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Management of Radioactive Residues from Uranium Production and Other NORM Activities

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MANAGEMENT OF RADIOACTIVE RESIDUES FROM URANIUM PRODUCTION AND OTHER NORM ACTIVITIES

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. Radionuclides of natural origin are ubiquitous in the environment, and in some geological formations have become sufficiently concentrated to be exploited for the purpose of uranium production. Uranium production[1], including mining, processing and management of radioactive residues, either as primary or secondary minerals, has long been recognized as needing regulatory control. Significant concentration of radionuclides of natural origin may also occur in other activities for commercially exploited minerals and/or in the residues from the processing of those other minerals.

1.2. NORM is defined as “Radioactive material containing no significant amounts of radionuclides other than naturally occurring radionuclides. The exact definition of ‘significant amounts’ would be a regulatory decision. Material in which the activity concentrations of the naturally occurring radionuclides have been changed by a process is included in naturally occurring radioactive material (NORM) [1].

1.3. A NORM residue is defined as “material that remains from a process and comprises or is contaminated by naturally occurring radioactive material (NORM)” [1]. For the purpose of this Safety Guide, residues can be in solid or liquid form. The term “NORM activity” is used to describe those activities involving NORM residues.

1.4. The fundamental safety objective of managing NORM residues is to protect people and the environment from harmful effects of ionizing radiation [2]. The management of NORM residues is important, as accumulating residues can have potential radiological impact on workers, members of the public, and the environment. As a result, regulatory control of these radioactive residues may sometimes be necessary. Unlike uranium production, the residues arising from non-uranium production activities, which may have been recycled, used in other applications or disposed of as waste, were not subject to appropriate regulatory control in the past even though they may contain radionuclides at level of radiation concern. In addition, radon and many of the very long half-lived radionuclides present in these NORM residues warrant management for current and future generations.

1.5. In contrast to uranium production, many of the industries and processes that generate NORM residues have not traditionally had an association with radiation regulation. Thus, the introduction of radiation protection requirements, in compliance with the IAEA Standards, could raise concerns with the

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[1] The term of “uranium production” includes mining of uranium ores by conventional methods (underground and open pit) or in–situ leaching (sometimes termed in-situ recovery) methods, and the milling or processing of the mined materials to produce uranium concentrate, including yellowcake or uranium slurry, as well as recovery of uranium as a secondary mineral or from another source.

industry and the public, especially where industries have been located in or near areas of high population. Equally, the introduction of such requirements can have a significant impact on the industries themselves if not planned and communicated properly.

1.6. NORM residues, particularly those generated in mining and mineral processing activities, differ from radioactive residues generated at, for example, nuclear power plants or medical facilities. They tend to be lower specific activity but can be generated in very large volumes. This has important implications for their management, including siting and engineering options. In some cases, NORM residues may have higher specific activities but small volumes. In such cases, residue management similar to the management of radioactive waste may be suitable.

1.7. Various publications in the IAEA Safety Standards Series are relevant to NORM and NORM residues, covering issues such as clearance and exemption levels for radionuclides of natural origin [4, 5], occupational radiation protection [6], control of radioactive discharges to the environment [7], predisposal management of radioactive waste [8], public protection from indoor radon and other natural radiation sources [9], remediation process for past practices [10], the transportation of NORM residues [11], and emergency preparedness and response [12]. However, there has been relatively little guidance specifically on the management of NORM residues (including NORM residues designated as waste) arising from other industries such as titanium dioxide pigment industries, metal smelting, phosphate fertilizer production, oil and gas production, coal burning, mineral sands exploitation, and water and sewage treatment.

1.8. Once published, this Safety Guide will supersede the Safety Guide on Management of Radioactive Waste from the Mining and Milling of Ores, IAEA Safety Standards Series No. WS-G-1.2, issued in 2002[2].

OBJECTIVE

1.9. The objective of this Safety Guide is to provide guidance to regulatory bodies, operators, technical support organizations and other interested parties on approach for safe management of NORM residues arising from uranium production and other activities, in accordance with the relevant Safety Requirements for protection of human health and the environment from exposure to ionizing radiation now and in the future [3, 4] and to avoid undue burden to the future generation.

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[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Management of Radioactive Waste from the Mining and Milling of Ores, IAEA Safety Standards Series No. WS-G-1.2, IAEA, Vienna (2002).

SCOPE

1.10. This Safety Guide addresses the management of the radiological hazards and risk associated with various types of NORM residues. It addresses both uranium production and other activities that produce very large quantities of NORM residues, such as processed tailings from mining and processing, and also activities that generate comparatively small volumes of residues, such as sludge and scales. Though the fundamental principles of managing these hazards and risk are similar, the options for the management of this broad range of materials necessarily are quite different.

1.11. The scope of this Safety Guide covers pre-operational, operational, decommissioning, closure and post-closure activities at facilities that generate NORM residues. It identifies organizational and regulatory requirements (including exemption and clearance for re-use, recycling and other use), and provides life cycle guidance on the site selection and evaluation and design of NORM residue management facilities through all phases, including the transfer to institutional control if necessary. It includes guidance on the conduct of safety assessment for facilities and activities involving NORM residues, including when a safety case[3] is appropriate (for example uranium production tailings).

1.12. This Safety Guide is intended to be applicable to the mining and processing of ores for the extraction of uranium, to other industries including mining and processing of other ores like thorium, the oil and gas industry, the phosphate industry, and other activities resulting in the production of NORM residues. Regulatory bodies should determine the extent to which this guidance should be applied to particular industries in accordance with a graded approach.

1.13. This Safety Guide is principally directed towards the management of residues generated by new facilities. It also applies to residues arising from the proposed decommissioning and remediation activities associated with those facilities.

1.14. This Safety Guide does not address the remediation of areas contaminated by residual radioactive materials arising from past activities. The requirements and guidance for the remediation of such areas are established in Ref. [4, 10]. The Safety Guide may, however, also be relevant to the review and upgrading of existing facilities and to legacy sites. It may not be practical to apply all of these recommendations to existing facilities and in such cases the regulatory body should decide the extent to which these recommendations apply. In accordance with national policies, appropriate steps may be taken to review the safety of existing facilities (including legacy sites or other abandoned sites) and, where reasonably practicable, to upgrade their safety in line with the relevant recommendations set out in this Safety Guide.

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[3] The safety case is the collection of scientific, technical, administrative and managerial arguments and evidence in support of the safety of a facility or activity.

1.15. The radionuclides contained in NORM residues may not be the only potential risk to human health and the environment. Other chemical constituents within the material may be capable of causing harm to human health and/or the environment and may have to be controlled under environmental regulations or occupational health and safety regulations. These include heavy metals, inorganic elements (e.g. arsenic) and various organic compounds. The potential for such non-radiological substances to cause detriment needs to be considered when planning the management of NORM residues. There is a particular need for regulators to take account of the non-radiological hazards that in some cases may represent the primary risk to people and the environment. Achieving a consistent regulatory approach to protect against these different hazards is a challenge for national regulators.

STRUCTURE

1.16. Section 2 provides an overview of NORM residues. The governmental, legal and regulatory framework needed for the safe management of NORM residues is described in Section 3. Protection of human health and the environment is described in Section 4. The regulatory control process and the management plans follow in Section 5, while Section 6 describes the recommended management strategies. Section 7 provides guidance on development of the safety case and supporting safety assessment. The concluding main part of the report is Section 8, which addresses the full life cycle and long term management of facilities and the NORM residues, from siting through long term institutional controls. Three appendices, the references and four supporting annexes complete the document.

2. OVERVIEW OF NORM RESIDUES

2.1. Exposure to the radiation arising from NORM residues is considered to be an existing exposure situation [4]. As articulated in paragraph 3.4 of GSR Part 3, if in any NORM residues, the activity concentration of any radionuclide in the ^{238}U or ^{232}Th decay series exceeds 1 Bq/g, or if the activity concentration of ^{40}K exceeds 10 Bq/g, the requirements for planned exposure situations apply.

2.2. When NORM residues occur in fertilizers, soil amendments and construction materials (or components of such), the requirements for existing exposure situations apply, irrespective of the activity concentrations (Ref. [4], para. 3.4(a), Footnote 17).

2.3. In addition to uranium production, the following industrial activities may generate residues that require regulatory concern based on information in Ref. [18] as well as other considerations:

(1) Extraction of rare earth elements;

(2) Production and use of thorium and its compounds;

(3) Production of niobium and ferro-niobium;

(4) Mining of ores other than uranium ore;

(5) Production of oil and gas;

(6) Manufacture of titanium dioxide pigments;

(7) The phosphate and potash industries;

(8) The zircon and zirconia industries;

(9) Production of tin, copper, aluminum, zinc, lead, and iron and steel;

(10) Combustion of coal;

(11) Water treatment.

2.4. Table 1 provides a general overview of the residues arising from uranium production and other industrial activities. Appendix A provides more details of the characteristics of the residues from uranium production. Residues of different origins vary significantly with respect to their radiological, chemical and physical characteristics. Uranium production generates a range of residues specific to the mining and processing methods as reflected in Table 1.

2.5. There are bulk amounts of residues, such as waste rock from uranium mining, mineral process tailings, phosphor-gypsum, red mud from alumina processing and metalliferous tailings. Of the different residues produced by NORM activities, bulk amounts of residues represent the greatest challenge, despite their relatively low specific activity, because of the large volumes produced, and the presence of very long lived radionuclides and (often) other hazardous substances, such as heavy metals.

2.6. Some residues may comprise a relatively small volume but be of relatively higher activity concentration, for example:

(a) Scales and sludge that may accumulate in pipes or process vessels in oil and gas production, coal production with radium rich inflow water, geothermal energy production and rare earth production;

(b) Anode slimes from electrowinning processes;

(c) Precipitated smelting dusts and slags;

(d) Rare earth extraction residues (e.g. thorium hydroxide);

(e) Residues from decontamination processes; and

(f) Contaminated equipment, process filters.

2.7. NORM residues in the form of scrap items can also be produced, such as pipes, valves, process vessels, pumps and machinery that have been contaminated with NORM residues, during operation and particularly during decommissioning of relevant facilities,.

2.8. Liquid residues of various origin, include process water; leaching fluids; rainfall runoff (from the process plant area, residue management area, residue and ore stockpiles); seepage from process tailings, stockpiles and waste rock management areas; and mine water (for example, groundwater which has entered open pits or underground mines).

Table 1: Type of residues arising from relevant industrial activities

Industrial activities	**Bulk residues**			**Medium to small amount of residues**				
	Tailings	**Waste rock**	**Liquid**	**Slags**	**Scale**	**Sludge**	**Precipitator dust**	**Intermediate product**
Conventional uranium production	X	X	X		X	X	X	
Heap leaching for uranium	X	X						
In-situ leaching for uranium			X					
Extraction of rare earth elements	X		X		X	X	X	
Production and use of thorium and its components	X							Thorium compound and concentrate
Production of niobium and ferro-niobium	X			X			X	Pyrochlore concentrate
Mining of ores other than uranium ore	X	X	X		X	X		
Production of oil and gas			X		X	X		
Manufacture of titanium dioxide pigments	X				X			
The phosphate and potash industries	Phophogypsum			Thermal production			X	
The zircon and zirconia industries							X	Fused zirconia
Metals production (Sn, Cu, Al, Fe, Zn, Pb)	Red mud			Tin and copper smelting		X	X	
Combustion of coal	Fly ash				X			
Water treatment						X		

3. GOVERNMENTAL, LEGAL AND REGULATORY FRAMEWORK

RESPONSIBILITIES OF THE GOVERNMENT

3.1. GSR Part 1 [3] requires that “the government shall establish a national policy and strategy for safety, the implementation of which shall be subject to a graded approach in accordance with national circumstances and with the radiation risks associated with facilities and activities, to achieve the fundamental safety objective and to apply the fundamental safety principles established in the Safety Fundamentals.”

3.2. The government should establish a national policy and strategy for the safe management of NORM residues. The national strategy should acknowledge existing frameworks, identify further industries that might need oversight, and coordinate the approaches to each. The policy and strategy should reflect, and be consistent with, the principles as set out in Ref. [2] and Sections 4-8 of this publication.

3.3. The policy and strategy for management of NORM residues should be coupled with the national policy and strategy guiding development of activities that generated NORM residues. It should address control of generation of residues, and encourage the recycling of NORM residues and their reuse in other applications, where safe and appropriate to do so. Recycling and reuse of NORM residues is discussed further in Section 6 as options for residue management, and more information on the application of these options is given in Annex II.

3.4. The policy and strategy for management of NORM residues should take account of the national policy and strategy for safety, for waste and for radioactive waste management. Countries may choose to integrate key elements of NORM residue management strategy into their national policy, legislative and regulatory instruments. In such cases, a national residue strategy that is “stand alone” may not be necessary.

3.5. The government should consider the need for, and the extent of, public involvement and coordination among relevant governmental organization during the development and implementation of the policy and strategy, including regulatory process. Increasing public consultation is a feature of the authorization process in many States. However, the responsibility for the regulatory decision remains with the regulatory body. The decision making process should be transparent, independent and justifiable, such that if a decision is challenged the regulatory body can explain how it was reached.

3.6. For the oversight of NORM, the government should first identify which industries within their State produce and/or process NORM. It should then identify the regulatory body or bodies appropriate to the industries to oversee NORM activities. If there are multiple activities or industries, there may be more than one regulatory body.

3.7. The government is required to establish and maintain the responsible regulators as independent bodies with authority, resources (staff and financial) sufficient to properly oversee activities [3]. For regulatory bodies that have not historically been involved in radiation protection regulation, this is likely to require cooperation with agencies and staff with relevant radiation expertise.

3.8. The government should coordinate the establishment of a national inventory of significant NORM residues, including legacy sites.

3.9. The government should establish legislation that allows the regulatory bodies to effectively manage NORM activities, where such legislation does not already exist. Such legislation should meet the requirements of the IAEA GSR Part 3 [4]. This should include provision for authorization through licensing and for establishing financial assurances by the operator, where these are required. Financial assurances are explained in more detail in Section 5.

3.10. For activities including uranium production, effective legislation will:

(a) prohibit production or storage of residues and wastes without a licence;

(b) enable the regulator to specify conditions to be attached to licences;

(c) make failure to comply with licence conditions an offence subject to enforcement action;

(d) require information and any associated fees to be provided with the application;

(e) require management plans;

(f) require financial guarantees for the purpose of remediation and institutional controls;

(g) require regulatory approval for significant changes to operations;

(h) require permission before any licence is transferred to another party; and

(i) prevent relinquishment of licences without regulatory approval.

3.11. For other activities, legislation should be commensurate with the risks and should take into account existing legislation and systems of control. Existing workplace health and safety or environmental protection regulations may provide adequate protection from radiation and hence further radiation specific legislation might not be required for those activities.

3.12. For all activities, legislation should enable the regulator to meet the regulatory approaches set out as Figure 1 in Section 5.

3.13. Given the range of industries concerned, several parties of government will carry responsibilities, and it is likely that several pieces of legislation will apply. It is important for effective and efficient regulation that responsibilities are formally coordinated through instruments such as Administrative Agreements or Memoranda of Understanding between agencies.

3.14. This coordination can be achieved under a single regulator acting for government, coordinating regulatory oversight across multiple industries. More commonly there will be multiple regulators. With multiple regulators any authorizations such as licences and conditions will need to be aligned.

3.15. Where an existing exposure situation (legacy sites) exists and there is no operator or body with responsibility for the site, the government has to take control and assume the responsibilities of the operator as set out in this document.

3.16. If, for any reason, the operator is no longer able to carry out its responsibilities, the regulator can revoke the authorization or licence to operate the facility and may assume responsibility for remediation and decommissioning by making use of the financial assurance that should be in place.

RESPONSIBILITIES OF THE REGULATORY BODY

3.17. The regulatory body is responsible for establishing guidance on application of legislation, regulatory review and assessment, authorization, operational oversight, and overseeing the operator's closure and decommissioning of a facility.

3.18. A key role of the regulatory body is to identify what industries, facilities and activities producing or managing NORM are likely to trigger the requirements of legislation, and to provide guidance to industry on its application. This will then start the notification and assessment process described in this Safety Guide. Uranium producers are likely to know this already, but for other industries this guidance will be important. Through the implementation of regulatory criteria that are based on the established laws, the regulatory body should determine those facilities or processes that require formal regulatory control and those where guidance on best practice is appropriate.

3.19. The regulatory body should consider an outreach programme to communicate with industries involved in the generation of NORM residues, to make the industry aware of the potential need for regulation and radiation protection.

3.20. The regulatory body should define the scope of regulatory responsibility. This will include determining whether licensing, registration, exemption, or notification is required for activities that it oversees. Section 5 provides more detail on the approach to regulatory control.

3.21. The regulatory body should establish standards for material clearance, sites to be released from regulatory control, and then set end state criteria for sites that it is regulating. It should oversee the operators' decommissioning plans and closure plan, including any institutional controls or long term monitoring, to verify that they continue to ensure progress to meet the end state criteria.

3.22. For some planned exposure situations, the regulatory body should set dose constraints or source constraints, where appropriate [4]. It should oversee compliance with requirements of licences, including inspection and enforcement activities as appropriate.

3.23. When applying regulations, the regulatory body should seek to encourage reuse and recycling of NORM residues, where the safety goals can be met and residues can be cleared from further regulatory control.

3.24. The regulatory body should ensure that it maintains the necessary technical expertise to evaluate processes and activities that generate NORM residues.

3.25. The regulatory body should ensure that the operator keeps relevant records concerning any facility that uses, handles or produces NORM residues, in particular where residues are held for long term management, and makes those records available. The regulatory body should require the operator to provide it with these records or a summary of records on a defined schedule.

RESPONSIBILITIES OF THE OPERATOR

3.26. The operator is required to notify the regulatory body of an intention to undertake a NORM related activity. It is required to provide the regulator access to the facility and undertake actions or provide information required by the regulator under the legislation.

3.27. The operator is responsible for all aspects of safety of the facility, including protection of workers, members of the public, and the environment from any hazards associated with the residues throughout the life of the facility, including decommissioning. The operator is required to comply with all legal and regulatory requirements, which for some operators will include collecting adequate baseline prior to site development and preparing a safety case and supporting safety assessments associated with siting, design, construction, commissioning, operation, decommissioning, closure and remediation if necessary.

3.28. The operator is responsible for developing facility/site specific policies and strategies that should be consistent with the national policy and strategy.

3.29. The operator is responsible for establishing and implementing an appropriate management system commensurate with the complexity and risk of the facilities and activities related to NORM residues.

3.30. By means of design measures, procedures and processes, the operator should identify and implement ways to minimize the generation of NORM residues. This could be achieved, for example, by increasing the efficiency of processes, or through the reuse and recycling of NORM residues.

3.31. Where applicable, the operator should maintain an up to date decommissioning plan, closure plan and related financial guarantee throughout the lifetime of the facility, including how it will meet end state criteria, which also will provide the basis for any financial assurance mechanism required.

4. PROTECTION OF PEOPLE AND THE ENVIRONMENT

GENERAL

4.1. The fundamental safety objective of managing NORM residues is to protect people and the environment from harmful effects of ionizing radiation, in compliance with the requirements and recommendations of the IAEA Safety Standards in Refs [4, 6, 15] and the International Commission on Radiological Protection (ICRP) [16, 17]. Given the broad spectrum of NORM residues arising from a wide range of activities, it is important that a graded approach to radiation protection and to management option is adopted. That is, the protection measures adopted should be commensurate with the magnitude and likelihood of exposures and risks.

4.2. The regulatory framework for NORM management is based on principles laid out in Ref. [4], which states: “For radionuclides of natural origin, exemption of bulk amounts of material is necessarily considered on a case by case basis by using a dose criterion of the order of 1 mSv in a year, commensurate with typical doses due to natural background levels of radiation.” It further states: “Material containing radionuclides of natural origin at an activity concentration of less than 1 Bq/g for any radionuclide in the uranium decay chain or the thorium decay chain and of less than 10 Bq/g for ^{40}K is not subject to the requirements … for planned exposure situations… hence, the concept of exemption from the requirements of these Standards does not apply for such material.”

4.3. The management of NORM residues is part of the management of a facility and activity as defined in IAEA Safety Standard GSR Part 3 [4], and radiation protection considerations are therefore governed by the principles of justification, optimization and dose limitation. The generation and management of NORM residues do not need to be justified since this will have been taken into account in the justification of the entire practice.

4.4. The adequacy of control measures taken to limit the radiation exposure of workers and the public should be verified by monitoring and surveillance, both inside and outside the facility.

4.5. In the generation of NORM residues, as well as in subsequent management steps, a safety culture that encourages a questioning and learning attitude to protection and safety and that discourages complacency, should be fostered and maintained [4].

4.6. Discharges to the environment from NORM facilities and activities that are subject to registration or licensing should be controlled in accordance with an authorization by the regulatory body and a constraint should be considered when estimating doses to workers and to members of the public (Ref. [4], para. 3.123). DS442 sets out the practical considerations in setting discharge authorizations [7].

PLANNED EXPOSURE SITUATIONS

OCCUPATIONAL EXPOSURES

4.7. Workers may be exposed during the generation of the NORM residues, during operations to process, re-use or recycle the residues, or during the long term management. The radiation protection program should set out how the protection of workers is optimized [4]. In all cases where the NORM residues are subject to regulatory control, the operator should prepare and implement a radiation protection program subject to regulatory approval [6]. Special considerations for mineral processing involving NORM can be found in Ref. [6] (para. 9.66-9.72).

4.8. Radiation protection in the generation of NORM residues is usually dealt with as part of the radiation protection program for the overall process that is producing the residues. For example radiation protection in the generation and handling of uranium mill tailings will be a part of the overall radiation protection program for the mill.

4.9. In other cases the NORM residue may be the only material in the whole process where the concentration of radionuclides is sufficient to generate doses requiring management, in which case the radiation protection program will be specific to the NORM residue. For example, for a rare earth facility, the main residues of interest may be thorium hydroxide that presents an important radiological risk that needs to be managed through the radiation protection program. This will also be the case where the NORM residues are pre-existing.

4.10. In general, occupational radiation protection in the management of NORM residues involves consideration of three main exposure pathways:

(a) External exposure to radiation (primarily gamma radiation) emitted by the material

(b) Intakes of material (primarily through dust inhalation); and

(c) Inhalation of radon (and sometimes thoron) released from material into the air[4].

4.11. Controlled areas may not need to be set up where only small quantities of unsealed radioactive material are used, e.g. for tracer studies in a research laboratory. They may also be unnecessary when only materials with low activity concentrations are handled, such as materials in various industrial activities involving NORM (Ref. [6], para. 3.79).

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[4] The terms “radon” and “thoron” include not only the parent radionuclides, ^{222}Rn and ^{220}Rn respectively, but also their short-lived progeny.

PUBLIC EXPOSURES

4.12. For NORM activities that belong to planned exposure situations, the radiation protection principles of optimization and limitation apply. The main limit applicable in the case of exposure from NORM residues is an effective dose of 1 mSv in a year, with a provision that in special circumstances a higher value of effective dose could apply in a single year, providing that the average effective dose over five consecutive years does not exceed 1 mSv per year (Ref. [4], Schedule III).

4.13. As most if not all NORM radionuclides are normally present in the environment, and contribute to natural background radiation, it is important that care be taken to distinguish between exposures arising as a result of the presence of NORM processing and residues, and those arising from natural background.

4.14. The dose limits should apply both during operations involving NORM residues, such as generation, re-use or recycling, or storage or disposal, and to exposures occurring after the cessation of such operations. During operations, doses can be assessed through direct monitoring of radionuclides in, for example ambient air or foodstuffs, or indirect monitoring of discharges and modeling the subsequent intakes and doses to members of the public. For after the cessation of such operations, end state criteria in conjunction with institutional control should ensure that public exposure are not greater than the order of 1 mSv in a year.

4.15. If several radiation facilities and activities are located at the same site, the dose constraints for public exposure should take into account all sources of exposure that could be associated with activities at the site, leaving an appropriate margin for foreseeable future activities at the site that may also give rise to exposure. Particularly in such cases, the regulatory body should require the operator(s) of the facility and activity on the site to develop constraints, subject to regulatory approval. Alternatively, the regulatory body may establish the dose constraint(s). Dose constraints are described in Ref. [4].

4.16. There should be reasonable assurance that these controls will remain effective for a specified period, and that during this period the dose constraint determined by the regulatory body will continue to be met.

4.17. The potential for public exposures in excess of the dose constraint arising from possible future re-development of, or unplanned intrusion into, closed NORM residue management facilities, should always be considered, and appropriate institutional controls prepared.

EMERGENCY EXPOSURE SITUATIONS

4.18. For the management of NORM residues, there are very few, if any, credible accident scenarios[5] that could lead to an emergency exposure situation. Emergency management arrangements for radiation exposures are therefore unlikely to be required.

4.19. Engineering controls may fail because of natural processes (such as erosion) or incidents may occur that result in the release of increased amounts of radionuclides to the environment. These may have radiation exposure implications; however, other non-radiological risks will generally dominate. Due consideration should be given to the probability of failure of such controls and to the likely impact in terms of the overall integrity of the facility and any public exposure or environmental consequences. As such, incidents generally do not fall under emergency management arrangements. Guidance for the management of non-radiological emergencies is outside the scope of this document.

4.20. Should the results from the safety assessment demonstrate that emergency exposure situations may occur in such facilities, the establishment of emergency preparedness and response is required, consistently with GSR Part 7 [12]. Recommendation and guidance supporting implementation of GSR Part 7 are provided in Ref. [13, 14].

4.21. In most cases any deviations from normal operations and small scale incidents should be managed within the framework of normal radiation protection program. Some arrangements in these circumstances may be needed for dealing with public concerns, provision of information and with non-radiological hazards (e.g. chemicals) present at the site but establishment of either on-site or off-site emergency plan is not warranted.

EXISTING EXPOSURE SITUATIONS

4.22. Radiation exposures to members of the public from NORM residues may occur as two categories of existing exposures situations:

(a) Where NORM residues from past activities and operating activities are giving rise to exposure of members of the public. Where members of the public have access to the site on which NORM residues are disposed of, exposure can arise directly from those residues, but exposure more commonly arises in the area surrounding the NORM residues where radionuclides have been dispersed by airborne or waterborne pathways, and emanation of radon;

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[5] The term “scenario” means a postulated or assumed set of conditions and/or events [1].

(b) When NORM occurs in fertilizers, soil amendments and construction materials (or components of such), the requirements for existing exposure situations apply, irrespective of the activity concentrations (Ref. [4], 3.4(a) Footnote 17).

4.23. For existing exposure situations with dose implications less than 1 mSv/y, no action with respect to radiological controls would normally be warranted.

4.24. For existing exposure situations with dose implications exceeding 1 mSv/y, then a protection strategy should be developed and implemented to ensure that any remedial action is justified and to optimize protection and safety, as described in Section 5 of Ref. [4]. Guidance and recommendations on remediation of contaminated sites from past practices can be found in Ref. [10].

4.25. There may be circumstances where the regulator determines that activities conducted in an existing exposure situation should fall under the system of regulatory control and be treated as a planned exposure situation. This guidance is not intended to preclude such actions on the part of the regulator.

PROTECTION OF THE ENVIRONMENT

4.26. IAEA Safety Standard GSR Part 3 [4] specifies that the protection of the environment means protection and conservation of populations of non-human species, both animal and plant, and their biodiversity; environmental goods and services such as the production of food and feed; resources used in agriculture, forestry, fisheries and tourism; amenities used in spiritual, cultural and recreational activities; media such as soil, sediments, water and air; and natural processes.

4.27. In most cases, the standard of radiation protection required to protect people from harmful effects is generally considered to also provide appropriate protection of the environment. In addition, protection of the environment from non-radiological (i.e. chemical and physical) impacts of activities is likely to be dominating the decision making process. Nevertheless there is a need to be able to demonstrate that the environment is protected from the harmful effects of radiation exposure in any situation in which NORM residues may be released into the environment [4]. The radiological environmental impact assessment will inform the impacts and, where appropriate, control measures. Ref. [25] provides a methodology for setting criteria to protect animals and plants.

NON-RADIOLOGICAL CONSIDERATIONS

4.28. Non-radiological hazards may arise from contaminants that are toxic in their own right, such as heavy metals, or they may cause harmful effects indirectly. An example of the latter is acid forming materials (such as sulphide), which may lead to the dispersion of otherwise relatively benign forms of contaminants into the general environment. Other concerns may arise not from the NORM materials themselves, but from materials associated with their generation or management. An example is excessive amounts of sediment eroded from the cover of a management facility for NORM residues entering water bodies. It is important that the overall planning of the management of NORM residues should include a broad assessment of all potentially harmful agents likely to be involved, and appropriate control measures should be adopted.

5. SYSTEM FOR REGULATORY CONTROL

GENERAL

5.1 The number of facilities involved in the processing of minerals and raw materials is very large, but few processes result in significant radiological hazards [18]. Selection of regulatory control should be commensurate with the associated hazards and risk. While regulatory intervention criteria should be based on reasonable and prudent precautions to ensure safety, it should be recognized that an inappropriate selection of regulatory intervention criteria could result in many facilities being regulated without any net benefit. For this reason, the concept of a graded approach is especially important in defining the scope of regulatory control.

5.2 NORM residues arising from uranium production should always be under regulatory control. In order to determine the optimum regulatory approach for NORM residues, the regulatory body should understand how, when and where elevated concentrations of natural radionuclides could occur in the activities identified in Section 2. It should therefore consider the processes, the materials and the residues in more detail, including an initial assessment of exposure or dose and consideration of the costs of regulation in relation to the benefits achievable.

5.3 A process that is applicable to the management of NORM residues, to illustrate the regulatory approach established in GSR Part 3, is shown schematically in Figure 1.

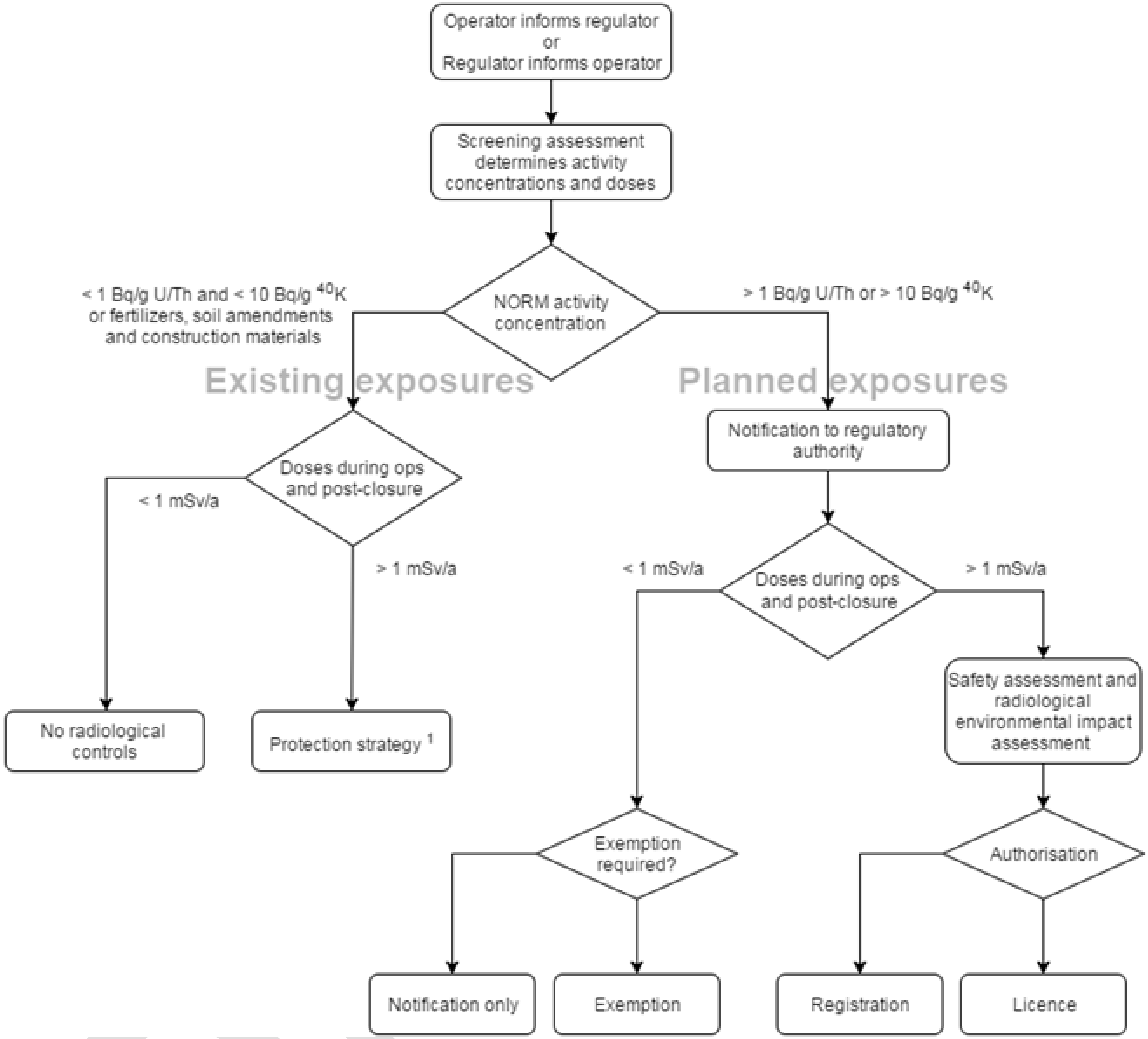

Figure 1. Stepwise and graded approach to the regulatory control of NORM residues in accordance with GSR Part 3 [4]

INVENTORY OF ACTIVITIES GENERATING NORM RESIDUES

5.4 The identification of the activities[6] that require regulatory concern is the first step in the regulatory control process. These activities can be identified by either operators or by the regulator. The list can be developed based on information in Section 2 with consideration of national circumstances.

5.5 A detailed understanding of the industrial activity concerned is essential for proper implementation of the graded approach. Therefore, an inventory should be made of the activities

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[6] Residues from uranium mining, especially heaped up waste rock materials, the activity concentrations of all radionuclides in the ^{238}U and ^{232}Th decay series are, in most cases, less than 1 Bq/g. Nevertheless, there is a potential health risk for which a safety assessment is mandatory. In some practices, the activity limit requiring a radiological risk assessment was set to 0.2 Bq/g for each of the radionuclides mentioned above.

producing or managing NORM residues, including a description of the processes, materials and associated exposures.

SCREENING ASSESSMENT

5.6 An operator that wants to start a facility belonging to the identified list of NORM industries within the State, in accordance with paragraph 3.6, should formally inform the regulatory body about its plans.

5.7 Upon receiving notification from the operator, or if the regulatory body has identified an industry belonging to the list of regulatory control, the regulatory body may require the operator to make an initial screening risk assessment to estimate:

(a) The activity concentrations in the raw materials, in processed materials and facilities, and in residues;

(b) The magnitude of doses to workers and members of the public arising from the operation;

(c) The level of optimization of radiation protection;

(d) The impact on the environment from long term management of residues;

(e) The impact of residues containing NORM or contaminated materials that may be recycled.

5.8 The screening assessment should be specific to the particular operation and should be agreed with the regulator. The assessment may be based on existing information relating to the operation, its processes and residue management methods, or be based on an agreed monitoring program to provide more data.

5.9 Possible outcomes of the screening assessment include exemption, notification (including periodic review), and authorization. If the effective dose in the potential planned exposure situation is equal to or exceeds a level of 1 mSv/y, authorization will likely apply.

5.10 For materials in which the activity concentrations do not exceed 1 Bq/g (10 Bq/g for ^{40}K) and thus, the exposure is considered to be an existing exposure situation, authorizations do not apply. Where the existing exposure situation potentially exceeds a reference level of 1 mSv/y, the regulator should develop a protection strategy. This might include either the allocation of responsibilities for residue management, or the provision of guidance on management.

5.11 If the screening assessment indicates that the activity concentrations in the residues exceed the exemption and clearance levels, and the dose may exceed 1 mSv/y, a more detailed safety assessment may need to be conducted. As described in Section 7 of this document, this may include:

(a) more realistic assumptions and exposure scenarios;

(b) the collection of more case specific data to improve the estimation of the source term and transfer parameters; and

(c) more complex models if considered appropriate.

5.12 In the event of a significant process change, or where external events have impacted the operation (flooding, fire, land slippage, subsidence), a new assessment may be required. The operator and regulator should review the situation after a mutually agreed period to check whether exemption is still appropriate.

GRADED APPROACH TO REGULATION

5.13 For industrial activities subject to the requirements for planned exposure situations, a graded approach to regulatory control should be adopted, in accordance with Requirement 6 of Ref. [4]. This means that the application of the requirements for planned exposure situations should be commensurate with the characteristics of the NORM activity, and with the magnitude and likelihood of the exposures. As stated in Section 4, where an existing formal licensing or regulatory process is in place for managing the radioactive residues, then that process should be followed.

5.14 An important feature of the graded approach in planned exposure situations is the provision for exemption and clearance, and for four different levels of regulatory control. These include:

(a) Notification;

(b) Exemption;

(c) Authorization in the form of registration; and

(d) Authorization in the form of licensing.

Notification

5.15 Requirement 7 of GSR Part 3 [4] states that an applicant/operator shall submit to the regulatory body a notification of intention to carry out the practice or to make any modifications with implications for radiation protection. In this way, the regulator remains informed of operations and important changes.

5.16 Notification alone may be sufficient provided that the exposures expected to be associated with the practice or actions are unlikely to exceed a small fraction of the relevant limits. There may be no further action by the applicant/operator or the regulator required beyond notification. In such cases, this Safety Guide can be used as guidance to assist best practice management of NORM.

Exemption

5.17 The regulatory body may decide that the optimum regulatory option is not applying regulatory requirements to the operator responsible for the material. The mechanism for implementing such a decision is the granting of an exemption for some or all aspects of the facility or activity. The general criteria for exemption (Ref. [4], Schedule I) are that:

(a) Radiation risks are sufficiently low as not to warrant regulatory control, or

(b) Regulatory control would yield no net benefit, in that no reasonable control measures would achieve a worthwhile return in terms of reduction of individual doses or of health risks.

5.18 For exposure to NORM, the general criterion for exemption is deemed to have been met if the dose (as determined in the screening assessment) is 1 mSv per year or less, above natural background levels of radiation.

5.19 Exemption of bulk amounts of material is necessarily considered on a case by case basis by using a dose criterion of the order of 1 mSv in a year, commensurate with typical doses due to natural background levels of radiation [Ref. 4, para. I-4]

5.20 In granting an exemption, the regulator may choose to exempt the operator from all or some of the regulatory requirements. The regulator should choose to grant a partial exemption only when the control measures that remain achieve a net benefit.

Authorization

5.21 Where further controls are appropriate they will be placed on the applicant/operator through the granting of an authorization. There are two levels of authorization — registration and licensing.

5.22 Facilities and activities requiring authorization are those where NORM is produced, processed, used, handled or stored on such a form and scale that consideration of the possible impact on workers, the public and the environment is required, beyond that done for the screening assessment.

Registration

5.23 Registration is the appropriate form of authorization when the applicant/operator needs to meet only limited obligations to ensure that workers, the public and the environment are adequately protected. These obligations would typically involve measures to keep exposures under review and to ensure that the management of residues and impacts of environmental discharge and working conditions are such that exposures are controlled, with doses not approaching or exceeding the dose limit.

5.24 Registration is best suited to those practices for which operations do not vary significantly. Typical practices that are suitable for registration are those for which the following conditions are fulfilled: (a) safety can largely be ensured by the design of the facilities and equipment, (b) the operating procedures are simple to follow, (c) the training requirements for safety are minimal, and (d) there is a history of few problems relating to safety in operations.

5.25 Such facilities and activities will require a safety assessment and a radiological environmental impact assessment, however, very simple generic assumptions and calculations are likely to be more appropriate than the more complicated safety assessments set out in Section 7.

5.26 For facilities and activities subject to registration, the strategies for NORM residue management set out in Section 6, and the safety considerations for long term management set out in Section 8, can provide useful guidance for best practice, but should be implemented only to the degree appropriate to the level of risk.

Licensing

5.27 Licensing is an appropriate form of authorization when an acceptable level of protection can be ensured only through the enforcement of more stringent exposure control measures. This is the highest level of the graded approach to regulation and its use is normally for practices involving exposure to residues involving substantial quantities of material (like uranium production facilities).

5.28 Such facilities and activities will require a safety assessment and radiological environmental impact assessment as set out in Section 7.

5.29 For facilities and activities subject to licensing, the strategies for NORM residue management set out in Section 6, and the safety considerations for long term management set out in Section 8, set out the general expectations for control. The regulator can specify in the licence those aspects required to effectively manage risks.

Clearance

5.30 Clearance is the removal of regulatory control from radioactive material or radioactive objects within notified or authorized practices, thus allowing the material or objects to be removed from the site without any further restrictions. The general criteria for clearance (Ref. [4] Schedule I) are that:

(a) Radiation risks arising from the cleared material are sufficiently low as not to warrant regulatory control, with no appreciable likelihood of occurrence for scenarios that could lead to a failure to meet the general criterion for clearance; or

(b) Continued regulatory control of the material would yield no net benefit, in that no reasonable control measures would achieve a worthwhile return in terms of reduction of individual doses or of health risks.

5.31 In terms of the processing of NORM and the management of NORM residues, it may be appropriate to establish a single set of levels both for exemption and clearance.

5.32 Clearance of NORM residues containing activity concentrations above 1 Bq/g (10 Bq/g for ^{40}K) may be appropriate, in certain situations, providing the regulatory body is satisfied that future exposures from such residues will not require the reinstatement of controls.

5.33 Clearance may be granted by the regulatory body for specific situations, on the basis of the criteria specified by the regulatory body, with account taken of the physical or chemical form of the radioactive material, and its use or the means of its management, for example specific clearance levels may be developed for metals, rubble from buildings and waste for management in landfill sites (Ref. [4], I-13, Footnote 65). Such clearance levels may be specified in terms of activity concentration per unit mass or per unit surface area.

5.34 For NORM residues that might be reused and recycled or disposed, inadvertently or intentionally, and become entrained in construction material, or impact drinking water, food and feed, a dose criterion of 1 mSv in a year above natural background levels of radiation should apply (Ref. [4], I-12c). Recommendations and guidance on use of residues as building materials is given in Ref. [9]. The reference level of about 1 mSv in a year applies to the dose received from exposure to gamma radiation from the building materials only (i.e. excluding any additional dose from ^{222}Rn or ^{220}Rn released from building materials into indoor air) (Ref. [9], para. 4.17-4.27).

FINANCIAL ASSURANCE

5.35 The objective of the financial assurance provision is to protect the government and community from liabilities arising from the operator failing to adequately decommission and/or remediate a site with NORM residues

5.36 Legislation should allow the regulator to require a financial assurance from the operator to cover all costs associated with decommissioning, remediation and long term institutional control of a site with NORM residues. It should be accessible only for the purpose of site remediation and any long term institutional control or for return to the operator in the event that it remediates the site in accordance with regulatory requirements.

5.37 In order to determine the amount of financial assurance, the regulatory framework should include provisions that require the operator to submit, prior to construction and operation of a facility, a plan that provides details of decommissioning, including any long term management of NORM residues, and how the approach will meet the required end state criteria. The plan should include cost estimates for this work and should be subject to regulatory approval as a condition of commencing operations.

5.38 The regulator should require the operator to establish a funding mechanism to ensure adequate funds are available for closure and for any ongoing institutional control. The amount will vary with time as liabilities increase due to impact of operations, and decrease with any progressive remediation, and as estimates become more accurate as the scheduled final decommissioning approaches. Operators can become insolvent at any time, so the funds need to be in place prior to the creation of liabilities. For many NORM residues the liability and the financial assurance should address the environmental remediation costs and radiological considerations.

5.39 The regulatory framework should include the requirement that the financial assurance instrument cannot be terminated without regulatory approval, and the amount should be revisited at some frequency commensurate with the risk of the NORM residue.

INTERESTED PARTIES

5.40 The regulator should ensure that the operator undertakes a consultation process with key interested parties, and for activities subject to authorization this should be a condition of registration or licensing.

5.41 Interested parties that should be involved in the consultation process include, but are not limited to:

(a) Residents and landowners affected;

(b) Indigenous groups;

(c) Local communities economically dependent on the operation or the land impacted; and

(d) Government agencies including regulatory bodies.

5.42 Consultation is a valuable tool in gaining support for a project. Interested parties also need to be part of the decision making process regarding future land uses. This will be an important part of setting end state criteria.

5.43 The government that is setting up a new NORM regulatory framework should consider undertaking a public engagement and education program. This can manage expectations and address potential concerns.

MANAGEMENT SYSTEMS

5.44 GSR Part 3 [4] requires that protection and safety are effectively integrated into the overall management system, and that the management system is designed and applied to enhance protection and safety. A good management system will describe the planned and systematic actions and will provide confidence that the requirements for protection and safety are fulfilled.

5.45 With respect to the facility, systems will need to address the life cycle of the residues, from generation until long term management, and the life cycle of relevant residues management facilities, including siting, design, construction, commissioning, operation, closure and decommissioning. Management systems will need to address the impacts and controls identified in the safety assessment including radiological environmental impact assessment. Management plans should be established, which includes for uranium production: residue management, radiation protection, environmental management, emergency preparedness and response, decommissioning and closure, monitoring and evaluation, stakeholder engagement, and transport. The recommended content of a residue management plan and a decommissioning plan applicable to uranium production are included in this Safety Guide as Appendix B and Appendix C, respectively.

5.46 Depending on the scale of the operation and nature of the risks, one or several management plans can be developed for other facilities and activities with NORM residues.

5.47 Radiation protection should be integrated with and incorporated into management systems for quality assurance, environment and workplace safety. Radiation protection performance indicators need measurable outcomes, including worker’s exposure and air and surface contamination monitoring results. It is important that radiation safety is not allowed to compromise protection from more significant workplace hazards or environmental impacts.

5.48 Refs. [19 to 21] provide guidance and reference for establishing a management system for NORM residues. The management systems described here are suitable for facilities, such as facilities for uranium production. The documents should be applied consistent with a graded approach and be commensurate with the degree of hazard and risk presented by the NORM residues. Operational limits and conditions should be developed on the basis of the following:

(a) The safety assessment and radiological environmental impact assessment;

(b) Design specifications and operating parameters and the results of commissioning tests;

(c) The importance and sensitivity of items to safety;

(d) The consequences of events following the failure of items; and

(e) The minimum staffing level that needs to be available to operate the facility safely.

5.49 The management plans should be reviewed by the operator:

(a) Regularly on an agreed frequency;

(b) Following modifications made to the facility or the type of residues;

(c) As part of the process of periodically reviewing the safety case (including as part of periodic safety review) for the facility;

(d) Following incidents or near misses[7]; and

(e) If there are changes in legal or regulatory conditions.

5.50 The review and consequent changes should be subject to regulatory approval.

6. STRATEGIES FOR NORM RESIDUE MANAGEMENT

GENERAL

6.1. This section addresses the general approach applicable for NORM residue management, including application in a graded approach of Safety Requirements established in Ref. [8]. It covers options for residue management through pre-treatment, treatment, conditioning, reuse and recycling, storage and retrieval and long term management of NORM residues. Minimization techniques in relation to NORM residues are discussed. More information on long term management of NORM residues is given in Section 8.

6.2. The steps involved in the management of NORM residues are:

(a) Assessment of potential arising of residues of various streams based on design on operation of similar facilities;

(b) Control of residue generation;

(c) Processing (sorting, characterization, segregation and treatment);

(d) Clearance, discharge, reuse and recycle; and

(e) Long term management.

6.3. The design of facilities that generate NORM residue will influence the optimization of protection from exposure due to radioactive residue and should therefore be considered with residue management in

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[7] The term “near miss” means a potential significant event that could have occurred as the consequence of a sequence of actual occurrences but did not occur owing to the plant conditions prevailing at the time [1].

mind. Operators should employ the principle of preventing undue burden on future generations into the design that favor: minimizing waste to be disposed of; minimizing the use of fresh water; minimizing the project footprint and its potential impacts; and the reuse and recycling of materials.

6.4. To avoid the need of long term management, options of clearance, discharge, reuse and recycle, and authorized disposal, including disposal at an existing waste disposal facility, should be used to the maximum extent possible, in compliance with relevant regulatory requirements. For instance, the segregation of NORM materials can reduce the volume of residues/waste requiring for long term management, as a result to reduce the amount of land or surface area needed. Segregation facilitates the reuse or recycling of residues, or conditioning and packaging the NORM residues for transport and long term management offsite.

6.5. The design, construction, operation and closure of facilities for the handling, storage and disposal of residues from NORM activities should be in accordance with the elements of a management system as outlined in Section 5. In particular, facilities should be constructed, operated and closed only according to approved plans and procedures.

6.6. The decommissioning and closure of the residue management facilities should be considered in all phases of the NORM activity, that is, during siting, design, construction and operation. Planning for the management of NORM residues at closure should already be addressed in the siting and design phase, and not be delayed until the closure stage. For example, taking measures at an early stage to reduce the migration of water-borne and airborne contamination to the surrounding environment will facilitate management of the closure phase.

6.7. The evaluation criteria and procedures used to select the preferred options and to develop the residue management strategy that will achieve the optimal balance among the considerations of regulatory requirements, national policy and strategy, costs, site and process characteristics should be clearly defined and presented to the different interested parties in the project, including the public.

6.8. Section 8 of this Safety Guide outlines the important characteristics and desirable features of the options that should be considered in the siting and management of residues from NORM activities, considerations in the design, construction, operation and closure of facilities, the release of materials and the factors for institutional control.

DEVELOPMENT AND IMPLEMENTATION OF RESIDUE MANAGEMENT PLAN

6.9. A residue management plan should be developed, implemented and updated accordingly, in compliance with relevant regulatory requirements and in consistency with the facility policy and strategy for safety, environmental management and waste management. The residue management plan should address various streams of residues taking into account of respective characteristics and provide full coverage of life cycle from generation until clearance, discharge, reuse/recycle and long term management. Further information on a residue management plan for uranium production is given in Appendix B.

6.10. At the design stage of any project, the operator should be aware of the quantity and quality of all materials, radioactive and non-radioactive, and be able to identify potentially harmful characteristics. This allows for the systematic and iterative consideration of all materials and potential risk at the design stage where it is easier to provide for proper mitigation, controls and management. This design work will ultimately support the safety assessment, which in turn will support licensing and permitting activities.

6.11. A characterization of residues is the important factor to determining appropriate controls. Characterization helps in developing a complete understanding of the physical, chemical and radiological characteristics of the residue(s) for sorting, shipping, processing, reuse and recycling, and for long term management.

6.12. The following information should be considered in the characterization of NORM residues:

(a) Sources and quantities of NORM residues;
(b) Physical and chemical characteristics;
(c) Significant pathways and exposure scenarios;
(d) Predicted impacts and risks from exposures;
(e) Predicted impacts and risks from non-radiological components; and
(f) Mitigation of impacts and risks.

6.13. The development of a cost effective residue management plan can be complex. The process also involves evaluating options for siting, design and construction, operation, management of residues streams (e.g., treatment, conditioning, recycling), decommissioning and consideration of long term institutional control. Factors include benefits, costs, detriments and any regulatory limits, constraints and reference levels. The process is also iterative as options are evaluated. For many residues, environmental considerations will dominate the radiological ones.

CONTROL OF RESIDUE GENERATION

6.14. The NORM activities should be designed to reduce, as far as practicable, the amount of residues and waste to be managed. This can be accomplished through the choice of appropriate NORM processes, and the recycle and reuse of equipment, materials and residues.

6.15. Design features and operational procedures for control of residue generation should consider the following aspects:

(a) Selection of design options, process and materials selection, construction methods, commissioning, and operation procedures that facilitate the control of residue generation throughout the entire life cycle of the facility, including the final decommissioning;
(b) Measures to avoid spill and adequate zoning to prevent the spread of contamination;
(c) Appropriate segregation of various streams of residues.

6.16. Residue quantities that need long term management should be kept to the minimum practicable [10]. Options for viable and safe re-use or recycling should be sought before designating NORM residues as waste, including authorized discharge, specific clearance for landfill and for reuse and recycle. Advice on re-use and recycling of NORM residues is given in Annex II.

PROCESSING

Pre-treatment

6.17. Pretreatment in general consists of collection, characterization, segregation, chemical adjustment and decontamination, including a period of interim storage.

6.18. This characterization step is important because it provides in many cases opportunities to segregate residues in terms of their physical, chemical and radiological features to be convenient to sequent management, including treatment, storage, clearance and reuse and recycle.

6.19. Residues should be well segregated based on physical, chemical and radiological characteristics and taking account of sequential options for generation control and treatment. Segregation should be designed and implemented to reduce the volume of residues/waste requiring for long term management. Specifically, segregation should facilitate the reuse or recycling of residues. In mining and mineral processing, segregation of non-mineralized or clean waste rock from mineralized waste rock is a pretreatment activity.

6.20. Scrap items such as pipes, valves, process vessels, pumps and machinery that have been contaminated with NORM residues should be decontaminated where practicable, in the interests of waste minimization.

Treatment

6.21. Treatment of radioactive residues includes those operations intended to improve safety by changing the characteristics of the residues. The basic treatment concepts are volume reduction, radionuclide removal and change of composition. Examples of such operations are: incineration of combustible waste or compaction of dry solid waste (volume reduction); evaporation, filtration or ion exchange of liquid streams (radionuclide removal); and precipitation or flocculation of chemical species (change of composition). Often several of these processes are used in combination to provide effective decontamination of a liquid residue stream. This may lead to several types of secondary residue to be managed (contaminated filters, spent resins, sludge).

6.22. Other options for liquid residue management include:

(a) Diversion of clean water away from sources of contamination;
(b) Reuse of residue water in the process circuit and dust suppression;
(c) Treatment to separate any solid NORM residues from suspension;
(d) Treatment of residual liquid to achieve discharge quality; and
(e) Optimised processes to reduce volumes.

6.23. Unless exposures are excluded or sources are exempt, authorization for discharges may be required. Further guidance can be found in Ref. [7].

Conditioning

6.24. Conditioning of NORM residues involves those operations that transform them into a form suitable for handling, transportation, storage and long term management. The operations may include immobilization, stabilization and packaging. Common immobilization methods include solidification of liquid residues, for example in cement. Stabilization methods can include dewatering and chemical adjustment.

6.25. Residues containing hazardous constituents that are mobile in the environment, or constituents that enhance the mobility of radionuclides, should be immobilized or stabilized. This is particularly important for the large volumes of mining and processing tailings and stockpiles of NORM residues from processed raw materials, such as phosphogypsum and red mud.

6.26. Removal of excess water from the tailings is important, both to reduce the potential for seepage of tailings liquor from the structure, and to allow the tailings to consolidate to prevent differential settlement and produce a firm mass for remediation. This may be achieved by deposition in thin layers, with each section being allowed to drain and dry by evaporation before the next layer is deposited. Alternatively, some installation of a drainage system prior to or during the emplacement of tailings may produce successful results. The use of wicks driven into the tailings after emplacement has been used with limited success.

6.27. The addition of a stabilizing agent (such as cement) to smaller quantities of some residues prior to deposition can significantly reduce the permeability of the residue, but due to the large volumes of material at uranium production sites, this method is not an alternative for consideration.

REUSE AND RECYCLING

6.28. Implementation of reuse and recycling options requires the availability of suitable criteria, especially clearance criteria, a suitable measurement methodology and suitable instrumentation. More information on reuse and recycling of NORM residues is given in Annex II.

6.29. The reuse, recycling and use of NORM residues for building materials should meet the criteria given in Ref. [9] and should only be implemented after the residues being released from radiological supervision.

STORAGE AND RETRIEVAL OF RESIDUES

6.30. Storage refers to the placement of the NORM residues in a facility where appropriate isolation and monitoring are provided. Storage may take place between and within the basic residue management steps. In some cases, storage may be used to facilitate the next step in the residue management, to act as a buffer within and between residue management steps, or in awaiting the decay of radionuclides until authorized discharge, authorized use or clearance can be allowed.

6.31. Storage may be appropriate for materials currently uneconomic to process but that might be subsequently retrieved. In such cases it is important that the management plan adequately manage the risk of stockpiles subsequently becoming liabilities.

PREPARATION FOR LONG TERM MANAGEMENT OF NORM RESIDUES

6.32. When no future reuse or recycling of the NORM residues is foreseen, the residues should be engineered or prepared to meet the acceptance criteria for long term management established with the approval of the regulatory body. These criteria define the radiological, mechanical, physical, chemical and biological properties of the residues. Long term management should use a graded approach based upon risk to workers, the public and the environment.

6.33. The location for long term management depends very much on the physical quantities of the residues. Bulk residues such as mine process tailings and phosphogypsum are often managed in a dedicated facility at the site where they are produced. In such cases the siting and design of the facility is critical to effective and safe long term management. This is discussed in Section 8.

Bulk residues

6.34. Bulk residues represent the greatest challenge, despite their relatively low specific activity, because of the large volumes produced, and the presence of very long lived radionuclides and (often) other hazardous substances, such as heavy metals. Such residues include mineral process tailings, raffinates, waste rock, and phosphogypsum, red mud from alumina processing and metalliferous tailings.

6.35. The preferred management option for achieving the protection goals will depend on specific conditions at the site, the characteristics of the ore body, the specifics of the mining and processing processes, and the characteristics of the tailings. The siting and design of the long term management facilities is an essential part of the overall project development, and should be addressed from the earliest stages of project development as discussed in Section 8.

6.36. Relocating tailings for closure would not normally provide the optimum strategy for management because of the large volumes involved. In considering relocation of tailings, radiological, non-radiological and environmental impacts introduced by the relocation itself would need to form part of the optimization assessment.

6.37. Options for managing waste rock and mineralized waste rock include their use as backfill materials in open pits and underground mines, and for construction at the mine site. Covering mineralized waste rock with inert waste rock should be considered. As with bulk minerals processing residues, the stability of piles of waste rock, and their resistance to erosion and rainwater infiltration, should be considered, to ensure that they do not result in unacceptable environmental impacts on the water catchment area (e.g. acid mine drainage).

6.38. Co-placement of waste rock with tailings is a procedure that can be considered for both underground and above ground management options in mining situations. However, chemical compatibility of the commingled material should be considered.

6.39. Subject to regulatory authorization, some residues may be suitable for reincorporation into the original environment possibly including dilution or selective mixing to reduce activity concentrations. An example would be monazite sands being reincorporated uniformly into the remediated workings of a minerals sands extraction operation.

Low-volume higher activity residues

6.40. Residues that arise in small quantities can be managed at off-site facilities or otherwise managed in a graded approach based on risk.

6.41. Small volumes of unmodified residues may be sealed into suitable containers and deposited together with other radioactive waste in designated containments or special landfills, or possibly placed deep within tailings management facilities that are destined for long term management. An option for some liquid residues, such as those from in situ leaching, may be injection into suitable geological formations or land application with some pretreatment.

6.42. Some residues may be suitable for interim storage to allow for decay of short-lived radionuclides such as ^{210}Pb and/or ^{210}Po.

6.43. After an appropriate treatment, low volume, high activity residues may be suitable for dispersion and dilution evenly throughout a large volume of low activity residues.

6.44. Medium quantities of residues that can be transported offer the possibility of taking residues to exiting management facilities, or co-locating the residues with wastes such as in landfills. If on site management is considered to be the best option, again, siting and design is an important consideration and is discussed in Section 8.

7. THE SAFETY CASE AND SAFETY ASSESSMENT FOR NORM RESIDUE MANAGEMENT

GENERAL

7.1. This section is specific to NORM residues for facilities for which licensing is the appropriate form of authorization when an acceptable level of protection can be ensured only through the enforcement of more stringent exposure control measures. This is the highest level of regulation of practices involving exposure to residues involving substantial quantities of material (like uranium production facilities).

7.2. Upon completing a screening level assessment (Section 5) and concluding that NORM residues may be an issue at a proposed facility, the operator should then be required to undertake several activities in order to fully understand the magnitude of the issue and to determine what will be required to manage it. This is accomplished through a thorough systematic assessment of potential radiological issues and other safety issues at all stages of activity and throughout the life cycle of the project. Consistent with the graded approach to managing radioactive materials, the level of effort required in the assessment will vary with the type of commodity or industry, the volumes of material, the level of activity, potential for exposure, and the complexity of the processes. In many cases, for NORM residues, very simple generic assumptions and calculations may replace more complicated safety assessments

7.3. The Fundamental Safety Principles [2] require in paragraph 3.15 that “safety has to be assessed for all facilities and activities, consistent with a graded approach. A safety assessment involves the systematic analysis of normal operation and its effects, of the ways in which failures might occur and the consequences of such failures”. The safety assessment has to address risks in the present and in the long term. While the basic requirements for the safety assessment for any facility and activity are set out in Ref. [24], additional information for the safety case and safety assessment specific for the predisposal and disposal of radioactive waste are provided in Ref. [8 and 23].

7.4. For activities related to NORM residue management, particularly for long term management of NORM residues (Section 8), safety case and safety assessment should be required before construction or implementation can commence. Ref. [26] provides further guidance and recommendations on safety case and safety assessment. The assessment of these aspects will, in general, have many commonalities with the safety assessment that is carried out to address associated radiation risk. The different assessments may be combined to save resources and to increase the credibility and acceptability of their results (Ref. [24], para.1.9).

7.5. A safety case and safety assessment is undertaken in conjunction with the planning and design of a proposed facility or activity. While planning a NORM residue facility and/or activity, the operator should start to prepare and develop a safety assessment that demonstrates the safety of the proposed facilities and/or activities and demonstrates that the proposed activities will be in compliance with the safety requirements and criteria set out in national laws and regulations. For uranium production and other significant activities a safety case will likely be required.

7.6. The safety assessment is a key component of the safety case and involves assessment of a number of aspects. The fundamental element of the safety assessment is the assessment of the radiological impact on humans and the environment in terms of both radiation dose and radiation risks. The other important aspects subject to safety assessment are site and engineering aspects, operational safety, non-radiological impacts and the management system.

7.7. A radiological environmental impact assessment should form part of the safety assessment. Ref. [25] provides recommendations and guidance on a general framework for performing prospective radiological impact assessments for facilities and activities, to estimate and control, using criteria, the radiological effects on the public and on the environment.

7.8. The key points to consider in conducting a safety assessment are:

(a) It should take place at the siting or design stage of the facility development and covers the full life-cycle of the facility, including post-closure;
(b) It includes a full characterization of all NORM sources and pathways, including radiological and non-radiological baseline characterization. Temporal considerations should also be considered (e.g. groundwater levels, diurnal radon fluctuations);
(c) It uses a graded approach in assessing the full range of activities and facilities related to NORM management;
(d) It is well documented and clearly shows how the assessment has led to improvements in design or operation; and
(e) It is updated as necessary to reflect material changes in operation or regulatory requirements.

7.9. The operator should use the safety assessment to establish specific operational limits, monitoring programme, conditions and administrative controls. The operator may wish to set an operational target level below the limits and controls to assist in avoiding any breach of those that may be approved.

7.10. The results of the safety assessment should provide the primary input to the authorizing documentation required to demonstrate compliance with regulatory requirements, with consideration of the integration of the whole life cycle of residue management. An important outcome of the safety assessment is the facilitation of communication between interested parties on issues relating to the facility or activity. The results of the safety assessment can be used to determine any necessary changes in the plans or design so that compliance with all requirements is ensured. The results are also used to establish controls and limitations on the design, construction and operation of the facility.

7.11. The various stages in the lifetime of the NORM residue facilities (i.e. siting, design, construction, operation, closure and post closure) and the activities (residue generation, processing, reuse/recycle, storage and disposal) should be taken into account in the safety assessment. The safety assessment should be periodically reviewed be revised as necessary to reflect changes in operation or regulatory requirements.

7.12. Regulatory frameworks should make provision for regulatory review and approval of safety cases.

SCOPE OF THE SAFETY ASSESSMENT

7.13. The scope and extent of the assessment should be commensurate with the site-specific issues that should be addressed. The results of the initial safety assessment should be factored into the selection of the site and design of the NORM management facility. The assessment should consider the significant scenarios and pathways by which workers, the public and the environment may be subject to radiological impact. The scope and depth should be sufficient to identify and evaluate relevant risk components over the lifetime of the facility. The models or methods used should allow the effects of the various hazards in the different management options to be compared in a consistent manner.

7.14. Both radiological and non-radiological components should be assessed in order to determine the optimization of radiological protection. The safety assessment of non-radiological impacts will also be required and governed by environmental protection legislation or worker health and safety legislation. While the assessment of non-radiological materials lies outside the scope of this Safety Guide, the approaches to assessment described here may also be of use in the assessment of hazards and risk posed by non-radioactive residues. Equally, existing robust systems to assess and manage environmental impacts and worker's health and safety might be valuable for radiological issues.

7.15. A safety assessment should generally include aspects such as:

(a) A description of the site and facility, including the maximum expected inventory radioactivity in process equipment, products and NORM residue and its acceptance criteria, the management facility and its characteristics, structures, systems and components, and the characteristics of items important to the safety of facility and activity.

(b) A description of NORM residue operations at the facility and management options outside the facility, including inventory and characteristics of residues.

(c) Systematic identification of hazards and scenarios associated with operational states and accident conditions and external events, special attentions should be paid to clearance, reuse and recycle due to long life cycle and uncertainty.

(d) An evaluation of hazards and scenarios, including screening of their combinations that may result in a failure of containment that result in release of radioactive material, to eliminate those of low likelihood or low potential consequences.

(e) Assessment of dose pathways including inhalation of radon/thoron where applicable.

(f) Assessment of the probabilities and potential consequences of the release(s) of radioactive material identified in the hazard evaluation by quantitative analysis and comparison of the results of the assessment with regulatory limitations.

(g) Establishment of operational limits, conditions and administrative controls based on the safety assessment. If necessary, the design for the management of NORM residue should be modified and the safety assessment should be updated.

(h) Documentation of safety analyses and the safety assessment for inclusion in the documentation supporting the licensing of the facility.

(i) The commissioning program.

(j) Organizational control of operations.

(k) Procedures and operational manuals for activities with significant safety implications.

(l) A program for periodic maintenance, inspection and testing.

(m) Monitoring and surveillance programs.

(n) The training program for staff.

(o) The emergency preparedness and response plan.

(p) The management system.

(q) Provisions for occupational radiation protection.

(r) Provisions for the decommissioning and remediation including financial assurance requirements, if applicable.

CONDUCTING A SAFETY ASSESSMENT

7.16. In general, a safety assessment should include:

(a) The context for the assessment;

(b) Description of the facility and operational activities;

(c) Development and justification of operational scenarios;

(d) Formulation and implementation of models;

(e) Analysis of results and comparison with assessment criteria;

(f) Revisions to the project or processes as appropriate; and

(g) Reiteration of assessment until compliance and optimized protection are achieved.

7.17. The context for the assessment includes the purpose and scope of the assessment, the philosophy underlying the assessment, the regulatory framework, the assessment endpoints, and the time frame for the assessment. The assessment covers the life cycle of the facility, including post-decommissioning.

7.18. The description of the facility and the operational activities should be sufficiently detailed to support the development of the operational scenarios and the subsequent safety assessment of those scenarios. This includes using the full characterization of the NORM residues and any non-radiological hazards in the assessment.

7.19. The set of safety assessment scenarios should take into account all relevant existing and potential risk arising for the facility or activities, and their interrelation and evolution over the lifetime of the facility or activity according to the safety case and the context for the assessment. Factors that affect stability of a tailings management facility, including natural and human activities, should be sufficiently addressed. The features, events and processes to be considered in the safety analysis are to be selected on the basis of a systematic approach, and justification should be provided that the identification of scenarios relevant to safety is sufficiently comprehensive.

7.20. Once the scenarios have been developed, the corresponding assessments should be carried out. This is commonly undertaken using assessment models. This should consider an inventory of the activities, physical conditions, and location of any wastes and other radioactive materials, together with any additional hazards. An assessment model may be developed from one or more of the following components: specialist knowledge, conceptual models, mathematical modelling, and computer simulations. Often specific models have to be developed for particular processes and/or system components. For the purposes of safety assessment, these components will need to be linked in such a way that it is possible to assess the potential radiological impacts of the facility and activities as a whole. The model linking and the use of more detailed models to support simplifications made for safety assessment purposes should be properly managed in accordance with relevant quality assurance measures.

7.21. In assessing operational scenarios, the following should be considered:

(a) A clear description of the endpoints for the assessment, together with a justification for their selection;
(b) If several facilities exist or are planned for the same site, the cumulative impact of all facilities;
(c) Initiating events including internal, external and human induced events;
(d) Both conservative and more refined ('realistic') calculations in completing the assessment;
(e) The possibility of inadvertent human intrusion after full closure;
(f) The need for any ongoing institutional control after closure and its duration; and
(g) Sensitivity analysis and uncertainties in the safety assessment.

7.22. Upon completion of the scenario assessment, the hazards identified should be quantified, screened and ordered in such a manner as to direct resources towards all significant and relevant hazards for the facility or activity. Hazards lacking the potential to cause harm to human health and/or the environment to a degree that exceeds relevant safety requirements or criteria, or which cannot be realized given the scope of the facility or activity being assessed, can be screened from the subsequent hazard analysis. In the re-evaluation of a safety assessment, such screening arguments should be reviewed to check that they remain valid.

7.23. The final output from the safety assessment will represent the operation's safety case, and will form the basis for any regulatory submissions. When presenting the safety case, the safety assessment calculations should be sufficient to provide comparisons with both the ultimate assessment endpoints and any alternative or sub-system safety or performance criteria. Guidance on the use of the safety assessment results should be provided. For example, it should be explained whether the safety assessment results (endpoints) will be compared directly with regulatory criteria (e.g. safety targets) or whether they will be used for illustrative or other purposes.

7.24. For acceptance of a safety case for a facility or activity, it is not in itself sufficient that the calculated doses are less than a dose constraint, since protection is required to be optimized. If the safety assessment results do not demonstrate compliance with safety requirements or criteria, the project components should be revisited and revised as necessary to develop a compliant safety assessment. These project revisions should then be re-assessed in order to demonstrate compliance and optimal protection. These steps should be repeated as necessary to achieve the goals of optimized protection of human health and the environment throughout the full life of the facility. It is not until this iterative process is complete that the concluding safety case should be finalized.

GRADED APPROACH TO SAFETY ASSESSMENT

7.25. It is important that a graded approach for imposing regulatory control is applied, bearing in mind existing occupational health, safety and environmental control measures. This includes the resource devoted to safety assessment. Additional controls should be applied only where these are necessary to reach an optimum level of radiation protection for the applicable NORM residue.

7.26. The safety assessment should be systematic and proportionate to the industry and risks that need be managed. For more complex projects, the safety assessment should be iterative, and with each iteration contributing to the optimization of radiation protection.

7.27. Due account should be taken of social and economic factors when determining what is the optimum level of protection and regulatory intervention. While the safety principles are the same for managing any amount of radioactive residues, regardless of origin, there may be significant differences in the practical focus of residue management programs in order to optimize protection.

7.28. Paragraph 3.3 of Ref. [24] states: ‘The main factor to be taken into consideration in the application of a graded approach is that the safety assessment has to be consistent with the magnitude of the possible radiation risks arising from the facility or activity’. The approach should also account for any releases of radioactive material in normal operation, such as authorized discharge and clearance, the potential consequences of anticipated operational occurrences and possible incidents or accidents, and the possibility of the occurrence of very low probability events with potentially high consequences. Three aspects to be considered in a graded approach are [24]:

(a) The magnitude of the possible radiation risks;

(b) The use of proven practices, procedures, and designs to manage risk; and

(c) The complexity of the facility and/or activity.

7.29. The application of the graded approach should be reassessed as the safety assessment progresses and a better understanding is obtained of the radiation risks arising from the facility or activity. The regulator should consider granting exemption from regulatory requirements if the safety assessment demonstrates that criteria regarding activity concentrations, and operational and post-operational source and dose constraints, will not be exceeded.

DOCUMENTATION OF SAFETY CASE AND SUPPORTING SAFETY ASSESSMENT

7.30. The safety case and supporting safety assessment should be documented to a level of detail and quality sufficient to allow for independent review and approval, taking into account the graded approach and relevant industry safety standards. It should meet all regulatory requirements governing the conduct of the safety assessment.

7.31. The documentation should be clearly written and include arguments justifying the approaches taken. Assumptions used in the safety case should be justified in the documentation, as must the use of generic information or standards. Because of the long time frames potentially involved, a plan for adequate record keeping over the expected project life should be considered in the safety case.

7.32. A regulator that is not a radiation expert may need to seek cooperation and advice from relevant expert agencies and staff when assessing and approving the safety case.

PERIODIC SAFETY REVIEWS

7.33. The safety assessment should be periodically reviewed in accordance with regulatory requirements. The review of management systems should include aspects of safety culture. In addition, the safety case and supporting safety assessment should be reviewed and updated:

(a) When there is any material change to the facility or to its radionuclide inventory that may affect safety;

(b) When changes occur in the site characteristics that may impact on the storage facility, such as encroaching industrial or municipal development;

(c) When significant changes in knowledge and understanding occur (e.g. from new research data or from monitoring and operating experience);

(d) When there is an emerging safety issue due to a regulatory concern or an incident; and

(e) Periodically, at predefined periods, as specified by the regulatory body.

7.34. If warranted by the risks and issues for the respective industry, the operator should carry out periodic safety reviews and implement any safety upgrades indicated by the review or required by the regulatory body. The results of the periodic safety review should be reflected in an updated version of the safety case for the facility.

8. SAFETY CONSIDERATION FOR LONG TERM MANAGEMENT OF NORM RESIDUES

GENERAL

8.1 To protect the public and environment from the radiological and non-radiological hazards over time, the siting, design, construction, operation and closure and decommissioning for residue management facilities should meet the requirements established by the regulatory body and the licensing conditions, through all phases and after decommissioning and closure. When residues are declared as radioactive waste, the requirements for disposal of radioactive waste should apply [23].

8.2 The location for long term management depends very much on the physical quantities of the residues. Bulk residues such as mine process tailings and phosphogypsum are generally managed at the site where they are produced. In selecting the site for management of bulk NORM residues, consideration should be given to the benefits of consolidating residues to limit the number of residue management sites.

8.3 Construction of facilities for managing large volumes of NORM residues, such as uranium mine or process tailings, are generally long term projects involving significant costs; therefore, any site, design or construction deficiencies should be identified before work begins or early in the process to prevent unexpected costs. Repairs to already completed work or remediation afterwards will most likely be cost prohibitive, time consuming, and in some cases impractical.

8.4 It is important that effective verification and quality control measures are in place during site characterization, design and construction to ensure that any engineered structures such as dams, berms, engineered liners, compacted layers meet the design specifications. The quality control program will also require testing of construction materials (e.g., tills and clay) to ensure they meet the design specifications.

SITING

8.5 The choice of location of facilities for the management of residues should take into consideration long term stability and optimize protection of human health and safety and the environment for the expected life cycle of the facilities under both normal operation and possible accident conditions. Sites should be selected giving consideration to features that may aid in the minimization of residues. For uranium production and other facilities, non-radiological environmental protection issues will usually dominate decision making.

8.6 The long term management facility for bulk residues is usually near the production site. It is however essential to identify the optimum site through step-wise site selection program and site characterization program. A preliminary evaluation of site characteristics should be made so as to identify any restrictions, in terms of radiological and environmental factors, at each proposed location, and to allow the selection of a small number of locations and possible preliminary design concepts for which the impacts can then be evaluated in detail. The final optimized choice of site obtained using the conceptual design for waste management should be assessed and the resulting safety assessment, which might be part of the environmental impact assessment, should be submitted to the regulatory body for review.

8.7 Characterization of the site is important when selecting a location for long term management of bulk residues. In selecting a site for large volumes of residues, an important consideration is to minimize the dependence on active institutional controls. Understanding the site, including temporal fluctuations, before design decisions for long term management are made is critical. Site characterization information needed to support design decisions should include the following:

(a) Local land management process;
(b) Climatology and meteorology;
(c) Geography, geomorphology;
(d) Population and local land use;
(e) Structural geology and seismology;
(f) Geochemistry (natural and process material);
(g) Mineralogy;
(h) Surface water and groundwater hydrology;
(i) Flora and fauna, including protected and endangered species;
(j) Archaeological and heritage issues; and
(k) Socioeconomic issues.

DESIGN AND CONSTRUCTION

8.8 A facility to for long term management of NORM residues and waste should be designed and constructed to preserve human health and safety and the environment, specifically to:

(a) Minimize water infiltration;
(b) Maintain long term stability and integrity of containment;
(c) Maximize the use of inert and stable materials as barriers for containment;

(d) Minimize potential erosion and accidental release of solids outside of containment by maximize the placement of residue material below ground level, or in some cases under water;

(e) Minimize the surface area impacted by the facility;

(f) Minimize the impact on the surrounding environment during operations and after closure;

(g) Minimize the potential groundwater contamination;

(h) Minimize the need to retrieve or relocate the residue at closure;

(i) Minimize the need for surveillance, maintenance and controls during operations and post-closure; and

(j) Minimize the number of residue management sites through consolidation of residues.

8.9 The design for a residue management facility should follow good practice to the extent practicable and be consistent with the applicable requirements for radiation and other aspects. Factors that should be part of the design process for the construction, operation and decommissioning include:

(a) Site characteristics;

(b) Residue characteristics including volume, chemical, physical and radiological properties;

(c) Capacity (including consideration of foreseeable accident scenarios) to ensure that sufficient space will be available during the operation, closure and decommissioning periods;

(d) Residue conditioning including neutralization, precipitation, thickening and evaporation;

(e) Potential for retrieval of residues either for relocation or re-processing for further resource extraction;

(f) Drainage and liquids management including seepage collection and treatment;

(g) Acid generating potential of the residues;

(h) Radiation protection measures which may include shielding, containment, and, radon and dust control;

(i) Site access control and control of movement between radiation zones and contamination zones;

(j) Results of inspections of the residues and their containment and any non-compliance issues;

(k) Ventilation in surface facilities including the filtration of airborne releases of radioactive material;

(l) Permeability of any cover and base, and the permeability criteria that are acceptable given the site and residue characterisations, including intrusion and leaking of liquids, and emanation of radon;

(m) Environmental monitoring of the facility including groundwater well installations, water and air sampling stations downstream of any effluent or airborne releases;

(n) Maintenance work and eventual closure;

(o) Re-vegetation;

(p) Long term stability and erosion control (e.g. dams, berms, slopes, covers) in relation to natural weathering processes and extreme natural events (e.g. flooding, droughts, tornadoes, earthquakes); and

(q) Control of inadvertent intrusion by people, plants or animals.

8.10 Detailed engineering design of the residue management facilities can be carried out after the site and the conceptual design have been approved by the regulatory body. At this stage, a further safety assessment, including optimization of protection, should be performed. If significant changes are made to the design of the management facilities at any stage, a further safety assessment, including optimization of protection, should be undertaken.

8.11 The detailed design should be supported, where appropriate, by fieldwork and laboratory or pilot plant studies and by safety assessment. The design should include a residues/waste management plan covering the management of tailings and waste rock, effluent treatment, seepage controls and operational monitoring and consideration of closure and post closure management.

8.12 A construction quality control program should be established at an early stage in the design process, be clearly defined and documented, and reassessed periodically. Effective implementation of a robust quality control program requires well-trained and dedicated staff. The quality control program should address specifications for tests to be carried out including test objectives and design criteria to be met, and completion of as-built plans.

8.13 A preliminary closure plan should be prepared during the design of the facilities, which, at a conceptual level, identifies and ranks the available options for their closure according to the results of the safety assessment and the optimization of protection. It should also specify the financial provisions necessary for the preferred option. The preliminary closure plan should be submitted to the regulatory body for approval.

OPERATION

8.14 The operator should ensure that the residue management plan and other operational plans are followed. The management plans should be modified and updated with feedback and lessons learned from the operation. This is important for maintaining and preserving the safety during operation and after closure.

8.15 The regulatory body should review, approve, and ensure that the residue management plan and other operational plans are followed by the operator during operation, closure, and decommissioning. The regulator should implement a suitable system to audit and inspect the operator’s compliance with approved management and operational plans.

8.16 As with other aspects of NORM management the regulatory body should take a graded approach to regulatory oversight commensurate with the scale of the risks under normal operation and foreseeable incident scenarios. If the operator fails to satisfactorily follow these plans the regulator should take appropriate action to address the non-compliance.

8.17 The residues/waste management facilities should be operated in accordance with the residue/waste management plan that was developed and modified in a manner consistent with the safety assessment, and the authorization or licence. This plan should describe in detail all aspects of the management of the residues/waste. In addition, the plan should be consistent with the quality assurance program and thus should include provisions for:

(a) Detailed and documented procedures for operation, maintenance, monitoring, quality assurance and safety;

(b) Training of personnel in the implementation of the procedures;

(c) Adequate surveillance and maintenance of all the structures, systems and components of the waste management facility that are important to safety;

(d) A system of controlled and supervised areas and clearance procedures for materials removed from the site;

(e) Timely submissions to the regulatory body of inspection reports, monitoring results and reports on unusual occurrences; and

(f) The development and exercise, where appropriate, of emergency preparedness and response plans for failures of the waste management facilities that may result in a significant reduction in the protection of human health or the environment.

8.18 Measures should be taken during operations, and consistently with the safety assessment, to limit the rates of release to the environment of contaminants in liquid and airborne effluents. Measures should be used to ensure that solid residues/waste remains under proper control so that the misuse of tailings is avoided. Releases of radon or radioactive dusts into the atmosphere and of radium and other radionuclides into surface water and groundwater by surface runoff or leaching from solid residues/waste should be minimized.

8.19 In certain cases, a confined water covering over tailings placed in a pit may be used as a radon barrier, and thereby obviate the need to perform dewatering to any significant degree. Closure plans, that rely on water coverings should consider the placement of the tailings (above or below grade), climate and the likelihood of the water cover to be both present and passively maintained over the long term; therefore, water covers are generally used only as temporary or interim radon barriers for residues placed above grade or where conditions do not support a permanent water cover.

DECOMMISSIONING AND CLOSURE

8.20 Requirements and recommendations for decommissioning supporting buildings and service of facilities for the long term management of NORM residues are established in Ref. [27 to 29].

8.21 Decommissioning and closure comprises:

(a) Design considerations and early planning;
(b) Preparation and approval of the final plan;
(c) The actual conduct of decommissioning;
(d) The management of residues resulting from decommissioning activities; and
(e) Implementation of institutional controls.

8.22 A preliminary decommissioning and closure plan should be prepared during the design phase and prior to construction of the facilities. The decommissioning and closure plan should identify and rank the available options for contamination control and decommissioning according to the safety assessment and end state criteria, with the goal of optimizing protection. The plan should also specify the financial provisions necessary for the preferred option. The preliminary decommissioning and closure plan is subject to regulatory review and approval.

8.23 A passive approach to design for decommissioning and closure should be the goal rather than a design that needs significant and ongoing maintenance. The passive approach design is dependent on the amount and type of residues or waste material. For example, uranium process tailings should be stabilized and covered by soil or water to limit radon emissions; mine waste can be covered with stable materials or placed in underground mine voids in geologically stable areas; and smaller quantities of scales can be placed in an engineered landfill. Liners to reduce the chance of future groundwater contamination are often necessary depending on risk.

8.24 Prior to the decommissioning and closure, regulatory criteria should be established for unrestricted or restricted use of material, equipment, structures and the site:

(a) Removal of material, equipment, structures, soil and rock, from regulatory control;
(b) Authorized reuse or recycle of equipment, structures and material; and
(c) Return of the site to its owner (which may be the State) at the end of decommissioning and closure.

8.25 Progressive closure and staged decommissioning should be undertaken to the extent reasonably practicable during operation.

8.26 The decommissioning and closure plan should be subject to review on the following basis:

(a) Periodically to take into account operations, outcomes of monitoring and progressive contamination control;

(b) Following modifications made to the facility or the type of radioactive residues being managed;

(c) If there are changes in legal or regulatory standards or anticipated future uses of the land.

8.27 Financial assurance requirements and principles are discussed in Section 5. The financial assurance should be reviewed periodically during the operational period and at the same time as the decommissioning plan to ensure that funds are adequate to cover the full closure costs and meet end state criteria.

8.28 A final decommissioning and closure plan should be subject to regulatory body approval and agreed to prior to the initiation of decommissioning activities and/or remediation. The final decommissioning and closure plan should address at least the following elements

(a) An assessment of the post-decommissioning and post-closure risks to individuals and the environment;

(b) Land ownership and future land use[8];

(c) End state criteria – radiological, environmental and landform – and how they were met;

(d) Decommissioning and decontamination procedures and techniques;

    - The potential for recycling or new use for residues, plant structures and equipment and items containing or contaminated by NORM;
    - Management of NORM residues, including those arising from decontamination of the facility;

(d) Remediation if essential;

(e) Final radiation survey of the site; and

(f) Long term monitoring and surveillance.

8.29 Management of residues arising from decommissioning activities should be considered in the residues/waste management plan and should be coordinated with decommissioning of facilities, structures and equipment.

8.30 NORM contaminated materials from operations or decommissioning can potentially use the same long term facilities as NORM residues. The decommissioning plan should consider mixing of materials from various waste streams, and its implications on consolidation, differential settlement, and risks of disturbance for salvaging.

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[8] If subsurface mineral rights are severed from the surface rights, those subsurface mineral rights should be purchased and put under institutional control.

8.31 Consideration for non-radiological constituents should be assessed for end-state criteria if is applicable.

8.32 A decommissioning and closure report should be prepared to demonstrate that the end state of the facility and site has been achieved as specified in the approval of final decommissioning and closure plan. The report is subject to review and approval of the regulatory body.

8.33 Based on review and necessary field verification, the regulatory body will decide on the termination of authorization for decommissioning and closure, and on release of the facility with or without restrictions, and any applicable long term management and institutional controls, as appropriate [28].

8.34 A system should be established to ensure that all records are maintained and updated accordingly among the operator, the regulatory body, the local government, and the entity responsible for implementing long term management and institutional control. The system should ensure any access of the facility and site are informed about the presence of a facility on the site in the past, and about the nature of the activities that were conducted at the site (Ref. [27], para. 9.7).

LONG TERM MANAGEMENT AND INSTITUTIONAL CONTROLS

8.35 The long term management period begins when operational buildings and supporting services have been decommissioned, all engineered containment and isolation features have been put in place, and the facility is in its final configuration. After decommissioning actions and closure are complete, the safety of the long term management facility should be provided for primarily by means of passive features including sign, characteristics of the site, and final covering in place, together with institutional control measures.

8.36 If a site cannot be released for unrestricted use, the site should be restricted and appropriate institutional controls will be necessary to ensure protection of human health and the environment over the long term. An institutional control custodian can be the government, usually an agency other than the regulator, or a qualified private entity. The custodian should provide periodic reports to the regulatory body or government on the performance of the site.

8.37 Institutional controls are put in place as needed to prevent intrusion into facilities and to confirm that the long term management area is performing as expected by means of monitoring and surveillance, as required by the regulatory body and in accordance with managing the site risks. Control may be active (for example, by means of monitoring, surveillance, remedial work, water diversion and treatment, and fences) or passive (for example, by means of land use controls, markers, records).

8.38 For some current or legacy sites this goal of a passive approach might not be fully achievable, and best efforts will have to be made to minimize the amount of active controls needed. If active controls are warranted, the operator should be required to provide sufficient funds to conduct necessary active controls measures and for the long term management of the site. The site and any remaining materials should not become a financial burden on the government or public.

8.39 If long term management and institutional controls are needed, financial assurances should be sufficient to cover the costs of monitoring, surveillance and control of the facility throughout the necessary time period.

8.40 The operator is responsible for preparing a proposed program for long term management, which should be reviewed and approved by the regulatory body. The design of the program should be based on safety assessments as described in Section 7, in which impacts on human health and the environment over an appropriate period into the future are considered.

8.41 The operator's safety case should state the period over which institutional controls will remain effective, and this should be subject to approval by the regulatory body. Scenarios postulating human intrusion, failure of engineered structures and changes in environmental conditions should be considered in the safety assessment.

8.42 As part of a long term management program, all relevant records of the characteristics of closed residue management facilities, restrictions on land use and ongoing monitoring and/or surveillance requirements should be maintained in accordance with applicable legal requirements and be available to interested parties, upon request.

MONITORING AND SURVEILLANCE

8.43 A monitoring and surveillance program should be designed and proposed by the operator and should be subject to regulatory approval. The program should be conducted and reviewed periodically by the operator prior to and during and after operation and decommissioning. The regulatory body should inspect and verify monitoring results throughout the lifetime of the facility and the period of long term management. The institutional controls custodian should ensure that the monitoring program is durable and continues, as warranted, following decommissioning. More detailed guidance is provided in the Ref. [30].

8.44 The monitoring and surveillance program consists of continuous or periodic observations and measurements to evaluate and verify the behavior of the residue management system. The information supports decision making at various stage of the development and also is used to evaluate the impact of the system on human health and the environment. It covers the measurement of radiological, environmental and engineering parameters. Further guidance on monitoring and surveillance programs at uranium production facilities is given in Ref. [30].

8.45 A graded approach should be taken to adapt the level of detail (duration frequency, locations for sampling, parameters) for monitoring programs with the level of risk`s associated with the facility.

8.46 The types, duration and frequency of monitoring should be adapted to each period in the lifetime of a facility: pre-operational period, operational period (including decommissioning operations) and post closure period.

Pre-operational phase

8.47 The pre-operational period includes site evaluation (selection, verification and confirmation) and safety assessment and design studies. The objectives are:

(a) To contribute to the evaluation of suitability of the site;
(b) To provide input for the design of the facility;
(c) To provide input necessary for the operational and post-closure safety cases;
(d) To establish baseline conditions, including determination of existing level of natural radioactivity at the site, for comparison with later monitoring results. This is especially important in respect of NORM residues, where the same radionuclides are already present in nature; and
(e) To aid in designing the monitoring program for the operational period.

Operational period

8.48 The objectives of the monitoring program during the operational period are:

(a) To provide data and confirmation of the performance of the long term management system;
(b) To check the performance of systems for effluent treatment and control, and air abatement if required;
(c) To provide early warning of any deviations from normal operation;
(d) To provide data on the discharge of radionuclides (e.g. rates, concentrations, and composition) to the environment, for use in predictive modelling and determination of exposures to the public;
(e) Evaluation of compliance with regulatory requirements.

Post-decommissioning and post-closure phase

8.49 The monitoring program for the period after decommissioning and closure should be conducted to demonstrate that the facilities are performing as predicted and should be used to:

(a) Detect abnormal radiological concentrations or activity in the environment that could be attributable to the long term management facility;

(b) Verify the performance and integrity of barriers;

(c) Validate the achievement of post-closure radiation exposure objectives;

(d) Inform control decisions, such as moves from active institutional control to passive institutional control to unrestricted release;

(e) Determine need for, and type of, monitoring and surveillance activities to be conducted during any institutional control period;

(f) Satisfy the principle of openness and transparency of information for interested parties;

(g) Evaluation of compliance with regulatory requirements.

8.50 The monitoring and surveillance program should specify the parameters to be monitored, the locations and frequencies for sampling, and the procedures for analysis and reporting, including the setting of appropriate action levels. Such a program should include measurement of:

(a) Indicators of environmental impacts, such as levels of radionuclides and non-radiological contaminants in air, water and soil;

(b) The physical integrity of structures and systems for NORM residue containment;

(c) Parameters that may assist in the interpretation of data, such as meteorological data, operational process data and waste stream data.

8.51 Annex I of Ref. [31] provides an example of the typical content of a long term surveillance plan for a uranium mill tailings site in the post-closure phase.

APPENDIX A. SPECIAL CONSIDERATIONS FOR RESIDUES FROM URANIUM PRODUCTION

URANIUM MILL TAILINGS

A-1. Uranium process tailings represent a challenge in terms of long term management because of the large volumes produced, content of long lived radionuclides, heavy metals and chemical hazards, and potential to generate acidic drainage.

A-2. Tailings contain all the radionuclides in the original ore, at concentrations near their concentration in ore, with the exception of the uranium isotopes and their immediate short lived decay products. Approximately 75% of the original radioactivity present in the uranium ore is retained in the tailings. Tailings are usually discharged as slurry containing about 20-50% solids into a purpose built water retaining structure or impoundment, either above or below grade.

A-3. There are few options for re-using tailings. Tailings, particularly the coarser size fractions, may be of use as a component of mine fill. However, engineering considerations can make this problematic as tailings slimes do not consolidate well alone. Where appropriate, uranium can be produced by processing of this material. The radiological implications of any such reuse will need to be considered.

A-4. The key issues which should be considered in the design of a tailings management facility include:

(a) The stability of the pit, underground mine void, or surface impoundment in relation to natural processes such as earthquakes, floods and erosion;
(b) The hydrological, hydrogeological and geochemical characteristics of the site;
(c) The chemical and physical characteristics of the tailings in relation to the potential for the generation and transport of contaminants;
(d) The volume of material that will be retained on the site as waste; and
(e) The use of neutralization agents, radium precipitating additives, artificial or natural liners, radon barriers and evaporation circuits, with the reliability, longevity and durability of such agents factored in.

A-5. A thorough investigation of these issues should be undertaken at an early stage when considering options for the management of tailings.

A-6. The option of relocating tailings to a more favorable site for closure would not normally be expected to provide the optimum strategy for management because of the large volumes of mining and milling waste that would be involved. However, if relocation of the waste is being considered, care should be taken to factor into the optimization all the significant radiological and non-radiological impacts that may be introduced by the relocation itself, including issues relating to the transport of large volumes of waste.

A-7. The design of a facility for the management of tailings should incorporate drainage systems to consolidate tailings before closure and to reduce excess pore water pressure. In the case of a surface impoundment or a pit, this could be achieved by the installation of a drainage system prior to or during the emplacement of tailings, or by the use of wicks driven into the tailings after emplacement. The base and cap of the impoundment should be built of a material of low permeability, if possible using material of natural origin. The addition of a stabilizing agent (such as cement) to the tailings immediately prior to their deposition has the potential to reduce significantly the permeability of the tailings mass, thus retarding the transport of contaminants and binding any pore water. However, in certain cases, confined and poor quality water covering in a pit may possess excellent characteristics as a radon barrier, thereby obviating the need to perform dewatering to any significant degree.

A-8. The principle that undue burden should not be placed on future generations leads to the conclusion that a passive approach to design for closure is preferable to a design that needs significant and ongoing maintenance. Such a passive approach is generally best achieved by disposal in pits excavated specifically for this purpose, in mined out pits or in underground mine voids in geologically stable sites. This option may eliminate or significantly reduce the need for surface disposal of tailings.

A-9. The decision on which approach to take should be optimized so as to match barrier characteristics with available site conditions. Mine or process residues disposed of below ground are less susceptible to surface erosion and to intrusion. The subsurface placement alternative generally necessitates less maintenance than surface tailings impoundments and eliminates the concern of a dam or dyke structure failure.

A-10. In the case of disposal in underground mines, the increase in structural integrity gained by using concrete with the tailings mass may allow mining to be continued immediately adjacent to the tailings. Prior to adopting this strategy, possible chemical interactions between the stabilizing agent, the tailings and the host rock should be carefully investigated to ensure that the transport of contaminants would not be enhanced at some time in the future.

A-11. Disposal of waste below ground level is typically less susceptible to surface erosion of material to the environment and to intrusion, and generally necessitates less maintenance than surface tailings impoundments. Closure entails sealing the openings to the underground disposal facility, thereby isolating it from the surface.

A-12. In the case of long term management of tailings in underground mines, the increase in structural integrity gained by using concrete with the tailings mass may allow mining to be continued nearby. Prior to adopting this strategy, possible chemical interactions between the stabilizing agent, the tailings and the host rock should be carefully investigated to ensure that the transport of contaminants would not be enhanced at some time in the future, or impact the active mine workings or the workers.

A-13. For the disposal of underground tailings, provided that the probabilities of geological disturbance to the site and of human intrusion into the site are deemed to be sufficiently low, no further controls may be necessary beyond archiving details of the location and characteristics of the waste and monitoring the site for a limited period.

A-14. Practical engineering solutions can be identified for some site specific problems associated with below ground level tailings disposal facilities. For example, if the hydraulic conductivity of the tailings mass is greater than that of the surrounding host rock, the use of a highly permeable envelope surrounding the tailings should be considered as a means of diverting groundwater around the tailings. In the case of a small and confined aquifer intersecting a pit or underground mine wall, localized grouting should be considered.

A-15. It is possible that an underground disposal of mine tailings at a particular site may not be feasible, owing either to site specific problems for which no engineering solutions can be identified, such as when placement is likely to result in contamination to groundwater, or to prohibitive cost. In such cases, the use of engineered surface impoundments may be the only viable option and should be considered.

A-16. As regards options involving the management of tailings in above ground impoundments, the tailings should be contained within low permeability engineered structures so as to reduce seepage. An above ground closure option would usually necessitate having greater institutional control than an underground option. Monitoring and maintenance programs should be implemented during the operational, closure and post-closure phases. This approach would entail lower initial costs but higher continuing costs.

A-17. A cover system that is designed to limit infiltration and radon emissions is necessary for bulk residues placed above grade. Cover materials that have been effective in reducing radon emissions include water, earthen materials, geosynthetics such as geomembranes and geosynthetic clay liners, and evapotranspirative barriers. Simple covers may contain one type of material; however, robust combinations of different materials are often required.

A-18. Cover systems designed to limit infiltration and radon emissions, may have a lateral drainage layer consisting of either coarse sand or gravel above a low permeability clay layer, and a top layer of durable rock for erosion protection. Depending on the climate and environment, a vegetative cover for erosion control, stabilization and limiting infiltration may be employed.

A-19. For an in-pit emplacement, the desired passivity in the closure may be achieved either by backfilling and capping with natural materials or by the establishment of a permanent water pond over the tailings. The latter option should include the application of a low permeability cover for the waste to reduce contact with the pond water. The subsurface conditions should be fully investigated in order to gain sufficient understanding to be able to ensure that the hydraulic pressure over the backfilled pit will not result in problems of groundwater contamination arising in the future.

A-20. The diffusion coefficient for radon in a saturated soil may be several orders of magnitude smaller compared with that of a dry soil. A water covering or saturated cover layer may therefore serve as an effective radon barrier though obviously in dry environments a different approach is required.

A-21. If warranted by risk, a groundwater detection program should be considered to avoid future legacy sites.

A-22. In addition to the emplacement of tailings in above ground impoundments, open pits and underground mine voids, there are other options for tailings management, such as the deposition of tailings in lakes. Monitoring and/or geochemical modeling may be required to show that a reducing environment has been established. However, some of these options may not be acceptable to the regulatory body or the public, and would require further study and evaluation.

A-23. Other disposal strategies for mill tailings that take different approaches for risk assessment may be appropriate and they should be evaluated on a case by case basis. For example, small quantities of mill tailings may be acceptable for disposal in facilities designed for low level radioactive waste, provided that the waste acceptance criteria of the facility are complied with.

HEAP LEACH RESIDUES

A-24. Heap leaching is a method used for processing low-grade uranium ore and typically involves the treatment of crushed or pelletized ore grade material with acid or alkali (or bacteria) on large engineered pads on the surface. Stope or block leaching of basted ore underground is also conducted. Most heap leaching operations produce medium sized residues, however, some may be quite large and considered on the same scale as large bulk.

A-25. Surface heap leach facilities require efficient containment and liquor collection systems, base liners and leak detection systems to protect the surface environment and groundwater resources.

A-26. Heap leach residues consist of process liquids generated during operation, the leached ore and potentially, ongoing release of solutions from infiltration of the closed facility. During operation, waste process solutions can be collected, treated and sent to adjacent evaporation ponds and/or injected into deep injection wells. In some cases, a separate residue storage dam may be required with characteristics similar to those of a tailings dam.

A-27. An important consideration is locating the heap leach pad to permit ease of decommissioning and isolation of the resulting residues in place, without relocation. Heap flushing and neutralization may be conducted at decommissioning. Following decommissioning, long term management of the NORM residues may still be required.

IN-SITU LEACHING URANIUM RESIDUES

A-28. In-situ leaching is carried out by drilling a pattern of injection and extraction wells into the ore-body and circulating leach liquor, which is either acid or alkali depending on the host sediments and ores. The uranium is extracted from the resulting “pregnant” solution by conventional solvent extraction or ion exchange methods and the now “barren” solution is reconstituted and re-injected into the leaching field. No conventional “tailings” are produced, but large volumes of liquid and small to medium amounts of solid residues can be generated.

A-29. A small fraction (0.5–2%) of the leach liquor is bled off and this bleed stream constitutes the largest volume of liquid residues from the process. Large volumes of liquid residues can also be generated where reconstitution of the ore-body aquifer is required following completion of recovery/mining, for example flushing of the aquifer. Smaller volumes of liquid water are generated from normal facility operation, including wash-down of equipment and spillages.

A-30. If the bleed stream is evaporated, elevated concentrations of radionuclides can remain, and if the bleed is treated chemically to remove radionuclides, these will usually be recovered in solid or slurry form.

A-31. In some cases, selenium and radium may be removed prior to land application or re-injection of the resulting water. In these cases, small amounts of residues need to be managed and ultimately disposed of.

A-32. The ore-body aquifer may require pretreatment prior to mining, commonly to remove calcium, and the resulting precipitates can contain elevated radium concentrations. General solid NORM residues generated in processing include process sludge and precipitates, filter media, and contaminated pipes, and equipment.

A-33. Liquid residues can be reduced or eliminated by evaporation, or discharged into aquifers or surface water-bodies. Injection to deep (and preferably well-confined) aquifers is a possible solution, as is to shallower aquifers, typically the mining aquifer itself.

A-34. In cases of injection of liquid residues into aquifers impact assessment with detailed hydrogeological modeling of the situation should be required. Restoration of groundwater can include natural attenuation, groundwater flushing to accelerate natural attenuation, injection of reducing agents or groundwater sweep and reverse osmosis. The more intensive restoration techniques should progressively be used if restoration is not proving adequate to achieve closure outcomes in an agreed reasonable time frame. More intensive methods require more energy and surface infrastructure, produce waste streams, and incur additional costs. Best practice is therefore to use the restoration technique that will achieve closure outcomes in an agreed timeframe with the minimum environmental impact.

A-35. Solid radioactive residues generated on an in situ leaching facility can include used pipes, pumps, filters, contaminated soil and radioactive sludge from ponds and from evaporation of waste liquids. These may be managed in a purpose built management facility, which will usually be on-site, or taken off-site.

APPENDIX B. RESIDUE MANAGEMENT PLAN FOR URANIUM PRODUCTION

B.1. The content of a facility specific residue/waste management program could include:

(a) The description of the processes in which the residues/waste is generated by the facility;
(b) A description of each of the streams and the efforts to avoid and minimize them;
(c) The limits and conditions necessary for the waste to be managed safely;
(d) A comprehensive list of the current and anticipated residue/waste arising and inventories for the facility;
(e) Definition of the facility specific waste management principles and objectives;
(f) Identification of residue/waste management options and associated steps as well as interdependences between residue/waste management steps;
(g) Justification of the selection of appropriate management options based on the above and international good practices;
(h) Demonstration that the facility specific residue/waste management program is compatible with national policy and strategy;
(i) Demonstration, if necessary, of how the safety case is affected by the residue/waste management program, e.g. a modification of the plan to incorporate longer storage than the building was originally designed for would impact the safety case.

B.2. The program should include provisions for:

(j) Keeping the generation of residue/waste to the minimum practicable, in terms of type, activity and volume, by using suitable technologies;
(k) Possible reuse and recycling of materials;
(l) Appropriate classification and segregation of waste, and maintenance of an accurate inventory for each residue/waste stream, with account taken of the available options for clearance and disposal;
(m) Collection, characterization and safe storage of residue/waste;
(n) Adequate storage capacity for the residue/waste expected to be generated (conditioned and unconditioned) and an additional reserve storage capacity;
(o) Ensuring that the residue/waste can be retrieved at any time within the anticipated storage period;
(p) Techniques and suitable procedures available for the retrieval of stored residue/waste;
(q) Processing radioactive waste to comply with waste acceptance requirements and to ensure safe storage and long term management including disposal;
(r) Safe handling and transport of residue/waste, in case there is a need;
(s) Adequate control of discharges of effluents to the environment.

APPENDIX C. DECOMMISSIONING PLAN FOR URANIUM PRODUCTION FACILITY

C.1. A decommissioning plan for a uranium production facility should include:

- Introduction of site location and history
    - amounts and types of material produced
    - activities undertaken
    - previous site assessments
    - applicable regulatory end state criteria to be met
    - current environmental and radiological conditions
- Geology and seismology
    - stratigraphic features
    - structural and tectonic features
    - geomorphic features
    - seismicity and ground motion estimates
- Geotechnical stability
    - site and uranium mill tailings characteristics
    - slope stability
    - settlement
    - liquefaction potential
    - disposal cell cover engineering design
    - construction considerations
    - disposal cell hydraulic conductivity
- Surface water hydrology and erosion protection
    - hydrologic description of site
    - flooding determinations
    - water surface profiles, channel velocities, and shear stresses
    - design of erosion protection
    - design of erosion protection covers
    - protecting water resources
- Groundwater protection
    - standards
    - monitoring results (baseline, during operation and post-operational)
    - hazard and risk assessment

    - exposure assessment
    - corrective action assessment
    - ground-water corrective action and compliance monitoring plans
- Air Quality
    - standards
    - monitoring results (baseline, during operation and post-operational)
- Radiation protection
    - engineering cover of the tailing facility (type of material, thickness, ability to prevent radon emissions in the long term)
    - radon attenuation
    - gamma attenuation
    - cover radioactivity content
- Decommissioning plan for land and structures
    - types of restrictions to the site for long term access controls
    - site access and need for institutional controls
    - discussion of long term stability and containment of residues and waste
    - types of engagement proposed for interested parties
    - description of the final form of land features, including demographics and possible receptors

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ANNEX I. RESIDUES TO BE ASSESSED FOR POSSIBLE REGULATORY CONTROL

Category	Material/operation	Radionuclide(s) with highest activity concentration	Typical activity concentration (Bq g^{-1})
Residues	Red mud (alumina production)	U-238, Th-232	0.1—3
	Phosphogypsum (H_2SO_4 process)	Ra-226	0.015—3
Slags	Niobium extraction	Th-232	20—120
	Tin smelting	Th-232	0.07—15
	Copper smelting	Ra-226	0.4—2
	Thermal phosphorus production	U-238	0.3—2
Scales, sludge and sediments	Scale (oil and gas production)	Ra-226	0.1—15000
	Scale (phosphoric acid production)	Ra-226	0.003—4000
	Residue (rare earth extraction)	Ra-228	20—3000
	Scale (TiO_2 pigment production)	Ra-228, Ra-226	<1—1600
	Scale (rare earth extraction)	Ra-226, Th-228	1000
	Sludge (oil and gas production)	Ra-226	0.05—800
	Residue (niobium extraction)	Ra-228	200—500
	Scale (coal mines with Ra rich inflow water)	Ra-226, Ra-228	Up to 200
	Scale (iron smelting)	Pb-210, Po-210	Up to 200
	Scale (coal combustion)	Pb-210	>100
	Sludge (iron smelting)	Pb-210	12—100
	Residue (TiO_2 pigment production)	Th-232, Ra-228	<1—20
	Sludge (water treatment)	Ra-226	0.1—14
Precipitator dust	Thermal phosphorus production	Pb-210	1000
	Fused zirconia production	Po-210	600
	Niobium extraction	Pb-210, Po-210	100—500
	Metal smelting	Pb-210, Po-210	Up to 200

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[I-1] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessing the need for Radiation Protection Measures in Work Involving Minerals and Raw Materials, IAEA Safety Reports Series, No 49, IAEA, Vienna (2006).

ANNEX II. REUSE AND RECYCLING OF NORM RESIDUES

II-1. Reuse can be defined as the reutilization of materials for the original purpose in their original form or in a recovered state. Recycling is the utilization of materials, tools and equipment for other than the original purpose, with or without treatment. The reuse and recycle options are attractive because there is strong economic incentive to use the large volume of residues, to avoid the costs associated with long term management. The decision of whether or not to reuse and recycle residues depends on many factors that are specific to a given stream of residue, industry or country. Implementation of reuse and recycling options requires the availability of suitable criteria, a suitable measurement methodology and suitable instrumentation.

II-2. The Euratom Basic Safety Standards [II-1] consider mixing of radioactive residues containing NORM with other materials as a means to reuse and recycle NORM residues. According to Ref. [II-1], deliberate dilution of radioactive residues, other than the mixing of materials that takes place in normal operations when radioactivity is not a consideration, should not be permitted, but the competent authority may authorize in specific situations the mixing of radioactive residues containing NORM with other materials to promote the reuse and recycling of these materials and to reduce public exposure. Some examples of reuse and recycling of NORM residues are as follows.

SCRAP METAL

II-3. Contaminated scrap metals from NORM industries, can in many cases be decontaminated by various methods. Details of decontamination methods as well as measurements principles and instrumentation for equipment in the oil and gas industry are given in IAEA Safety Report No. 34 [II-2]. The decontaminated metals can be recycled. The contaminated scrap may also be melted in dedicated ovens used for those materials only. The natural radionuclides often go to the slag. The metals will be clean and can be reused. Depending on the activity concentration, the slag can also be reused if relevant requirements can be met.

II-4. Smelting of contaminated scrap is generally a regulated practice, and complies with requirements set by the regulatory body. Transport of contaminated items is required to comply with the requirements of the transport regulations.

SLAG

II-5. Slag from NORM industries can be used as landfill or in road construction. An example of the latter is the use of slag from the thermal phosphorus production industry in road construction in Florida, USA and in the Netherlands [II-3].

FLY ASH

II-6. Fly ash from coal-fired stations is recycled in many cases in building materials, for instance, as additives to concrete or in lightweight building materials. While use of fly ash in concrete blocks for building construction may not be of concern in some Member States, others regulate the resulting levels of permissible radiation in the concrete blocks and the importation of cement with activities exceeding certain radiation limits.

PHOSPHOGYPSUM

II-7. There are several options for phosphogypsum recycling, such as a fertilizer additive, in road construction and as a building material. Detailed information can be found in IAEA Safety Report No. 78 [II-3]. Treatments to improve soils for agricultural use often employ natural gypsum, but phosphogypsum may be recycled for use in soils as well. However, there are not only radiological issues in the recycling of phosphogypsum in agriculture. Other associated contaminants, like cadmium or fluorine, may have an impact on the applicability of recycling of this residue in agriculture.

II-8. Phosphogypsum, when subjected to compaction, can be transformed into a solid of valuable strength. In tests, it has been shown to be used effectively as a binder to stabilize on-site soil and as a replacement for shell and clay in road and parking lot construction. This results in tremendous saving on the construction cost of utilizing phosphogypsum as compared to the traditional method of construction. Radiation monitoring during the construction of the roads, indicated no health hazards, either to the construction crews or the residents living in the areas.

II-9. Some countries use activity concentration limits that prohibit in practice the recycling of phosphogypsum in building materials. In other countries the requirements are more relaxed.

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ANNEX III. SAMPLING AND DETERMINING RADIONUCLIDE ACTIVITY CONCENTRATIONS

INTRODUCTION

III-1. For some NORM sites and materials, it may be useful to conduct an initial screening assessment that is designed to eliminate from further regulatory consideration a site that poses a low level hazard. Elimination methods involve sampling and analysis of residues and waste to determine the activity levels.

III-2. Activity concentrations below 1 Bq/g (10 Bq/g for ^{40}K) are usually unnecessary to regulate. Materials requiring sampling and analysis could be encountered in large quantities with moderate or low activity concentrations (e.g. ore, tailings, slag) or in smaller quantities with the possibility of high activity concentrations (e.g. mineral concentrates, scale, sludge, precipitator dust). Accordingly, the sampling method and analysis sensitivity requirements may vary depending on the assessment to be made.

III-3. The most probable radionuclides of interest for which activity concentrations need to be determined are:

- For the uranium decay series: ^{238}U, ^{226}Ra, ^{210}Pb and ^{210}Po;
- For the thorium decay series: ^{232}Th, ^{228}Ra and ^{228}Th.

SAMPLING OF MATERIAL

III-4. The amount of material giving rise to exposure at any one time could be large, and exhibit a significant range of activity concentrations. The activity concentration may also vary over the time periods, as in the case of occupational radiation protection (e.g. one year). To the extent practicable, both of these variations need to be taken into account when developing a suitable materials sampling strategy.

III-5. The number of samples collected for analysis is important for obtaining a reasonable estimate of the average activity concentration — the greater the number of samples collected and analyzed, the greater the confidence in the figures that are reported. There is a point, however, where any further gain in accuracy is no longer worth the time and resources needed to produce the data. Accuracy is also affected by other factors such as the degree to which the samples are representative of the material.

MEASUREMENT ACCURACY AND QUALITY ASSURANCE

III-6. Adequate confidence in the results of analyses is ensured if the samples are analyzed at a suitably accredited laboratory and if the level of accuracy of the analytical technique is commensurate with the activity concentration criterion against which the material is being checked. If an accredited laboratory is not available, the analytical techniques can at least be validated against appropriate reference materials. Problems due to cross-contamination between samples and contamination of equipment can be avoided by exercising an appropriate level of care during sampling and at the laboratory.

III-7. The distribution of activity concentrations in a material may span an order of magnitude or more. In order not to distort the distribution at the low end, the lower limit of detection (LLD) needs to be sufficiently below the activity level against which the measurements are being compared. For instance, when a material is being compared with the 1 Bq/g (10 Bq/g for ^{40}K) activity concentration value, an LLD of 0.1 Bq/g (10 Bq/g for ^{40}K) would be appropriate.

ANALYTICAL TECHNIQUES

III-8. Having defined the main radionuclides of interest and the required measurement sensitivity, appropriate analytical protocols can be considered. Analysis techniques for determining activity concentrations of individual radionuclides in solid materials can be time-consuming and expensive. The techniques employed for a particular sample therefore need to be chosen judiciously.

III-9. For general screening of the total radioactivity it is often adequate to perform gross alpha–beta counting, applying suitable corrections for self-absorption. It is a relatively quick and inexpensive technique for determining the total activities of the alpha emitting and beta emitting radionuclides, from which the ratio of the two can be obtained. On its own, this technique does not give reliable information on individual radionuclides. However, the alpha–beta ratio can provide clues as to the radionuclide composition, which may be useful in deciding upon subsequent analysis steps. Obviously, if the total activity concentration is less than the activity concentration criterion for individual radionuclides, then no further analysis is necessary. Counting times are selected to obtain the required LLD for the materials concerned (i.e. about 10% of the applicable activity concentration level).

III-10. For analysis of the individual radionuclides of interest, the following analytical techniques can be applied:

- X ray fluorescence (XRF) spectrometry:
    - The XRF method is widely used to measure the elemental composition of materials, and is well suited to the rapid determination of uranium and thorium. There are two types of spectrometer, both of which can be used for this application:
        - Wavelength dispersive spectrometers, in which photons are separated by diffraction on an analysing crystal before being detected;
        - Energy dispersive spectrometers, in which the detector allows the determination of the energy of the photon when it is detected; these spectrometers are smaller and cheaper

than wavelength dispersive spectrometers, and the measurement is faster, but the resolution and detection limit are not as good.

- Inductively coupled plasma atomic emission spectroscopy (ICP-AES):
    - ICP-AES is used for the chemical analysis of aqueous solutions of rocks and other materials, and is suitable for the determination of a wide range of major elements and a limited number of trace elements.
    - Sample preparation involves the digestion of the powdered material with 40% (v/v) hydrofluoric acid mixed with either perchloric or nitric acid. Some minerals such as chromite, zircon, rutile and tourmaline will not completely dissolve using this digestion procedure. For samples containing substantial amounts of these minerals, XRF analysis is probably more appropriate.
- Inductively coupled plasma mass spectroscopy (ICP-MS):
    - ICP-MS is used to determine trace elements in aqueous solutions. The technique is well suited for determination of uranium and thorium. The sample preparation procedure is the same as that for ICP-AES.
- High energy gamma spectrometry (high purity germanium crystal (HPGe)):
    - This technique provides a quantification of the important radionuclide ^{226}Ra, along with ^{228}Ra and ^{228}Th. The method can also be used to quantify the ^{238}U concentration, but with a higher LLD.
- Low energy gamma spectrometry (HPGe):
    - This technique entails a relatively short counting time of 4 h, and gives a quantification of ^{238}U and ^{210}Pb (as well as ^{235}U). It is possible for the technique also to provide a determination of ^{226}Ra (as well as radionuclides of lesser interest: ^{227}Ac, ^{231}Pa and ^{230}Th), but with a higher LLD.
- Sample digestion and alpha spectrometry:
    - This technique is suitable for quantifying the ^{210}Po concentration. It involves a relatively long counting time.

III-11. The application of the above mentioned techniques is summarized in Table III-1. The minimum sample size needed is in each case about 10 g. When analyzing for ^{238}U or ^{232}Th, the following conversions from ppm to Bq/g are required:

1 ppm uranium = 0.012436 Bq/g ^{238}U

1 ppm thorium = 0.004057 Bq/g ^{232}Th

III-12.For material associated with most industrial processes it is adequate to have a basic analytical infrastructure consisting of XRF in combination with a background shielded thin-window HPGe gamma spectrometry system. Only in those processes where ^{210}Po is of concern will radiochemical techniques in combination with alpha spectrometry be required. Although ^{40}K is unlikely to be of concern, its activity concentration can be determined at no additional cost, especially if both XRF and gamma spectrometry are used for radionuclide analyses. This may be useful when ^{40}K is present in significant concentrations, since it can be used to deduce information on other radionuclides and to improve the quality assurance of the measurements.

TABLE III-1. ANALYTICAL TECHNIQUES FOR DETERMINING RADIONUCLIDE ACTIVITY CONCENTRATIONS

Radionuclide	Suitable technique	Comment
U-238, Th-232 (and K-40)	XRF, ICP-AES, ICP-MS	Sensitivity of 1 ppm uranium or thorium achievable with any of these techniques (equivalent to about 0.01 Bq/g ^{238}U and 0.004 Bq/g ^{232}Th)
Ra-226, Ra-228, Th-228 (and K-40)	High energy gamma spectrometry	**(i)** The presence of uranium may interfere with the direct determination of ^{226}Ra **(ii)** For indirect determination of ^{226}Ra, gas-tight sealing for 3 weeks is needed to ensure equilibrium with progeny (^{214}Pb, ^{214}Bi) **(iii)** LLD of 0.1 Bq/g requires equipment that is well shielded from background radiation **(iv)** High sensitivity (>25%) and high resolution HPGe detectors required **(v)** Counting times of a few hours per sample will be adequate **(vi)** High density materials (>2.5 g/cm^3) may need self-absorption corrections
Pb-210	Low energy gamma spectrometry	**(vii)** Self-absorption corrections required **(viii)** LLD of 0.1 Bq/g requires equipment that is well shielded from background radiation **(ix)** Counting times of a few hours per sample will be adequate

Po-210	Sample digestion + alpha spectrometry	**(x)** Microwave acid digestion required **(xi)** Validated radiochemical separation techniques required **(xii)** Counting times of a few hours per sample will be adequate to achieve an LLD of 0.1 Bq/g

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