collectors and shrouds are commercially available (Drilling Rig Manufacturer A, 2009). NIOSH sought to quantify reductions in respirable dust emissions associated with LEV from a dowel drilling machine in a controlled setting. For these concrete drilling rigs, NIOSH found that close-capture dust collection hoods ("boots") fitted onto each drill on the array reduced respirable dust concentrations by 89 percent compared with drilling without the boots. The equipment tested included an array of five drill bits and associated hoods (NIOSH EPHB 334-11a, 2008). These dust collectors are also commercially available (Minnich, 2009a; EZ-Drill, 2009).

NIOSH recommends several modifications to typical concrete drilling rig dust collection equipment. OSHA anticipates that these upgrades could help ensure that optimal dust collection efficiency is maintained over time. The modifications include using smooth ducts and maintaining a duct transport velocity of 4,000 feet per minute to prevent duct clogging; providing pipe clean-out points; installing pressure gauges across dust collection filters so the operator can clean or change the filter at an appropriate time; and installing static pressure taps in hoods and vacuum gauges on the operator's panel, enabling the operator to confirm that the hoods are operating as designed (NIOSH EPHB 334-11a, 2008). Furthermore, a video of concrete drilling using dust collection equipment showed an initial plume of dust that lasted 5 to 15 seconds after the worker activated the drill (Minnich, 2009b). OSHA also believes that the overall collection efficiency would be improved by activating the exhaust suction prior to initiating drilling and deactivating it after the drill bit stops rotating. Over the course of the work shift, modifications such as those suggested by NIOSH and OSHA would both reduce worker exposure levels.

OSHA finds that both water-fed bits with sufficient water flow, and a combination of wet methods and dust collectors, further reduce exposures to the extent that the majority of workers experience silica exposure levels less than 50 µg/m^3. Exposure results from the late 1990s for workers operating or tending rock drilling rigs support this conclusion. With one exception, the 13 workers who operated or tended rock drilling rigs equipped with either water-fed bits or water-fed bits and dust collectors experienced silica exposure levels less than 50 µg/m^3 (ERG-C, 2008). The respirable dust levels from four sites, from which the silica results were obtained, ranged 50 µg/m^3 to 400 µg/m^3. The silica content in the respirable dust ranged from below detectable to 25 percent of the respirable fraction. Sample durations ranged from 408 to 480 minutes. Associated bulk dust samples contained up to 40 percent silica. The one exception was a result of 61 µg/m^3 (17 percent quartz, 450 minutes duration) for a worker operating one of two side-by-side rock drilling rigs, each of which used less than 1 gallon of water during the work shift to implement its “wet methods” that rainy day (ERG-C, 2008). In contrast, a water flow rate of 0.2 gallons per minute (equal to 1 gallon every five minutes, or 12 gallons per hour) is typically recommended for the type of equipment used (Organiscak and Page, 1995, as reported in Reed et al. [2008]).

Both the rock and concrete drilling rigs are increasingly available with dust collectors that draw air from around the point where the drill bit(s) enter the rock or concrete. Modifications to dust collector discharge areas (e.g., cyclones, shrouds, distance) have reduced exposure from this source by 63 to 89 percent (reported in NIOSH EPHB 334-11a, 2008). Research shows that in the vicinity of the rock drilling rig, dust collector dumping operations were the largest single contributor of airborne respirable particulates. Maksimovic and Page showed that in rock drilling rigs this source contributed 38 percent of the respirable dust emissions, while the deck shroud contributed 24 percent, and the table bushing contributed 24 percent (reported in Reed et al., 2008). These figures indicate that a 63- to 89-percent reduction in discharge dumping emissions can translate into a 24- to 34-percent reduction in the overall airborne particulate burden near the rig.[286]

NIOSH also tested a similar ventilation system: the dust collector boxes used by roof bolters in the mining industry (vacuum system pulls dust through the drill steel back to the collector box, where it is captured on a filter). NIOSH concluded that when maintained properly, these systems can be “very effective in capturing and removing dust generated by drilling” (Colinet and Thimons, 2007). These authors report that effectiveness can be increased by adding dust collector bags to the system. With collector bags added, filter loading was reduced by 80 percent (so the filter needs cleaning less often and lasts longer), and it was much easier for the bolter operator to service the box, resulting in far less dust exposure (Colinet and Thimons, 2007). Listak and Beck (2008) reported that the collector (with bag) ran longer between filter cleaning and captured more than 99 percent of a test dust. Since the test dust was finer than typical drilling dust, the collector would capture at least as much dust produced by the drill.

The same investigators suggested air curtains as another option for reducing roof bolter silica exposure underground. In this case, a fan pulls air through a filter and releases this cleaned air over the worker, enveloping the worker in a curtain of clean air (Colinet and Thimons, 2007). Laboratory tests showed a 40- to 60-percent reduction in dust levels under the curtain and respirable quartz levels that were 40 µg/m^3 below concentrations in a nearby area (Goodman et al., 2006).

Wireless or tethered remote controls are becoming more readily available for some types of construction equipment. A concrete drilling rig tested by NIOSH was fitted with a commercially available remote control that permitted the operator to activate the rig from a moderate distance (e.g., 5 to 20 feet)

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[286] A 63-percent reduction in the 38-percent dust emissions attributed to discharge dumping operations could result in a 24-percent reduction in the overall level of respirable dust near the drilling rig (0.63 x 0.38 = 0.24, and 0.89 x 0.38 = 0.34).

(NIOSH EPHB 334-11a, 2008; Minnich, 2009b). OSHA anticipates that when workers have access to wireless controls, this technology can help minimize worker silica exposure by permitting the worker to move freely within the local work area. When given an opportunity, workers typically step away from plumes of visible dust (Lynch, 2002; Minnich, 2009b; Modern Contractor Solutions, 2009).

Cecala et al. (2005) studied modifications designed to lower respirable dust levels in an enclosed cab on a 20-year-old surface drill at a silica sand operation. The researchers incorporated a number of modifications into the drill's filtration and pressurization system, along with other areas, to improve performance. They studied respirable dust levels collected inside and outside the cab before and after modification. They found that effective filtration and cab integrity (e.g., new gaskets, sealing cracks) to maintain a positive-pressure environment are the two key components necessary for dust control in an enclosed cab. OSHA notes that cabs benefit the operator in the cab and do not affect the worker’s exposure during positioning or hole-tending activities.

By using a high-efficiency particulate air (HEPA)-filtered vacuum instead of compressed air to clean holes, worker exposure from this source could be eliminated, except when workers empty the vacuums. Because the vacuum nozzle must be inserted into each hole (potentially hundreds to thousands), workers using vacuums to clean holes are likely to require extra time to complete the task compared with using compressed air, which requires less precision.

Feasibility Finding

Feasibility Finding for Workers Using Drilling Rigs

Based on the information presented in Table IV.C-67, OSHA preliminarily concludes that construction sites have already achieved exposure levels of 50 µg/m^3 or less for more than half (54 percent) of workers operating rock and concrete drilling rigs. Although a few of these workers were using drilling rigs with no controls, most of these exposures were achieved through the use of one or more controls. The controls used include: 1) wet dust suppression methods (water-fed drill bits, misting points of dust release, and in some cases using a more powerful water pump than typically provided with the drilling rig), 2) shrouds and hoods connected to dust extraction equipment, and 3) managing dust collection dump points. Twelve of 13 workers using drilling rigs associated with one or more of these controls on the test date had exposure levels less than 50 (the 13th worker used an inadequate water flow rate). Note that there are 9 samples associated with the use of enclosed cabs and 13 samples associated with the use of the controls mentioned in this paragraph (a total of 22 samples associated with some kind of exposure control). As noted previously, however, OSHA acknowledges that the available data might underestimate the proportion of rock and concrete drillers using rigs that might require controls.

To reliably achieve exposure levels of 50 µg/m^3 or less, employers of workers who use drilling rigs must ensure that both water and local exhaust air flow are used and optimized each time the drill is operated. For concrete drills that are heavily used, optimization might include adding improvements recommended by NIOSH to help ensure that effective dust collection is maintained over time (convert from rough to smooth ducts with sufficient transport velocity, add pipe cleanout points, and include pressure gauges to indicate filter loading and hood function). If excessive exposure persists, rig owners can take additional steps. They can modify the dust extractor to better capture the particles released as the drill starts and stops. If the dust extractor is activated simultaneously with the drill, the extractor likely will not have reached full power before the drill begins generating dust. By activating the dust extractor before the drill starts and by turning the dust extractor off only after the drilling stops, the dust extractor will be able to capture silica particles that would otherwise escape into the work zone air. Rig owners can also modify (enclose, or moisten) the dust collector discharge area to minimize re-suspension of dust at dust collection areas. Additionally, use of hand-held compressed air nozzles for cleaning holes must be replaced with HEPA-filtered vacuums to avoid suspension of crystalline silica containing dust.

These controls will benefit all workers working around the drilling rig, not just rock drill operators. Drilling rig operators who spend at least part of their shift in an enclosed cab or have the option of remote controls will experience exposure levels that are even lower. These methods are already in use by some drillers (ERG-C, 2008).

Some drilling rig operators, who already experience very high exposures (e.g., the 10 percent of workers with exposure levels exceeding 250 µg/m^3 in Table IV.C-67), will need to wear a respirator until their exposures have been effectively controlled.

In summary, OSHA preliminarily concludes that for most workers operating most rock and concrete drilling rigs, silica exposure levels of 50 µg/m^3 can be achieved most of the time by using additional exhaust ventilation, water spray equipment, and HEPA-filtered vacuums. Further measures may be required for the workers who are currently most highly exposed.

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Rock-Crushing Machine Operators and Tenders

Description

Rock crushing machines are used to crush rocks, concrete, or construction rubble down to sizes suitable for various construction uses.[287] Workers control machine functions and clear foreign or impacted material from the machine. Once crushed, material exits the hopper and is carried along conveyor belts into a pile or into secondary and tertiary crushers (ERG-C, 2008). Rock crushing operations might also include magnetic separation, powdering, and vibratory screening (sieving).

Workers can be exposed to silica generated during crushing operations while they manage the machine's controls, oversee the operation, and signal the tractor operator (typically a worker in the heavy equipment operator job category) about dumping loads into the crusher hopper. At most construction sites, the worker overseeing machine function spends a substantial portion of the shift in a "crow's nest" next to the primary hopper to allow the operator to view the inside of the hopper, at which point the operator's breathing zone is about 5 to 10 feet from the edge of the hopper opening. The operator's platform is typically not enclosed and has an area of about 10 square feet.

The same worker might also periodically tend the rock crushing machinery from platforms or on the ground at various points along the moving conveyor belts, ensuring that foreign material (wood, rebar, wire) does not proceed through the process. The worker might also pick up debris that has fallen off the conveyor belts, or clear material that becomes impacted in the crusher, hoppers, or belts. At some construction sites, particularly where construction rubble contains a significant amount of foreign material, other workers (e.g., laborers, belt pickers, utility operators) perform these tasks (ERG-C, 2008).

Table IV.C-68 summarizes job categories, major activities, and sources of exposure of rock crushers.

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[287] Rock crushing operations at fixed sites are considered quarrying operations and fall under the jurisdiction of the Mine Safety and Health Administration. Only "portable" rock crushing operations, such as those associated with construction sites, fall under OSHA jurisdiction.

IV.C-68

Job Categories, Major Activities, and Sources of Exposure

of Rock-Crushing Machine Operators and Tenders

Job Category*	**Major Activities and Sources of Exposure**
Worker Operating Rock Crushing Machines	Managing mobile rock crushing machine function while working at control position(s). • Dust from crushing, grinding, and screening operations. • Dust from open transfer of silica-containing materials (e.g., open conveyors, material loading or discharge points, sizing screens). Working at access points tending crushers and conveyers to clear foreign or impacted material. Keeping the area clean (picking up debris). • Dust from crushing, grinding, and screening operations. • Dust from open transfer of silica-containing materials (e.g., open conveyors, material loading or discharge points, sizing screens).

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the operation.

Source: ERG-C, 2008.

Baseline Conditions and Exposure Profile

The exposure information available to OSHA for rock crushers is limited to workers either controlling the machine, or alternately controlling and tending the equipment to clear foreign or impacted material; no construction industry data are available for workers strictly tending crushing machines without also spending time operating them. Table IV.C-69 summarizes the exposure results for workers associated with crushing machines. These results come from three OSHA Special Emphasis Program

(SEP) inspection reports (OSHA SEP Inspection Reports 11345975, 2116507, 300441862).[288] Although limited, these values represent the best data available to OSHA for workers involved in rock crushing operations.[289]

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[288] Two of the OSHA SEP inspection reports are associated with the construction industry, and one is associated with the asphalt paving products industry; however, at the time of the evaluation, the rock crusher at the asphalt industry site was recycling concrete construction debris with no more (and possibly fewer) exposure controls than is typical for a construction site (OSHA SEP Inspection Report 2116507).

[289] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) calculated assuming no additional exposure during any unsampled portion of the shift. Unless explicitly stated otherwise, all results discussed in the additional controls section are also 8-hour TWAs calculated the same way. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

IV.C-69
Respirable Crystalline Silica Exposure Range and Profile for Rock-Crushing Machine Operators and Tenders

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean (μg/m³)**	**Median (μg/m³)**	**Min (μg/m³)**	**Max (μg/m³)**		**<25 (μg/m³)**	**≥25 and ≤50 (μg/m³)**	**>50 and ≤100 (μg/m³)**	**>100 and ≤250 (μg/m³)**	**>250 (μg/m³)**
Rock Crusher (machine operators and tenders)	5	798	300	172	1,860		0 0%	0 0%	0 0%	1 20%	4 80%

Notes: All samples are personal breathing zone (PBZ) results and represent 8-hour time-weighted average (TWA) exposures with the assumption that no additional exposure occurred during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Source: ERG-C, 2008.

In Table IV.C-69, the exposure profile for workers operating crushing machines summarizes five 8-hour TWA silica exposure results based on samples of 2 to 8 hours duration. Sample results range from 172 micrograms per cubic meter (μg/m^3) of air to 1,860 μg/m^3, with a median of 300 μg/m^3 and a mean of 798 μg/m^3.

Based on a review of ERG-C (2008), OSHA finds that baseline conditions for construction workers associated with rock crushing machines include the use of some form of dust suppression additive (e.g., water, asphalt), but application is either inconsistent or inefficient. Workers typically do not use engineering controls or dust-suppressing work practices. Because the sample results summarized in Table IV.C-69 were obtained under baseline conditions, OSHA estimates that the baseline median exposure for workers using concrete crushers is represented by the median value (300 μg/m^3) reported in Table IV.C-69.

At one of the construction sites, where full-shift respirable quartz PBZ results of 172 μg/m^3 and 300 μg/m^3 were measured, workers stated that conditions were atypical on the day of sampling: the supply of asphalt, which was usually added to the primary hopper to control dust, had run out early in the day. A water hose was aimed at the conveyer instead (ERG-C, 2008). Although these data might not represent typical conditions at this site, they indicate the potential for exposure in poorly controlled conditions. The highest results for this job category (1,380 μg/m^3 and 1,860 μg/m^3) were obtained at another construction site where a water mist was applied at two points on the crusher (OSHA SEP Inspection Report 11345975). Although the OSHA official who visited this work site commented favorably on the attempt to use a wet dust suppression method, OSHA noted that the construction site could achieve better dust control using techniques such as matching spray nozzle to the situation, adjusting spray position and angle, and modifying water flow.

Additional Controls

The primary additional controls for rock crushers include improving water application methods, applying wetting agents and/or dust suppressant materials, installing local exhaust ventilation (LEV) at the hopper and other locations along the conveyors, using enclosed operator control stations equipped with LEV (which benefits the worker only when inside the station), and employing work practices that position the worker away from dust-generating processes as much as possible (e.g., using remote control devices, implementing management controls to limit the amount of foreign material that enters the crusher).

Wet Methods

As noted in the previous section, the water spray might not have been optimal in the cases available to OSHA. As will be shown here, the use of greater quantities of water, multiple water spray (mist) outlets into the hopper and along conveyor belts, and better designed and directed water sprays effectively reduce the exposures of workers both while they are controlling the crushing machine and while they are working as tenders at access points or on the ground.

Evidence that improved water dust control can reduce silica levels is provided by a full-shift (PBZ) silica result of 54 μg/m^3 obtained for the operator of a stationary crusher at a temporary concrete recycling facility using fine-mist water spray (ERG-concr-crush-A, 2001).[290] Multiple water spray nozzles were located at the crusher hopper, the post-crusher conveyer, the sizing screens exit point, and each

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[290] Although it could be disassembled and moved, this equipment was not mobile, and the crusher system size was more typical of an extensive fixed location crushing operation (ERG Concr Crush A, 2001). Therefore, the exposure profile (Table IV.C-69) does not include exposure results associated with this crusher.

major transfer point, including the point where crushed material eventually fell to a pile on the ground. The crusher operator controlled the nozzles from a panel in the control booth. The number of nozzles in action varied according to site conditions. The objective was to eliminate all visible dust using the least amount of water. The crusher staff noted that water sprayers were checked frequently and replaced if they became clogged, dripped, or squirted water, rather than producing a mist spray. At this site, the machine operator spent much of the shift inside a poorly sealed booth directly over the crusher, but left the booth frequently to spray extra water (large droplets from a hose with a garden nozzle) as material was dumped into the crusher. During the shift, this worker also inspected conveyers and shoveled dry impacted crushed concrete from clogged hoppers and conveyers (performed without dust suppression). Silica concentrations inside the booth were below the limit of detection (LOD) (19 µg/m^3 in this case), while the concentration outside the booth was higher (103 µg/m^3) over the entire shift.[291] OSHA estimates that if the water hose (used by the operator at the crusher) had provided a finer mist, and if water spray had been available at the clogged hoppers cleared by the operator, then this operator's exposure level would have been well below 50 µg/m^3 on this sampling date. However, wet ground conditions meant that the concrete being crushed was wetter than usual, which might have helped minimize airborne dust. More extensive water application would be necessary on days when the ground was dry.

An international report on wet dust control methods for rock crushers in India offers further strong evidence that water mist reduces silica for rock crushing operations under some circumstances. At several small, tightly clustered rock crushing machine sites in India, five initial respirable quartz results obtained during dry crushing operations ranged from 60 µg/m^3 to 360 µg/m^3, with a median of 290 µg/m^3 and a mean of 246 µg/m^3 (Gottesfeld et al., 2008). Although the stationary (movable, but apparently not mobile) crushers were mechanized (powered), the workers loaded the crusher hopper manually and carried off the crushed material by hand in sacks. None of the crushing machines was equipped with an operator's booth. Among the sites evaluated for this study, the bulk stone quartz content ranged from below 4 percent to 27 percent, with an additional 3 to 6 percent cristobalite at some sites.

Results were markedly lower when water spray systems were installed. Of the 150 small Indian crushing mills in the study area, 40 subsequently agreed to install atomizing water spray dust suppression systems.[292] The 18 follow-up breathing zone and area samples collected during the monsoon season range from 5 µg/m^3 to 55 µg/m^3, with a median of 11 µg/m^3, and a mean of 14 µg/m^3 (sampling durations not reported).[293] A second set of follow-up samples were collected during the dry season. These 27 post-control dry season samples (15 PBZ and 12 area samples), obtained over approximately 2 to 5 hours, range from 10 µg/m^3 to 630 µg/m^3, with a median of 20 µg/m^3, and a mean of 63 µg/m^3. Gottesfeld et al.

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[291] Results reported as "none detected" are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

[292] The water spray systems were provided by an international partnership studying silica exposure in the crushing mills, where the workforce primarily consisted of tribal women and adolescent girls (Gottesfeld et al., 2008).

[293] The researchers intended for both area and personal breathing zone samples to represent individual worker exposures. They placed sampling pumps in a stationary location in the immediate work area when workers were reluctant to wear a sampling pump.

(2008) note that the higher sample results observed after spray systems were installed (29 percent exceeded 50 µg/m^3) might have been due to one or more spray nozzles that did not function and neighboring rock crushing mills that did not have dust control equipment (dust drifted between neighboring operations). Although the wide exposure range indicates that elevated exposure occurred occasionally, both the median and the mean were dramatically lower after the control system was installed.

Table IV.C-70 summarizes the Gottesfeld et al. (2008) results obtained before and after water spray installation. This table shows that, after water spray installation, even during the dry season, 55 percent of the breathing zone and area results were less than 25 µg/m^3, and just one result (4 percent) exceeded 250 µg/m^3. In contrast, before the water mist system was added, all results exceeded 50 µg/m^3, and 60 percent were greater than 250 µg/m^3, a condition similar to those in OSHA's exposure profile for workers associated with rock crushing machines.

OSHA acknowledges that the small mechanical crushing machines evaluated by Gottesfeld et al. (2008) are not completely analogous to the rock crushers used on U.S. construction sites. The authors mentioned that workers loaded the crusher manually, suggesting that the crushers might have been lower power and crushed less material per minute than the equipment typically used in the United States, where front-end loaders dump tons of rock at a time into crusher hoppers and the pieces of concrete and stone often weigh several hundred pounds. However, the workers in India used more manual processes than are typical of U.S.-based rock crushing, putting the breathing zone of more Indian workers in closer proximity to the primary exposure sources: crushers, conveyer belts, and discharge. The medians of the data collected in the United States and in India prior to installation of the water spray dust suppression system, are remarkably similar (300 µg/m^3 vs. 290 µg/m^3, respectively). However, without further detail on the rock crushing activities in India, OSHA is unable to determine if similar water spray systems would be equally effective if installed on the rock crushing equipment typically used in the United States. Though the more manual process used by the Indian workers puts them in closer proximity to dust sources, OSHA cannot determine from the available information if the (presumably) lower power of these crushers and manual operations mean dust is generated at a lower rate, making misting more effective than it might be with the types of equipment typical in the United States. OSHA is interested in receiving additional information on the effectiveness of water mist and other dust suppressant methods with construction industry crushing machines in the United States.

IV.C-70
Comparison of PBZ Respirable Quartz Results for Rock Crusher Activities in India Before and After Installation of Water Spray Controls

			Quartz Exposure				**Quartz Result Distribution among Exposure Ranges**				
Job Category	**Number of Samples**	**Respirable Dust**	**Mean (μg/m^3)**	**Median (μg/m^3)**	**Min-Max (μg/m^3)**		**<25 (μg/m^3)**	**≥25 and ≤50 (μg/m^3)**	**>50 and ≤100 (μg/m^3)**	**>100 and ≤250 (μg/m^3)**	**>250 (μg/m^3)**
Rock Crusher in India—before controls added[A]	5	2.63	246	290	60 to 360		0 0%	0 0%	1 20%	1 20%	3 60%
Rock Crusher in India—after atomizing water spray added (monsoon season)[B]	18	0.19	14	11	5 to 55		17 94%	0 0%	1 6%	0 0%	0 0%
Rock Crusher in India—after atomizing water spray added (repeated in the dry season)[C, D]	27	0.96	63	20	10 to 630		15 55%	4 15%	4 15%	3 11%	1 4%

Notes: The duration was not available for all samples, but when reported they ranged from 102 minutes to 319 minutes. Quartz in stone = 4 to 27 percent; cristobalite in stone = 3 to 6 percent.

This table summarizes and compares quartz results obtained by Gottesfeld et al. (2008) in India under two conditions: during dry rock crushing and after water spray dust control was added (measured in two seasons). The information in this table are not intended as a substitute for the exposure profile for rock crushers in the United States, which appears in Table IV.C-69. Cristobalite exposure is not presented here.

[A] Results from TWA PBZ quartz samples. Mean for the cristobalite result was 90 μg/m^3.
[B] Results are from 6 PBZ and 12 area quartz samples (an area sample was collected in the worker's immediate area if a worker was reluctant to wear a pump; the investigator intends these samples to represent a reasonable approximation of the worker's exposure). All cristobalite results were below the limit of detection (mean of 20 μg/m^3).
[C] Results are from 15 PBZ and 12 area quartz samples. Most cristobalite results were below the limit of detection (mean of 30 μg/m^3).
[D] Investigators hypothesized that spray nozzles malfunctioned in a few cases and neighboring rock crushing mills without dust controls might also have influenced some results.

Source: Gottesfeld et al., 2008.

ERG-C (2008) discusses water dust control techniques in greater detail. For small-scale high-energy crushing activities (workers breaking concrete with jackhammers), ERG reports that a directional mist adjusted for maximum dust control reduced operator exposure by 70 to 90 percent. Based on these results, OSHA estimates that crusher operators could achieve similar reductions with more extensive and improved water delivery systems.

Spray systems are commercially available as original equipment options on some mobile crushers can be added as retrofits or can be added by the owner as shop installations (Komatsu America, 2007; NESCO-dust-control, 2007; NESCO-products, 2007; NESCO-spray, 2007). Replacement nozzles are readily available. It is important to match the nozzle type and spray pattern to the dust source (i.e., location within the crushing machine) that is to be controlled (Bartell and Jett, 2005; Spray Systems, no date). Spray systems can be installed for remote control activation (ERG-concr-crush-A, 2001; NESCO-dust-control, 2007).

Other wet dust suppression options that can offer a substantial benefit include water expanded into foam, steam, compressed water fog, and wetting agents (surfactants added to water to reduce surface tension) (ERG-C, 2008). For example, given a set of conditions, an effective foam system can be designed to predictably achieve nearly any dust control objective, including dust control objectives for rock crushing (Midwest-Edwards, 2009). Simple foam has a short period in which it is effective (20–30 minutes in some climates) (Midwest-Edwards, 2009), but that amount of time is sufficient for material to pass through a crushing machine. Although ERG was not able to specifically determine the effectiveness of dust suppressants for reducing rock crusher exposures, OSHA believes that when used properly and consistently, they could reduce silica concentrations at least as effectively and more consistently than directional water mist spray alone (i.e., dust suppressants such as foams can achieve an exposure reduction of 70- to 90-percent, or possibly greater).

Local Exhaust Ventilation

The use of LEV systems at feed hoppers and along conveyor belts can also be somewhat effective in reducing respirable quartz levels. The available data, however, suggest that LEV alone is not always effective in substantially reducing exposure levels associated with mobile crushing equipment. One sample, obtained by Ellis Drewitt (1997) for an Australian worker crushing quartzite with a dust extraction system as the only control method, resulted in an 8-hour TWA respirable quartz result of 300 µg/m^3. ERG-C (2008) describes this study in more detail.

Another international report, this one from Iran, describes a site where workers used rock crushers with LEV. Bahrami et al. (2008) evaluated small mechanized, stationary, “traditional” (loaded by hand) stone crushing operations before and after the controls were added. The authors report that respirable dust results (area samples) were 99 percent greater without the use of LEV at hoppers, rotary grinders, screeners, and conveyor belts at eight different rock crushing operations producing quartz powder in Iran. The average respirable dust results for 20 area samples collected at four points on crushers prior to the installation of LEV range from 111,000 µg/m^3 to 179,000 µg/m^3. After the installation of LEV, the mean area respirable dust results for 20 follow-up samples range from 770 µg/m^3 to 1,480 µg/m^3.[294] The LEV systems were associated with a marked decrease in respirable dust.

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[294] Before controls were installed, area samples revealed mean respirable dust concentrations of 111,000 µg/m^3 at hoppers, 153,000 µg/m^3 at secondary screeners, 170,000 µg/m^3 at primary screeners, and 179,000 µg/m^3 at rotary grinders. After the LEV systems were installed, mean respirable dust levels in similar areas were reduced to 770 µg/m^3 at secondary screeners, 1,300 µg/m^3 at primary screeners, 1,440 µg/m^3 at rotary grinders, and 1,480 µg/m^3 at hoppers. PBZ respirable silica levels were 30 µg/m^3 for administrative workers (9

Bahrami et al. (2008) also sampled the respirable quartz exposure among rock crushing workers after the LEV systems were installed.[295] Because of the high percentage of silica in rock in the Iranian quartz powder production region, worker silica exposure levels were not reduced to the extent that they might have been in another area. Among 20 personal silica samples for process and hopper-filling workers associated with rock crushers after LEV was installed, the mean PBZ respirable quartz results were 190 µg/m^3 to 400 µg/m^3 respectively (Bahrami et al., 2008). Despite the LEV systems, rock crushing site workers' personal exposure levels continued to exceed 100 µg/m^3.

These levels would likely have been lower if the rock had not been nearly pure silica. As a hypothetical example, if the respirable dust sample had contained the more typical 12 percent silica on the filter, OSHA estimates that the corresponding initial uncontrolled airborne silica concentrations would have been 92 µg/m^3 to 178 µg/m^3. Furthermore, if samples obtained under controlled conditions (with LEV installed) had contained 12 percent silica, the results would have ranged from 27 µg/m^3 to 56 µg/m^3. However, in reality airborne silica concentrations were somewhat higher: bulk samples of this Iranian rock contained 85 to 97 percent quartz. Regardless, as with the rock crushers in India described by Gottesfeld et al. (2008), the equipment used in Iran is not necessarily directly analogous to U.S. rock crushers used in the construction industry.

Although LEV shows promise for some types of construction equipment, it has yet to be proven practical for mobile construction rock crushing equipment. As described below (see Combination of Controls), a notable amount of air (6,500 to 8,500 cubic feet per minute [cfm], with a wet air scrubber system) must be exhausted from crushing machines used underground in the mining industry. A somewhat lesser amount might suffice above ground, but other challenges would need to be overcome, and this technology has not become popular for dust control in the construction industry. The challenges include problems with maintaining airtight enclosures around the crusher and conveyers on this type of equipment, which vibrates violently, and with housing a power generator, fan, and air-cleaning device of sufficient size on the mobile crusher chassis. One alternative, where the machine can be left in place for days at a time, is to use a portable generator and large industrial vacuum suction system with air cleaner on one platform (e.g., a parked trailer), connected by ductwork to the nearby crushing machine. Due to the vibration generated by crushing equipment, maintaining an airtight enclosure would likely require that the construction site also maintain numerous replacement parts and perform daily maintenance on the housing.

Crusher Operator Control Booth

An isolated and ventilated operator control booth can significantly reduce the respirable quartz exposures of workers associated with rock crushing to the extent that they are able to spend time in the booth. In the same study of the South Australian extractive industry (mentioned above), six full-shift respirable quartz results obtained for rock crushing operators who controlled the dry process from inside air-conditioned cabins range from less than or equal to the limit of detection (LOD) of 30 µg/m^3 to 165 µg/m^3, with a median of 60 µg/m^3 (Ellis Drewitt, 1997). At least two of the sampled workers occasionally exited the cabins to free machinery blockages. When compared with the measurement of 300 µg/m^3 reported above for the rock crushing operator using LEV but no cabin, the median of 60 µg/m^3 represents

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samples), 170 µg/m^3 for drivers/loader operators (11 samples), 190 µg/m^3 for process workers (12 samples), and 400 µg/m^3 for hopper workers (8 samples) (Bahrami et al., 2008). The LEV system was not described.

[295] Personal silica samples were not obtained before LEV systems were installed.

an exposure reduction of 80 percent. Other studies of operator cabs also report silica or dust exposure reductions ranging from 80 percent to greater than 90 percent (Cecala et al., 2003, 2005; ERG-C, 2008). Cab and booth design features are discussed in ERG-C (2008).

Other Control Options

Mobile rock crushing machines (e.g., track mounted) are available with remote controls as standard equipment (Komatsu America, 2010). The remote operations permits the operator to stand back from the crusher or move upwind of dust emissions and the commercial availability of remote controls indicates that operators find it useful to move away from the equipment at times. Though no exposure data are available for this type of equipment, OSHA estimates that remote operation can reduce operator exposure to the extent that this method permits the operator to control the machine from a more protected location (e.g., the cab of another vehicle or a portable control booth). For example, even if the operator only spends 25 percent of the shift away from intense dust exposure, the average exposure level could be reduced by 200 μg/m^3 (25 percent of the exposure profile mean of 798 μg/m^3 is approximately 200 μg/m^3). A rock crusher operator observed by ERG spent most of the shift operating the crusher from a (poorly) enclosed booth and only occasionally exited to perform a manual action (ERG-concr-crush-A, 2001). This operator spent approximately 85 percent of the period of crusher operation inside the booth and 15 percent outside the booth, which the operator reported was typical.

Combination of Controls

Underground coal crushing operations (NIOSH-longwall, no date) demonstrate the extent to which engineering controls can control respirable dust. On longwalls in coal mines, respirable dust levels in air leaving the crusher area have been reduced to between 260 μg/m^3 and 990 μg/m^3 by using a combination of water spray and exhaust ventilation (OSHA estimates that if this dust contained a typical 12 percent quartz, the corresponding airborne silica concentration would be 31 μg/m^3 and 119 μg/m^3). On the underground crusher described by NIOSH, the water spray is applied by three or four full-cone spray nozzles at each location, delivering 8 to 10 gallons of water per minute to the crusher entrance, the area above the crusher hammer, the crusher discharge area, and conveyer belt transfer points, where it is important that the spray bars span the width of the conveyer or process. In addition, a ventilation fan paired with a wet air scrubber system removes dust from 6,500 to 8,500 cfm of air drawn from the crusher discharge and conveyer belt transfer areas. These areas must be fully enclosed for the ventilation system to perform optimally. This example described by NIOSH used a water-powered ventilation system to minimize electrical hazards. Finally, to address another source of dust, spring-loaded scrapers clean the top and bottom of the conveyer belt, after which the conveying side of the belt is cleaned with water sprays and a rotating brush.

An underground coal mine is a worst-case scenario (at construction sites, rock crushers are typically located outdoors). Nevertheless, this example outlines the types of respirable dust controls that NIOSH has demonstrated to work best on different parts of a crushing system (NIOSH-longwall, no date). As noted previously, for the construction industry, challenges associated with this combination of controls include maintaining a tight enclosure around a mobile crushing machine (this equipment vibrates violently) and the space required on a mobile machine for both the water and LEV systems. An industry representative suggested that using a combination of foam (at the crusher jaw) and water sprays (at conveyers and discharges) might be a more effective option for mobile equipment (Midwest-Edwards, 2009).

Feasibility Finding for Workers Using Rock Crushers

Based on the information in this section, OSHA preliminarily concludes that all workers using rock crushers (100 percent, from Table IV.C-69) are currently exposed to silica at levels exceeding 50 µg/m^3, and to achieve the proposed level of 50 µg/m^3 all will require additional controls. Silica exposure controls for mobile crushers include operators' booths, remote control devices, and water spray (optimally with foam application systems).

The silica exposure level of most workers who operate rock crushing machines primarily from a control panel can be reduced to a level of 50 µg/m^3 or less with the use of enclosed, air-conditioned, and properly ventilated operator's booths, in combination with water spray dust suppression. This conclusion is based in part on ERG's assumption that the activities of this portion of rock crushing operators in the United States are similar to those performed by the Australian fixed plant operators who experienced a median silica level of 60 µg/m^3 when they were able to spend much of the shift at the control panel and only occasionally cleared blockages. OSHA agrees with ERG's estimate that rock crushing operators in the U.S. construction industry can achieve similar exposure levels by controlling crushing equipment from protective booths/cabs.

Furthermore, OSHA estimates that still lower results can be achieved by using a combination of controls: results of 50 µg/m^3 or less can be achieved for workers in booths/cabs operating rock crushers fitted with water sprays, which improve dust control around the crushers on the infrequent occasions when the operators do need to exit their booths to clear impacted material. Information presented by Gottsfeld et al. (2008) showed that median exposure levels were reduced from 290 µg/m^3 to less than 25 µg/m^3 (more than 90 percent reduction) when water spray systems were installed on rock crushing equipment in India. While the full impact of water sprays on mobile rock crushers in the United States is not well defined, OSHA notes that if well maintained water spray systems offer even just a 50 percent reduction in exposure, this will be sufficient to reduce the silica exposure of operators using control booths/cabs from the median of 60 µg/m^3, reported by Ellis Drewitt (1997), to a median of 30 µg/m^3 for workers using the combination of controls (protective operator's booth and water spray). Thus, most crusher operators who work under these conditions can achieve results of 50 µg/m^3 or less most of the time.

If the crusher cannot be fitted with a control booth, an alternative involves a remote control device that permits the operator to run the crusher from the cab of another vehicle or a temporary control tower fitted with a booth. Heavy equipment operators who are able to spend most of their shift in an enclosed cab usually experience silica exposure levels of 50 µg/m^3 or less (see Section IV.C.24 – Heavy Equipment Operators). The greater the distance between the operator and the crusher, the fewer environmental controls the cab or booth will need to manage exposure. OSHA notes that this control method does not protect workers other than the operator.

Wet spray methods can greatly reduce the exposure levels of operators who must clear impacted material from hoppers, pick debris from belts, and work around active crushing equipment. Although the information from Gottesfeld et al. (2008), mentioned above, suggests water spray can markedly reduce exposure levels for otherwise unprotected workers, the available information is insufficient to show that exposure levels for workers who spend significant time (e.g., more than an hour, or approximately 15 percent of the shift) tending the crusher from outside the booth can consistently be maintained at levels of 50 µg/m^3 or less. However, an extensively maintained water spray system, which an operator can adjust remotely to suppress dust, will maintain worker exposures at levels for which a half-facepiece respirator will provide sufficient protection. A foam system, in combination with extensive water spray and remote control, would reduce some operator exposure levels further (i.e., below 100 µg/m^3 or even possibly 50 µg/m^3). While the available information is insufficient to confirm that this level could be achieved for most operators most of the time, this method shows promise, and OSHA seeks additional information (see below).

Although cabs are currently unusual on construction rock crushing machines, the protective enclosures can be located in a separate portable booth or in the cab of another vehicle (remote control operation). Remote control systems and water mist systems are either standard or optional equipment on some mobile rock crushers, and all crushers and associated machinery (conveyers, sizing screens, discharge points) can be retrofit with water spray and foam systems (Midwest-Edwards, 2009; Komatsu America, 2007; Komatsu America, 2010; NESCO-dust-control, 2007).

In summary, OSHA estimates that the combination of a climate-controlled protective enclosure (i.e., an operator's booth/cab) and an effectively designed (and maintained) water spray system will control the exposure levels of operators to the level of the proposed PEL of 50 µg/m^3 or less, providing the operator is able to spend at least 85 percent (approximately 7 of 8 hours) of the shift in the protective enclosure (a typical ratio, according to the operator evaluated by ERG [ERG-concr-crush-A, 2001]).

Employers who cannot provide protective enclosures for their workers over at least 85 percent of the shift also have the option of ensuring consistent and effective water mist (and foam) application to control worker exposures. While available data is inadequate to indicate whether using water mist is alone sufficient to reduce these workers' silica exposures to below 50 µg/m^3, this control method still offers a notable benefit. OSHA preliminarily concludes that by consistently using properly directed water mist spray (or foam) at the points indicated above, even the most highly exposed rock crushers can achieve silica results in a range that is compatible with use of a respirator with an assigned protection factor of 10 (i.e., a half-facepiece respirator). Under the proposed PEL of 50 µg/m^3, the maximum use concentration of a half-facepiece respirator would be 500 µg/m^3.

Based on the information presented here OSHA preliminarily concludes that the proposed PEL of 50 µg/m^3 is feasible to the extent that workers operate the crushing machinery from a protective enclosure, use water spray systems to suppress dust, and only occasionally leave the cab. In situations where a worker must tend a crushing machine from outside of the protective enclosure for more than an hour per shift, the proposed PEL may not be feasible; however, a well-maintained water spray system and a half-mask respirator will provide sufficient protection.

OSHA acknowledges that information is sparse regarding how commonly remote control operations are used from within protective enclosures during rock crushing on construction sites in the United States. The agency is seeking additional information to determine how common and effective these methods are, and whether there are barriers to placing cabs on crushing equipment or using separate portable or vehicle-based enclosures. Additionally, OSHA is interested in knowing more about the use, limitations, and effectiveness of foam dust suppression systems for rock crushers on construction sites..

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Tuckpointers and Grinders

Description

Tuckpointers and other grinders work with masonry or concrete using hand-held tools fitted with rotating abrasive grinding blades, discs, or small drums. Tuckpointers are a subset of grinders who specialize in removing deteriorating mortar from between bricks and replacing it with fresh mortar. Other grinders use various grinding tools to smooth, roughen, or reshape concrete surfaces (including forming recesses or slots). This second group also includes workers who use hand-held power tools to remove thin layers of concrete and surface coatings, if present (e.g., performing small-scale spot milling, scarifying, scabbling and needle-gunning).[296] Although tuckpointing is most necessary for exterior wall maintenance and so generally occurs outdoors, construction workers who perform concrete surface grinding work both indoors and outdoors (ERG-C, 2008).

Tuckpointing work proceeds in two alternating phases: first, the dusty job of grinding old mortar from between bricks on a section of wall, and second, replacing it with fresh mortar, an activity that does not typically generate dust. At larger job sites, tuckpointing is performed by multiple workers standing a few feet apart, often working from platforms and scaffolding. In addition to grinding, the initial phase includes a cleaning step, during which the worker brushes dust and debris from the joints, although water or compressed air are sometimes also used for this purpose. The second phase involves at least one tuckpointer preparing batches of new mortar (sand, cement, and water), which is distributed to all the site's tuckpointers who use it to refill the joints between bricks (ERG-C, 2008).

Workers who grind on concrete also do other work with concrete when they are not grinding. They might mix fresh concrete to repair damaged surfaces that they previously removed. At some sites, they also perform "sacking"—rubbing a porous sack of cement and silica flour over a damp concrete surface to seal small holes in the concrete surface (ERG-C, 2008).

The varying levels of exposure of workers who grind mortar or concrete are determined by different work practices and environments. When workers reach above shoulder height, debris can fall into their breathing zone, entraining fine particles in the same direction. Additionally, the speed with which dust disperses from the breathing zone of workers is limited at indoor sites or where tarp-style shrouding is erected around the workers to minimize the spread of dust from the construction site during tuckpointing or grinding. Table IV.C-72 presents a summary of the primary activities associated with silica exposure of workers in each job category.

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[296] This section covers workers who use hand-held tools. Workers performing large-scale milling, scarifying, and scabbling activities with driving or walk-behind equipment are covered in Section IV.C.29 – Millers Using Portable or Mobile Machines in this technological feasibility analysis.

Table IV.C-72

Job Categories, Major Activities, and Sources of Exposure of Tuckpointers and Grinders

Job Category*	Major Activities and Sources of Exposure
Tuckpointer	Using hand-held angle grinders to remove deteriorating mortar from joints between bricks. • Dust from high speed abrasive grinding of mortar. • Dust disturbed when debris removed from newly ground joints (brushing or using compressed air).
Other Grinder	Using various hand-held power grinding tools on concrete and other building materials to smooth or modify the surface (including cutting recesses). • Dust from abrasive action on concrete surfaces (e.g., grinding, milling). • Dust from sweeping and brushing (housekeeping). • Dust from “sacking” to seal imperfections in concrete surfaces (occasional).

*Job categories are intended to represent job functions; actual job titles might differ and responsibilities might be allocated differently, depending on the facility.

Source: ERG-C, 2008.

ERG-C (2008) reviewed documents showing that the portion of a shift during which grinders work varies widely, from 1 hour up to a full 8-hours or longer. Tuckpointers, however, frequently divide their shifts between grinding and replacing mortar, completing work on one wall segment before beginning the next one, thus the grinding portion of the task is often completed in half the shift (approximately 4 hours) (NIOSH EPHB 247-20, 2001).

Baseline Conditions and Exposure Profile

OSHA reviewed 153 exposure results associated with tuckpointers and 48 results obtained for workers performing various other types of grinding on concrete.[297] These 201 results, summarized in Table IV.C-72, represent the best data available to OSHA for tuckpointers and grinders. Of these results, 148 (from NIOSH evaluations, OSHA Special Emphasis Program [SEP] inspection reports, and other

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[297] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) calculated assuming no additional exposure during any unsampled portion of the shift. Unless explicitly stated otherwise, all results discussed in the additional controls section are also 8-hour TWAs calculated the same way. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A – Methodology.

published and unpublished sources) were previously considered in the ERG exposure profile (ERG-C, 2008).

For the present exposure profile, OSHA has also included a number of silica results that were either identified too late to include in the ERG-C (2008) report or were excluded from that work, pending clarification of their status or other missing information.[298] Overall, the 201 results for tuckpointers and grinders range from less than the limit of detection (LOD) (in this case, reported as 5 micrograms per cubic meter [μg/m^3] for an 8-hour time weighted average [TWA])[299] to 75,152 μg/m^3.[300] The exposure profile in Table IV.C-72 indicates that nearly 70 percent of the results (140 out of 201) exceed 100 μg/m^3.

Although much of the information available to OSHA primarily relates to tuckpointing and workers using power hand tools for surface grinding, OSHA has identified several international reports that include information on worker silica exposures from hand-held milling equipment (recess millers and related small tools using rotating drum or router-style blades). Lumens and Spee (2001; also included in Lumens, 2004) collected 53 samples for concrete recess millers in the Netherlands. The investigators obtained silica results ranging from below the LOD (not provided) to 6,900 μg/m^3, with a mean level of 700 μg/m^3 and an average sample period of 6.5 hours. The authors note that in addition to using conventional milling equipment, some of these workers operated saws and milling tools fitted with local exhaust ventilation (LEV). There was no mention of water-fed milling equipment. In a separate international study, Nij et al. (2003; also presented in Lumens, 2004) surveyed 13 Dutch recess millers and found that two (15 percent) used tools fitted with LEV. Therefore, OSHA presumes that most of the 53 Dutch recess millers evaluated by Lumens and Spee (2001) used no controls. Taken together, this information suggests that the international hand-milling experience is similar (in scope and use of controls) to that of grinders in the United States. One European study suggests, however, that peak exposure to millers might sometimes be substantially higher (NIOSH ECTB 247-15a). Data obtained

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[298] These results, newly incorporated into the current exposure profile, come from a variety of sources. They include several results obtained by OSHA and NIOSH for tuckpointers and grinders working with or without controls that ERG had described but had not included in the exposure profile pending clarification of status (OSHA SEP Inspection Report 108772393; NIOSH ECTB 233-123c; NIOSH EPHB 247-20, 2001; NIOSH ECTB 247-15a, 2001; NIOSH ECTB 247-12, 2000). OSHA also added new values provided by Woskie (2009) and Heitbrink and Collingwood (2005); one other result (below the LOD) from that latter source was excluded because the sampling period was excessively short (14 minutes), leading to an LOD of greater than 800 μg/m3. Furthermore, OSHA notes that four results, originally provided by NIOSH in draft form, are now publicly available in NIOSH ECTB 247-14 (2000). Finally, OSHA clarified that workers using hand-held milling equipment have more similarities to tuckpointing and grinding than to the workers operating larger milling equipment addressed in another section of this analysis. Therefore, OSHA has consolidated like equipment in these respective groups. For example OSHA removed previously included results for gas-powered walk-behind router operators on the basis that the equipment is more similar to walk-behind milling equipment than to hand-operated grinders (OSHA SEP Inspection Report 300442977). These walk-behind router results and follow-up readings contained in the same source are now part of the exposure profile in Section IV.C.29 – Millers Using Portable or Mobile Machines in this technological feasibility analysis.

[299] The minimum result of 5 μg/m3 was obtained using a BGI (manufacturer) cyclone operated at 4.2 liters per minute (Woskie, 2009).

[300] Results reported as “none detected” are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

under experimental conditions by Hallin (1983) imply that respirable quartz exposures of hand-held mill operators using no controls continuously throughout an 8-hour shift can be as high as 32,000 µg/m^3.

IV.C-72
Respirable Crystalline Silica Exposure Range and Profile for Tuckpointers and Grinders

	Exposure Summary			Exposure Range		Exposure Profile				
Job Category	**Number of Samples**	**Mean (μg/m³)**	**Median (μg/m³)**	**Min (μg/m³)**	**Max (μg/m³)**	**<25 (μg/m³)**	**≥25 and ≤50 (μg/m³)**	**>50 and ≤100 (μg/m³)**	**>100 and ≤250 (μg/m³)**	**>250 (μg/m³)**
Tuckpointers										
Outdoors, uncontrolled	83	1,601	631	12	12,616	3 3.6%	2 2.4%	7 8.4%	12 14.5%	59 71.1%
Outdoors, some form of local exhaust ventilation (LEV) dust control	56	368	70	10	6,196	10 17.9%	12 21.4%	11 19.6%	8 14.3%	15 26.8%
Under other working conditions	12	7,198	793	146	75,153	0 0.0%	0 0.0%	0 0.0%	1 8.3%	11 91.7%
Mixing mortar for tuckpointers	2	15	15	12	18	2 100.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Tuckpointing Subtotals	**153**	**1,568**	**330**	**10**	**75,153**	**15** **9.8%**	**14** **9.2%**	**18** **11.8%**	**21** **13.7%**	**85** **55.6%**
Grinders										
Outdoors, no controls	14	260	211	56	737	0 0.0%	0 0.0%	3 21.4%	4 28.6%	7 50.0%
Outdoors, with LEV	2	46	47	40	53	0 0.0%	1 50.0%	1 50.0%	0 0.0%	0 0.0%
Indoors, no or general ventilation only	9	450	221	117	1,730	0 0.0%	0 0.0%	0 0.0%	5 55.6%	4 44.4%
Indoor with LEV	11	96	107	12	208	2 18.2%	2 18.2%	1 9.1%	6 54.5%	0 0.0%
Indoor, overhead grinding	6	2,053	2,442	81	3,831	0 0.0%	0 0.0%	1 16.7%	0 0.0%	5 83.3%
Tunnel, natural draft	3	597	628	178	985	0 0.0%	0 0.0%	0 0.0%	1 33.3%	2 66.7%
Tunnel, overhead with LEV/remote	3	7	5	5	10	3 100.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Grinding Subtotals	**48**	**479**	**142**	**5**	**3,831**	**5** **10.4%**	**3** **6.3%**	**6** **12.5%**	**16** **33.3%**	**18** **37.5%**
Totals	**201**	**1,308**	**260**	**5**	**75,153**	**20** **10.0%**	**17** **8.5%**	**24** **11.9%**	**37** **18.4%**	**103** **51.2%**

Notes: All samples are personal breathing zone (PBZ) results and represent 8-hour time-weighted average exposures with the assumption that no additional exposure occurred during any unsampled portion of the shift.

IV.C-72
Respirable Crystalline Silica Exposure Range and Profile for Tuckpointers and Grinders

	Exposure Summary			Exposure Range			Exposure Profile				
Job Category	**Number of Samples**	**Mean (μg/m^3)**	**Median (μg/m^3)**	**Min (μg/m^3)**	**Max (μg/m^3)**		**<25 (μg/m^3)**	**≥25 and ≤50 (μg/m^3)**	**>50 and ≤100 (μg/m^3)**	**>100 and ≤250 (μg/m^3)**	**>250 (μg/m^3)**

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Sources: ERG-C, 2008; OSHA SEP Inspection Report 108772393; NIOSH ECTB 233-123c (1999); NIOSH EPHB 247-14 (2000); NIOSH EPHB 247-20 (2001); NIOSH EPHB 247-15a (2001); NIOSH ECTB 247-12 (2000); Collingwood and Heitbrink (2007), Blute et al. (1999), Woskie (2009).

Baseline Conditions and Exposure Profile for Tuckpointers

ERG-C (2008) reviewed working conditions for tuckpointers and determined that they typically work outdoors, with no special controls. They frequently work on scaffolding platforms or swing stages, and several tuckpointers often work in close proximity to each other. Tuckpointers also routinely brush dust and debris away from newly ground joints.

Table IV.C-72 summarizes the 83 8-hour TWA personal breathing zone silica results available to OSHA for tuckpointers working outdoors with no particular exposure controls. Overall, 71 percent of the results for baseline conditions (59 of the 83 results) exceed 250 μg/m^3, demonstrating why workers performing this construction task are noted as having among the highest silica exposures in the construction industry (ERG-C, 2008). Tuckpointing is also considered one of the tasks for which silica exposure is the most difficult to control. In the Table IV.C-72 exposure profile, results for uncontrolled outdoor conditions are represented by a median of 631 μg/m^3. The mean, 1,601 μg/m^3, shows the influence of a few exceptionally high results, including the highest exposure level of 12,616 μg/m^3 for a tuckpointer working outdoors—in this case, on the wall of a church where three other workers were also exposed to levels that, while lower, were still extremely elevated (741 μg/m^3 to 1,604 μg/m^3). These levels are in the same overall range as those that have been reported or reviewed by Flanagan et al. (2003), Yasui et al. (2003), Flynn and Susi (2003), and Meeker et al. (2009), and in additional reports from NIOSH and others as summarized in ERG-C (2008).

Table IV.C-72 also shows that even higher results are reported for tuckpointers working under other conditions, including in areas with limited air circulation (e.g., a courtyard, or between a wall and a plastic tarp) or where dust controls are attempted in a manner offering little or no benefit (e.g., wetting the wall before grinding, or using damaged LEV equipment). In contrast, some of the lowest exposure levels reported for tuckpointers, represented by two results of less than the LOD (12 μg/m^3) and 18 μg/m^3, are associated with workers who primarily mixed fresh mortar and delivered it to other tuckpointers, who used the mortar to fill joints between bricks. These low results for workers who spent time moving between tuckpointers replacing mortar indicate that silica concentrations are low during periods of the shift when workers are not grinding mortar.

Tuckpointers experience some benefit from LEV, even when conditions of use are not optimal. The median (70 μg/m^3) of 56 results for outdoor tuckpointers using some form of LEV (excluding those reported as using damaged equipment) is approximately one-tenth the median for outdoor uncontrolled tuckpointing (631 μg/m^3).

Baseline Conditions and Exposure Profile for Other Grinders

Working either outdoors or indoors, grinders use various hand-held grinding and milling equipment to smooth or abrade concrete. Based on evidence from NIOSH and OSHA SEP inspection reports, ERG-C (2008) determined that when working outdoors, grinders use dust controls infrequently. When working indoors, control measures are typically limited to leaving a window open or adding a fan to circulate air within the work area, although some workers attempt LEV. OSHA has preliminarily determined that baseline conditions for grinders are best represented by the range of working conditions associated with results summarized in Table IV.C-72. Thus, the median exposure level presented in Table IV.C-72 for grinders also represents the median baseline exposure.

As presented in Table IV.C-72, the 48 results for grinders range from 5 μg/m^3 to 3,831 μg/m^3, with a median of 142 μg/m^3. Values summarized by Croteau et al. (2002), Lynch (2002), Flynn and Susi (2003), Flanagan et al. (2003), and numerous NIOSH and other reports noted in ERG-C (2008) also indicate similarly elevated exposure among workers performing grinding.

Grinder exposure levels tend to be elevated regardless of the work environment, but the amount of air movement appears to help keep some exposures from reaching levels that might otherwise have occurred. Table IV.C-72 shows only a minimal difference between median uncontrolled outdoor silica exposures (14 results with a median of 211 µg/m^3) and uncontrolled exposures that occurred indoors (9 results with a median of 221 µg/m^3); however, outdoors where air can circulate more freely, a greater proportion of the values fall below 100 µg/m^3 (21 percent). Furthermore, the exposure levels for three workers grinding in tunnels (178 µg/m^3 to 985 µg/m^3) suggest that some of the same factors influence exposure levels of tunnel workers as affect indoor workers (117 µg/m^3 to 1,730 µg/m^3). All results for both indoor- and tunnel-based grinders were above 100 µg/m^3. While grinding performed in a tunnel with only natural ventilation had a somewhat higher median value (628 µg/m^3) than the grinders working in indoor environments without exposure controls, peak values for indoor workers were more than half again as high (176 percent) as the peak values for the tunnel workers. Indoor workers often lack even the natural ventilation that can help keep silica concentrations from building up to extremely high levels.

Shrouds for grinding equipment are increasingly available; however, at sites that attempt LEV dust control, the NIOSH reports available to OSHA suggests that these methods are generally not implemented in the most effective manner. For example, one worker sampled on multiple dates experienced dust leaks at the hose connection to the vacuum, which eventually fell off (NIOSH-construction-site-16, 1998). A worker at another site evaluated by NIOSH cleaned the vacuum by shaking it and banging it on the wall, which likely created a second source of dust exposure (NIOSH EPHB 247-15a, 2001). Nevertheless, compared with workers who use no controls, the median values provided in Table IV.C-72 for workers using LEV are notably lower, both outdoors (47 µg/m^3) and indoors (107 µg/m^3).

Table IV.C-72 also presents summary information indicating that workers grinding overhead can experience very high silica exposure levels (median value of 2,442 µg/m^3 for 6 results from two sites, both evaluated by OSHA (OSHA SEP Inspection Report 300555026). (OSHA notes that, although substantially elevated, this median value of 2,442 µg/m^3 is well within the range of tuckpointing results, which can exceed 75,000 µg/m^3.) In this case, four workers at one job site spent part of the 4-hour sampling period smoothing surfaces and the remainder of the period grinding overhead grooves into precast concrete in a grinding maneuver with some similarities to tuckpointing and that likely removed more material than if they were strictly smoothing surfaces (OSHA SEP Inspection Report 300555026). The supervisor indicated that the grooves were usually installed at the factory or outdoors before the precast section was installed. This situation demonstrates how lack of planning can cause grinders to work in less favorable environments (and positions) than they might if requirements for installing the groove had been better planned.

Some concrete grinders perform “sacking” as part of their normal activities. Flanagan et al. (2003) compiled 13 silica results for workers performing sacking and although the median geometric mean was 30 µg/m^3, 40 percent (5 of the 13) results exceeded the American Conference of Governmental Industrial Hygienists’ (ACGIH’s) crystalline silica threshold limit value (TLV) of 50 µg/m^3. The respirable dust samples contained a mean quartz content of 11 percent. These results were provided in summary form and lacked sufficient detail to include them in the exposure profile (Table IV.C-72). NIOSH ECTB 233-104c (1999) obtained an 8-hour silica sample associated with an exposure of 64 µg/m^3 (18 percent silica on the filter) for a worker performing only sacking during the shift. The same report indicated that three other workers performed sacking in addition to concrete grinding during their shifts. Based on this information, OSHA concludes that sacking contributes only modestly to the overall silica exposure for concrete grinders who perform this task during a portion of their shift; however, controlling exposure levels during sacking would be necessary in order to reduce grinders’ silica exposures to below 50 µg/m^3. Workers performing sacking are not presented separately in OSHA’s exposure profile.

Additional Controls

Additional Controls for Tuckpointers

As indicated in Table IV.C-72, 81 percent of tuckpointers are currently exposed to silica at levels above 50 µg/m^3, so additional controls are required to reduce their exposure. Control options include LEV—requiring both enhanced equipment and worker training—and wet grinding methods. These control options are discussed in more detail in the paragraphs that follow.

Local Exhaust Ventilation

Recent dust control efforts for tuckpointing have focused on using a dust collection hood (also called a shroud) that encloses most of the grinding blade and a vacuum cleaner system that is used to suction (exhaust) air from these hoods to collect dust and debris. These shroud and vacuum combinations (standard for tuckpointing LEV dust control) generally capture substantial amounts of debris, but air monitoring results summarized in Table IV.C-72 show that even with these controls, silica exposures often continue to exceed 100 µg/m^3, usually by many times (e.g., 27 percent of results exceed 250 µg/m^3 when workers use LEV for outdoor tuckpointing). A series of studies has shown that LEV control methods for tuckpointers can be improved dramatically by improving air flow rates through shrouds, ensuring that the air flow rates are maintained over the course of the work, and taking steps to train workers to use tools correctly. These studies are described in the following paragraphs.

Computational and laboratory studies found that an air flow rate of 80 to 85 cubic feet per minute (cfm) is needed to efficiently capture dust generated by angle grinders used for tuckpointing (Heitbrink and Bennett, 2006; Collingwood and Heitbrink, 2007).[301] This air flow rate captures most dust, as long as the shroud fully encloses the grinding blade. For tuckpointing, this means that dust is efficiently captured only if the airflow rate remains steady at the recommended flow rate and if the shroud fits snuggly against the wall, with minimal gaps due to work practices or variations in the wall surface.

Even a small decrease in flow rate has a negative impact on shroud effectiveness. Laboratory tests conducted by Heitbrink and Bennett (2006) indicate that a vacuum and shroud used by tuckpointers during grinding can reduce exposure levels by a factor of more than 400 under ideal circumstances,[302] but this factor would drop to 10 if vacuum airflow was slowed from 80 cfm to 30 cfm. Furthermore, computational modeling showed that even a modest decrease in the airflow rate, from 85 cfm to 70 cfm,

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[301] ACGIH (2010), in Figures VS-40-01 to VS-40-03, recommends 25 cfm to 60 cfm per inch of blade diameter. For a 4-inch tuckpointing blade, 25 cfm/inch of diameter is equivalent to 100 cfm, slightly higher than the 80 to 85 cfm used by Heitbrink and Bennett (2006) and Collingwood and Heitbrink (2007).

[302] In this case “ideal circumstances” were defined as a gap between shroud and wall of no greater than 0.5 inch at any time. This means that the wall structure must be even and intact, and the mortar must be in good condition—not chipped, cracked, or recessed more than 0.5 inch at any point during the tuckpointing. This is considered the ideal circumstance for studying the effects of air flow rate on dust capture. Investigators recognize, however, that most walls requiring tuckpointing are not in good condition, and this factor cannot be controlled at construction sites. This limitation increases the importance of managing the vacuum air flow rate, which can be controlled by selecting appropriate equipment and encouraging workers to use it correctly.

cuts the shroud's ability to capture dust by more than half. As a result, the estimated worker exposure level would be twice as high as it would have been if the air flow rate had remained constant at 85 cfm.[303]

During typical use of these grinders, however, many factors can cause the air flow rate to diminish, such as grinding debris clogging the vacuum, vacuum hoses—or vacuums—that are too small, incorrect direction of the grinding wheel, and too large of a gap between the lowest surface (mortar) and the shroud.[304] Controlling these factors can improve the performance of tuckpointing grinder shrouds. Other factors, such as work technique and wall condition, interfere with the way the shroud fits against the wall, but only some of these factors can be controlled.

The following paragraphs describe several features that can enhance the efficacy of vacuum cleaners to maintain proper air-flow rate and thus reduce worker silica exposure.

Cyclonic Pre-separators

Collingwood and Heitbrink (2007) experimentally observed that air flows decreased substantially as grinding debris accumulated in the vacuum cleaner. They found that as the vacuum filled with debris, an initial flow rate of 80 cfm fell to levels as low as 30 cfm.

One option for reducing exposure during grinding is using vacuum cleaners that include cyclones to collect debris before the air reaches the filters. Cyclonic pre-separators minimize the accumulation of debris on filters in the vacuum, enhancing the ability of the vacuum cleaner to maintain the initial air flow rate. When testing a vacuum cleaner model equipped with a cyclonic pre-separator, Collingwood and Heitbrink (2007) showed that the collected debris caused the average air flow rate to decrease only from 90 cfm to 77 cfm.

In addition, using actual grinding debris obtained from tuckpointing worksites, Heitbrink and Santalla-Elías (2009) experimentally confirmed that vacuum airflow is quickly affected by dust load on vacuum cleaner bags and filters. In vacuum cleaners designed with filters, laboratory tests showed large pressure losses across filter material as the filters became clogged with dust. Pressure losses from clogged filters translate into reduced air flow, which in turn limits how well a shroud attached to the vacuum captures dust. As the vacuum collects debris, vacuum airflow diminishes rapidly until the filter is properly cleaned according to the vacuum manufacturer's instructions.[305] During particularly dusty activities (such

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[303] The highest result for outdoors uncontrolled tuckpointing is greater than 12,000 μg/m^3 (see Table IV.C-72). As a practical frame of reference, decreasing a hypothetical initial worker exposure of 12,000 μg/m^3 by a factor of 400 (equal to 99.75-percent reduction) would result in a level of 30 μg/m^3. When decreased by a factor of 10, the same initial 12,000 μg/m^3 exposure would be reduced to 1,200 μg/m^3.

[304] Combinations of hoods and vacuums have been evaluated in the past and were typically found to offer some level of silica exposure reduction, but exposure levels remained high (Nash and Williams, 2000; Echt and Sieber, 2002; Croteau et al., 2002; Yasui et al., 2003, Meeker et al, 2009). These studies focused on other aspects of grinder-shroud use and were usually less prepared to provide the higher air flow rates used in the studies described in this section, or to confirm that air flow rates remained constant throughout the test periods.

[305] Industrial vacuum cleaners use filters that can be cleaned and reused many times. These vacuum cleaners often include a feature that allows the vacuum to clean its own filter using a beater or puffs of air blown in

as mortar removal), the vacuum is required to capture more than 20 pounds of debris, including fine dust that cakes onto filters.

Heitbrink and Santalla-Elías (2009) also evaluated two different brands of commercially available vacuum cleaners incorporating cyclonic pre-separation (Tiger-Vac, 2007; Dustcontrol-DC2800, 2009). Air flow rates for both of these vacuums was “largely unaffected” by debris accumulation up to 35 pounds. Debris accumulation also had very little effect on the flow rate measured before and after the filter was cleaned. Furthermore, during the Collingwood and Heitbrink (2007) field trials, these vacuum cleaners did not lose as much air flow as the vacuum cleaners designed with vacuum cleaner bags (bags are a more common pre-separation method but are also subject to clogging).

As an alternative to integrated cyclone vacuums, portable cyclones and cyclones intended to retrofit shop-style vacuums are becoming commercially available (Oneida, 2009). OSHA is not aware, however, of any tests showing whether the retrofit equipment offers the same benefit or whether the available models are sufficiently rugged for construction site use.

Larger Vacuum Hoses

To achieve the air flow rates needed for capturing debris during the grinding phase of tuckpointing, vacuums equipped with a cyclonic pre-separator require a 2-inch inside-diameter hose (to reduce resistance in the hose, which slows airflow), rather than a 1.5-inch hose. Some vacuums might require a minor modification to adapt them for use with a 2-inch suction hose; in that case, the existing connection for a 1.5-inch hose can be replaced with a few inches of schedule 40 PVC (polyvinyl chloride) pipe and reducers available from a hardware store.[306]

A 2-inch hose minimizes losses that otherwise would limit vacuum air flow; however, air flow rates must remain above 76 cfm to maintain sufficient air velocity in the hose to prevent debris from accumulating and plugging the hose (Collingwood and Heitbrink, 2007). ACGIH (2010) recommends an air velocity of 3,500 feet per minute to prevent debris such as mortar from accumulating in the hose. An air flow rate of 76 cfm provides this air velocity. OSHA notes that accumulated material in the hose would further decrease the air flow rate.

Larger Vacuums

Another method for reducing exposure is using larger, more capable vacuum cleaners. NIOSH EPHB 247-20 (2001) reported on a field trial of ventilated grinders (i.e., grinders fitted with shrouds) attached to an oversized vacuum cleaner, which used two vacuum cleaner motors in parallel and also includes a cyclonic pre-separator. These two features, combined with a large, 1.7 square meter (m^2) filter area, means that the powerful vacuum could generate a greater air flow rate (111 cfm) than smaller vacuums, including an identical vacuum (same model) with just one motor (76 cfm).[307] The second motor

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the reverse direction to dislodge dust.

[306] To maximize the inside diameter of the hose connection, the PVC pipe and reducer assembly can be sized to fit snugly around the outside of the existing hose connection.

[307] The vacuums were Dustcontrol DC3700 model vacuums (one with a second motor factory installed). This model has been replaced with the DC3800 in the company catalog (Dustcontrol-Catalog-Chap3, 2009; Dustcontrol-DC3800, 2009)

also provides more power so the vacuum could be expected to maintain that flow rate for longer under the dust loads created by tuckpointing than is typical of smaller vacuums.

During the field trial of this large and powerful vacuum, NIOSH measured the amount of debris collected, the percent of silica in the collected debris, and the concentration of respirable dust in the surrounding air when two otherwise identical vacuums were run at two different flow rates (76 cfm and 111 cfm) (NIOSH EPHB 247-20, 2001). NIOSH made these measurements over two days while two construction workers performed grinding for tuckpointing, each using the vacuum at a different air flow rate. Data show that at the higher 111 cfm air flow rate, the shroud captured more debris while maintaining breathing zone respirable dust exposure levels that were lower (by one-half) than the levels achieved at the 76 cfm air flow rate. On both days, estimated silica levels were also lower (19 µg/m^3 and 26 µg/m^3) for the worker using the 111-cfm flow rate compared with estimated silica levels for the worker using the lower flow rate (49 µg/m^3 and 60 µg/m^3).

Special accommodations must be made for large vacuum cleaners. For example, hanging the 84-pound vacuum at the side of a scaffold or swing stage is necessary. Additionally, construction sites might require heavier duty circuits to use this type of vacuum.

The following discussion summarizes how worker training can also help to maintain proper air-flow rate and thus reduce worker silica exposure

Work Practices

In addition to using vacuums equipped with features to optimize flow rates and minimize filter loading, workers must be trained to ensure they are operating grinders correctly. Computational modeling showed that to efficiently capture particles, the direction of the grinding wheel must rotate from the uncut mortar into the exhaust takeoff section of the shroud. Workers also need to use care in adjusting the grinding depth to the minimum depth necessary and in holding the shroud close against the wall. Minimizing the space between the shroud and wall to the extent practical is critical for optimal capture of the pulverized dust emitted from the grinding point (Heitbrink and Bennett, 2006; Collingwood and Heitbrink, 2007). However, when mortar or bricks are in poor condition, it is not always feasible to maintain the ideal minimum gap between the lowest surface (e.g., cut mortar) and the shroud to less than 0.5 inches. In that case, dust capture will be less effective than it would have been under optimal conditions.

Workers also need training to know when to clean vacuum filters. Filter caking causes pressure losses that eventually limit air flows in even the most powerful vacuums. These air flow limitations fluctuate in a predictable cycle: First, as debris accumulates, the pre-filter becomes caked with collected dust and air flow decreases; then, periodically, the worker shifts to a new position on the surface being worked and moves the vacuum cleaner or at least turns it off and then on. These activities cause a modest portion of the caked debris to fall off the pre-filter, increasing flow rates temporarily. Heitbrink and Collingwood (2005) showed that unless the filter is properly cleaned following manufacturers' recommendations, these cyclic increases are short-lived, and airflows decline again rapidly.

To assist workers in determining when it is time to run a filter cleaning cycle, vacuums should be fitted with a gauge indicating filter pressure (Heitbrink and Santalla-Elias, 2009). Construction site policies must also ensure that vacuum equipment is routinely maintained and kept in good working order.

Studies have shown that worker training improves dust capture even for vacuum designs that do not maximize air flow rate. Even when workers used standard vacuums designed with bags, filters, and 1.5-inch hoses (all features that ultimately decrease air flow rates as debris accumulate), Collingwood and

Heitbrink (2007) found that if those workers were trained to periodically dislodge debris on filters, 64 percent of tuckpointer results (14 out of 22) were reduced to levels less than 100 µg/m^3. Furthermore, 32 percent of results (7 out of 22) were 50 µg/m^3 or less (Collingwood and Heitbrink, 2007). The authors report a geometric mean result of 60 µg/m^3, which represents a 95-percent reduction compared with the geometric mean of 1,140 µg/m^3 for a group of tuckpointing exposure levels obtained from numerous other construction worksites and used for comparison.[308]

Ultimately, worker training alone is not enough; using enhanced vacuum features is also necessary to maintain optimal air flow rates. Field trials at construction sites conducted by Collingwood and Heitbrink (2007) demonstrated the effects these factors had on air flow rates. In that study, although the trained workers took steps to remove debris from filters, most vacuums still did not maintain flow rates of 80 cfm or more.

Wet Methods

Tests of wet grinding methods on concrete show large reductions in airborne respirable dusts when workers use equipment that supplies sufficient and appropriately directed water as a stream or mist (ERG-C, 2008). Akbar-Khanzadeh et al. (2007) found that wet grinding reduced geometric mean silica concentrations by 98 percent, compared with dry grinding. Even with wet methods, however, airborne silica concentrations were still high (959 µg/m^3) during periods of intensive grinding on concrete. Although beneficial for dust management, aesthetic concerns (stained bricks, water marks) make this control method less desirable where appearance is important—for example, on the face of a brick building. Furthermore, when using wet concrete grinding methods, workers must use compressed air-driven grinders or grinders with sealed electrical motors to avoid the electrical hazard of working around water.[309] Pneumatically powered heavy-duty angle grinders are commercially available (Ingersall-Rand-3445, 2009).

Additional Controls for Grinders

As indicated in Table IV.C-72, 83 percent of grinders are currently exposed to silica at levels above 50 µg/m^3, so additional controls will be required to reduce their exposure. Control options include LEV, wet grinding methods, remote operations, sustainable design, and—for grinders who perform sacking—substitution. These control options are discussed in more detail in the paragraphs that follow.

Local Exhaust Ventilation

The LEV-based exposure controls for surface grinding function similarly to the LEV-based controls for tuckpointing described in the previous paragraphs, as tuckpointing is simply a specialized

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[308] For this comparison, Collingwood and Heitbrink (2007) report that they used a database of silica exposure values collected by OSHA and compiled during numerous construction site inspections. Qualifying data from this Shields (2000) database were included in ERG's exposure profile (ERG-C, 2008) and in OSHA's present exposure profile.

[309] Motors for most right-angle grinders are air cooled. A small fan draws air into the body of the grinder and blows air through the electrical windings for the electric motor. This inlet is near the grinder head; thus, water could easily be drawn into the grinder, creating the risk of electrocution.

form of grinding. Tuckpointing is normally done on mortar between bricks, whereas grinding is performed on concrete (similar materials composed of cement, sand, and additives). In both cases a shroud encloses an abrasive disc- or wheel-style blade in order to capture the high-speed particles released from material pulverized by the blade. Concrete and the mortar removed during tuckpointing are both mixtures of cement, sand, and water.[310]

Surface grinding differs from tuckpointing, however, in the shape and location of the surfaces that are worked. For one, tuckpointing is generally limited to exterior masonry. Additionally, the aggressive cutting action of the tuckpointing blade tends to remove a greater volume of material at a faster rate than the smoothing action of the surface grinding blade, and so tuckpointing generates higher concentrations of dust (tuckpointing and grinding are compared in Table IV.C-72).

The air flow through surface grinding shrouds has not been as rigorously assessed as has air flow during tuckpointing; however, based on the similarities between grinding and tuckpointing, OSHA has preliminarily determined that the factors that influence vacuum flow rate for tuckpointing are equally important to LEV dust controls for all types of surface grinding, and for other hand-operated power tools as well. Collingwood and Heitbrink (2007) note that "vacuum cleaners will probably continue to be an important control option for respirable dust exposures in construction for dust exposure sources such as mortar removal, concrete grinding, hole drilling, and brick cutting where water application is impractical."

Because the same factors that cause air flow to decline during tuckpointing have the same effect on air flow during other tasks such as surface grinding, the same measures are as effective in controlling air flow rate decline. Additionally, surface grinders are challenged to an equal extent as tuckpointers by the need to maintain the grinder shroud as close as possible to the surface being worked, in order to better capture the maximum quantity of particles.

Akbar-Khanzadeh and Brillhart (2002), Akbar-Khanzadeh et al. (2007), and Echt and Sieber (2002) reported silica exposure reductions when workers used LEV shrouds with vacuum attachments during surface grinding; however, silica exposure results have been inconsistent and range from modest to extremely high. For example Akbar-Khanzadeh and Brillhart (2002) measured short-term personal silica concentrations of 30 $\mu g/m^3$ to 1,000 $\mu g/m^3$ during periods of intensive grinding when workers used LEV, but when a breeze increased air circulation in the area concentrations ranged from 40 $\mu g/m^3$ to 750 $\mu g/m^3$.

These investigators usually considered the vacuum capacity ratings provided by the vacuum manufacturer when matching suction equipment to grinding shrouds, but actual air flow rates were either not evaluated or not checked using effective methods over the entire course of the vacuum cleaning cycles.

Although not always a focus of these grinder LEV studies, similarities in vacuums, hoses, and shrouds mean that actual vacuum cleaner air flows associated with grinder LEV were affected by the same normal pressure losses inherent in the system as have been reported for tuckpointing LEV systems. Similarly, air flows declined further as grinding debris accumulated, and so in most cases the air flow rate (usually measured once per shift or less) published in grinder studies was not maintained as debris accumulated on filters.

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[310] The primary difference between concrete and mortar is the ratio of cement, sand, and other ingredients. Concrete is intended to stand alone and is fortified with stone aggregate, while mortar is intended to hold bricks together and so is created thin enough to be forced between bricks and is formulated to adhere well to masonry.

Echt and Sieber (2002), for example, reported respirable quartz concentrations ranging from 44 µg/m^3 to 260 µg/m^3 during 2- to 3-hour surface grinding tasks with LEV at a construction site. Each day, one or two 18-pound bags of debris were collected in a vacuum cleaner. Focused on other details, the investigators measured actual air flow rates three times over the course of five sampling days, reporting an air flow range from 86 to 106 cfm.[311] As noted in the discussion of additional LEV controls for tuckpointers, Heitbrink and Santalla-Elías (2009) found that portable shop vacuum air flow is affected by filter loading (regardless of the tool attached to the vacuum), but the effect is only detected if multiple measurements are collected frequently (e.g., before and after dust is knocked from the filter and before and after the vacuum is turned off and on). Using more extensive measurements (continuous data logging every 8 seconds), Collingwood and Heitbrink (2007) evaluated the same vacuum model used by Echt and Sieber (2002) and found that average initial air flow was 71 cfm, which declined to 48 cfm over the task-based work sessions during which trained workers performed normal tuckpointing, knocking the dust from filters using the manufacturer's recommended method as deemed necessary.[312]

These changes in air flow can have a dramatic effect on dust capture. As discussed in the previous section on the review of additional controls for tuckpointers, experimental testing conducted by Heitbrink and Bennett (2006) indicates that a vacuum and shroud used for tuckpointing might reduce exposure levels by a factor of more than 400 under ideal circumstances, but this factor would drop to 10 if vacuum air flow was slowed from 80 cfm to 30 cfm.[313] In addition to indicating the importance of providing sufficient air flow through grinding shrouds and ensuring that the air flow remains relatively constant, these findings suggest shroud and vacuum LEV for grinders likely can perform better than previous studies have indicated.

In some cases underpowered vacuums were used to test grinder shroud effectiveness. Evaluating the effect of a standard shop vacuum and shroud on worker exposure during periods of intensive surface grinding, Akbar-Khanzedah et al. (2007) determined that this LEV system reduced silica exposure levels by 99.7 percent, to a level of 155 µg/m^3. The grinder in this study was fitted with a 6-inch diameter blade. Based on the ACGIH (2010) criteria air flow rate of at least 25 cfm per inch of blade diameter, an air flow of 150 cfm is recommended. The shop vacuum manufacturer's published "free air flow" rate was 106 cfm,[314] meaning that actual air flow was substantially lower. At best, the air flow was between one-half and two-thirds the level recommended by ACGIH (2010). In fact, during a tuckpointing field evaluation, Heitbrink and Floit (2003) observed that the actual air flows for this vacuum were between 74 cfm and 26

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[311] In this configuration, the vacuum did not use a cyclonic pre-filter (Echt and Sieber, 2002).

[312] OSHA notes that this comparison does not account for possible differences in hood entry loss for surface grinding shrouds compared to tuckpointing grinding shrouds (judged to be minor), or for other factors not reported in the reports by Echt and Sieber (2002) and by Collingwood and Heitbrink (2007).

[313] Heitbrink and Santalla-Elías (2009) found that vacuum air flow rates declined from 80 to 30 cfm when vacuums captured 35 pounds of grinding debris in a laboratory test. Collingwood and Heitbrink (2007) showed that at construction sites, debris collected by vacuum shrouds during tuckpointing caused the average air flow rate to decrease from 80 cfm to 30 cfm. Furthermore, computational modeling showed that even a modest decrease in the airflow rate, from 85 cfm to 70 cfm, cuts the shroud's ability to capture dust by more than half.

[314] "Free air flow" is air flow without accounting for various pressure losses including debris accumulation on the filters, resistance in the vacuum hose, and various static pressure losses throughout the vacuum.

cfm (and filter pleats were filled with debris). Again, a vacuum with different characteristics would have improved dust capture by the grinder shroud and further reduced worker exposure levels. The study is useful, however, in demonstrating that a typical construction site vacuum has limitations. Surface-grinder LEV requires more capable vacuums. The effect is increasingly important when workers use larger grinding wheels.

Based on the information presented here, OSHA has preliminarily determined that as typically used, LEV can reduce the silica exposure levels of workers using surface grinders, but even the reduced levels will routinely exceed 100 µg/m^3, particularly indoors or in enclosed work areas. Worker exposures will likely decrease further if grinding shrouds are fitted to vacuum cleaners with the characteristics recommended previously in the discussion of additional controls for tuckpointing. The extent of this improvement has not been fully evaluated, but similarities between tuckpointing and surface grinding suggest that under ideal circumstances the improvement could be as great as that described for tuckpointing. As with tuckpointing, however, other conditions at the worksite also influence worker exposure. For example, keeping the grinding shroud in close contact with the work surface in corners and at the outer edges of flat surfaces is not always possible. To grind in these areas, workers will need to switch tools (e.g., small grinding implements intended for detailed work, also fitted with LEV). Furthermore, curved surfaces (such as cylindrical columns or tanks with curvature greater than can be accommodated by the available shrouds) and blemished concrete do not offer a flat surface.

Wet Methods

Wet methods are an option when workers can use pneumatic grinders on concrete surfaces where emphasis is on structural integrity rather than aesthetics (e.g., parking garages, support columns, surfaces that will be covered during build-out). Wet methods are effective with other high-energy tools that use an abrasive wheel (see Section IV.C.28 – Masonry Cutters Using Stationary Saws); however, results for wet concrete grinding are less conclusive. For example, Akbar-Khanzadeh et al. (2007) measured a silica exposure level of 959 µg/m^3 during periods of intensive concrete grinding using wet methods (compared with a level of 155 µg/m^3 for LEV dust controls). ERG-C (2008) described the benefits and drawbacks of wet methods. Based on that report, OSHA notes that there are still substantial challenges to using wet dust control methods for surface grinding.

Remote Operations and Combined Controls

Grinders who are able to distance themselves from the grinding point in addition to using LEV have substantially lower silica results than those whose breathing zone is within arm's length of the grinding blade. Wooskie (2009) provided information on three grinders who smoothed an overhead surface using a grinding tool fitted with LEV (shroud and HEPA-filtered vacuum, not described further) and attached to a pole during tunnel construction. The workers rested the pole on a movable support that acted as a cantilever and allowed the workers to press the grinder against the overhead surface (at some distance ahead) by pressing down on the opposite end of the pole.[315] A remote switch allowed the workers to activate the grinder and vacuum from the grinder control position. The three 1- to 2-hour personal breathing zone (PBZ) samples obtained for these workers were all below the LOD (29 µg/m^3 to 41 µg/m^3 in this case, based on an assumed 10 µg per sample LOD) for the period monitored, or 5 µg/m^3 to 10 µg/m^3 as 8-hour TWAs. Respirable dust results were between 9 µg/m^3 and 94 µg/m^3 during the period monitored, indicating that the workers experienced very little dust in their breathing zones during this task.

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[315] Shop-made equipment should always be evaluated by the site safety representative to confirm it does not create an additional hazard.

Sustainable Design

When precast concrete is formed, sustainable design practices should indicate necessary grooves, cutouts, and contours so they can be cast into the concrete, nearly eliminating the need for high-silica-exposure activities such as grinding and cutting to produce these features. Careful form placement can also reduce the need for grinding to remove bulges and blemishes often caused by shifting or flawed forms. A factory evaluated by OSHA usually placed grooves in the precast concrete delivered to the construction site. On one occasion when the factory neglected to perform this task, workers experienced extremely elevated silica exposures while grinding overhead grooves at the construction site (OSHA SEP Inspection Report 300555026). These exposures (four results all between 2,420 μg/m^3 and 3,830 μg/m^3), the highest for workers grinding on concrete, would have been eliminated if the factory had been more reliable. When grinding is necessary to finish a precast concrete piece, the task should be performed as much as possible at the casting factory, where dust control equipment should already be at hand.

Grooves and other simple design features can also be included in the forms used for concrete cast in place, although this practice might increase the time required to assemble and remove the forms.

Substitution

Grinder operators who also perform “sacking” to seal imperfections in concrete surfaces can use alternate materials and methods to eliminate silica dust. Construction contractors can switch to concrete patching compounds that create the desired surface without labor-intensive finishing that involves rubbing dry concrete powder over the surface. Over the past decade, newer types of commercially available patching materials have begun replacing traditional sacking and patching methods previously used to repair concrete surface defects, thus eliminating that potential source of silica exposure (Sambol and Chusid, 2006). These patching compounds are suitable for patching both cast-in-place and precast concrete surfaces.

Where traditional methods are still in use, worker silica exposures can be reduced by using low-silica sacking powder (e.g., Portland cement) or by using mortar or concrete sacking powders made with silica sand that is larger than respirable size. For example, as part of the dry mix, some construction contractors performing sacking use 30-mesh sand instead of 60-mesh or smaller sand particles (Sambol and Chusid, 2006). A 30-mesh sand contains a maximum particle size of approximately 230 micrometers (μm), compared with 100 μm for a 60-mesh sand or even smaller particles for sands with larger mesh numbers. Washing can remove the very fine respirable size particles (1 to 10 μm).

Mean quartz levels for sacking results reported by Flanagan et al. (2003) indicate that quartz was below the limit of detection in more than half (54 percent) of the samples for this activity, suggesting that many workers already use these alternate materials and methods.

Feasibility Finding

Feasibility Finding for Tuckpointers

Based on data summarized in Table IV.C-72, OSHA preliminarily concludes that few tuckpointers (19 percent) currently experience results of 50 μg/m^3 or less and that those with low exposure levels are generally associated with mortar replacement and related tasks, rather than the grinding phase of this job. To reduce exposure levels, the vast majority of tuckpointers require additional controls.

Even with additional controls, OSHA preliminarily concludes that silica exposure levels of 50 µg/m^3 or less cannot reliably be achieved for tuckpointers. OSHA also preliminarily concludes, however, that with shrouds and vacuums that are selected and used in a manner consistent with the practices observed during the field trials reported by Collingwood and Heitbrink (2007), tuckpointing worker exposures can usually remain within the maximum use concentration (MUC) for a half-facepiece respirator with an assigned protection factor (APF) of 10, as published in 29 Code of Federal Regulations (CFR) 1910.134.[316] After evaluating 22 results for trained tuckpointers who used vacuums selected for filtration efficiency and ability to provide the required initial air flow rate through the shroud, Collingwood and Heitbrink (2007) determined that "a worker using a tuckpoint grinder with LEV will generally have adequate exposure reduction from a respirator with an assigned protection factor of 10."[317,318]

Based on the work of Collingwood and Heitbrink (2007), OSHA has preliminarily determined that for tuckpointer silica exposures to remain within the MUC for a respirator with an APF of 10, vacuum cleaners used for debris collection during tuckpointing must meet the minimum characteristics of the vacuums tested by Collingwood and Heitbrink (2007). Specifically, vacuums must have the ability to provide at least 80 cfm to 85 cfm air flow through the shroud and include filters at least 99 percent efficient. Additionally, the authors recommend that in order to maintain the minimum air flow rate, the vacuum should 1) incorporate a pressure gauge that indicates when the air flow rate is too low, 2) include a relatively large final filter with efficiencies greater than 99.5 percent for particles of 0.3 µm, and 3) include a hose of 2-inch inside diameter.[319, 320] Additionally, workers will require training on operating

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[316] The construction industry respiratory protection standard (29 CFR 1926.103) is identical to 29 CFR 1910.134, in which the requirements are published.

[317] Further exposure assessment will always be needed at the site to determine the correct level of respiratory protection, "as exposures will probably vary with worksite conditions such as wind and the extent to which the job is enclosed" (Collingwood and Heitbrink, 2007).

[318] Under the proposed permissible exposure limit (PEL) of 50 µg/m3, a half-facepiece respirator with an APF of 10 would have an MUC of 500 µg/m^3.

[319] A 2-inch hose will minimize losses that otherwise would limit vacuum air flow; however, air flow rates must remain above 76 cfm to maintain sufficient air velocity in the hose to prevent debris from accumulating and plugging the hose (Collingwood and Heitbrink, 2007). Accumulated material in the hose would further decrease the air flow rate.

[320] Meeker et al. (2009) came to a similar conclusion after evaluating tuckpointers using different equipment. During brief periods of intensive mortar grinding, short-term results ranged from 190 µg/m3 to 850 µg/m3 when workers used shop vacuums connected to grinder shrouds purchased with the grinding tool as a set. The investigators reported a 90 to 93 percent exposure reduction during this task compared to uncontrolled mortar grinding (up to 25,800 µg/m3). Vacuum bags and filter maintenance, shroud design, and vacuum hose diameter were cited as areas for possible future improvements.

grinders and shrouds correctly for better dust control and knowing when to clean vacuum filters and hoses (which might be necessary frequently).

For practical convenience and efficiency, additional vacuum features that will extend the filter cleaning cycle (e.g., from 5 minutes to 30 minutes) include a filter area greater than 1.5 square meters and a cyclonic pre-separator that separates most debris from the air stream before it reaches the filter. When challenged in the laboratory and on construction sites with debris from mortar grinding, vacuum cleaners with these characteristics performed better than vacuums without pre-separators (i.e., with vacuum bags or with filters alone) (Collingwood and Heitbrink, 2007; Heitbrink and Santalla-Elias, 2009).

A vacuum and shroud system with all the characteristics presented here, used by trained workers under ideal conditions, where a gap of 0.5 inch or less can be maintained, would reduce the exposure level of most tuckpointers to levels approaching 50 µg/m^3. Workplace conditions are not ideal, however, and OSHA preliminarily concludes that this level cannot reliably be achieved for tuckpointers most of the time, and that respiratory protection will be required. Using the controls described previously, as well as a half-facepiece respirator, should provide sufficient protection.

Feasibility Finding for Grinders

Based on information presented previously, OSHA preliminarily concludes that the exposure level of most grinders can be reduced to levels below 100 µg/m^3 through the use of improved vacuum suction devices. OSHA notes that properly sized vacuums used in a manner that provides greater and more consistent air flow, as described in the discussion of tuckpointers, will also benefit workers using hand-held power grinding tools.

Among the 13 grinders who used functioning LEV systems (see Table IV.C-72, combined indoors and outdoors), 53 percent already experience exposure levels less than 100 µg/m^3. Based on the review provided, OSHA estimates that the silica results of all grinders who are currently exposed at levels above 100 µg/m^3 can be reduced to 100 µg/m^3 or less by using vacuums that provide the ACGHI (2010) recommended airflow rate of 25 cfm per inch of blade. This conclusion is supported by information indicating that vacuums used in LEV studies of concrete-surface grinders did not meet this recommended air-flow rate, and that less-than-optimal air flow can have a severe effect on dust capture (as outlined in the discussion of additional controls for tuckpointers). In this case, information for tuckpointing operations applies equally to surface-grinding activities because both tasks involve high-energy abrasive grinding on similar materials (mortar and concrete), shrouds used on both types of grinding equipment need to enclose most of the blade and fit closely to the work surface, and the (often identical) vacuum cleaners used to provide suction for the LEV shrouds are subject to the same factors that reduce air flow rates as debris accumulate. These factors are described by Heitbrink and Bennett (2006), Collingwood and Heitbrink (2007), and Heitbrink and Santalla-Elias (2009).

OSHA also estimates that under ideal grinding conditions (i.e., flat surface, no edges or corners), the same vacuum system described under the feasibility finding for tuckpointers will reduce the exposure level of all grinders to 50 µg/m^3 or less; however, construction sites vary and generally include less-than-ideal conditions (e.g., overhead, curved surfaces, inner corners, substantial high or low spots, and outer edges where the shroud cannot be kept in full contact with the surface). Grinder operators will need to switch tools (to small grinding implements intended for detail work, also fitted with LEV) to work these areas.

Even if they use specialized tools to work difficult areas, information is insufficient to confirm that levels of 50 µg/m^3 or less can be achieved reliably for grinders working indoors on surfaces with curves, corners, or edges (i.e., on most surfaces). Thus OSHA has preliminarily determined that workers using LEV to grind in indoor or enclosed worksites will need to wear respirators while grinding overhead, curved surfaces, inner corners, substantial high or low spots, and outer edges of concrete surfaces. Based on the extent that LEV is able to reduce exposures (including all indoor and overhead work, as shown in Table IV.C-72), OSHA preliminarily concludes that for these workers, a half-facepiece respirator with an APF of 10 will likely provide sufficient protection under the proposed PEL of 50 μg/m^3.

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Underground Construction Workers

Description

Tunneling accounts for most of the construction work performed underground and includes the construction and renovation of underground tunnels, shafts, chambers, and passageways.[321] Tunnel construction techniques include tunnel boring, drilling and blasting, excavation, pipe jacking, and microtunneling.[322] Additional underground construction work that can occur in tunnels includes activities such as chipping, sawing, milling, and grinding that also routinely occur at aboveground construction sites. Based on information contained in ERG-C (2008), OSHA has preliminarily concluded that for the purposes of this analysis underground construction activities can be considered as three major groups: 1) activities related to explosive blasting (not addressed in this analysis), 2) activities related to tunneling with rapid excavation machines (addressed here), and 3) construction activities that are also typically conducted aboveground (addressed elsewhere in this technological feasibility analysis).

During activities related to explosive blasting, excavation of the ground within a tunnel is cyclic, alternating between drilling, blasting, ventilating, and excavating. For safety reasons, explosive blasting is performed when the tunnel is vacant, and reentry is allowed only after exhaust systems clear the air. Therefore, these explosive blasting workers (the first group) are not addressed in this analysis. (Excavating and drilling workers are included in the second and third groups, respectively, as discussed below.)

For rapid, large-scale tunneling operations, construction workers in the second group might use rapid excavation machines (such as roadheaders, continuous miners, and tunnel-boring machines [TBMs]), which use aggressive grating action to cut into the rock face (ERG-C, 2008). Workers working on or supporting tunneling operations (tunnel borers) might be exposed to silica when they operate excavation or in-tunnel transportation equipment, tend the equipment (e.g., conveying belts, excavating machinery), lay track, extend utility lines as excavation machinery advances, and remove excavated material from the tunnel. There is no above-ground equivalent for this group, and this technological feasibility section on underground construction specifically

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[321] It should be noted that tunneling for the purpose of extraction (e.g., for coal or minerals) is considered a mining operation and falls under the jurisdiction of the Mine Safety and Health Administration. Tunneling for other purposes is regulated by OSHA.

[322] Pipe jacking is a tunneling technique in which powerful hydraulic jacks push (advance) specially designed pipe through the ground. Excavation of soil takes place at the front of the pipe string manually or mechanically. The process requires workers to occasionally enter into the pipeline being jacked to clear obstructions or make connections at junctions (Pipe Jacking Association, no date and 2006). Pipe jacking is typically done with pipes 42 to 120 inches in diameter (Caron Pipe Jacking, Inc., 2008). Microtunneling is used to construct smaller diameter pipelines, which are typically too small for humans to enter. Microtunneling uses a remotely controlled microtunnel boring machine (MTBM) with the pipe jacking technique to install pipelines (ASCE 36-01, 2001).

addresses the silica exposure levels and exposure control options for these workers involved in tunnel boring.[323]

The third group of workers includes the heavy equipment operators, hole drillers, saw operators, grinders, and millers who are involved in underground construction and demolition activities during various phases of tunnel construction. For this group, OSHA preliminarily concludes that silica exposure resulting from the specific activity of the worker (e.g., grinding) in tunnels is comparable or even reduced compared with exposure encountered doing similar work in an enclosed, aboveground environment, as addressed in specific sections dedicated to these activities elsewhere in this report (e.g., Section IV.C.32 – Tuckpointers and Grinders). Therefore, the technological feasibility analysis applicable to these workers appears in those other sections. The OSHA underground construction standard requires that “the linear velocity of air flow in the tunnel bore, in shafts, and in all other underground work areas shall be at least 30 feet (9.15 m) per minute where blasting or rock drilling is conducted, or where other conditions likely to produce dust, fumes, mists, vapors, or gases in harmful or explosive quantities are present” (29 CFR 1926.800(k)(3)). OSHA concludes that general ventilation at tunnel construction sites can be superior to that found at many indoor work sites.

As a result, silica concentrations are less likely to become elevated in tunnels observing OSHA ventilation requirements than in indoor spaces, for which no such specific ventilation requirement exists. At some tunnel construction sites, workers’ mean silica exposure level is similar to the mean exposure for all workers performing the same task in a variety of settings. For example, Blute et al. (1999) report respirable quartz levels between 10 micrograms per cubic meter (µg/m^3) and 1,640 µg/m^3 (mean 280 µg/m^3) associated with 10 workers using chipping equipment on concrete during the cut and cover phase of tunnel construction. In contrast, Section IV.C.26 – Jackhammer and Impact Drillers indicates that the 109 available results for all such workers, operating indoors and out, range from 12 to 3,059 µg/m^3 (mean 297 µg/m^3).[324] However, underground workers in one category—drill operators, in particular roof bolters—are shown at times to experience higher exposures in tunnels than at other construction sites, perhaps because of increased drilling frequency and a greater proportion of work conducted above chest height (please refer to Section IV.C.25 – Hole Drillers Using Hand-Held Drills).

Most dust control techniques available to the general construction industry (wet methods, local exhaust ventilation [LEV]-equipped tools, enclosed operator cabs, and increased general ventilation) are also available below ground (29 CFR 1926.800; Bakke et al., 2002; Blute et al., 1999; Tunnel Construction Consultant A, 2003). Please refer to the appropriate sections of this report for a further discussion of processes, exposure levels, conditions, and silica dust control options available for workers performing typical construction activities (Sections IV.C.24 – Heavy Equipment Operators, IV.C.25 –

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[323] Typical job titles for workers in the tunnel borer job category include rapid excavation machine operator, locomotive operator (carries workers and equipment between tunnel entrances and excavation machines), mechanic (maintains the rapid excavation machinery and conveyer belt systems), miner (lays track and extends water, air, and electrical lines as excavation machines advance), and bottom shaft worker (removes excavated material from the tunnel).

[324] In Europe, BGIA (2008) indicated that median respirable dust and quartz exposure levels measured for workers involved in tunnel driving and shaft construction (specifically shotcreting to stabilize new tunnel walls) dropped by approximately 50 percent (from 100 µg/m^3 to 50 µg/m^3 of respirable quartz) in the five years after 2000 compared with the previous five years. The authors attribute this change to the increased use of wet-spraying, low-silica additives, improved ventilation, and more intensive measures to capture and suppress dust (wetting excavated material, using air filtration, and maintaining driving surfaces) (BGIA, 2008).

Hole Drillers Using Hand-Held Drills, IV.C.26 – Jackhammer and Impact Drillers, IV.C.27 – Masonry Cutters Using Portable Saws, IV.C.29 – Millers Using Portable or Mobile Machines, IV.C.30 – Rock and Concrete Drillers, and IV.C.32 – Tuckpointers and Grinders). Note that for workers performing any construction activity, additional exposure due to proximity specifically with tunneling operations (e.g., rapid excavation machines) is analogous to that received by tunnel borers.

Job categories, major activities, and sources of exposure of underground construction workers involved in rapid excavation are summarized in Table IV.C-73.

Table IV.C-73

Job Categories, Major Activities, and Sources of Exposure for Underground Construction Workers

Job Category*	**Major Activities and Sources of Exposure**
Underground Construction Worker (Tunnel Borer)	Excavating, removing debris, operating rapid excavation machines, transporting workers and equipment, laying track and installing/extending utility lines (air, water, electrical), performing maintenance and repair, and others. • Dust from rapid excavation and related support activities. • Dust from open transfer of silica-containing materials. • Dust from working in close proximity to ventilation system exhaust air.

*Job categories are intended to represent job functions; actual job titles might differ, and responsibilities might be allocated differently, depending on the operation.

Source: ERG-C, 2008.

Baseline Conditions and Exposure Profile for Tunnel Borers

The majority of exposure information for tunneling workers is associated with TBMs. These exposure data, previously described by ERG-C (2008), were obtained at two tunnel construction sites, one evaluated by NIOSH and one by OSHA.[325] Although limited, these data represent the best data available to OSHA for underground construction workers involved in tunneling. No monitoring data were available to OSHA to represent the exposures of tunneling workers using other types of rapid excavation equipment.

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[325] As noted in Section IV.A – Methodology, all results included in the exposure profile are 8-hour time-weighted averages (8-hour TWAs) calculated assuming no additional exposure during any unsampled portion of the shift. Unless explicitly stated otherwise, all results discussed in the additional controls section are also 8-hour TWAs calculated the same way. Assumptions made in calculating 8-hour TWAs are discussed in Section IV.A - Methodology.

The exposure profile for tunnel borers is shown in Table IV.C-74. This table summarizes 27 full-shift 8-hour time-weighted average (TWA) personal breathing zone (PBZ) silica samples obtained for workers associated with tunnel excavating machines at two construction sites, one evaluated by NIOSH and another by OSHA (NIOSH ECTB 233-119c, 1999; OSHA SEP Inspection Report 1027696576). Sample results range from 7 µg/m^3 to 257 µg/m^3, with a median of 12 µg/m^3 and a mean of 41 µg/m^3.[326] More than half (56 percent) of the sample results are less than or equal to the LOD, and 78 percent of the results are less than or equal to 50 µg/m^3. When silica was detected in the sample, it was present as between 5 and 17 percent of the dust on the filter. Job titles of sampled workers include TBM operator, drill operator, mechanic, locomotive or brake operator, miner, welder, electrician, bottom shaft worker, and inspector. At both construction sites, TBMs were equipped with engineering controls that included water sprayers, LEV systems, and shields designed to reduce the release of rock fragments and dust as the TBM cut (ERG-C, 2008).

Two respirable quartz results (46 µg/m^3 and 38 µg/m^3) were obtained for workers inside the TBM’s enclosed, ventilated operator booth (NIOSH ECTB 233-119c, 1999; OSHA SEP Inspection Report 102769676). These data suggest that workers in enclosed booths already experience levels below 50 µg/m^3.

Two additional results, 136 µg/m^{3}a and 87 µg/m^3, were obtained for workers who spent part of their time in the enclosed booth and part of their time outside the TBM (OSHA SEP Inspection Report 102769676). The OSHA report noted that the tunnel’s ventilation system had not been extended the full length of the tunnel (providing less fresh air into the TBM than required) and recommended an increase in the air flow through the TBM’s LEV system and an increase in the amount of water sprayed on the machine’s rotating cutting wheels. A combination of these factors likely contributed to the elevated exposures.

In the tunneling operation evaluated in NIOSH ECTB 233-119c (1999), additional exposure control was provided by the tunnel’s dilution ventilation system, two water spray bars positioned at the tunnel conveyor belt transfer points, and four water spray hoses at the cutter head. ERG identified 22 full-shift respirable quartz results obtained by NIOSH for workers performing activities inside the TBM trailing gear or outside of the TBM where these controls were operating. These 22 results range from 7 µg/m^3 to 257 µg/m^3, with a median of 12 µg/m^3 and a mean of 35 µg/m^3. Only four samples (18 percent) exceed the proposed permissible exposure limit (PEL) of 50 µg/m^3.

The highest two results, 124 µg/m^3 and 257 µg/m^3, were obtained at the same site for two workers who loaded and unloaded the locomotive flat cars and assisted with crane operations at the bottom of the tunnel’s shaft. NIOSH (NIOSH ECTB 233-119c, 1999) attributed these elevated results to the workers’ position near the tunnel shaft (which acted as the exhaust air duct for the tunnel’s ventilation system) and, possibly more significantly, proximity to the last transfer point for rock moving from the horizontal belt conveyor to the vertical bucket conveyor. Although a water spray bar was reportedly located at each of two other transfer points in the tunnel, engineering controls were absent from this last transfer point. NIOSH (NIOSH ECTB 233-119c, 1999) recommended the use of a spray bar or LEV at the transfer point or enclosure of the transfer point. The other two elevated results, 55 µg/m^3 and 75 µg/m^3, were obtained for two miners operating equipment in the TBM trailing gear, laying track, and extending water and air

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[326] Low value of 7µg/m^3 (the limit of detection [LOD]) is as reported by the investigator (NIOSH ECTB 233-119c, 1999). Note that OSHA’s crystalline silica analytical method for determining the LOD (ID-142) has a reported LOD of 10 µg/m^3. Results reported as “none detected” are assigned a value equal to the LOD. The LOD is determined individually for each sample based on the volume of air sampled and the method used to analyze the sample, therefore, the limit of detection varies between samples. See Section IV.A – Methodology for additional information on LODs.

lines. NIOSH (NIOSH ECTB 233-119c, 1999) suggests that these two exposures might be associated with the booster fan malfunction on the third sampling day, which reduced the tunnel's exhaust volume by 10 to 20 percent. The other 21 workers (78 percent) in and around the tunnel and boring equipment experienced exposure levels less than 50 µg/m^3. These samples were obtained during the first and second sampling days. The elevated results described here demonstrate the potential for worker exposures to occur at tunneling sites, but in this case the results may be examples of upset conditions, when systems normally in place to protect workers were not properly implemented or had malfunctioned.

Based on the findings of a Norwegian study (Bakke et al., 2002), these results might underestimate the extent and high end of exposure for electricians and operators associated with TBMs (ERG-C, 2008). The study authors reported a median PBZ silica result of 490 µg/m^3 for 43 Norwegian TBM workers. The results represent randomly selected 5- to 8-hour periods during 10-hour workshifts. Although the TBM had an enclosed operator cab, the study authors noted that the operator usually left the door open in order to monitor the conveyor belt (Bakke et al., 2002). The study authors did not indicate other controls associated with the TBM or whether ventilation problems might have been a factor in these elevated silica results. The report noted, however, that the TBM was not operated every day because of repair work on the TBM and on the ventilation ducts, suggesting less than optimal operation. Therefore, these higher exposures might be associated with poor controls and work practices.

Two additional investigations also report elevated silica exposure results for underground construction workers engaged in tunneling operations (Oliver and Miracle-McMahill, 2006; Woskie et al., 2002). The results from these studies were not included in the exposure profile because they did not provide sufficient information as outlined in Section IV.A – Methodology. Oliver and Miracle-McMahill (2006) collected 70 samples (PBZ and area) over an 18-month period for tunnel construction workers using a tunnel jacking technique on the Central Artery/Tunnel (CAT) project in Boston, Massachusetts. Approximately 63 percent of the samples exceeded the current OSHA PEL; two other results approached the PEL (actual silica levels not provided). Investigators calculated the PEL using OSHA's general industry silica PEL equation based on the percent of quartz in a respirable dust sample[327]. The study did not evaluate the effectiveness of in-place engineering controls, aside from noting that environmental controls were "inadequate."

Investigators also focused on pipe jacking operations on the CAT project. CAT underground construction workers involved in pipe jacking entered into the pipeline to manually excavate soil, chip away obstructions, and clear debris. Woskie et al. (2002) reported a maximum silica result of 333 µg/m^3 for eight full-shift PBZ samples obtained on workers during CAT pipe jacking operations. Approximately 38 percent of the samples exceeded the OSHA PEL (actual silica levels not provided), suggesting the

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[327] In this case, although evaluating a construction industry activity, the investigator elected to compare silica exposure results with OSHA's gravimetric general industry PEL for silica. This might be due to the fact that the construction industry PEL for silica is based on the units millions of particles per cubic foot (mppcf), requiring an obsolete analytical method not available through most analytical laboratories. Instead, laboratories typically report silica air sampling results as mass-based gravimetric values (e.g., mg/m^3) for respirable dust, along with the percent silica, which are also used in the gravimetric general industry PEL for silica. Investigators compare these results with the gravimetric general industry PEL because the units are compatible. An alternative has been available since 2008, when OSHA published a compliance directive, National Emphasis Program (NEP)–Crystalline Silica CPL 03-00-007 (Appendix E), providing a conversion factor to convert air sampling results between mppcf and mg/m^3 or µg/m^3. However, some investigators have continued in their studies to use the more familiar gravimetric units and compare construction industry air monitoring results with the gravimetric general industry PEL for silica.

possibility for overexposure for workers engaged in pipe jacking. The authors calculated the PEL using OSHA's general industry silica PEL equation based on the percent of quartz in a respirable dust sample. The exposure controls associated with the pipe jacking operations were not addressed.

Based on descriptions of tunneling workers' activities and rapid excavation operations discussed in ERG-C (2008) and the best available literature, OSHA finds that baseline conditions for this group of workers include wet methods (water sprayers), LEV systems (for tools, excavating equipment, and conveyor transfer points), general dilution ventilation (ventilation requirements in OSHA's underground construction standard), and enclosed operator cabs (which may or may not be properly used). The results summarized in Table IV.C-74 were obtained under some or all of these conditions. The supplemental information presented above suggests that at certain construction sites the values in Table IV.C-74 might underestimate the exposure of some workers.

Additional Controls

Additional Controls for Underground Construction Workers

The majority of tunnel borers work inside the TBM trailing gear or outside the TBM. The primary exposure controls for these workers include water sprays positioned at cutting heads and conveyor transfer points, and LEV at cutting heads. For the limited number of workers who ride inside the machine's enclosed, ventilated cab (including drill operators and cutter-head mechanics), this represents another control. Wet methods and LEV are preferable, however, because they suppress dust at the source, thereby benefiting workers both inside *and* outside the cab.

As previously noted, the two respirable quartz results obtained for workers inside the TBM's enclosed booth are 46 $\mu g/m^3$ and 38 $\mu g/m^3$ (NIOSH ECTB 233-119c, 1999; OSHA SEP Inspection Report 102769676). The results in the Bakke et al. study for cabs equipped with enclosed cabs do not provide an accurate representation of an enclosure's ability to reduce exposure because, in this case, the operators usually left the door open. As such, the operators were not isolated from the respirable dust and high exposures resulted. OSHA estimates that improved filtration systems should further lower exposures.

Table IV.C-74
Respirable Crystalline Silica Exposure Range and Profile for Underground Construction Workers

	Exposure Summary			**Exposure Range**			**Exposure Profile**				
Job Category	**Number of Samples**	**Mean (μg/m³)**	**Median (μg/m³)**	**Min (μg/m³)**	**Max (μg/m³)**		**<25 (μg/m³)**	**≥25 and ≤50 (μg/m³)**	**>50 and ≤100 (μg/m³)**	**>100 and ≤250 (μg/m³)**	**>250 (μg/m³)**
Underground Construction Worker (tunnel borer)	27	41.4	12.0	7.0	257.0		16 59.3%	5 18.5%	3 11.1%	2 7.4%	1 3.7%

Notes: All samples are personal breathing zone (PBZ) results and represent 8-hour time-weighted average exposures with the assumption that no additional exposure occurred during any unsampled portion of the shift.

This exposure profile assumes that the distribution of the available exposure samples represents the distribution of actual workers and facilities in this industry. OSHA seeks additional information to better describe the distribution of exposures in this industry.

Source: ERG-C, 2008.

The water sprays and LEV provided by the TBM, as well as the tunnel's dilution ventilation system, are associated with a baseline median of less than or equal to 12 µg/m^3 (Table IV.C-74). The potential for higher exposures is possible as indicated by two full-shift PBZ respirable quartz results of 124 µg/m^3 and 257 µg/m^3 for a bottom shaft worker. These results were attributed to the worker's position near the tunnel shaft and an uncontrolled material transfer point (ERG-C, 2008). OSHA estimates that these exposures would be substantially reduced with effective controls at the material transfer point.

Additional controls for workers outside TBMs, in addition to ensuring the full operation of the TBM engineering controls, include ensuring optimum operation of ventilation systems installed inside tunnels, improving application of water sprays wherever dust is generated, enclosing conveyer transfer points, and taking other steps to reduce dust from conveyers. NIOSH IC-9465 (2003) provides step-by-step instructions for checking whether dust controls in hard rock tunnels (bored by TBMs) are performing well and identifying problem areas, noting that hidden leaks in existing ventilation are common and can result in elevated dust levels because the ventilation system simply fails to deliver enough air.

NIOSH currently recommends 100-feet-per-minute air flow across the full diameter of the tunnel if the rock contains more than 10 percent silica (this airflow is more than three times the minimum required under 29 CFR 1926.800). Air velocities two to four times higher have been used for operations where increased amounts of air contaminants were anticipated.

Bakke et al. (2001) obtained 63 personal exposure samples for Norwegian construction workers at four tunneling sites where one of two different explosives had been used for blasting. Arithmetic mean concentrations (with data partitioned by explosive type) were 11 µg/m^3 and 34 µg/m^3 for workers performing tasks in the tunnels after the blasting phase was complete. Airflow in the tunnels was 1,400 cubic meters per minute (m^3/min) to 2,500 m^3/min, which, given the tunnel diameter, corresponds to a minimum of 40 to 70 feet per minute (in some cases more)—or at least 130 percent to 200 percent of the rate required by OSHA's 29 CFR 1926.800. This study demonstrates that, using higher ventilation rates, the average exposure to construction workers underground was maintained at levels that were less than the average of 41 µg/m^3 presented in Table IV.C-74 for workers in the United States.

If tests reveal that water sprays along the length of the tunnel and controls on conveyer belts are not working effectively, water sprays and controls should be upgraded (NIOSH IC-9465, 2003). Reports noted in ERG-C (2008) indicate that improving water spray quality (droplet size, direction of spray) and quantity, and ensuring adequate water pressure (100 pounds per square inch) and filtration can increase the effectiveness of water as an exposure control. Routine nozzle inspection, maintenance, and replacement are required (ERG-C, 2008). Achieving optimal wetting at the cutting head offers the best opportunity for controlling dust at its source, and the wetted material is less likely to contribute dust as conveyers carry it away. Research on coal mines, reported in the NIOSH IC-9465 (2003) discussion of hard rock tunnels, indicates that increasing the number of spray nozzles on the shearer drum (e.g., from 17 to 46) can reduce respirable dust by 60 percent. Although more costly, using foam spray can reduce dust levels another 20 to 60 percent compared with plain water (NIOSH IC-9465, 2003).

Conveyer belts and their transfer points, including those that are located in hard rock tunnels produced by TBMs, are a notorious source of dust. NIOSH (NIOSH IC-9465, 2003) recommends enclosing conveyer transfer points and adding water sprays. If dust is still released, NIOSH suggests adding exhaust ventilation to the enclosures. An effective cleaning mechanism (e.g., belt scraper) can help minimize the conveyer belt as a source of silica exposure. When additional controls are needed, both the top and the bottom of the belt should be wet to suppress dust (NIOSH IC-9465, 2003).

ACGIH (2010) offers recommendations for enclosing and adding exhaust ventilation to conveyers. These designs are used in many settings where materials are conveyed. For example, in the structural clay industry (addressed in Section IV.C.21 – Structural Clay), NIOSH evaluated a facility that, along with other controls, used enclosures at conveyer transfers and drop points (e.g., into bins) associated with mineral grinding machinery (NIOSH ECTB 233-108c, 2000). Full-shift silica exposure levels were 13 µg/m^3 and 67 µg/m^3 in this area, compared with the typical median of approximately 100 µg/m^3 for workers associated with structural clay grinding areas in other facilities. Wetting agents, which increase particle agglomeration when added to water spray, also reduce airborne dust levels at material transfer and discharge points.

Another control option involves increasing the effectiveness of the tunnel's general dilution ventilation system by ensuring that the duct extends to the face of the tunnel and is free of leaks, and that routine maintenance is performed.

Feasibility Finding

Based on the information presented in this section, OSHA preliminarily concludes that exposure levels are already within the range of the proposed PEL of 50 µg/m^3 for most workers inside TBMs that have enclosed cabs and fully functioning water spray and ventilation systems. This conclusion is based on the 8-hour TWA result of 46 µg/m^3 from a 560-minute sample for a TBM operator whose control equipment appeared to function well (ERG-C, 2008). Another result of 38 µg/m^3 was obtained over 440 minutes for a worker in the forward portion of the TBM cab at another site and indicates that even when conditions outside the TBM are dusty, the cab filtration system can maintain levels of 50 µg/m^3 or less. Where exposures do exceed 50 µg/m^3 in the cab, the construction site will need to improve maintenance of the TBM cab, cab filtration, and ventilation and water spray systems in the tunnel.

OSHA also preliminarily concludes that tunnel construction sites can achieve silica results of 50 µg/m^3 or less for most tunnel workers outside TBMs most of the time by making sure current controls are operating optimally (e.g., TBM water sprays and LEV, as well as the tunnel's dilution ventilation system). The median result for workers operating under these conditions is less than or equal to 12 µg/m^3 (ERG-C, 2008). For bottom shaft workers (removing excavated material from the tunnel), who might at times have exposures greater than 100 µg/m^3, other controls to reduce exposures to the proposed PEL include additional water sprays or more consistent use of existing sprays. Additional sources of respirable dust, such as conveyer transfer points, should be either treated with water spray, covered and exhausted, or both. Using some or all of these methods, the construction sites represented in Table IV.C-74 achieved silica exposure levels of 50 µg/m^3 or less for 78 percent of tunneling workers. By applying the same controls to areas where excessive exposure occurs, this level can likely be achieved for the vast majority of workers associated with tunnel boring.

Exposure data on which to base a conclusion for workers associated with other types of tunneling equipment (e.g., pipe jacking) are not available (ERG-C, 2008).

As previously noted, workers performing activities not specific to tunneling, such as grinding, hole drilling, or chipping, receive similar exposures from their equipment as workers performing those same activities aboveground in enclosed environments (e.g., indoors). Refer to the relevant sections of this report for further information on exposure and controls for those activities.

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SUMMARY OF THE TECHNOLOGICAL FEASIBILITY ANALYSIS

The Agency has preliminarily concluded, on the basis of its technological feasibility analysis, that the proposed permissible exposure limit (PEL) of 50 micrograms per cubic meter (µg/m^3) is the lowest achievable exposure limit in most operations most of the time through the use of engineering and work practice controls.

To demonstrate the limits of feasibility, OSHA's analysis examines the technological feasibility of the proposed PEL of 50 µg/m^3 and an alternative PEL of 25 µg/m^3. In total, OSHA analyzed technological feasibility in 108 operations in general industry, maritime, and construction industries. This analysis addresses two different aspects of technological feasibility: (1) the extent to which engineering controls can reduce and maintain exposures; and (2) the capability of existing sampling and analytical methods to measure silica exposures.

Feasibility Determination of Sampling and Analytical Methods

As part of its technological feasibility analysis, OSHA examined the capability of currently available sampling methods and sensitivity[328] and precision of currently available analytical methods to measure respirable crystalline silica (please refer to the "Feasibility of Measuring Respirable Crystalline Silica Exposures at The Proposed PEL" section in Chapter IV of the PEA). The Agency understands that several commercially available personal sampling cyclones exist that can be operated at flow rates that conform to the ISO/CEN particle size selection criteria with an acceptable level of bias. Some of these sampling devices are the Dorr-Oliver, Higgens-Dowel, BGI GK 2.69, and the SKC G-3 cyclones. Bias against the ISO/CEN criteria will fall within ±20 percent, and often is within ±10 percent.

Additionally, the Agency preliminarily concludes that all of the mentioned cyclones are capable of allowing a sufficient quantity of quartz to be collected from atmospheric concentrations as low as 25 µg/m^3 to exceed the limit of quantification for the OSHA ID-142 analytical method, provided that a sample duration is at least 4 hours. Furthermore, OSHA believes that these devices are also capable of collecting more than the minimum amount of cristobalite at the proposed PEL and action level necessary for quantification with OSHA's method ID-142 for a full shift. One of these cyclones (GK 2.69) can also collect an amount of cristobalite exceeding OSHA's limit of quantification (LOD) with a 4-hour sample at the proposed PEL and action level.

Regarding analytical methods to measure silica, OSHA investigated the sensitivity and precision of available methods. The Agency preliminarily concludes that the X-Ray Diffraction (XRD) and Infrared Spectroscopy (IR) methods of analysis are both sufficiently sensitive to quantify levels of quartz and cristobalite that would be collected on air samples taken from concentrations at the proposed PEL and action level. Available information shows that poor inter-laboratory agreement and lack of specificity render colorimetric spectrophotometry (another analytical method) inferior to XRD or IR techniques. As such, OSHA is proposing not to permit employers to rely on exposure monitoring results based on analytical methods that use colorimetric methods.

For the OSHA XRD Method ID-142 (revised December 1996), precision is ±23 percent at a working range of 50 to 160 µg crystalline silica, and the SAE is ±19 percent. The NIOSH and MSHA XRD and IR methods report a similar degree of precision. OSHA's Salt Lake Technical Center (SLTC) evaluated the precision of ID-142 at lower filter loadings and has shown an acceptable level of precision is achieved at filter loadings of approximately 40 and 20 µg corresponding to the amounts collected from

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[328] Note that sensitivity refers to the smallest quantity that can be measured with a specified level of accuracy, expressed either as the limit of detection or limit of quantification.

full-shift sampling at the proposed PEL and action level, respectively. This analysis showed that at the proposed PEL, the precision and SAE (sampling and analytical error) for quartz (at the mentioned filter load) are ±27 and ±23 percent, respectively, and for cristobalite the precision and SAE are ±23 and ±19 percent, respectively. These results indicate that employers can have confidence in sampling results for the purpose of assessing compliance with the PEL and identifying when additional engineering and work practice controls and/or respiratory protection are needed.

For example, given the SAE for quartz at a filter load of 40 µg, employers can be virtually certain that the PEL is not exceeded where exposures are less than 38 µg/m^3, which represents the lower 95-percent confidence limit (i.e., 50 µg/m^3 minus 50*0.23). At 38 µg/m^3, a full-shift sample that collects 816 L of air will result in a filter load of 31 µg of quartz, or more than twice the LOQ for Method ID-142. Thus, OSHA believes that the method is sufficiently sensitive and precise to allow employers to distinguish between operations that have sufficient dust control to comply with the PEL from those that do not. Finally, OSHA's analysis of PAT data indicates that most laboratories achieve good agreement in results for samples having filter loads just above 40 µg quartz (49-70 µg).

At the proposed action level, the study by SLTC found the precision and SAE of the method for quartz at 20 µg to be ±33 and ±28 percent, respectively. For cristobalite, the precision and SAE at 20 µg were ±27 and ±23 percent, respectively. OSHA believes that these results show that Method ID-142 can achieve a sufficient degree of precision for the purpose of identifying those operations where routine exposure monitoring should be conducted.

However, OSHA also believes that limitations in the characterization of the precision of the analytical method in this range of filter load preclude the Agency from proposing a PEL of 25 µg/m^3 at this time. First, the measurement error increases by about 4 to 5 percent for a full-shift sample taken at 25 µg/m3 compared to one taken at 50 µg/m^3, and the error would be expected to increase further as filter loads approach the limit of detection. Second, for an employer to be virtually certain that an exposure to quartz did not exceed 25 µg/m^3 as an exposure limit, the exposure would have to be below 18 µg/m^3 given the SAE of ±28 percent calculated from the SLTC study. For a full-shift sample of 0.816 L of air, only about 15 µg of quartz would be collected at 18 µg/m^3, which is near the LOQ for Method ID-142 and at the maximum acceptable LOD that would be required by the proposed rule. Thus, given a sample result that is below a laboratory's reported LOD, employers might not be able to rule out whether a PEL of 25 µg/m^3 was exceeded.

Finally, there are no available data that describes the total variability seen between laboratories at filter loadings in the range of 20 µg crystalline silica since the lowest filter loading used in PAT samples is about 50 µg. Given these considerations, OSHA believes that a PEL of 50 µg/m^3 is more appropriate in that employers will have more confidence that sampling results are properly informing them where additional dust controls and respiratory protection is needed.

Based on the available information, OSHA preliminarily concludes that it is technologically feasible to reliably measure exposures of workers at the proposed PEL of 50 µg/m^3 and action level of 25 µg/m^3. OSHA notes that as concentrations lower than 50 µg/m^3 are analyzed, the sampling and analytical error increases, and the variability in measurements of exposures is higher (i.e. variability at the proposed action level of 25 µg/m^3 is higher than that for the proposed PEL of 50 µg/m^3). However, OSHA believes that measurement of exposures at the proposed action level and PEL are sufficiently precise to permit employers to adequately determine when additional exposure monitoring is necessary under the standard, when to provide workers with the required medical surveillance, and comply with all other requirements of the proposed standard.

Feasibility Determination of Control Technologies

OSHA has relied on a variety of sources of information to develop its technological feasibility analysis for controlling worker exposures, including NIOSH reports, OSHA Special Emphasis Program (SEP) Inspection Reports, site visits, contractor reports, case studies, and personal communications. Based on this information, the Agency has identified 23 industries in the general industry[329] and maritime sectors and 12 construction activities, together having a total of 108 operations, that are potentially affected by the proposed silica standard.

The Agency developed an exposure profile for all sectors except the engineered stone and landscape contracting industries. For these two industries, data satisfying OSHA's criteria for inclusion in the exposure profile were unavailable (refer to Methodology section for criteria). However, the Agency obtained sufficient information in both of these industries to make feasibility determinations. Each feasibility analysis contains a description of the operations in an industry, the baseline conditions for that industry (including the silica samples collected), additional controls necessary to achieve exposure levels at 50 μg/m^3, and feasibility findings for each operation. Although the Agency's technological feasibility analysis includes information about materials that some employers use as alternatives to silica or silica-containing materials, none of OSHA's conclusions about feasibility depends on the use of substitute materials as a control measure. The Agency recognizes that substitute materials might also present health risks, and that some substitutes might not produce optimal results.

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[329] Note that OSHA's technological feasibility analysis contains 21 general industry sections. The number is expanded to 23 in this summary because Table IV.D-1 describes the foundry industry as three different sectors (ferrous, nonferrous, and non-sand casting foundries) to provide a more detailed analysis of exposures.

Feasibility Findings for the Proposed Permissible Exposure Limit of 50 ug/m^3

Table IV.D-1 summarizes all the industry sectors and construction activities studied in the technological feasibility analysis and shows how many operations within each can achieve levels of 50 µg/m^3 through the implementation of engineering and work practice controls. The table also summarizes the overall feasibility finding for each industry sector or construction activity based on the number of feasible versus not feasible operations. For the general industry sector, OSHA has preliminarily concluded that the proposed PEL of 50 µg/m^3 is technologically feasible for all affected industries. For the construction activities, OSHA has determined that the proposed PEL of 50 µg/m^3 is feasible in 10 out of 12 of the affected activities. Thus, OSHA preliminarily concludes that engineering and work practices will be sufficient to reduce and maintain silica exposures to the proposed PEL of 50 µg/m^3 or below in most operations most of the time in the affected industries. For those few operations within an industry or activity where the proposed PEL is not technologically feasible even when workers use recommended engineering and work practice controls (seven out of 108 operations, see Table IV.D-1), employers can supplement controls with respirators to achieve exposure levels at or below the proposed PEL.

Feasibility Findings for an Alternative Permissible Exposure Limit of 25 ug/m^3

Based on the information presented in the technological feasibility analysis, OSHA believes that engineering and work practice controls identified to date will not be sufficient to consistently reduce exposures to PELs lower than 50 µg/m^3. The Agency believes that a proposed PEL of 25 µg/m^3, for example, would not be feasible for many industries, and the use respiratory protection would have to be required in most operations and most of the time to achieve compliance.

However, OSHA has data indicating that an alternative PEL of 25 µg/m^3 has already been achieved in several industries (e.g. asphalt paving products, dental laboratories, mineral processing, and paint and coatings manufacturing in general industry, and drywall finishers and heavy equipment operators in construction). In these industries, airborne respirable silica concentrations are inherently low because either small amounts of silica containing materials are handled or these materials are not subjected to high energy processes that general large amounts of respirable dust.

For many of the other industries, OSHA believes that engineering and work practice controls will not be able to reduce and maintain exposures to an alternative PEL of 25 µg/m^3 in most operations and most of the time. This is especially the case in industries that use silica containing material in substantial quantities and industries with high energy operations. For example, in general industry, the ferrous foundry industry would not be able to comply with an alternative PEL of 25 µg/m^3 without widespread respirator use. In this industry, silica containing sand is transported, used, and recycled in significant quantities to create castings, and as a result, workers can be exposed to high levels of silica in all steps of the production line. Additionally, some high energy operations in foundries create airborne dust that causes high worker exposures to silica. One of these operations is the shakeout process, where operators monitor equipment that separates castings from mold materials by mechanically vibrating or tumbling the casting. The dust generated from this process causes elevated silica exposures for shakeout operators and

Table IV.D.1—Summary of Technological Feasibility of Control Technologies in

General and Maritime Industries and Construction Activities Affected by Silica Exposures

Industry Sector	**Total No. of Affected Operations**	**No. of Operations for Which the Proposed PEL Is Achievable With Engineering Controls and Work Practice Controls**	**No. of Operations for Which the Proposed PEL Is NOT Achievable With Engineering Controls and Work Practice Controls**	**Overall Feasibility Finding for Industry Sector**
Asphalt Paving Products	3	3	0	Feasible
Asphalt Roofing Materials	2	2	0	Feasible
Concrete Products	6	5	1	Feasible
Cut Stone	5	5	0	Feasible
Dental Equipment and Suppliers	1	1	0	Feasible
Dental Laboratories	1	1	0	Feasible
Engineered Stone Products	1	1	0	Feasible
Foundries: Ferrous*	12	12	0	Feasible
Foundries: Nonferrous*	12	12	0	Feasible
Foundries: Non-Sand Casting*	11	11	0	Feasible
Glass	2	2	0	Feasible
Jewelry	1	1	0	Feasible
Landscape Contracting	1	1	0	Feasible
Mineral Processing	1	1	0	Feasible

* Section 8 of the Technological Feasibility Analysis includes four subsectors of the foundry industry. Each subsector includes its own exposure profile and feasibility analysis in that section. This table lists three of those four subsectors individually based on the difference in casting processes used and subsequent potential for silica exposure. The table

does not include captive foundries because the captive foundry operations are incorporated into the larger manufacturing process of the parent foundry.

Table IV.D-1—Summary of Technological Feasibility of Control Technologies in

General and Maritime Industries and Construction Activities Affected by Silica Exposures

Industry Sector	Total No. of Affected Operations	No. of Operations for Which the Proposed PEL Is Achievable With Engineering Controls and Work Practice Controls	No. of Operations for Which the Proposed PEL Is NOT Achievable With Engineering Controls and Work Practice Controls	Overall Feasibility Finding for Industry Sector
Paint and Coatings	2	2	0	Feasible
Porcelain Enameling	2	2	0	Feasible
Pottery	5	5	0	Feasible
Railroads	5	5	0	Feasible
Ready-Mix Concrete	5	4	1	Feasible
Refractories	5	5	0	Feasible
Refractory Repair	1	1	0	Feasible
Shipyards (Maritime Industry)	2	1	1	Feasible
Structural Clay	3	3	0	Feasible
Totals	**89**	**95.5%**	**4.5%**	

Table IV.D-1—Summary of Technological Feasibility of Control Technologies in General and Maritime Industries and Construction Activities Affected by Silica Exposures

Construction Activity	Total No. of Affected Operations	No. of Operations for Which the Proposed PEL Is Achievable With Engineering Controls and Work Practice Controls	No. of Operations for Which the Proposed PEL Is NOT Achievable With Engineering Controls and Work Practice Controls	Overall Feasibility Finding for Activity
Abrasive Blasters	2	0	2	Not Feasible
Drywall Finishers	1	1	0	Feasible
Heavy Equipment Operators	1	1	0	Feasible
Hole Drillers Using Hand-Held Drills	1	1	0	Feasible
Jackhammer and Impact Drillers	1	1	0	Feasible
Masonry Cutters Using Portable Saws	3	3	0	Feasible
Masonry Cutters Using Stationary Saws	1	1	0	Feasible
Millers Using Portable and Mobile Machines	3	3	0	Feasible
Rock and Concrete Drillers	1	1	0	Feasible
Rock-Crushing Machine Operators and Tenders	1	1	0	Feasible
Tuckpointers and Grinders	3	1	2	Not Feasible
Underground Construction Workers	1	1	0	Feasible

Totals	**19**	**78.9%**	**21.1%**	

often contributes to exposures for other workers in a foundry. For small, medium, and large castings, exposure information with engineering controls in place show that exposures below 50 μg/m^3 can be consistently achieved, but exposures above an alternative PEL of 25 μg/m^3 still occur frequently. With engineering controls in place, exposure data for these operations range from 13 μg/m^3 to 53 μg/m^3, with many of the reported exposures above 25 μg/m^3.

In the construction industry, OSHA estimates that an alternative PEL of 25 μg/m^3 would be infeasible in most operations because most of them are high energy operations that produce significant levels of dust, causing workers to have elevated exposures, and available engineering controls would not be able to maintain exposures at or below the alternative PEL most of the time. For example, jackhammering is a high energy operation that creates a large volume of silica containing dust, which disburses rapidly in highly disturbed air. OSHA estimates that the exposure levels of most workers operating jackhammers outdoors will be reduced to less than 100 μg/m^3 as an 8-hour TWA, by using either wet methods or LEV paired with a suitable vacuum.

OSHA believes that typically, the majority of jackhammering is performed for less than four hours of a worker's shift, and in these circumstances the Agency estimates that most workers will experience levels below 50 μg/m^3. Jackhammer operators who work indoors or with multiple jackhammers will achieve similar results granted that the same engineering controls are used and that fresh air circulation is provided to prevent accumulation of respirable dust in a worker's vicinity. OSHA does not have any data indicating that these control strategies would reduce exposures of most workers to levels of 25 μg/m^3 or less.

Overall Feasibility Determination

Based on the information presented in the technological feasibility analysis, the Agency believes that 50 μg/m^3 is the lowest feasible PEL. An alternative PEL of 25 μg/m^3 would not be feasible because the engineering and work practice controls identified to date will not be sufficient to consistently reduce exposures to levels below 25 μg/m^3 in most operations most of the time. In those circumstances respiratory protection would be necessary to comply with the alternative PEL. Additionally, the current methods of sampling analysis create higher errors and lower precision in measurement as concentrations of silica lower than the proposed PEL are analyzed. However, the Agency preliminarily concludes that these sampling and analytical methods are adequate to permit employers to comply with all applicable requirements triggered by the proposed action level and PEL.