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Remediation Process for Areas Affected by Past Activities and Accidents

DRAFT SAFETY GUIDE

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1. INTRODUCTION

BACKGROUND

- 1.1. This publication is a revision of a Safety Guide published in 2007 as IAEA Safety Standards Series No. WS-G-3.1, Remediation Process for Areas Affected by Past Activities and Accidents, and supersedes it. WS-G-3.1 provided guidance on how to meet the requirements in IAEA Safety Standards Series No. WS-R-3, Remediation of Areas Contaminated by Past Activities and Accidents, issued in 2003. WS-R-3 was ultimately superseded in 2014 when the IAEA issued the IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [1], jointly sponsored by the IAEA and seven other international organizations. GSR Part 3 introduced three different types of exposure situation^{1,2} (i.e. planned, emergency and existing exposure situation), in order to take consideration of ICRP Publication 103 [2]. In addition, in the period since 2007, several other important Safety Requirements publications have been revised and published (e.g. [3-9]), necessitating a revision of WS-G-3.1.
- 1.2. A variety of past activities and accidents have resulted in contamination of a large number of areas by residual radioactive material, and a need for remediation. The affected areas are located in many regions of the world and in different types of environments. The types of activities and accidents that resulted in contamination include:
- (a) Activities that were never subject to regulatory control or that were subject to regulatory control but not in accordance with current requirements, such as those of GSR Part 3 [1]. Such activities may have involved the industrial processing of radioactive material, the mining and processing of uranium or thorium ores, and the management of residual materials, including radioactive waste;
 - (b) Accidents involving release of radioactive material at facilities, such as nuclear installations, hospitals, industrial facilities, or research facilities;
 - (c) Activities involving an uncontrolled release of radioactive material (e.g., releases during transport of radioactive material, decommissioning of facilities, radioactive waste management activities);
 - (d) Testing of nuclear weapons;

¹ For the purpose of establishing practical requirements for protection and safety, GSR Part 3 [1] distinguishes between three different types of exposure situation: planned exposure situations, emergency exposure situations and existing exposure situations, which together, cover all situations of exposure for which GSR Part 3 applies.

² Dose constraints are applied to planned situations, while reference levels are applied to emergency exposure situations and existing exposure situations. Reference level is defined in GSR Part 3 [1] and discussed in more detail in Section 3 of this Safety Guide.

- (e) Incidents³ involving release of radioactive material, such as due to a malicious act.
- 1.3. In August 2015, the IAEA published *The Fukushima Daiichi Accident* [10], consisting of a Report by the IAEA Director General and five technical volumes. Technical Volume 5 *Post-Accident Recovery* includes sections on remediation, management of contaminated material and radioactive waste, and community revitalization and stakeholder engagement. Relevant lessons from the remediation work carried out at Fukushima have been incorporated in this Safety Guide.
- 1.4. Remediation is defined as “any measures that may be carried out to reduce the radiation exposure due to existing contamination of land areas through actions applied to the contamination itself (the source) or to the exposure pathways to humans” [11]. Complete removal of the contamination is not implied. While progress is being made in the remediation of contaminated areas worldwide, work remains to be done. In some instances, the remediation is likely to require major resources in terms of time, funding, personnel, skills and equipment, and engagement with the affected community. In some cases, the party responsible for the contamination may need to be identified.
- 1.5. Remediation of a contaminated area may pose radiological, non-radiological, and physical risks to workers, the public and the environment⁴, and social and psychological impacts on affected communities. Planning and conducting of remediation are subject to the requirements in GSR Part 3 [1], as well as relevant national requirements. The IAEA Safety Standards Series No. SF-1, *Fundamental Safety Principles* [12] presents the fundamental safety objectives and principles of protection and safety. Requirements designed to meet the fundamental safety objective “to protect people and the environment from harmful effects of ionizing radiation” [12] and to apply the Fundamental Safety Principles during remediation are established in GSR Part 3 [1].
- 1.6. Remediation of contaminated areas is also subject to the requirements established in GSR Part 1 (Rev. 1) on *Governmental, Legal and Regulatory Framework for Safety* [5], which defines the components of a comprehensive administrative and legal system, and assigns responsibilities to the different national authorities involved. The requirements established in

³ The term ‘incident’ is defined as “Any unintended event, including operating errors, equipment failures, initiating events, accident precursors, near misses or other mishaps, or unauthorized act, malicious or nonmalicious, the consequences or potential consequences of which are not negligible from the point of view of protection and safety” [1].

⁴ The environment is defined as “the conditions under which people, animals and plants live or develop and which sustain all life and development; especially such conditions as affected by human activities” [11]. Protection of the environment is defined as “protection and conservation 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, water and air; and natural processes such as carbon, nitrogen and water cycles” [11].

IAEA Safety Standards Series No. GSR Part 4 (Rev. 1) on Safety Assessment for Facilities and Activities [7] are also applicable.

- 1.7. Remediation of a contaminated area may give rise to residual materials⁵ containing radioactivity, some of which may have to be managed as radioactive waste. Requirements for the management of radioactive waste are established in IAEA Safety Standards Series No. GSR Part 5 on Predisposal Management of Radioactive Waste [3] and IAEA Safety Standards Series No. SSR-5 on Disposal of Radioactive Waste [4].
- 1.8. Many IAEA Safety Standards address topics relevant to the planning and implementation of remediation (for example, radiation protection, waste management, safety assessment, engagement of interested parties⁶ and others); however, this is the only Safety Guide that specifically covers the process of remediation. Therefore, it covers the broad array of situations and circumstances for which remediation may be required, and the full scope of work to be planned and implemented as part of remediation.
- 1.9. Many of the safety requirements found in GSR Part 3 [1] are applicable to remediation and should be taken into consideration in the development of the national remediation framework. Requirements 1-5 address the general requirements for protection and safety. In addition, Requirements 6-16; 19-28; 31-32 apply. Requirements 43-46 defining the requirements for emergency situations are relevant because unexpected events may occur during the remediation and appropriate arrangements should be made in advance. Requirements 47-49 are specific to remediation of existing exposure situations and form the basis for this Safety Guide. Requirement 52 addresses occupational exposure for the remediation worker. These requirements are further elaborated in this Safety Guide.

OBJECTIVE

- 1.10. The objective of this Safety Guide is to provide guidance on planning and implementing the requirements for the remediation of areas contaminated by past activities and accidents or incidents. It is intended to be used by governments, national authorities, regulatory bodies, operators and other parties involved in remediation of areas and, in the case of an accident or incidents involving radioactive material, contributing to the recovery process.

⁵ Residual materials can include media and debris that may be recycled or reused, radioactive waste and non-radioactive wastes that require proper interim storage and ultimately, disposal in a facility that has been engineered for the type of waste to be disposed of.

⁶ An interested party is defined as “a person, company, etc., with a concern or interest in the activities and performance of an organization, business, system, etc.” [11]. “Interested parties have typically included the following: customers, owners, operators, employees, suppliers, partners, trade unions; the regulated industry or professionals; scientific bodies; governmental agencies or regulatory bodies (national, regional and local) whose responsibilities may cover nuclear energy; the media; the public (individuals, community groups and interest groups); and other States, especially neighbouring States that have entered into agreements providing for an exchange of information concerning possible transboundary impacts, or States involved in the export or import of certain technologies or materials. [13]

SCOPE

- 1.11. The scope of this Safety Guide includes all aspects of the remediation of areas that have been contaminated as a result of unregulated or unauthorized human activities that could cause long-term radiation exposure, and for which a decision of control needs to be taken.
- 1.12. In this Safety Guide, the term ‘areas’ is used in its broadest sense and can include land, surface and ground waters, residential areas and industrial site areas⁷, and structures thereon. These areas may have been contaminated as a result of inadequate practices for radioactive waste management and disposal, accidental radioactive releases to the environment that did not meet regulatory requirements, nuclear or radiological accidents, nuclear weapon tests, incidents involving releases of radionuclides by users of radioactive material, or past practices that were not adequately controlled, for example, past practices on an authorized site. This Safety Guide also applies to radioactive discharges from facilities that were managed in accordance with less stringent requirements than those that are applied today. It could also be relevant in the event of a malicious act involving radioactive material.
- 1.13. The scope of this Safety Guide does not apply to facilities that are currently under regulatory control and that may have had incidents, including accidents, resulting in contamination of localized areas within the boundaries of the authorized facility that are not covered as part of routine activities. In addition, this Safety Guide does not include the cleanup of contaminated areas that is carried out as part of the planned decommissioning of facilities under regulatory control and in accordance with the conditions of authorization, or to planned closure of disposal facilities including those associated with authorized mining operations.
- 1.14. The term decommissioning refers to “the administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a facility (except for the part of a disposal facility in which the radioactive waste is emplaced, for which the term ‘closure’ instead of ‘decommissioning’ is used)” [8]. Decommissioning is an authorized process primarily concerned with decontamination and dismantling of buildings and structures. Decommissioning can entail activities that are similar to remediation (also an authorized process), such as removal of contaminated soil from an area within the authorized boundary of a facility, but in this case, such removals are normally referred to as cleanup activities and are typically performed under the authorization for decommissioning.
- 1.15. Conversely, abandoned and presently unauthorized industrial site areas (or “sites”), such as former uranium mines and mills and former radium processing facilities, may have buildings and structures that are taken down by actions consistent with the decommissioning process,

⁷ A geographical area that contains an authorized facility, authorized activity or source, and within which the management of the authorized facility or authorized activity or first responders may directly initiate emergency response actions. For the purposes of this safety guide, the term ‘site’ will be used synonymously with ‘site area’.

although such removals would typically be carried as part of a site-specific remedial action plan.

- 1.16. While this Safety Guide is focused on radiological protection, in the context of the principles of justification⁸ and optimization⁹, it is appropriate to also address physical, non-radiological risks, and other factors (which will often have to be controlled under separate regulations). Some of the recommendations in this Safety Guide, therefore, relate also to physical or non-radiological risks to the extent that consideration should be given to interrelationships between the various control measures for different types of risk.

STRUCTURE

- 1.17. Section 2 addresses government responsibilities and the establishment of laws, regulations and a strategic approach to remediation based on the principles of radiation protection. Guidance is given on regulatory oversight and funding of remediation and on the involvement of interested parties. Section 3 defines the four phases of remediation and the fundamental radiation protection principles that support remediation. Guidance on the first three phases is provided in subsequent sections: Section 4 addresses the remediation process, Section 5 deals with site evaluation, and Section 6 addresses the implementation of remediation. Section 7 sets out the approach to the management of residual materials generated during remediation, including those that have to be managed as radioactive waste. Section 8 provides guidance on post-remediation management, the fourth and final phase of the remediation process. Additional supporting information is provided in four annexes. Annex I gives an example of a table of contents of a site-specific remedial action plan. Annex II provides guidance on dose assessment for remediation purposes. Annex III discusses optimization of site remediation, and provides practical aspects and an example of how to derive reference levels. Annex IV discusses self-help actions that can be advised by the responsible party, the regulatory body or the government to members of the public who are continuing to live in contaminated areas.

2. NATIONAL FRAMEWORK FOR REMEDIATION

- 2.1. Successful remediation requires a well-developed national remediation policy and corresponding strategy, and the legal and regulatory framework necessary to implement the policy and strategy (see Ref. [10]). The national policy should establish the principles each

⁸ Justification is defined as “the process of determining for an emergency exposure situation or an existing exposure situation whether a proposed protective action or remedial action is likely, overall, to be beneficial; i.e., whether the expected benefits to individuals and to society (including the reduction in radiation detriment) from introducing or continuing the protective action or remedial action outweigh the cost of such action and any harm or damage caused by the action” [1].

⁹ Optimization is defined as “the process of determining what level of protection and safety would result in the magnitude of individual doses, the number of individuals (workers and members of the public) subject to exposure and the likelihood of exposure being as low as reasonably achievable (ALARA), economic and social factors being taken into account” [1].

State believes should guide its approach to remediation, and the national strategy should establish the plan of action for implementing the policy. The national framework should also provide for radioactive waste management, establishment of radiological criteria, assignment of a responsible party for remediation, including in cases for which no owner can be identified, arrangements for incidents and accidents during remediation, mechanisms for interaction with the public and between regulatory bodies, and other relevant aspects. Together, the policy, the strategy, and the legal and regulatory framework that enable their implementation, define the national framework for remediation. This framework may be integrated into the existing national framework, for example, on radioactive waste management, or may be stand-alone.

- 2.2. A national framework for remediation should be established to avoid an ad hoc approach, as far as possible.
- 2.3. Planning of essential and urgently required elements of post-accident recovery, such as waste management and disposal strategies for the large volumes of residual materials, including material generated from remediation following accidents, should be undertaken as part of emergency preparedness; initiation of planning during an emergency without advanced planning should be avoided, to the extent possible.

GOVERNMENTAL, LEGAL AND REGULATORY FRAMEWORK

- 2.4. Requirements on the governmental, legal and regulatory framework for safety of facilities and activities are established in GSR Part 1 (Rev.1) [5]. These requirements address the need to establish a national policy and strategy for safety and to promulgate the necessary laws and statutes. Requirement 9 specifically states that “the government shall establish an effective system for protective action to reduce undue radiation risks associated with ... contamination from past activities or events, consistent with the principles of justification and optimization”.
- 2.5. Requirement 1 of GSR Part 1 (Rev.1) [5] states 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 radiation risks associated with facilities and activities”. In addition, Requirement 2 of [5] states that “the government shall establish and maintain an appropriate governmental, legal and regulatory framework for safety, within which responsibilities are clearly allocated”. According to Para. 2.5 of [5], this framework shall set out “the safety principles for protecting people — individually and collectively — society and the environment from radiation risks, both at present and in the future”.
- 2.6. The governmental, legal and regulatory framework should form the basis for defining the national strategic approach for remediation to address the health, safety and environmental

aspects of areas affected by past activities and accidents. The framework should incorporate laws and regulations that:

- (a) Provide a mechanism to identify the responsible party for the planning and implementation of remediation, including in cases for which no owner can be identified;
- (b) Provide a mechanism for identifying and evaluating areas affected by past activities and accidents, and for deciding on and prioritizing the need for remediation, taking into account that the identification and prioritization of contaminated areas should be aided by the involvement of government agencies other than the regulatory body and by other interested parties, including the public. The national strategy should provide for their input into the process;
- (c) Set objectives and principles for remediation, including:
 - (i) The requirement for remedial actions to be justified and optimized with due consideration of the need to define reference levels to properly comply with the applicable radiation protection principles and criteria, as well as other factors that should be considered;
 - (ii) The adoption of a graded approach in which the remedial actions applied to a particular affected area are commensurate with the risks associated with that area;
 - (iii) The condition to enable an open and transparent process for making decisions concerning remedial action plans and activities;
- (d) Assign responsibilities for the development of remediation strategies; for the planning, implementation and verification of the results of remedial actions; for the provision of the necessary human and technical resources, equipment and supporting infrastructure; and for regulatory oversight of remediation;
- (e) Ensure that for each authorized facility and activity, provisions are made to ensure remediation in case of accidental release;
- (f) Assign responsibilities and make provision for emergency preparedness and response;
- (g) Make provision for regular public information exchange with regard to the development, implementation and verification of the remedial action plan, and for the involvement of interested parties in the decision making process;
- (h) Specify measures for ensuring that:

- (i) Adequate finances and funding mechanisms are in place and responsibilities are assigned for the financing of remedial actions (including any actions needed for post-remediation institutional control), as well as associated radioactive management activities, that are proportionate, manageable and economically sustainable;
 - (ii) Provision is made for adequate funding to be available if organizations or individuals are unable to meet their liabilities;
- (i) Make provision for the safe management of residues from remediation activities which, when such residues are to be managed as radioactive waste, is conducted in accordance with the overall national policy and strategy for the management of radioactive waste;
 - (j) Provide the basis for establishing any restrictions that may be placed on the use of or access to the area before, during and, if necessary, after remediation;
 - (k) Assign responsibility for record keeping that covers the nature and extent of contamination; the decisions made prior to, during and after the implementation of remedial actions; and information on verification of the results of the remediation, including the results of all monitoring programmes after completion of the remedial actions.
- 2.7. The government, the regulatory body and other national authorities should be actively involved in the development of the national framework for remediation.

NATIONAL POLICY

- 2.8. Within the framework the national policy should establish principles to help focus the investigations and analysis of remedial options. The basic principles to consider for any remediation policy should include, but not be limited, to: 1) protecting human health and the environment; 2) complying with all relevant and applicable laws and requirements; 3) adoption of a graded approach in which the remedial actions applied to a particular affected area are commensurate with the risks associated with that area; 4) ensuring remediation is justified and optimized; 5) ensuring cost-effectiveness; 6) establishing a preference for sustainable solutions, including evaluating active versus passive remedial options¹⁰; and 7) ensuring an open and transparent process for making decisions concerning remediation.

NATIONAL STRATEGY

- 2.9. The national strategy for remediation should provide a mechanism for identifying and evaluating contaminated areas, making decisions on the need for remediation, and where there are multiple areas within a State's boundaries, establishing an order of priority for action. It

¹⁰ Active remedial options involve ground-breaking or physical work, and passive options involve allowing natural dispersion and decay (e.g. natural attenuation) to reduce the hazards and include land use control. Both options, active and passive, involve monitoring and surveillance to verify the option is behaving as expected, in accordance with the remedial action plan and the authorization [11].

should be taken into account when making such decisions that it may be necessary to involve, and ensure liaison between, various government agencies, regulatory bodies, and other interested parties, such as land owners.

- 2.10. The starting point for a national strategy for the remediation of areas affected by past activities is identification and characterization of contaminated areas within national boundaries; this, in turn, is followed by evaluation of such areas and setting national priorities regarding remediation. Prior industrial activity is typical of these areas. As such, these areas (urban or remote) are less likely to involve displaced populations and there may be less pressure to take prompt action.
- 2.11. The starting point for remediation of areas affected by incidents or accidents follows the termination of release and deposition of radionuclides and may begin during the transition from an emergency exposure situation to an existing exposure situation [14]. Once adequate characterization information is available, the necessity of remediation can be evaluated and remedial actions can be identified, as appropriate. Development of a strategy for the characterization of radioactivity, and delineation of areas inappropriate for social and economic habitation are important inputs for the transition from emergency to existing exposure situation, as well as for developing the site-specific remedial action plan (see Ref. [14]). For areas affected by accidents, socioeconomic and political pressure may be greater because the affected areas warranting remediation may be large, and may involve private and public lands that were previously inhabited. In situations where there are displaced populations, the interest of the inhabitants to return may exert a large influence on remediation, for example, on the timeframe to implement remediation. By comparison, the plan for remediation of areas affected by past activities may be more flexible because such time pressure may be considerably smaller. During this period, appropriate protective actions to protect the public would still be undertaken. The amount of time that would be needed for remediation to address an existing exposure situation would be dependent on the prevailing circumstances and site-specific factors.
- 2.12. Requirement 7 of GSR Part 1 (Rev. 1) [5] establishes the need and conditions for “the coordination of different authorities with responsibilities for safety within the regulatory framework for safety”. Various authorities, including the regulatory body, may have an interest in remediation due to their particular responsibilities. Some of these authorities, however, may be unfamiliar with the principles of radiation protection. Para. 2.18 of [5] states in this regard “Where several authorities have responsibilities for safety within the regulatory framework for safety, the responsibilities and functions of each authority shall be clearly specified in the relevant legislation. The government shall ensure that there is appropriate coordination of and liaison between the various authorities... This coordination and liaison

can be achieved by means of memoranda of understanding, appropriate communication and regular meetings. Such coordination assists in achieving consistency and in enabling authorities to benefit from each other's experience".

- 2.13. The national strategy to address areas affected by past activities and accidents (as set out in the legal and regulatory framework) should be integrated and coordinated at an early stage of the process, especially where the relevant authorities have limited human and technical resources available so that:
- (a) National laws and regulations are applied in a coherent manner;
 - (b) The drafting or revision of national laws and regulations related to remediation is facilitated;
 - (c) Duplication of effort amongst different authorities is avoided or minimized to the greatest extent possible;
 - (d) National priorities are set regarding areas that require remediation;
 - (e) Funding mechanisms are in place for ensuring that each authority can meet its particular responsibilities;
 - (f) The use of financial resources for remediation is justified and optimized;
 - (g) The authorities communicate and consult with the public, the media and other interested parties in a coordinated and consistent manner.

SITE-SPECIFIC REMEDIATION STRATEGY

- 2.14. In addition to establishing a national remediation strategy, it is also necessary to develop a site-specific remediation strategy that takes account of all relevant factors, such as the prevailing circumstances and conditions in the remediation area, that should be considered in the planning and implementation of the remediation.

SITE-SPECIFIC REMEDIAL ACTION PLAN

- 2.15. A site-specific remedial action plan should be developed by the responsible party, taking account of the site-specific remediation strategy.
- 2.16. The site-specific remedial action plan should include, but not be limited to, consideration of the following aspects:
- (a) The overall safety objective of protecting people and the environment, now and in the future, from the harmful effects of radiation;
 - (b) The importance of assigning responsibilities for all aspects of the remediation process;
 - (c) The basic principle that remedial actions be justified and optimized;

- (d) The consideration of non-radiological hazards and the implication of the competent authorities for these hazards;
- (e) The importance of selecting and achieving a remediation end state that provides long term protection and sustainability with consideration of short term benefits versus adverse impacts;
- (f) The need for a formal process including means of engagement with all relevant interested parties to identify areas that may need to be remediated, evaluate the risks, assign priorities, and adopt a graded approach such that level of effort and oversight is commensurate with risk, taking into account the possible levels of exposure in comparison with the applicable reference levels and the need to avoid any deterministic effects on humans and reduce the risk of stochastic effects;
- (g) A means for evaluating a range of possible remediation and waste minimization technologies that may be applied, as appropriate;
- (h) The identification of the basic approach to dose reduction, i.e., the choice between actions to remove contaminated material and actions to modify the exposure pathways to humans, taking into account factors, such as worker dose, short term impacts relative to long term benefits, volume of radioactive waste generated, and others;
- (i) The need for urgent protective actions (such as access controls) to prevent further exposure in the area to be remediated and to prevent the spread of contamination into other areas (outside of the remediation area);
- (j) Any arrangements necessary, in the interests of public safety, for obtaining access to or use of private property;
- (k) Communication with and involvement of interested parties in decisions regarding the development and implementation of protection and remediation strategies, as appropriate;
- (l) The availability of adequate funding for the remediation, including funding of the management of the waste, media and/or debris generated;
- (m) Minimizing the generation of radioactive waste and managing such waste in accordance with the national framework of safety (including policy and strategy) for radioactive waste management;
- (n) Employing clearance, reuse, and recycling to the extent practicable;
- (o) The need for any post-remediation monitoring, surveillance and institutional controls (such as access restrictions);

- (p) Ensuring formal arrangements for record keeping and communication during all stages of remediation, specifying who is responsible to perform these functions at each stage, which records should be kept, to whom they should be submitted and communicated, and for how long they should be retained.
- (q) Analysis and interpretation of historical records from past activities, including records of inspection, incidents, as well as site physical and environmental data.
- (r) The need to impose institutional controls or restrictions on land use during or after remediation.
- (s) Monitoring the efficacy of the remedial action plan through evaluation of coupling environmental monitoring data and contaminant transporting modeling.
- (t) Mechanism ensuring that formal approval by the regulatory body is performed prior to the implementation of each step of the remedial action plan and that the verification of a previous step is done. This mechanism should provide a step-wise process for approval, verification and financing of the remediation, with the adequate flexibility to review past decisions and to adjust the remedial action plan, as appropriate. Financial control of the program could be coupled with this procedure.

2.17. While the elements described above are common to all remediation strategies, the approach to remediation of areas affected by past activities may differ from that for remediation of areas affected by accidents. This is a reflection of the differences in the types and numbers of areas involved and their characteristics, the amounts and extent of contaminated material, the urgency of the need for remediation, and the level of disruption to daily life. The remediation of an area affected by an accident is likely to be more complex in terms of the social, economic and health issues, and in some cases, the environment and the nature and extent of the contamination, and it will be impacted by the protective actions implemented and restrictions imposed during the emergency response and the transition from emergency to existing exposure situation (see Ref. [14]).

2.18. Contaminated areas should be identified and subject to a preliminary characterization with respect to their locations, the types and properties of the contaminants, the boundaries and environmental characteristics of the areas and their use by humans, the populations actually or potentially exposed, and any other relevant parameters. This information should be documented in an inventory of affected areas.

2.19. The preliminary characterization data, including all types of contaminants not limited to radioactive substances, should be used as a basis for prioritizing the affected areas listed in the inventory. The characterization should include an assessment of the implied levels of risk to

human health in relation to the applicable reference levels, and environmental impacts, including potential effects on neighbouring States, and other factors, such as socio-economic considerations, availability of funds, availability of feasible remediation techniques and equipment, and availability of relevant scientific data.

- 2.20. Within a State's boundaries, the identification and prioritization of multiple areas needing remediation should also consider the differences in overall efforts needed for remediation of a particular area, where the amount of effort should be commensurate with risk. In cases where there is high uncertainty or little to no information, making it difficult to evaluate risk, more characterization and monitoring should be undertaken to provide adequate information to evaluate remediation sites.
- 2.21. At the earliest opportunity, the identification and prioritization process for the remediation strategy should involve relevant national authorities, institutions and other interested parties, and should make use of input from members of the public, industry and other relevant interested parties (e.g. scientific bodies, special interest groups, non-governmental organizations). The entire process should be properly recorded by use of a transparent and traceable documentation system that is updated, as necessary, to take account of changing circumstances and new information.

REGULATORY OVERSIGHT

- 2.22. Specific roles and responsibilities of the government, the regulatory body or other relevant authorities, and other parties responsible for remediation are delineated in Requirements 47, 48, 49, and 52 of GSR Part 3 [1]. In general, the government is responsible for ensuring that existing exposure situations that have been identified are evaluated to determine which occupational exposures and public exposures are of concern from the viewpoint of radiation protection. Additionally, the government is responsible for identifying those persons or organizations responsible for areas with residual radioactive material. The government and the regulatory body or other relevant authority is responsible for ensuring that remedial actions are justified, and protection and safety are optimized. The responsible party should, in general, establish the necessary arrangements for the planning and implementation of remediation, and the post-remediation monitoring and surveillance to assess the efficiency and effectiveness of the remediation, including support for self-help actions.
- 2.23. Para. 2.15(d) subordinated to Requirement 2 of GSR Part 3 [1] requires that the legislation established as part of the governmental, legal, and regulatory framework for safety establishes and provides for the maintenance of "an independent regulatory body with clearly specified functions and responsibilities for the regulation of protection and safety" (including radiation protection).

- 2.24. To fulfil its responsibilities as defined in GSR Part 1 (Rev.1) [5], the regulatory body should have the appropriate resources, including properly trained and experienced staff, facilities and financial commitments. Its responsibilities should include:
- (a) Identifying and quantifying potentially contaminated areas and the associated responsible parties;
 - (b) Prioritizing contaminated areas;
 - (c) Establishing or confirming remediation criteria and the objectives of the remedial actions to ensure health, safety and environmental protection;
 - (d) Developing regulatory guidelines for the planning, approval and conduct of the remedial actions;
 - (e) Making provision for emergency preparedness and response in authorization, as appropriate;
 - (f) Reviewing and approving the remedial action plan, including any post-remediation institutional controls that may be necessary;
 - (g) Developing criteria and methods for assessing the adequacy of the implementation of remedial actions;
 - (h) Approving or authorizing remedial actions;
 - (i) Reviewing and approving the time when remediation activities should be initiated;
 - (j) Monitoring the remediation activities during implementation;
 - (k) Performing regulatory inspections, involving independent measurements where appropriate, to verify that health, safety and environmental requirements and the conditions of the approval or authorization are being met;
 - (l) Evaluating reports on unplanned events;
 - (m) Taking appropriate enforcement actions whenever health, safety and environmental requirements and the conditions of the approval or authorization are not met;
 - (n) Reviewing and approving significant changes in the remedial action plan, including procedures or equipment that may have an impact on health, safety or the environment;
 - (o) Coordinating with other regulatory bodies with oversight roles and responsibilities;
 - (p) Reviewing the final radiological survey report, which is to be conducted as part of the Final Remediation Report, upon completion of remediation and verifying that all final conditions, including the authorized remediation endpoint(s), have been met prior to terminating regulatory control over the area;

- (q) Evaluating and authorizing revisions to remediation activities and/or to institutional controls, if compliance with the remediation end point criteria is not achieved, such that the remediation process can be adaptively managed;
 - (r) Authorizing termination of regulatory control over the area when the remediation process is satisfactorily completed, stipulating monitoring, surveillance, restrictions or other institutional controls, as required; and
 - (s) Ensuring opportunities for public participation are available throughout the remediation process and that the decision-making process is transparent to members of the public.
- 2.25. Many factors can influence the extent of authorization and approvals required by the responsible party for carrying out the remedial actions. Such factors may include the scope and complexity of the remediation and the range of regulatory bodies with jurisdiction over the contaminated area subject to the remediation. Authorizations (e.g. registration or licensing) and approvals may be required from the regulatory body (e.g. for radiation protection and safety) to ensure health and safety of the workers engaged in the remediation work, protection of members of the public and the environment, and safety and security of radioactive waste. The authorities concerned may provide advice on possible means to achieve compliance with the requirements and criteria for authorization, for example, by means of guidance documents.
- 2.26. The regulatory framework should provide guidance on how remedial options are to be evaluated, in order to find an appropriate balance between exposure to the workers and the public, technical feasibility, economic, environment, social impacts, public acceptance, and other relevant factors.
- 2.27. Regulatory oversight of remediation work is necessary before, during, and where appropriate, after remediation and should follow the same principles as planned exposure situations. This includes routine inspections during remediation to visually assess the state of the remediation area (including the compilation of photographic records), to check that remedial actions are consistent with the authorized site-specific remedial action plan, and to identify the need for any corrective action or modification to the site-specific remedial action plan to address unforeseen changes. Annex I provides an example of the contents of a site-specific remedial action plan.
- 2.28. Depending on the conditions of the authorization, regulatory oversight might also be needed to verify the levels of education, training, certification and competence of radiation protection personnel and occupationally exposed workers, and to verify accreditation of analytical laboratories. For sites subject to post-remediation institutional control, the relevant authority should maintain an appropriate level of oversight in order to verify that the site remains safe and secure, that any access control measures have not been compromised, that new exposure

pathways have not developed and that the remediation objectives and end point criteria continue to be met, and to ensure that a system of record-keeping is established and maintained.

FUNDING OF REMEDIATION

- 2.29. As stated in Para. 5.10(a) subordinated to Requirement 49 of GSR Part 3 [1], “for the remediation of areas with residual radioactive material deriving from past activities or from a nuclear or radiological emergency ..., the government shall ensure that provision is made in the framework for protection and safety for ... the identification of those persons or organizations responsible for the contamination of areas and those responsible for financing the remediation, and the determination of appropriate arrangements for alternative sources of funding if such persons or organizations are no longer present or able to meet their liabilities”.
- 2.30. In accordance with the ‘polluter pays’ principle¹¹, when the responsible parties who have caused contamination or allowed it to occur can be identified, those parties should be held responsible for financing the remediation and its funding. However, it should be recognized in the regulatory framework that circumstances, in many instances, may be complex and it may not be possible to identify the responsible parties, or the total remediation costs may be disproportionately high in comparison with the actions of the organization that is causing or has caused the contamination; for example, the contamination may have been caused by changes to exposure pathways that were unforeseen when a discharge authorization was given or by an accident. The economic costs apportioned to an organization may also be such that they could lead to its bankruptcy and consequent inability to pay. The regulatory framework should, therefore, include provisions to ensure that appropriate arrangements for alternative sources of funding are in place, even when the responsible parties are unable to meet their liabilities. Costs may fall wholly or in part on the original polluter, current site owners, industry, developers, local communities, provincial/state or national governments.
- 2.31. The laws and regulations should make provision for ensuring that adequate funding is available for remediation. Funding mechanisms for any necessary remedial actions, including the management of radioactive waste generated by the remediation process, should be established and the reliability of the funding sources should be assured before any physical work is undertaken. If adequate funding for implementation of a site-specific remedial action plan cannot be assured, the relevant authority should not authorize the start of any remediation work. Nevertheless, if current conditions are anticipated to cause significant risk to the public or the environment, certain restrictions, such as site access controls, establishing physical

¹¹ In environmental law, the ‘polluter pays’ principle is enacted to make the party responsible for producing pollution (i.e., causing contamination) responsible for paying for the damage done to the natural environment [15].

barriers (e.g., fencing), adding specific security controls, land use deed restriction, or urgent needs for short-term remedial actions, may be necessary.

- 2.32. Since the apportionment of liabilities may be contentious (particularly when large sums of money are involved, and formally designating an area as requiring remedial or protective actions may impact the value of the surrounding properties), the responsible authority should engage with relevant interested parties to negotiate voluntary and cooperative action. An early, proactive approach with relevant interested parties may avoid the need for enforcement action during a later phase of the remediation process.
- 2.33. Adequate and proportionate funding should be provided to enable the regulatory body or relevant authority to ensure remediation activities are reviewed, authorized, and implemented in compliance with the authorization.
- 2.34. Remediation should be funded by the responsible party. In cases where it is not possible to identify a responsible party for the remediation or where adequate funding is not available by the responsible party, it is the responsibility of the government to assign a responsible party for the remediation and to ensure adequate resources are available. The regulatory framework should consider the application of both options.
- 2.35. The relevant authority should review the financial arrangements on a regular basis to ensure that adequate funding will continue to be available, despite any changes in the remedial action plan resulting from new information generated during the course of remediation.

INVOLVEMENT OF INTERESTED PARTIES

- 2.36. The need and conditions for communication and consultation with relevant interested parties, including the general public are established in Refs. [1] and [5]. Para. 4.67 of GSR Part 1 (Rev. 1) [5] describes the requirement of the regulatory body to “set up appropriate means of informing interested parties, the public and the news media about the radiation risks associated with facilities and activities, the requirements for protection of people and the environment, and the processes of the regulatory body” and in particular, to ensure “consultation through an open and inclusive process with interested parties residing in the vicinity of authorized facilities and activities, and other interested parties, as appropriate”. There is also an obligation of the designated responsible party to inform the public of planned and ongoing remediation activities. The interested parties could include: those responsible for the contamination, regulatory bodies, responsible authorities, local authorities, property owners, tenants, potential developers, liability insurance companies, nearby communities, technical experts, those responsible for funding remediation, environmental groups, and possibly others.

- 2.37. The involvement of interested parties is essential to the success of any remediation and should be sustained throughout the remediation process, from the initial site evaluation to the completion of remedial actions and, where appropriate, the transition to post-remediation institutional control. The involvement should include a dialogue involving an exchange of information between the regulatory body or responsible party and two or more parties in which every participant should have the possibility to express and discuss their positions and views regarding the remediation to develop a mutual understanding, participation in the decision making process regarding the planning and implementation of remedial actions, broader public communication, and where possible, engagement of interested parties to allow for their direct or indirect involvement in remediation efforts. The involvement of interested parties should be implemented as early as practicable and needs to be tailored to the nature of the remediation project, as well as the stage of remediation. It should be recognized that the type of engagement, the roles of different parties, and any communication strategy should be established as soon as possible and could vary over the course of the remediation process.
- 2.38. Responsibility for the engagement of interested parties lies jointly with the relevant authority with lead responsibility for the remediation, the regulatory body and other relevant authorities, and the party or parties responsible for the planning and implementation of remedial actions (and, where appropriate, for implementation of institutional control). The relevant authorities need to be clear about who is responsible for providing which type of information and to whom, as documented in communication and engagement strategies for the project. Efforts should be made to coordinate information dissemination to avoid contradictory messages to the public. At an early stage, the relevant authorities should reach an agreement with the party responsible for the planning and implementation of the remedial actions with regard to consultation and/or information sharing with interested parties and the broader public. A clear statement of the actions to be taken by each party, and the timing of such actions, helps to ensure that harmonized public relations are established and conflicting messages on activities or timing are avoided. Such an approach is instrumental in building confidence and trust between all parties. In addition, the relevant authority should reach a tentative decision regarding land use and end state in harmonization with the public and other interested parties.
- 2.39. Interested parties should be encouraged to contribute to the decision making process through formal and/or informal input¹² throughout the planning and implementation of the remediation process. Such input can be directed to the government, the regulatory body, other relevant authorities, and the party responsible for the remediation. During the decision making process,

¹² Some examples of formal input could include written requests for information, submission of comments during formal consultation processes, written reporting of concerns or issues, and others. Some examples of informal input could include telephone calls, discussions, information sharing, and others.

the needs, wishes and recommendations of the interested parties should be taken into account and evaluated against the safety requirements, scientific and technical aspects, and financial constraints. To ensure transparency and accountability, justification of remedial action plans being undertaken, a description of how relevant factors were taken into account to select the remedial option(s) through application of the optimization process, and the basis for the selected remediation decision(s) should be clearly explained in a timely manner.

3. APPLICATION OF THE PRINCIPLES OF RADIATION PROTECTION

3.1. The requirements set out in GSR Part 3 [1] — many of which are applicable to remediation — include general requirements for protection and safety, together with more specific requirements for each of the following three types of exposure situation:

- (1) “A *planned exposure situation* is a situation of exposure that arises from the planned operation of a source or from a planned activity that results in an exposure due to a source” [1] — this includes the planned decommissioning, any necessary site cleanup carried out after cessation of the operation of a facility and prior to release of the site from regulatory control, and planning work to ensure health and safety of workers;
- (2) “An *emergency exposure situations* is a situation of exposure that arises as a result of an accident, a malicious act or any other unexpected event, and requires prompt action in order to avoid or to reduce adverse consequences” [1];
- (3) “An *existing exposure situation* is a situation of exposure that already exists when a decision on the need for control needs to be taken” [1].

A situation involving exposure to residual radioactive material from a past activity or accident, including the remediation of the affected area, is treated as an existing exposure situation.

3.2. Para. 5.26 subordinated to Requirement 52 of GSR Part 3 [1] states that: “Employers shall ensure that the exposure of workers undertaking remedial actions is controlled in accordance with the relevant requirements on occupational exposure in planned exposure situations as established in Section 3”. In accordance with this requirement, a radiation protection programme is generally required, in which exposure of workers is justified and optimized and subject to a limit of the effective dose for occupational exposure of 20 mSv per year [1]. Guidance on meeting the requirements for occupational exposure is given in the IAEA Safety Guide on Occupational Radiation Protection [16].

3.3. Principle 10 of SF-1 [12] states: “Protective actions to reduce existing or unregulated radiation risks must be justified and optimized”. Requirements in support of this principle are set out in paras 2.9 and 2.10 of GSR Part 3 [1].

- 3.4. Referring to what is termed the graded approach to protection and safety, para. 2.12 subordinated to Requirement 1 of GSR Part 3 [1] states: “The application of the requirements for the system of protection and safety shall be commensurate with the radiation risks associated with the exposure situation”. The graded approach applies to all types of exposure situation, including existing exposure situations, and should be adopted as part of the approach to remediation.
- 3.5. Consistent with GSR Part 3 [1], the graded approach is applied in the planning and implementation of remediation to determine the appropriate level of analysis, documentation and the necessary actions and regulatory oversight, such that effort is commensurate with risk. Corresponding criteria, relevant to the situation, should then be set. The process should consider the relative importance to safety and security, the magnitude of the hazard involved and its duration, the characteristics of the situation, the relative importance of radiological and non-radiological impacts and other relevant factors. The graded approach helps to identify the key areas of the assessment where the highest contribution to doses and risk are to be expected, to direct the effort to these specific areas to minimize the overall costs of the remediation.
- 3.6. If, during the site evaluation process, a situation is found where the generic criteria for avoiding severe deterministic effects and/or for reducing the risk of stochastic effects (see Appendix II of GSR Part 7 [9]) could be exceeded, characterization of the situation needs to be undertaken, and urgent protective actions and other response actions should be implemented as required in GSR Part 7 [9]. Once adequate information is available regarding the situation, such areas should also be given priority for the remedial actions to be planned and, as appropriate, implemented.

REFERENCE LEVELS

- 3.7. As part of the Requirement 47, Para. 5.2 of GSR Part 3 [1] states: “The government shall ensure that, when an existing exposure situation is identified, ...appropriate reference levels are established”. A reference level, in the context of existing exposure situations, is “the level of dose or activity concentration above which it is not appropriate to plan to allow exposures to continue to occur and below which optimization of protection and safety should be implemented” [1]. For an area affected by a past activity or accident, it is a means for prioritizing the need for remediation. A reference level is not a remediation endpoint criterion and should not be treated as a limit. Reference levels should be used prospectively in the remediation planning phase and retrospectively as a benchmark for evaluating the effectiveness of the protective actions that have been implemented.

- 3.8. As part of the Requirement 48, Para. 5.8 of GSR Part 3 [1] states: “Reference levels shall typically be expressed as an annual effective dose to the representative person in the range of 1–20 mSv or other corresponding risk quantity, the actual value depending on the feasibility of controlling the situation and on experience in managing similar situations in the past”. Selecting a reference level involves making a judgement based on qualitative, as well as quantitative factors. Care should be taken to set the reference level only after taking into account the prevailing circumstances and the relevant factors, including the levels of residual activity in the environment, environmental conditions and the lifestyles of impacted communities. Doing otherwise could unnecessarily restrict the range of options that should be considered. Reference levels are established or approved, and periodically reviewed as necessary, by the government, the regulatory body or another relevant authority and typically established on a case-by-case basis dependent on the particular prevailing circumstances.
- 3.9. National authorities, taking into account the prevailing circumstances, choose to adopt reference levels to progressively improve the situation [17]. It may be considered advantageous to select a reference level. In light of experience and resource availability, this reference level can then be revised downwards so as to improve the situation progressively. Such reference levels can facilitate timely decision-making on remediation strategies and the effective deployment of resources; however, when establishing reference levels, consideration should again be given to the principles of justification and optimisation. Consideration should also be given to the need to clearly communicate the iterative approach to interested parties, such as local communities in the vicinity of the remediation area.
- 3.10. Remediation reference levels are typically expressed in terms of annual effective dose incremental to the contributions from natural background radiation.
- 3.11. In practice, reference levels could be converted, as appropriate, into derived operational quantities (e.g. activity per unit area, per unit weight or per unit volume; gamma dose rates at 1 m height for a defined surface) to aid in their application and to guide planning and implementation of remediation. These operational quantities derived from the reference levels are used to guide remedial actions. Annex II provides guidance on how to conduct dose assessment for the purposes of remediation. Annex III provides more details regarding how to account for various factors in the selection of a reference level.

JUSTIFICATION

- 3.12. Remediation should be justified, that is, a determination made that the benefit of remediation to individuals and society outweighs the resulting harm or damage (including impacts from radiation). Remedial options should be justified, by use of decision-aiding techniques and processes, as necessary, resulting in a positive balance of all relevant factors that are to be

considered in remediation planning and implementation. These factors may include, but are not limited to:

- (a) short and long term reduction of radiological doses to the public;
- (b) the health and safety risks to the remediation workers during remediation;
- (c) the potential impact to the environment caused by the remediation work;
- (d) the reduction in health risks and risk perceptions of the local population;
- (e) the reduction in environmental impacts;
- (f) the financial cost of the remediation, the social costs and disruption;
- (g) waste management options and availability of waste disposal facility;
- (h) the anticipated end use of the impacted area; and
- (i) input and expectations of interested parties.

The justification of any additional doses received by members of the public while remediation is being conducted should also be duly considered.

- 3.13. Balancing the factors relevant to remediation planning and implementation through the justification process may be very difficult. This complexity may increase when remediation is due to a large accident, affecting the way people lived prior to the accident; in such case, justification should be applied in determining whether to allow people to live permanently in the affected areas and to define the conditions for this, following a graded approach [9, 13].
- 3.14. In the process of justification, consultation with relevant experts may be necessary and the involvement of the interested parties is also essential. The decision-making process should, therefore, cover far more than radiation protection and should involve all appropriate governmental and societal decision-making agencies.

OPTIMIZATION

- 3.15. Optimization is applied making the best use of resources in reducing radiation risks, once the remedial actions have been justified. The process of optimization should be conducted in consultation with relevant interested parties. Optimization is specific to the exposure situation and the prevailing circumstances and is a structured, iterative process that is applied to plan and implement remediation .
- 3.16. The aim of optimization of remedial actions is to determine which remedial options will lead to exposures and potential exposures being as low as reasonably achievable, economic and social factors being taken into account. In this process, the evaluation of dose should be as realistic as possible, and based on the quality and reliability of the available information. In application, dose can be influenced by human behaviour, which implies limitations in the use

of the 'representative person'¹³ concept. There could be a need to consider different exposed groups based on their level of exposure.

- 3.17. Optimization entails the selection of the preferred option from a set of justified remedial options, such that the nature, scale and duration of the associated remedial actions provide the maximum net benefit. Optimization of the whole remedial option must be performed, as well as across each of the component remedial actions. Out of this process comes the remediation endpoint, a target state to achieve at which a specific task or process will be considered completed [11].
- 3.18. The criteria that have been developed will not necessarily be those that provide the lowest dose, since dose reduction is only one of several attributes considered. The priority should be first to reduce all doses, and to optimize below the reference level. In some cases, the distribution of dose could be uneven.
- 3.19. The preferred option may lead to extensive remediation, but not necessarily to the restoration of initial conditions that existed before the contamination. In some cases, restrictions on land use may be the outcome of the optimization process.

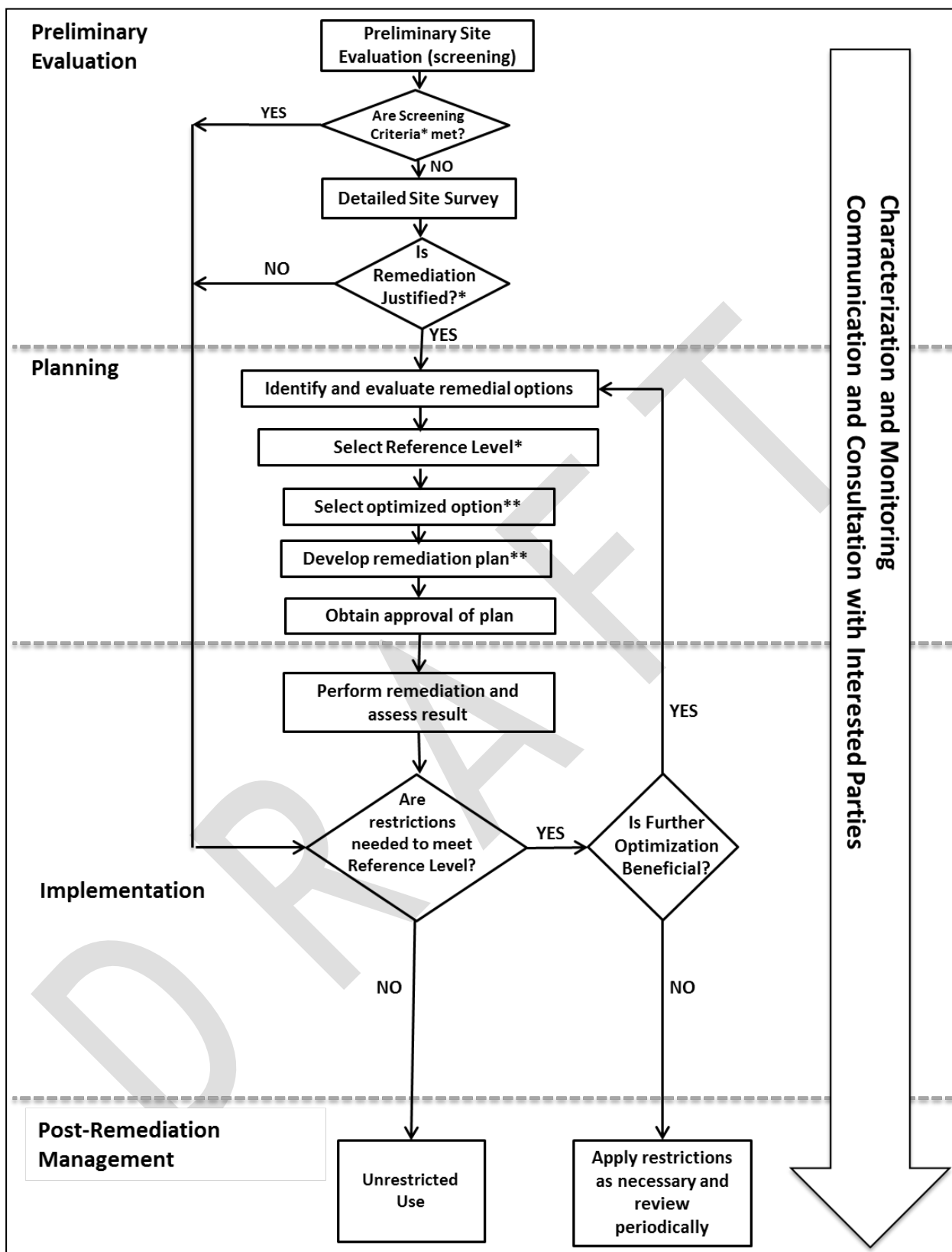
4. THE REMEDIATION PROCESS

- 4.1. The remediation process should be based on a step-by-step approach, applying the fundamental principles of radiation protection, including justification and optimization.
- 4.2. The remediation process can be broadly described in terms of four phases: site evaluation, planning of remediation, implementation of the remedial action plan, and post-remediation management. This process can be applied to areas affected by past activities and accidents. A similar approach may be undertaken for the planning and implementation of remediation following incidents other than accidents, such as malicious acts. The process is shown schematically in FIG. 1.
- 4.3. The site evaluation phase includes a preliminary evaluation of the available information about the site, including the activity concentrations in environmental media, an assessment of radiation doses arising from the elevated levels of radionuclides, an examination of historical records, and compilation of available information from records, local residents, and other sources, as applicable. Based on the outcome of this preliminary evaluation, a detailed survey to characterize the site may be necessary. At the end of the detailed survey, a critical decision should be made as to whether or not remediation is justified, taking into account, for example, reduction of doses, costs, technical feasibility and societal factors.

¹³ Representative person is defined as "an individual receiving a dose that is representative of the doses to the more highly exposed individuals in the population" [1].

- 4.4. The remediation planning phase involves the establishment of a reference level for the highest planned residual dose (see 3.8), and corresponding derived operational quantities for individual remedial action, identification and evaluation of the various options for remediation that may be considered. An optimized remedial option, along with a justified alternative option should be identified. The alternative option is to be implemented in the event that the optimum option is not viable or cannot be implemented. In cases when there is high uncertainty or if little or no information is available about a contaminated area, it may be necessary to identify a number of potentially feasible options that could be undertaken, taking into account that each option may be a combination of active and passive measures. A schedule identifying key decision points by which missing information will be collected and at which time adequate information will be available to select the final remedial option should also be developed in such situations.
- 4.5. The remedial options being considered for implementation are captured in the site-specific remedial action plan. The site-specific remedial action plan, once developed, is submitted to the relevant authority for approval (see Annex I).
- 4.6. The next phase of the process is implementation of remediation. During the implementation phase, remedial actions are carried out in accordance with the approved remedial action plan. The step-by-step approval of remedial actions by the regulatory body, with assessment and evaluation of lessons learned during the previous steps, can be effective approach. The outcome of the remediation is assessed and decisions are made regarding further actions.
- 4.7. The final phase is post-remediation management. If the use of or access to the remediated area does not need to be restricted, the area is released from regulatory control for unrestricted use and no further action is required. If, however, restrictions on the use of or access to the site are needed, the process enters a post-remediation phase in which some form of authorized institutional control(s) should be put in place and maintained. Monitoring and surveillance may also be continued, for example, if engineered structures or systems were part of the remediation.
- 4.8. Radiological contamination of the environment will evolve due to natural attenuation and loss, natural processes (such as contaminant migration), or human actions. The time dependence of the contamination calls for step-by-step implementation of the site-specific remedial action plan, with consideration of monitoring and characterization data. This time-dependence, and especially the possibility of migration of radionuclides, should already be taken into account in the site evaluation phase. A time-frame for the site evaluation and for the institutional control after remediation should be defined as part of the remediation process.

- 4.9. The remediation process should allow for a continuous review and analysis of the circumstances and the adaptation of the site-specific remedial action plan as needed. This could include reconsideration of the protection and safety criteria and/or the needs and conditions for those living in the area.
- 4.10. In the case of remediation after a nuclear or radiological emergency, those having roles and responsibilities in relation to the subsequent remediation should be identified at the preparedness stage and they should be involved during the transition from the emergency to the existing exposure situation [14]. This will allow for a smooth transition towards the long term recovery efforts that may encompass remediation.



* - Assume a screening criterion of 20 mSv/a to start, based on Para. 6.21 on dose levels that can inform the decision regarding the need for remediation.

** - To ensure maximum net benefit, taking account of prevailing circumstances and conditions, including those related to safety and protection, as well as socio-economics, available funds, and others.

FIG 1. Representative scheme for remediation of a contaminated area.

5. SITE EVALUATION

- 5.1. Contaminated or potentially contaminated areas should be identified and prioritized for remediation as an outcome of establishing a national remediation priority list and implementing the national strategy (see Para 2.8) for remediation as informed by a site evaluation.
- 5.2. In the post-emergency phase, the remediation will be initiated once control has been gained over the releases and adequate characterization information has been collected and evaluated to identify appropriate remedial actions to be undertaken. Further details on the transition from emergency to existing exposure situation can be found in Ref. [14].

PRELIMINARY SITE EVALUATION

- 5.3. Once an area is suspected of being contaminated, there is a need to determine if it is contaminated and if so, to what extent. This is accomplished by conducting a preliminary site evaluation. A first step in this evaluation is to determine whether or not remediation is required (see para. 6.21 for criteria). If preliminary site evaluation confirms contamination, it is important to also consider the area adjacent to the site, as contamination may have migrated from the site area. The historical use of the site, and the materials used and produced on the site, will guide the planning and type of sampling and analysis to be done during the preliminary site evaluation. In some cases, it may be determined that remediation is not necessary if restrictions are put into place.
- 5.4. Areas which are not contaminated above the reference levels may be released for unrestricted use (see para. 6.21), recognizing that there may be other reasons not related to radiological contamination that may require consideration for possible restrictions.
- 5.5. The preliminary site evaluation is carried out with the following objectives:
 - (a) To identify related past activities that occurred in the area, including on the site, that could have caused contamination;
 - (b) To identify the source of contamination and the possible extent and characteristics of radiological (and non-radiological) contamination and other hazards (characterization);
 - (c) To determine the extent to which the site poses a threat to human health or the environment;
 - (d) To provide input into the design of the follow-up detailed site survey;
 - (e) To assess the possible migration of contaminants into surrounding areas;
 - (f) To identify the parties who may have been responsible for the contamination;
 - (g) To confirm the need for further evaluation or remediation.

- 5.6. Relevant information pertaining to the site, both current and historic, should be gathered. This may include information on the nature and extent of the activities carried out, the past and present owners or tenants, the location and boundaries of the site, buildings, buried material, physical barriers, geological and hydrogeological characteristics, nearby water resources and their use by the public, types of soil, human activities in the vicinity (including any interactions with the contaminated site itself), and as appropriate, the presence of endangered or protected species.
- 5.7. The information should be collected from sources, including old operational records, past radiological and non-radiological surveys, and local government records. Information may also be obtained through site visits (involving the gathering of Global Positioning System (GPS) data and photographic information), as well as through consultations with past and present owners and employees, local industry, residents and government officials.
- 5.8. When a site visit is made, the purpose of the visit should be explained to the local community. Access to local knowledge is vital, particularly if the team visiting the site is not familiar with the site and its surrounding area. It is important to identify individuals with the best knowledge of the area who may be consulted or employed as guides during surveys that are undertaken as follow up to the preliminary site evaluation, particularly where there is a lack of information (e.g. no maps, plans, or records) or where the visit will first have to focus on the location of structures and site boundaries.
- 5.9. An initial characterization of an affected area being evaluated, which is conducted as part of the preliminary site evaluation, may include taking limited measurements of direct radiation. Limited sampling of materials for analysis may also be carried out. Any preliminary sampling programme should be planned in advance, to the extent possible, and should focus on sampling in those areas identified as contaminated, as well as in areas with a high public occupancy.
- 5.10. The information collected during the preliminary site evaluation should be used to determine if there is a problem by making a preliminary screening based on projected effective dose and existing clearance levels (See Annex II, Dose Assessment for Remediation Purposes). If the screening analysis suggests a concern, the information collected should be used to estimate the scope of remediation and to identify individuals and wildlife that may be at risk. It should also be used to determine the type, quality and quantity of the measurements that will be necessary for deciding on the full nature and extent of the remediation required.
- 5.11. A preliminary estimation of the potential types and volumes of materials that could be generated during remediation, their handling and storage, as well as their ultimate use or

disposal should be developed. This estimation should be revisited at different stages of the remediation, such as during selection of remedial options (see chapter 6).

- 5.12. Decision making at this step may need to be done in the context of potentially incomplete information. Future plans, actions, and communication regarding results thus far should be presented in terms of estimates, approximations, or ranges, but such actions should not be deferred pending more information.
- 5.13. The need to establish a monitoring programme should be evaluated and implemented, as appropriate, and consistent with the conditions in the area. Data generated through characterization or the monitoring programme should be used to make informed remediation decisions.
- 5.14. A system for collecting and maintaining records of the actions taken during the initial site evaluation should be developed and documented, consistent with the national strategy (Section 2), regulations (Section 2), and standards (Section 6).

DETAILED SITE SURVEY

- 5.15. If the preliminary characterization study confirms the need for further evaluation, a detailed site survey should be carried out to validate the findings of the initial evaluation and to provide the information needed for:
 - (a) Determining the nature and extent of the contamination;
 - (b) Identifying receptors¹⁴, and providing input to a conceptual site model (defining key sources and pathways of exposure), and corresponding dose assessment or risk assessment models;
 - (c) Assessing the individual doses associated with the contaminated area;
 - (d) Evaluating environmental, occupational and public health and safety issues during remediation;
 - (e) Justifying the remediation.
- 5.16. The detailed site survey requires the selection and calibration of suitable instruments, the use of appropriate sampling and measurement techniques, and recording of data. The survey should involve the necessary data collection techniques (including consideration for quality assurance and quality control processes); e.g. sampling of surface and subsurface soil, ambient

¹⁴ The conceptual site model provides an overview of the key aspects and their connection on a site. The conceptual site model specifically identifies relevant sources of contamination, contaminant transport pathways, receiving environments and receptors of exposure to facilitate estimation of activity concentrations in the environment and ultimately, dose. This model synthesizes and confirms what is already known about a site in support of decision-making. In the conceptual site model, the receptors represent the human populations that may be at risk from exposure due to the contamination.

gamma dose rate measurements, sampling of airborne radioactive material, and sampling of water, and biota.

- 5.17. The design of the survey should be determined by the conditions in the area, the type and extent of the contaminants in the potentially affected environment, and the available resources. Special consideration should be given to situations involving:
- (a) Members of the public living directly on contaminated land;
 - (b) Members of the public directly using surface water or groundwater downgradient of the contaminated area;
 - (c) The wildlife and the type of ecosystem in the contaminated area;
 - (d) The use of contaminated material from the area in local dwellings and structures;
 - (e) Site-specific conditions, such as climatic factors, physico-chemical conditions, environmental pathways, and resident wildlife species;
 - (f) Agricultural activities carried out in the contaminated area or in the vicinity of it (e.g. crop growing; irrigation of crops with contaminated water; application of contaminated sewage sludge on crops; grazing animals).
- 5.18. The data gathered in the survey should be compiled into a survey report, which is then assessed to support decisions on remedial options.
- 5.19. The next step is the justification of remedial actions, as described in Paras 3.12-3.14.

6. PLANNING OF REMEDIATION

- 6.1. This section reflects the second phase of the remediation process, as identified in FIG. 1. Planning for remediation is initiated if it is determined that remediation is justified through the detailed site survey (see Section 5).
- 6.2. A systematic approach is needed to ensure that decisions regarding the appropriate (i.e., justified and optimized) remediation strategy and remedial options for the situation are made in a timely manner. Financial resources are usually limited, the work can be labour intensive, and equipment costs can be high. In addition, it is often necessary to make critical decisions based on incomplete historic records. Therefore, the work needs to be scheduled as efficiently and effectively as possible, and in a manner that avoids the need for corrective action at a later stage, to the extent possible. Planning for remediation should begin as soon as a decision has been made that remediation is justified. Careful and considered planning allows the early identification and consideration of the many factors that may have an impact on the final outcome, such as type and extent of contamination (e.g. in groundwater, soil, surface water, etc.), types and quantities of wastes generated, the adequacy of financial provisions, public opinion, regulatory compliance, and the availability of proven technologies. Timely attention

to actual or perceived issues can often prevent further deterioration of the situation, avoid unforeseen consequences, and allow better and more sustainable decisions to be made as the remediation proceeds, while maintaining confidence and trust of interested parties. Careful and considered remediation planning also helps to ensure the best use of limited available funding, especially when dealing with complex remediation situations, such as those for which there is high uncertainty, making it difficult to evaluate risk (e.g., situations for which there is a complex environment and/or inadequate information and data).

- 6.3. In areas contaminated by past activities, it may be possible to remove localized areas of relatively higher contamination (e.g. hot spots; materials, such as leaves, organic debris or dust, where contamination can concentrate). Doing so may provide an opportunity for application of passive safety measures (e.g. consolidation of materials into a facility with an engineered cover and a long service life). This should be performed in consultation with interested parties. Remediation strategies involving extensive removal of materials could lead to the generation of large volumes of debris (such as felled trees or vegetation, soil, non-radioactive or radioactive waste) that then need to be characterized, categorized, in some cases cleared (if applicable), and processed for recycling, reuse, storage or disposal. Generation of large volumes of materials should be avoided to the greatest extent practicable. By comparison, strategies for areas affected by accidents may rely much more on measures to reduce exposure pathways (e.g. agricultural countermeasures). Such strategies should form the basis of the remediation action plan.
- 6.4. Remediation planning needs to be based on clearly defined remediation objectives. The overall objective is to transition the area into a state such that the potential impacts to the public and the environment are reduced to an acceptable level. The objective can be expressed in terms of dose and end state, and any eventual restrictions regarding the use of the site. This can be determined through a process of optimization, which will be specific to each particular remediation situation and area. The remediation objectives should be well thought out, practical, and achievable in the short and long term, with consideration of potential impacts during and after remediation. Remediation objectives are focused on the protection of humans and the environment (including flora and fauna) against radiological, non-radiological and physical impacts and risks. This includes health and safety of workers while they undertake the remedial work, and protection of members of the public during and after remediation. From an environmental protection perspective, impacts on surface water, groundwater, soil and air should also be considered.
- 6.5. In the case of remediation following an emergency situation after an accident, data collected during the emergency exposure situation should be used as appropriate.

- 6.6. Establishing remediation objectives is the responsibility of the persons or organizations responsible for the planning, implementation and verification of remedial actions (para. 5.12, [1]). However, early participation of the relevant interested parties (in particular, local residents) is important to ensure a successful outcome.
- 6.7. Objectives and their priority may differ based on the source of the contamination. For example, in a post-accident situation, return of the land to its previous use may be most important. By comparison, in areas contaminated by past activities, especially those that are relatively remote from inhabited areas, the use of the area for economic benefit may be an important consideration. Possible regional development planning may also have to be taken into account.

SELECTION OF REMEDIAL OPTIONS

- 6.8. If it is predicted that, based on the results of the preliminary site evaluation, the area will not meet the criteria for unrestricted release, appropriate remedial options should be identified and an options study performed to compare the respective benefits and impacts. This study should include, but not be limited, to:
 - (a) an assessment of the technical feasibility of the remedial options being considered and available technologies;
 - (b) a review of the potential safety issues during and after remediation;
 - (c) an assessment of doses to workers and the public due to exposure before, during and after the remediation; considerations for characterization, monitoring and sampling;
 - (d) the amount of residual materials (including radioactive waste) that will be generated;
 - (e) the processing, storage, transportation and disposal of radioactive and non-radioactive waste;
 - (f) estimates of the costs and other resources associated with the design and implementation of each possible remedial option; and
 - (g) institutional controls that may be required after remediation, as applicable.

These options should cover a broad range of conditions relevant to the situation and should be based on a set of credible exposure scenarios. Other non-radiological considerations should be taken into account, as appropriate. In some cases, non-radiological considerations may even be the driving factor of the remediation process. Input from interested parties, consistent with the national remediation strategy, should be sought and considered as part of the evaluation process.

- 6.9. Remedial actions may result in additional exposure to members of the public and this should be taken into account in the evaluation process.

- 6.10. The types and amounts of residual materials (including debris, radioactive and non-radioactive waste) potentially generated as a result of each remedial option should be carefully assessed during the planning process and taken into account in the selection of remedial options. Throughout the remediation process, generation of large volumes of residual materials (including waste) should be avoided to the greatest extent possible.
- 6.11. A remedial option that generates waste with no known disposal pathway or with significant risk of unplanned release to the environment (e.g. liquid waste that may spill, or leak into the environment when stored) should also be avoided. When evaluating remedial options in terms of their potential for waste generation, the full range of waste management strategies should be evaluated, including waste minimization, reuse, recycling, clearance¹⁵ and specific clearance¹⁶.
- 6.12. Criteria that may be used in evaluating, justifying, and optimizing remedial options include, but are not limited to:
- (a) level of protection of human health and the environment;
 - (b) degree of compliance with national laws and requirements;
 - (c) time-frame and natural attenuation;
 - (d) long-term effectiveness and permanence;
 - (e) reduction of waste toxicity;
 - (f) reduction in mobility of radionuclides and other contaminants;
 - (g) reduction of volume of waste;
 - (h) availability of waste storage and disposal facilities;
 - (i) increase of access to land and resources;
 - (j) short-term effectiveness;
 - (k) feasibility of remediation (e.g. ease of performing the remediation);
 - (l) costs; and
 - (m) public acceptance.

A multi-attribute decision-making process that weights the criteria according to what is most important to interested parties could be used.

¹⁵ Clearance is defined as “removal of regulatory control by the regulatory body from radioactive material or radioactive objects within notified or authorized facilities and activities [11]. Remediation is an authorized activity and it can be necessary to clear radioactive materials and objects from work sites during implementation.

¹⁶ The concept of “specific clearance” may be used in categorizing materials generated during remediation for recycling, reuse, or disposal, for example, in municipal landfills. “For example, specific clearance levels may be developed for metals, for rubble from buildings and waste for disposal in landfill sites [1].

- 6.13. The aim of remediation is, ultimately, to reduce the risks associated with areas affected by radioactive material due to the past activities or accidents, commensurate with the intended use of the site (other risks, social and economic factors taken into account). Therefore, when considering remedial options, it might not always be necessary to undertake significant remediation if the desired remediation objectives can be largely achieved through an optimized and sustainable approach involving a more moderate degree of remediation. A compromise may sometimes have to be accepted between what would otherwise have been the optimum remedial option and the option that is possible with the funding actually available. This may result in a site requiring the imposition of institutional control, or additional institutional controls, beyond that originally envisaged.
- 6.14. Considerations of the living conditions and radiological exposure of workers and the public working or living in contaminated territories should be taken into account when considering remedial actions. Issues, such as environmental protection and management, use and trade of materials, food, commodities, and waste, should be duly considered. In post-accident cases, it is important to ensure coordination as early as possible between the emergency response team and the development of the site-specific remediation plan (see Ref. [14]).

SAFETY AND ENVIRONMENTAL ASSESSMENTS

- 6.15. Information obtained from safety and environmental assessments of an existing exposure situation can aid in justifying and optimising options for remediation. Estimates of present and future doses for the representative person are key elements of the justification and optimisation process. The assessment of radiological impacts to flora and fauna is an additional factor within the optimization process as well. Dose calculations to the representative persons should be performed regularly along the remediation process and remediation activities modified, as needed, to minimize dose. Annex II provides further discussion of dose assessment as it pertains to remediation.
- 6.16. Safety and environmental impact assessments will achieve the greatest results when they are conducted in accordance with planned guidelines: either site- and project-specific guidelines, or generic guidelines that have been developed within the national regulatory framework.
- 6.17. Radiological, non-radiological, and physical hazards and risks associated with the various remediation activities proposed in the site-specific remedial action plan should be identified in safety and environmental assessments submitted for authorization to the regulatory body or relevant authority/authorities, as established in the regulatory framework. Assessments should be performed for each proposed remedial activity and should include potential impacts to workers, the public and the environment. This should address potential incidents, including accidents, that may occur during remediation, as well as the doses received while

implementing the remediation work. The site-specific remedial action plan should also detail the protective actions that will be taken to ensure the health and safety of workers and the public, and protection of the environment (see Ref. [18]).

- 6.18. In any decision making process, a key parameter in selecting the appropriate remedial option is the distribution of individual doses (i.e. the existing exposure situation) for the population affected by the contamination in the area. Ingestion of contaminated foodstuffs or inhalation of contaminated dust can represent major exposure pathways, and the associated doses before remediation need to be estimated on the basis of model predictions. Where possible, such predictions should be supported by site-specific characterization data and data generated through the radiological monitoring programmes, assuming realistic exposure scenarios. The distribution of doses could be uneven in some circumstances, and the application of the representative person in those cases may have limitations.
- 6.19. Where possible, radiological doses should be projected based on available measurements, with consideration of predicted fate of radionuclides as influenced by site-specific conditions, and noting model assumptions. Calculation of projected doses requires modelling in the context of a conceptual site model that depicts key sources, exposure pathways and their connections with dose receptors (e.g. humans, wildlife). In general, the models used should be as realistic as is appropriate for making dose projections and should be tailored to the specific needs at each phase in the process. Incorporating excessive conservatism can result in significant and unrealistic over-prediction of radiological doses, risks or impacts, leading to unjustifiable options that have not been optimized to account for the situation. In addition, such overstatement of risk could create unwarranted concerns and corresponding expectations of interested parties, particularly for those living in areas close to the remediation site. Therefore, the model that is applied should be fit for purpose and readily able to address all relevant exposure pathways and to use site-specific data, wherever possible. It should be recognized that generic values could also be used for initial (scoping) analysis or in cases where use of generic values does not significantly change the final dose prediction. Models should be tested and validated, as appropriate, taking account of uncertainty. Particular attention should be paid to ensuring model assumptions are relevant to the circumstances under consideration. Refer to Annex II for a more detailed discussion of dose assessment.
- 6.20. The system of protection established in GSR Part 3 [1] provides a high degree of protection of the environment. Methods and practical criteria to perform and evaluate the outcomes of such assessments are being further developed (see Ref. [18]).

JUSTIFICATION, OPTIMIZATION AND EVALUATION OF REMEDIAL OPTIONS

- 6.21. Remediation should be focused on reduction of long-term radiological exposures to the public. For remediation planning following emergencies involving releases of radioactive material, consideration should be given to the reference level, generic and operational criteria, applied in response to the emergency. In addition, consideration should be given to the protective actions implemented in response to the emergency, their effectiveness and achieved levels of residual dose. The starting points for decisions on remediation are long-term projected doses. Selection of remedial actions to reduce long-term exposures should be made on the basis of reference levels derived from the highest planned residual dose (see Annex III). The following dose levels can inform the decision regarding the need for remediation:
- (a) If the long-term projected doses before the implementation of remedial actions are above 20 mSv/y, remediation is likely justified;
 - (b) If such doses are below 1 mSv/y, remediation is unlikely to be justified;
 - (c) If such doses are between 1 and 20 mSv/y, then the implementation of remedial actions should be set “depending on the feasibility of controlling the situation and on experience in managing similar situations in the past” (Para. 5.8, [1]).
- 6.22. Selection of the reference level may have a strong influence on the amount of waste generated during remediation. In general, the lower the reference level, the higher the volume of waste generated. Therefore, selection of an appropriate reference level is critical in optimizing materials management to prevent or minimize waste generation (Section 8).
- 6.23. The remedial options under consideration should be assessed against criteria to determine the justified option(s). Optimization of radiological protection for the justified option(s) should then be performed. The assessment should include consideration of the types and volumes of residual materials (including wastes) that are generated by each option. On the basis of this optimization, a preferred option should be selected that also takes into account non-quantitative considerations, such as social, environmental, economic and political aspects, after consultation with interested parties. It could also be beneficial to identify alternative options, which could be implemented in the event that it is not possible to implement the preferred option.
- 6.24. In considering the long term effectiveness of remediation, the influence of physical, chemical, geological and other factors on the environment should be evaluated. In particular, contamination of groundwater may not become apparent for some time and may lead to contamination at some distance from the source. Such considerations should be documented in the site-specific remedial action plan, in the final remediation report, and in the institutional control programme.

- 6.25. In some circumstances, remediation may be required to protect the population. In such cases, remediation may be justified on the basis of attributable health effects amongst people in current and future generations (in addition to other factors being considered as part of justification). While in most cases the cost of remediation, in terms of aspects such as disruption and inconvenience, will be borne by the present population, remedial actions taken to protect the present generation should be designed such that predicted impacts to the health of future generations will not be greater than the levels of impact that are acceptable today.
- 6.26. Characterization involves the determination of the nature and activity of radionuclides present in a specified place and is conducted as part of site evaluation. The results of site evaluation should be reported to the regulatory body and the regulatory review of the site evaluation should constitute a key step in the decision making process. Interested parties should be involved in this process at an early stage before decisions are finalized.
- 6.27. The decision making process to select appropriate remedial options should be transparent. To build and maintain trust with interested parties and the affected population, the roles of different parties need to be clearly identified, together with the aims and objectives of the engagement process. The degree to which the process will affect the decision should be clear.

SITE-SPECIFIC REMEDIAL ACTION PLAN

- 6.28. A site-specific remedial action plan¹⁷, prepared in accordance with regulatory requirements, showing that remediation can be accomplished safely is to be prepared for the remediation of each contaminated area. The site-specific remedial action plan should be subject to the approval of the regulatory body prior to its implementation.
- 6.29. The process of developing a site-specific remedial action plan should take advantage of lessons learned from similar remediation projects that have been completed in the past, whether national or international. This exemplifies the importance of establishing and maintaining a system of record-keeping for any remedial action plan, as discussed in para. 9.6.
- 6.30. The site-specific remedial action plan and associated monitoring requirements should be designed and implemented to identify possible adverse health, safety and environmental impacts of the contaminants and to optimize protection. These considerations apply to the workers performing the remediation, the public and the environment.

¹⁷ “A remedial action plan, supported by a safety assessment, is prepared and is submitted to the regulatory body or other relevant authority for approval. ... The remedial action plan is aimed at the timely and progressive reduction of the radiation risks and eventually, if possible, at the removal of restrictions on the use of or access to the area” [1]. Annex I contains a sample outline of a site-specific remediation plan and the type of information to consider to adequately document the assessment of remedial options and the selection of the preferred alternative.

- 6.31. There should be a clear understanding by the interested parties of the remediation objectives as an integral part of any successful remediation. The means for determining when these objectives have been met should be clearly stated so that remediation is not unnecessarily continued beyond the point at which it is justified and optimized.
- 6.32. Plans should be provided for both the remediation work and the necessary actions for post-remediation, such as maintenance, monitoring and institutional controls to enforce restrictions on land use and buildings, if applicable. Although institutional controls may last for a long period of time, they are part of post-remediation management, as defined in this context, and should thus be covered in the site-specific remedial action plan.
- 6.33. Once the regulatory body has approved the site-specific remedial action plan, it should be implemented as soon as practicable.
- 6.34. As remediation progresses, the plan should be updated to reflect any changes or provisions relating to the conduct and progress of the remediation. Regulatory review and approval should be obtained accordingly.

7. IMPLEMENTATION OF REMEDIATION

- 7.1. Site evaluation and remediation planning support the development of the site-specific remedial action plan. Once this plan has been authorized by the regulatory body, implementation of the selected remedial action(s) should be initiated to achieve a timely and progressive reduction of radiation risks (FIG. 1). The steps within the implementation phase are: execution of the site-specific remedial action plan and determination of whether the remediated area can be released for unrestricted use. Other considerations during this phase should include, but not be limited to: (a) management of residual materials (including radioactive waste, non-radioactive waste, and materials that can be cleared for recycling or reuse); (b) assessment of the effectiveness of remedial actions relative to the expected outcome; (c) verification of the results; and (d) engagement of interested parties.
- 7.2. Remedial actions should be conducted within an integrated management system [6]. Activities for remediation, transportation and waste management should be performed by properly trained individuals, in accordance with approved working procedures. Working procedures should be prepared for each activity in the context of the broader site-specific remedial action plan. In the development of the integrated management system, the need for the acquisition and retention of records and information relevant to the area being remediated should be emphasized.
- 7.3. Implementation should be conducted in accordance with the requirements in the authorization granted by the regulatory body or other relevant authority.

- 7.4. The responsible party for implementation of the remedial actions should have, or should have access to, competent staff to adequately address the following areas:
- (a) Safety requirements of any permits or authorizations issued;
 - (b) Compliance with regulatory standards and issues;
 - (c) Radiological analysis, environmental impact assessment (including characterization), radiation protection and safety assessment;
 - (d) The integration of occupational radiation protection with other areas of health and safety, including conventional industrial safety;
 - (e) Data collection, analysis, and record keeping;
 - (f) Environmental monitoring;
 - (g) Management systems [19];
 - (h) Geological and hydrogeological processes and dynamics;
 - (i) Environmental modelling to predict spatiotemporal trends in radionuclide release, transport, and fate, resulting in current and future doses;
 - (j) Residual material and radioactive waste management¹⁸ [20, 21];
 - (k) Security of the area;
 - (l) Project management; and
 - (m) Communication with and engagement of interested parties (including the public).
- 7.5. Throughout the implementation of remedial actions, the responsible party must ensure the health and safety of workers, including when contractors are used to perform specific tasks and functions.
- 7.6. Non-radiological risks (i.e., those relating to hazards due to chemical contamination) and physical risks would also likely be present, and existing staff may not be familiar with the various aspects of the requirements for protection against these risks. Appropriate levels of control, supervision and training should be provided to ensure the health and safety of workers with respect to all hazards and risks.
- 7.7. All persons involved in the remediation should be made familiar with the contaminated area, the hazards and corresponding risks that may be present, and the relevant procedures for the safe and effective performance of their duties. Specialized training may be needed in certain areas of work. For some activities, the use of training models and scenarios for training can

¹⁸The term “radioactive waste management” includes all administrative and operational activities involved in the handling, processing (i.e. pretreatment, treatment and conditioning), transport, storage and disposal of radioactive waste [1].

enhance safety and efficiency. Training of all workers is an essential element of the site-specific remedial action plan.

RADIATION PROTECTION DURING REMEDIATION

- 7.8. As part of the Requirement 52, Para. 5.26 of GSR Part 3 [1] states that: “Employers shall ensure that the exposure of workers undertaking remedial actions is controlled in accordance with the relevant requirements for occupational exposure in planned exposure situations.” Verification of the effectiveness of specific protective and remedial actions is important throughout the remediation process. This involves comparison of the actual radiological exposures against the initial estimates, and the measures established for their control. If the actual exposures significantly differ from the initial estimates, the plan should be revised to account for the actual conditions being experienced. In cases where the actual exposures exceed those predicted, an investigation should be undertaken to improve understanding of the situation, and to prevent actual doses that are higher than anticipated.
- 7.9. Doses to members of the public resulting from remediation activities should be controlled under a system of radiation protection. Any such doses should be justified on the basis of the net benefit resulting from remediation. Justification should include consideration of the reduction of the annual dose resulting from remediation.
- 7.10. If, during the course of remediation, unexpected radiation levels are detected, appropriate measures must be taken to ensure health and safety of workers. Appropriate measures may include securing the area, safely stopping work, and evaluating the new conditions. Once the new conditions are understood, it may be necessary to revise the site-specific remedial action plan accordingly and obtain approval from the regulatory body to the restart remediation activities.

MONITORING AND ONGOING SURVEYS DURING REMEDIATION

- 7.11. During implementation of remedial actions, monitoring will be required within and around the area being remediated to confirm that the work is proceeding in a safe and compliant manner consistent with the remedial action plan. Monitoring is needed to verify that contamination is neither migrating into nor out of the area where work is being conducted, that any changing or unexpected conditions are identified in a timely manner and, overall, that the regulatory requirements are being met [22].
- 7.12. Monitoring of occupational exposure and the work environment will also be required as part of the radiation protection programme (see Requirements 20 and 24 of GSR Part 3 [1]). While this is best regarded as a normal part of operations, the data collected will be complementary to the wider monitoring programme.

- 7.13. The nature and the extent of the monitoring programme should be predetermined on the basis of the site- and situation-specific conditions (e.g. physicochemical attributes of the site and the surrounding ecosystem), the characteristics of the contamination, and the remedial actions designed to improve the situation. The monitoring programme should address all potential risks and exposure pathways, and should be modified, as necessary, over the course of the implementation of remediation, for example, based on monitoring results [22]. Examples are the mechanical stability of tailing dams, release of radiological and non-radiological contaminants in the environment, migration of contaminants in the environment (e.g. groundwater, surface water), erosion of contaminated soil and wind-blown migration of contaminated dust, and potentially many others. The monitoring performed before and during remediation should be designed to provide continuity with the post-remediation monitoring activities. Appropriate modelling may help in establishing a meaningful and cost-efficient monitoring program.
- 7.14. Monitoring data should be recorded, evaluated to verify compliance with regulatory requirements and the remediation objectives, and archived for traceability and to facilitate trend analysis over the longer term. This will allow evaluation of the effectiveness of remediation. Monitoring data should be used for communication with interested parties and, in conjunction with other information, for ongoing optimization and updating of planned activities. Several types of surveys, with different objectives, may be necessary during the remediation process (e.g. detailed area characterization surveys, surveys during remediation, and surveys to confirm that the objectives of the remediation have been achieved). The types and frequency of each survey should be described in the site-specific remedial action plan. Provision should be for changes in the type and frequency of surveys and monitoring if situations arise that might lead to a change in radiological conditions or in case where radiological conditions are not as anticipated (e.g. including increased monitoring to gain additional understanding of a situation, and reduction in monitoring if the situation is stable and has improved due to the effectiveness of remedial actions).
- 7.15. Procedures should be established to ensure that abnormal conditions relevant to protection and safety should be reported to the regulatory body and, as appropriate, other interested parties. Reporting levels should be based on a graded approach in consultation with interested parties. During implementation of remedial actions, unexpected situations may arise that necessitate adjustment of the planned activities and, in some cases, more far-reaching modification of the site-specific remedial action plan.
- 7.16. The responsible party, the regulatory body or other relevant authority, or the government should provide guidance in instances where self-help actions are to be carried out at a local or individual level. This necessitates an ongoing evaluation of the effectiveness of such actions

through a monitoring programme, to provide adequate support on how to further improve the situation. Self-help measures are further discussed in Annex IV.

- 7.17. The requirement for a monitoring programme and ongoing surveys presupposes the availability of suitably functioning and calibrated equipment, and the trained staff that are needed to operate it and to interpret the results (see Requirements 4, 14, 32 of GSR Part 3 [1]). Calibration procedures for sampling and measurement equipment, developed as part of the management system, and calibration records should be maintained to demonstrate the integrity of generated data.

EMERGENCY PREPAREDNESS

- 7.18. Emergency arrangements commensurate with risks, and as applicable for various aspects of the remediation, should be established, maintained and described in the site-specific remedial action plan and in accordance with the requirements and guidance given in Refs [9, 14, 23, 24]. These arrangements should also cover aspects related to communication with the public and other interested parties.
- 7.19. In case of remediation after a nuclear or radiological emergency, reassessment of hazards and risks, and their potential consequences, and putting in place appropriate emergency arrangements is to be done during the transition from emergency to existing exposure situation consistently with Ref. [14].
- 7.20. Personnel should be trained in emergency procedures. Provision should be made for the testing and updating of these procedures by conducting periodic exercises.

DEALING WITH ABNORMAL EVENTS

- 7.21. Responsible parties should also ensure that procedures for dealing with abnormal events that may occur during remediation are established and put into place. In case of such events happening during remediation, the responsible parties should without delay notify the regulatory body, the public and affected interested parties, as appropriate.

SECURITY IN THE AREA

- 7.22. Appropriate security measures, commensurate with the identified risks, should be established and maintained to restrict access to the area throughout the remediation and post-remediation process, as applicable [3, 4, 6, 25, 26].

RELEASE OF AREAS

- 7.23. Once implementation of a selected remedial action has been completed, the responsible party “shall perform a radiological survey after completion of remedial actions to demonstrate that

the end point conditions, as established in the remedial action plan, have been met”, as stated in paragraph 5.14(d) of GSR Part 3 [1]. The results of this survey should then be used to assess and evaluate compliance with the end point conditions established in the site-specific remedial action plan to decide whether the established objectives of the remediation have been achieved or if additional actions are still needed.

- 7.24. The final decision on how to proceed will be dependent on an assessment of residual doses against the pre-set reference levels. There are several possible outcomes of the remediation process:
- (a) Use of and access to the area may be unrestricted;
 - (b) Use of some or all of the area may need to be restricted and control may need to be established, for example, through a system of planning consents;
 - (c) Access to the area may need to be restricted and measures may need to be put into place to enforce this.

UNRESTRICTED USE

- 7.25. If the chosen remedial action involved the removal of the contamination and its source, and the conditions for the unrestricted use have been met, as established in the remedial action plan, then the area can be released without restrictions.

RESTRICTED USE

- 7.26. In cases where a remediation cannot be justified and optimized, or the reference level cannot be achieved, specific restrictions on the future uses of the contaminated areas may need to be put into place. Specific restrictions should be established to control the removal of residual materials from the area or the use of such materials for other purposes, such as use as backfill material on the remediation site or elsewhere.
- 7.27. A decision to impose restrictions should be made by the responsible authority and should be based on a residual dose assessment, as well as an evaluation of the justification of the restrictions being considered.
- 7.28. The term ‘restricted use’ refers to “the use of an area or of materials subject to restrictions imposed for reasons of radiation protection and safety” [11]. Some types of use may be allowed, while others are not; for example, in certain cases, the use of an area for forestry may be possible but its use for agriculture may be prohibited. Similarly, the use of an area for recreational, industrial or certain agricultural purposes may be appropriate, but its residential use may not be. Where a significant part of the exposure due to residual contamination arises via the food chain, the use of agricultural countermeasures, restrictions on fish consumption,

drinking water advisories, or other similar measures should be considered in the context of the sources and pathways potentially leading to exposure of receptors to contamination. Impacts of the residual contamination on aquifers should also be considered in this evaluation. Countermeasures for the use of such water for the production of food or feed should be evaluated.

- 7.29. The records collected should be stored for a period of time as deemed appropriate by the regulatory body. This would ensure that the decisions and actions taken, as well as the results achieved could be reviewed, as needed, in the future. This is particularly important in the post-remediation phase.
- 7.30. If remediation objectives have been met after modification of the pathway between a source and the receptor (e.g. installation of an impermeable barrier), the area should only be released with appropriate restrictions. These restrictions would be in the form of institutional controls on the use of the area, for example, to ensure that restrictions on future use are followed.
- 7.31. In cases of restricted use, further surveillance and monitoring may be required to confirm the long term effectiveness of the remediation, and controls may need to be imposed or relaxed on the basis of the monitoring results (see Section 9 on Post-Remediation Management).
- 7.32. If, after the authorized remedial actions have been carried out, the chosen end points have not been met, or doses have not been optimized, the responsible party should determine the next course of action. Such options may include evaluation of whether further remediation is justified or whether the area should be released with restrictions. Once the next course of action has been decided, the responsible party should submit a proposal to the regulatory body for authorization to proceed. If conditions have changed or additional information has been collected to demonstrate that further remediation is justified, the process (illustrated in FIG. 1) should again be followed, starting at the stage at which the options are to be identified (see paragraph 6.2).

RESTRICTED ACCESS

- 7.33. In line with paragraph 5.15(c), item (i), of GSR Part 3 [1], specific restrictions to control access by unauthorized persons to remediated areas may need to be continued after remedial actions have been completed. This would be the case in situations where a significant dose could be incurred over a relatively short period. The degree of any such restrictions should be determined by the regulatory body, depending on the types and levels of residual contamination. Access control measures may vary from the placement of warning signs to establishment of fencing or barriers of various types with controlled access points. Area control personnel should have the legal authority to deny access to the area, if required. The regulatory body or other authorized party should periodically review the conditions in such

restricted areas to verify compliance with requirements, and make amendments or changes to the authorization, as necessary, for implementation by the responsible party.

FINAL REMEDIATION REPORT

- 7.34. According to Para 5.14(e) of GSR Part 3 [1], the responsible party shall submit a final remediation report, including a final radiological survey, to the regulatory body or other relevant authority, to demonstrate that the endpoint conditions for the remediation have been met.
- 7.35. The regulatory body should review the integrity of the final remediation report and use the information that has been provided to verify the responsible party's determination of the nature, extent and duration of any post-remediation control measures and their effectiveness.

RECORD KEEPING AND INFORMATION

- 7.36. A system for collecting and maintaining records of the actions taken should be developed and documented in the site-specific remedial action plan, and implemented in accordance with the approved plan.
- 7.37. Records are required to be kept to document the remediation and any lessons learned and changes made during its implementation (see paragraphs 5.10(d) and 5.12(g) of GSR Part 3 [1]). The regulatory body or other authorized body should specify the content and retention period of records. Such records should include, but not be limited to:
- (a) The basis for justification and optimization of decisions and selection of remedial option(s);
 - (b) Descriptions of activities performed;
 - (c) Identification of areas that were remediated and those with residual levels of contamination remaining, including the nature and extent of contamination;
 - (d) Specifications of any areas that remain restricted and the restrictions that apply;
 - (e) Statements of any zoning and other restrictions or conditions;
 - (f) Data from the monitoring and surveillance programmes;
 - (g) Documentation of the types and quantities of residual materials (including waste) produced and of their management and disposition;
 - (h) Documentation on the waste (e.g. quantities and characteristics), where it was produced, how it has been treated or handled, where it is being stored or disposed of, and the date of the waste production, including clearance authorizations granted (generic or conditional);

- (i) Occupational health and safety records for the remediation workers and other exposed individuals;
 - (j) Information on verification of the results of remedial actions, including the results of all monitoring;
 - (k) Costs and financial guarantees;
 - (l) Involvement of interested parties;
 - (m) Documentation of the decision making process, including who was involved and the outcomes of any conflict resolution processes;
 - (n) Any continuing responsibilities for the site;
 - (o) Statements of lessons learned.
- 7.38. A record of each task carried out during remediation should be maintained. Accurate and complete information concerning the locations, configurations, types and amounts of radionuclides remaining in the area after remediation is essential and should be acquired and maintained. These records may be used to demonstrate that the remediation objectives have been met, and as a baseline for the situation post remediation, against which to compare future surveillance records and monitoring data. The records should be made available to interested parties, as appropriate.
- 7.39. The regulatory framework should provide for appropriate record keeping and maintenance of records to capture relevant information regarding the exposure situation, the remediation process and its result. This is particularly important where restrictions are imposed on access to areas and on the activities that may be conducted in such areas. A complete set of records should be maintained, such that interested parties can access information to aid any subsequent actions necessary for the removal of any restrictions imposed or to undertake additional activities in the area in a safe manner. Within the regulatory framework, all relevant interested parties should be consulted and kept informed of the area specific strategy and activities.

8. MANAGEMENT OF RESIDUAL MATERIALS GENERATED DURING REMEDICATION

GENERAL APPROACH

- 8.1. The remediation of a contaminated area may generate large amounts of diverse residual materials, some or all of which may be contaminated with radionuclides. Such residual materials may be generated during the different phases of the remediation process, and could include:

- (a) residual radioactive material following a nuclear or radiological accident;
- (b) residual industrial process materials, such as sediments, scale, water treatment resins, mineral tailings, mineralized rock, or others;
- (c) soil and vegetation (which may or may not be significantly contaminated);
- (d) contaminated liquids, such as water used for decontamination, contaminated surface water, or contaminated groundwater;
- (e) surface contaminated objects, such as piping, tanks, heavy equipment, structural steel, buildings, tools, swabs, or others;
- (f) contaminated clothing and personal protective equipment;
- (g) liquid and solid residues from hygiene and changing facilities; and
- (h) liquid and solid residues from sample analyses. Such materials may also be generated during the initial phases of a remedial action plan, during the site evaluation and planning options, or before performing remedial actions.

- 8.2. To the extent possible, waste generation should be prevented [27]. Materials generated during remediation should be managed in accordance with the waste management hierarchy and also in a manner consistent with GSR Part 5 [3]. This involves prevention or restriction of the generation of waste *“in the design of facility and planning of activities that have the potential to generate radioactive waste”* [3], as the first step, followed by minimization, reuse and recycling. Where no such options are feasible, the waste shall be disposed of [4].
- 8.3. Planning for remediation should take an integrated approach to the management of residual materials, including radioactive waste, throughout all phases of remediation through to disposal. This should include consideration of a range options for materials management, including, storage and disposal options of waste on the remediation site.
- 8.4. In case of a nuclear or radiological emergency, residual materials containing or contaminated with radionuclides may be generated by the emergency itself and/or the emergency response actions implemented. Guidance on emergency arrangements to be put in place for safe and effective waste management as part of the overall emergency preparedness and to be implemented as early as possible after the emergency, particularly during the transition from emergency to existing exposure situation, is given in [14].
- 8.5. The management of such residual materials should ensure the short and long term protection of human health and the environment. Risks to human health and impacts to the environment may arise not only from radioactive constituents but also from non-radioactive constituents, as well as physical hazards, all of which need to be taken into account in an integrated

management approach to ensure protection and safety. In many cases, physical and non-radiological hazards may be dominant, for instance, in the case of asbestos waste with light tritium contamination, or phosphogypsum residue from the production of phosphoric acid. Proper safety measures and personnel protective equipment must be put into place to minimize risk.

- 8.6. Safety and security of residual materials (including waste) should be ensured during all stages of their management, using a graded approach, which takes into account the level of associated radiological and other risks [3, 4]. In doing so, the volumes and characteristics of the residual materials, and the feasibility of different management options should be considered. Some of these materials could be reused on-site as part of the remediation activities, while others would need to be disposed of on-site, or safely stored until disposal. In some cases, it may not be possible for the material to be maintained or used onsite. In such cases, it would be necessary to characterize, screen, and transport the material elsewhere for recycling, reuse, or for temporary storage or long term disposal at a facility authorized to store or dispose of the material.
- 8.7. It is important to recognize that not all residual material will be contaminated such that it meets the classification of radioactive waste. Therefore, before the material is declared as waste, the basic waste management principle of waste minimization should be applied¹⁹. The principle of the management of residual materials containing or contaminated with radioactivity that are generated during remediation is provided in para. 3.29 of the IAEA Fundamental Safety Principles [12], which states: "...The generation of radioactive waste must be kept to the minimum practicable level by means of appropriate design measures and procedures, such as recycling and reuse of material". In line with this principle, the following step by step approach should be adopted:
- (1) The need to minimize the amount of potentially hazardous residual materials generated during remediation should be recognized as an important factor to be considered when optimizing the design of the remediation process;
 - (2) Any material meeting the criteria for clearance from regulatory control should be identified and the regulatory body should be requested to authorize the clearance of such material;

¹⁹ "Radioactive waste must be managed in such a way as to avoid imposing an undue burden on future generations; that is, the generations that produce the waste have to seek and apply safe, practicable and environmentally acceptable solutions for its long term management. The generation of radioactive waste must be kept to the minimum practicable level by means of appropriate design measures and procedures, such as the recycling and reuse of material." (para. 3.29 of Ref. [12]).

- (3) Any radioactive material that does not meet the criteria for clearance should be investigated for possible recycling or reuse, ideally in the affected area;
 - (4) Any radioactive material that does not meet the criteria for clearance or for which recycling or reuse is not feasible should be classified as waste and managed accordingly. Management strategies should be consistent with the national waste management policy and strategy and should consider both storage and disposal needs, as well as the possible existence of different types of radioactive waste that require different management solutions.
- 8.8. Residual materials should be sampled and characterized in terms of their physical, mechanical, chemical, radiological and biological properties. Based on this characterization, residual materials should be segregated for future management, such as treatment or disposal. The volumes and characteristics of the different types of residual materials that have been generated should be recorded to facilitate their further management. Characterization should provide assurance that the residual material meets the acceptance criteria for its future management.
- 8.9. For materials that are to be managed as radioactive waste, characterization provides assurance that the material meets the corresponding acceptance criteria and should assist in defining the proper waste management activities.
- 8.10. Segregation of residual materials on the basis of characterization data is particularly important for maximizing the amount of material that can be cleared from regulatory control, recycled, or reused. This then minimizes the volume of material to be managed as radioactive waste, and identifies the type and most appropriate future management option(s) (see Figure 1 and Figure 2 of Ref. [28]). For instance, the segregation of small volumes of contaminated soil from much larger volumes of uncontaminated soil with similar physical characteristics would allow significant volumes of soil to be cleared from regulatory control. The issue of segregation, as others, is finally to be decided as part of the multi-attribute decision-making process of the remediation, with input from interested parties.

CLEARANCE OF RESIDUAL MATERIALS

- 8.11. Clearance is defined as “removal of radioactive material or radioactive objects within authorized practices from any further regulatory control by the regulatory body” [11]. Schedule I of GSR Part 3 [1] defines the general criteria for clearance which allows material that meets the clearance criteria to be released from regulatory control. The general criteria are expressed as numerical values of individual dose and define numerical values of radionuclide specific activity concentrations for clearance without further consideration.

- 8.12. Paragraph I.13 of GSR Part 3 [1] allows for specific clearance to be granted by the regulatory body for specific situations. Such values are derived on the basis of the general criteria for bulk amounts of solid material (Table I.2 of GSR Part 3 [1]), taking into account the physical and chemical form of the material, and its envisaged future use or means of disposal. In such cases, clearance criteria may be specified by the regulatory body in terms of either activity concentration per unit mass or activity concentration per unit surface area. To ensure that as much material as possible can be released from regulatory control, it may be appropriate for the regulatory body to define clearance on a case by case basis using the existing general criteria.
- 8.13. The concept of specific clearance ('conditional clearance')²⁰ for material disposition implies some form of ongoing regulatory oversight of the means of disposition. Such oversight should involve ongoing requirements on stewardship of the area, future land use and institutional controls to mitigate against the risks of intrusion following closure and the normal period of active controls.
- 8.14. Where feasible, surface contaminated objects should be decontaminated, as appropriate, to enable them to be approved for clearance. This should preferably be carried out at or near the remediation site to minimize any spread of contamination. Contamination that has been removed should be managed as radioactive waste arising from the decontamination process.
- 8.15. Clearance of residual materials and equipment from a remediation site should be performed in accordance with clear, detailed and rigorous procedures under the control of the radiation protection staff on the site to ensure that the material has been properly checked for compliance with the relevant clearance criteria. This process should be subject to regulatory oversight.

RECYCLING AND REUSE OF RESIDUAL MATERIALS

- 8.16. To minimize the amounts of residual material generated during remediation that requires management as radioactive waste, all reasonable options, which ensure an adequate level of safety, should be investigated for the residues to be recycled or reused.
- 8.17. The recycling or reuse of residual materials generated during remediation should be subject to compliance with the relevant national policies, and regulatory requirements.
- 8.18. Mixing and or blending of residual materials with other materials of similar characteristics, (e.g. as part of construction materials for dams, roadbeds, or waste disposal cells on the footprint of the remediation site; during ploughing of soil), may occur during remediation.

²⁰ The term 'conditional clearance' is sometimes used instead of 'specific clearance'. The concept of clearance (including 'conditional clearance') will be further developed in DS500.

Such an approach could be considered when and where there is a need or convenience for enabling residual materials to be safely recycled or reused.

MANAGEMENT OF RADIOACTIVE WASTE

National policy and strategy

8.19. When a residual material is designated as radioactive waste, its management should follow the overall national framework for radioactive waste management. The national framework for radioactive waste management is usually documented in the form of a national policy, together with a national strategy. These strategies address different types of radioactive waste (for instance, radioactive waste from nuclear, industrial and health care facilities) and serve as a means for achieving the national goals and requirements set out in the national policy statement. Management options that can be implemented in accordance with the IAEA Safety Standards and that are based on established, proven technologies (methods, techniques, equipment and processes) should be identified and considered to ensure that such management is safe, technically optimal and cost effective. Further details on the establishment of a national policy and associated strategies for radioactive waste are given in Refs [3, 4, 29].

Waste classification

8.20. Radioactive waste should be classified to optimize the waste management process. Radioactive waste is most commonly classified according to the method of disposal. The classification scheme provided in the Safety Guide GSG-1 [28] should be considered when managing radioactive waste arising from remediation activities. The waste should be segregated according to its classification, in order to facilitate its temporary storage on-site, clearance when possible, through to storage or disposal.

Management Options

8.21. Radioactive waste should be safely stored (as needed, in the short term) and ultimately, disposed of (in the longer term) in authorized facilities for the waste category. Where possible, decisions on waste management options should be made proactively, in advance of waste or material generation. In cases where this is not possible, the decision should be made as soon as possible after waste generation.

8.22. For demonstration of safety, the selected management option should be subject to an appropriate authorization process as established in the national legal and regulatory system, as part of the remedial action plan. Interested parties should participate in these processes as necessary. The aspects of the different steps in managing these wastes, as well as the necessary technical, economic, environmental and social considerations should be duly taken into account in the selection of options.

Predisposal management

- 8.23. Predisposal management should be carried out in accordance with the requirements established in GSR Part 5 [3] and should follow the guidance provided in Refs [20, 30]. Predisposal management includes processing, storage and transport of waste [11].
- 8.24. Storage of radioactive waste is relevant throughout the phases of remediation, either between management steps or within them. Bulk quantities of radioactive waste are usually stored at the site of generation, in engineered surface containments, as appropriate. Costs, logistical aspects, and consideration for potential health, safety, and environment impacts often prohibit transport of such wastes.
- 8.25. Moderate to large quantities of radioactive waste with possibly high activity concentrations, or other radioactive material (such as yellowcake on past mining sites), may be stored under cover at the site where it was generated or at another suitable site, pending disposal at a more appropriate time. Areas where high activity concentration radioactive wastes are stored may require enhanced security to implement systems necessary to establish and track nuclear material inventories, control access to and detect loss or diversion of nuclear material, and ensure the integrity of those systems and measures [31]. It is essential that, when identifying management options for such waste, the only options considered are those for which a short or medium term management plan is in place from the outset. This includes the identification of a suitable disposal site and adequate financial arrangements.
- 8.26. If radioactive waste is to be stored for significant periods of time, consideration should be given to the possibility of degradation of waste or waste packaging during the period of storage. For example, prolonged storage of organic material from remediation of residential or agricultural areas could create the potential for spontaneous combustion and/or the generation of flammable gases. Although storage of radioactive waste may expedite the remediation process, the implications of having to move the waste to and from the storage facility should be evaluated early in the planning process.
- 8.27. Storage cannot be considered the ultimate solution for the management of radioactive waste, which requires a defined end point, such as disposal, to ensure safety and security. However, radioactive waste containing predominantly radionuclides with relatively short half-lives may be kept in storage until the radioactivity has decayed to a level at which the material may be disposed of as non-radioactive waste.
- 8.28. Safe transport of radioactive waste is ensured by complying with the IAEA Regulations for the Safe Transport of Radioactive Material [32].

Disposal

- 8.29. Disposal is the final step in the management of radioactive waste. The requirements for disposal are set out in IAEA Safety Standards Series No. SSR-5 [4]. The management of most types of radioactive waste involves concentration and/or containment of the waste. The waste is then placed in a disposal facility with an acceptable assurance of safety, without the intention of retrieval. When identifying the most appropriate type of disposal facility, account should be taken of the volume, physical form, chemical characteristics and radionuclide content of the radioactive waste. In the case of remediation, disposal options may not be immediately available. This is not a reason to postpone commencement of remediation.
- 8.30. It is good practice to minimize the footprint size and number of disposal sites. Consideration should, therefore, be given to the consolidation of waste, to the extent possible, into a centralized disposal facility rather than having multiple facilities at various locations. Consideration also should be given to practical issues, such as availability of a suitable site and to the overall national framework to the long term management of radioactive waste, as set out in the national policy statement. Accurate records of disposal site size and locations should be maintained.
- 8.31. As with all aspects of remediation, the involvement of interested parties in decisions on the management of remediation residues is essential in gaining wide acceptance of the final outcome of a remediation project. People in the locality of the remediated site may have concerns if some residual material is left on site. Measures should be taken to reassure the public that the site is more stable, and that health risks are lower than those before the remediation and have been reduced to acceptable levels. Similarly, measures should be implemented to reassure the public near the disposal site that the facility is secure and managed such that risks to their health, safety and the environment are low.

RELEASE OF AREAS FROM REGULATORY CONTROL

- 8.32. Radionuclide specific criteria can be used by the regulatory body to determine whether it is appropriate to release of areas from regulatory control; however, differences in circumstances between situations sometimes require additional consideration. These differences could relate to considerations, such as management options, waste characteristics, site characteristics, demographics, future land use and the risk of non-compliance with future restrictions. Recognition of these differences can be important in ensuring that as much material as possible may be released from regulatory control, and it may be more appropriate in some situations for the regulatory body to consider clearance on a case by case basis using the existing general criteria.

9. POST-REMEDATION MANAGEMENT

- 9.1. Planning for post-remediation management should be initiated at the commencement of planning of the remediation itself.
- 9.2. Once the remediation is complete, post-remediation management is initiated (FIG. 1). The post-remediation phase addresses how the remediated area should be managed once the remediation has been completed for an area. The complexity of this phase will depend on whether restrictions on use or access need to be imposed, and what those restrictions are. Even where there are no restrictions in place, some level of surveillance, monitoring, and engagement of interested parties may be necessary. It is important that this phase is not neglected; otherwise, the full benefits of remediation may not be realized.
- 9.3. Post remediation management includes the justification and implementation of any institutional controls, and the periodic re-evaluation of the effectiveness and robustness of the remedial actions taken. If a determination is made during re-evaluation, in consultation with the relevant parties that the action is less effective than anticipated, additional actions may be necessary.
- 9.4. Institutional controls should be implemented, where appropriate, to verify effectiveness of remediation over time. For example, it is necessary for a qualified person to routinely inspect and sign off on the integrity of engineered structures. Future monitoring and surveillance should be appropriate to future land use.
- 9.5. If the government has approved habitation and the reestablishment of social and economic activities in areas with long lasting residual radioactive material (see also [14]), the regulatory framework for post remediation management should include the processes and procedures necessary for the continuing control of exposure with the aim of establishing conditions for sustainable living in the long term.

REMOVAL OF RESTRICTIONS

- 9.6. If the institutional control, and in particular, the monitoring and surveillance programme, has verified the long term effectiveness of the remedial measures and the long term reduction of radiation levels through natural processes in eliminating unacceptable risks to human health and unacceptable impacts to the environment, consideration should be given to removing some or all of the restrictions that have been applied to the area. This could allow reduction or cessation of the extent of monitoring and/or surveillance, recognizing that some activities (such as the periodic inspection of engineered structures by a qualified person) will need to be carried out into perpetuity. If the option of ending or reducing these activities is considered,

the value of the monitoring and surveillance in promoting and maintaining public confidence should be taken into account.

RECORDS

- 9.7. According to Para. 5.10(d) of GSR Part 3 [1], the government is responsible for ensuring a person or organization is identified and held responsible for establishing and maintaining a system for retrieving and amending the records covering the full scope of the remedial action.

INTERESTED PARTIES AFTERCARE AND PUBLIC COMMUNICATION

- 9.8. Communication with and engagement of interested parties should have commenced during initial site investigations and continued through the entire remediation process. It is important that this engagement is continued in the post remediation phase.
- 9.9. Where there are restrictions placed on use of or access to the land, communication with and engagement of interested parties will need to be ongoing. There should be a commitment documented in the site-specific remedial action plan to review the need for restrictions and monitoring at some future time, and to review the amendments or changes made to the plan to reflect current conditions.
- 9.10. In some circumstances, local interested parties may adopt self-help measures as a way of reducing radiation doses (for example, washing of crops from their gardens, or not growing certain crops). The need for, and efficacy of, these measures will need clear and careful explanation. Training and further education will need to be provided to the local interested parties about self-help measures. Too much reliance on self-help measures is inappropriate, given that the acceptance and implementation of these measures cannot be guaranteed, regardless of the level of interaction with interested parties. Further information on self-help measures is given in Annex IV.

MONITORING AND SURVEILLANCE PROGRAMME

- 9.11. In line with Para. 5.16 of GSR Part 3 [1], a monitoring and surveillance programme is required to be prepared for any remediated areas where restrictions are maintained after remediation has been completed, and, even if no restrictions have been maintained, to verify long term effectiveness of remediation. The programme should be subject to periodic review and to approval by the regulatory body [22].
- 9.12. The extent of such monitoring and surveillance plans should be based on the residual risks, their respective degrees of uncertainty, and on the need to verify the long term stability of the radiological and other conditions [22]. Monitoring and surveillance programmes should be tailored to specific situation and can include environmental monitoring (e.g. activity

concentrations in soil, water and air, biological indicator species and foodstuffs, concentrations of non-radiological contaminants), whole body monitoring (if applicable), dose rates and assessment, and risk or impact assessment.

- 9.13. Decisions regarding the routine maintenance of monitoring and surveillance programmes should be documented in the site-specific remedial action plan, and results from such programmes should be documented and made readily available to interested parties to assist in developing and maintaining public confidence (see paragraph 5.12(e) of GSR Part 3 [1]).

DRAFT

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Annex I

EXAMPLE OF A TABLE OF CONTENTS FOR A SITE-SPECIFIC REMEDIAL ACTION PLAN

I-1. “A remedial action plan, supported by a safety assessment, is prepared and is submitted to the regulatory body or other relevant authority for approval. The remedial action plan is aimed at the timely and progressive reduction of the radiation risks and eventually, if possible, at the removal of restrictions on the use of or access to the area” [1]. An example Table of Contents for a remedial action plan is provided below. Headings can be deleted or additional headings inserted to suit the type and condition of the site for which the remediation is being planned.

Summary

1. Introduction
 - 1.1. Scope of remediation
 - 1.2. Remediation objectives
 - 1.3. Organization and management
 - 1.3.1. Staffing resources
 - 1.3.2. Roles and responsibilities
 - 1.3.3. Time schedule
 - 1.3.4. Coordination expectations with other organizations
2. Regulatory control
3. Site history
 - 3.1. Past operations
 - 3.2. Ownership records
 - 3.3. Production records
4. Site characteristics
 - 4.1. Location and key features, including man made features such as existing above ground and below ground utilities
 - 4.2. Local and regional demographics, current and future land uses , current and future land users
 - 4.3. Geology, seismicity and hydrogeology of site
 - 4.4. Surface water, wetlands, streams, rivers, lakes, ponds, etc.
 - 4.5. Groundwater

- 4.6. Type of climate, weather patterns, seasonal characteristics, rainfall
- 4.7. Maps and plans (may need multiple maps and plans at various scales and aerial photos)
5. Area investigation activities
 - 5.1. Detailed description of the area(s) investigated
 - 5.2. Previous analytical data
 - 5.3. Initial evaluation of data and identification of hazards
 - 5.4. Assessment of radiological exposures relative to the historic and newly collected data
 - 5.5. Evaluation of uncertainties
 - 5.6. Identification of data gaps and investigative strategy to fill gaps, as necessary
6. Site and area contamination survey
 - 6.1. Simple site and area survey and sampling methods
 - 6.2. Survey strategy
 - 6.3. Sample analysis
 - 6.4. Radionuclides of interest
 - 6.5. Non-radiological contaminants of interest
 - 6.6. Presentation of data
7. Dose assessment
 - 7.1. Doses received by members of the public
 - 7.2. Doses received by remediation workers
 - 7.3. Radiation protection programme
 - 7.3.1. Protection of the public during remediation activities
 - 7.3.2. Health and safety of workers
 - 7.4. Prioritization of areas for remediation and public risks
8. Risk assessment
 - 8.1. Table of site components with issues and risks itemized
 - 8.2. Evaluation of risks and consequences
 - 8.3. Risk rankings
 - 8.4. Risk management strategies

8.5. Residual risk after implementation of management strategies

9. Assessment of environmental impacts

10. Development of remedial action options

10.1. General approach to investigating and evaluating options

10.2. Overall objectives of the options analysis

10.3. Preliminary identification of general response actions and available remediation technologies

10.4. Development and screening of options

10.5. Detailed analysis of options

10.5.1. Threshold criteria

10.5.2. Balancing criteria

10.5.3. Modifying criteria

10.6. Identification of potential remedial actions (including interim actions)

10.7. Development of specific site work plans, including possible arrangements for incidents and accidents during remediation

11. Post-remediation planning

11.1. Long term care and maintenance

11.2. Monitoring and surveillance

11.3. Monitoring schedule

11.4. Monitoring of performance criteria

11.5. Responsibilities for assessing monitoring data

11.6. Costs of remediation and post-remediation activities

12. Residue management plan

12.1. Opportunities for minimization of residues

12.2. Identification and characterization of residues

12.3. Residues to be cleared from regulatory control

13. Residues to be recycled or used as by-products

14. Residues to be managed as radioactive waste

14.1. Predisposal (pretreatment, treatment, conditioning)

- 14.2. Storage
- 14.3. Transport
- 14.4. Disposal

15. Communication with interested parties

- 15.1. List of parties identified
- 15.2. Engagement, consultation and communication plan.
- 15.3. Issues and concerns raised
- 15.4. Record of consultations

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Annex II

DOSE ASSESSMENT FOR REMEDIATION PURPOSES (PARTIALLY ADOPTED FROM THE SAFETY GUIDE RS-G-1.8 [II-1])

OBJECTIVES

II-1. The purpose of the dose assessment for the public living under existing exposure situations is to decide on the necessity of remediation in areas that are affected by elevated levels of radionuclides. The assessment of doses also provides information on the importance of the exposure pathways, which provides input for justification and optimization of remedial actions. To avoid inappropriate allocation of resources, the estimated doses a 'representative person' receives or could potentially receive should, therefore, be estimated as realistic as possible.

II-2. To determine annual radiation doses due to the elevated levels of radionuclides, all the components of both the external exposure and the internal exposure caused by environmental radiation should be taken into account. Special methods of measurement and data processing should be applied to identify the dose components contributed by particular environmental radiation sources.

II-3. Radiation doses received by the 'representative person' cannot be directly measured. Therefore, mathematical models are needed to convert monitoring results into dose estimates. The models should simulate the major pathways contributing significantly to the exposure of the population groups under consideration.

II-4. Different models for radiological assessment with varying degrees of complexity exist. The level of detail and the complexity of the modelling needed should reflect the magnitude of the predicted doses.

II-5. To the extent possible, available data from measurements of activity levels in environmental media such as: air, soil, vegetation, crops, foodstuffs, water and sediments and data from individual measurements, such as data from whole body counting for internal dosimetry and individual doses for external dosimetry, should be used to validate these models.

HUMAN EXPOSURE PATHWAYS

II-6. An exposure pathway defines routes from a source of radionuclides and/or radiation to a target individual or a population through media in the environment. The main human exposure pathways considered in this Safety Guide are:

- (a) External exposure from radionuclides deposited on the ground or building surfaces (walls, roofs and floors) or vegetation (trees, bushes, grass);
- (b) Ingestion of radionuclides with food or beverages;

(c) Inhalation of resuspended radionuclides deposited on the ground or building surfaces.

II-7. The importance of the various exposure pathways depends on:

- (a) The radiological properties of the material released (e.g. alpha-, beta- or gamma emitters, physical half-life);
- (b) The physical and chemical properties of the radioactive material and its migration characteristics;
- (c) The site-specific mechanism for dispersion and migration and influencing factors, e.g. meteorological conditions, environmental characteristics such as climate, type of vegetation;
- (d) Places of residence (indoors, outdoors) and the lifestyle of the exposed population groups.

II-8. In existing exposure situations, exposure pathways are usually relatively well defined and not likely to change rapidly. The external exposure and the ingestion of agricultural and/or natural foodstuffs containing radionuclides may contribute substantially to doses. Due to the continuous migration of long-lived radionuclides into deeper soil layers, the levels of ambient dose rates decline: additionally, the importance of resuspension and, therefore, of the inhalation pathway decreases with time.

EXPOSURE GROUPS

II-9. For the estimation of exposures to the public arising from residual radioactivity, GSR Part 3 [II-2] suggests the application of the concept of the 'representative person'. The representative person is an individual receiving a dose that is representative of the doses to the more highly exposed individuals in the population under consideration. Reference levels of dose established by the regulatory body for the existing exposure situation of the public generally apply to the dose of the representative person. The ICRP has provided guidance to assist in the determination of the representative person [II-3].

II-10. The representative person for a particular set of circumstances should be selected carefully. Adequate attention should be paid to population groups with special living habits, as appropriate. Their living patterns and habits of consumption of food and water could give rise to pathways and elevated exposure levels that are unanticipated by conventional analysis.

II-11. There may be different groups of the most exposed people for different exposure pathways and some individuals may be members of more than one such group. In this situation, the representative person should be defined on the basis of the calculated sum of doses via all exposure pathways, which should be compared with the reference levels.

II-12. The doses for representative persons in situations of existing exposure should be defined according to realistic habits so as to provide realistic dose assessments that can be used as a basis for making decisions on remedial actions and to enable an unbiased optimization process for ensuring adequate allocation of human and financial resources.

EXTERNAL EXPOSURE

II-13. The external dose to the representative person in conditions of existing exposure should be determined on the basis of ambient dose rate data determined during environmental monitoring campaigns by means of a simple calculation model. Such calculations should include human behavior, shielding from buildings, the reduction of ambient dose rates through radioactive decay, migration into deeper soil layers and the loss of activity from surfaces through weathering, human activities, the relationship between the measured gamma dose in air and the effective dose, and the seasonal variation of relevant parameters.

II-14. The most exposed group of the population for external exposure in conditions of existing exposure usually comprises those persons working mainly outdoors (such as foresters, herdsman and field workers) and those persons living in one- or two-storey houses constructed of light materials (such as wood). Estimations of typical occupation time periods spent by such a group in living, working and rest areas, both indoors and outdoors, at various typical locations in the different seasons are best made by means of conducting personal interviews.

II-15. The set of measurements of dose rates performed at various locations where a representative person would usually live, both outdoors and indoors, can be used directly to assess the existing external doses. To define the contribution of a particular radiation source to the external dose, methods of in-situ gamma spectroscopy should be applied with subsequent assessment of the dose due to the elevated activity levels; the natural background has to be subtracted as appropriate.

II-16. As an alternative source of data from environmental monitoring, the levels of soil deposition of particular radionuclides in the area assessed can be used for estimation of the external dose due to radionuclides. With the use of radionuclide specific conversion coefficients, this data can be converted into ambient dose rate values above undisturbed ground (e.g. lawns), ploughed soil or solid surfaces (e.g. asphalt or concrete).

II-17. Model parameters accounting for the attenuation of dose rates in typical rural and urban locations relative to a reference surface (an infinite plain area, usually a lawn), should be determined prior to dose assessment by making a series of field measurements or by modelling radiation conditions in settlements, dwellings and other locations.

II-18. The uncertainties associated with the estimation of external doses can be substantially reduced if some crucial parameters are determined by measurements, such as the shielding of the buildings in a

specific area and the time people spent outdoors. Confidence in assessments will be improved, if the result of dose assessments can be validated through comparison with the data obtained from individual dose monitoring performed in particular time periods.

INTERNAL EXPOSURE

Ingestion

II-19. The internal doses to a representative person in existing exposure situations due to the ingestion of contaminated food and/or drinking water, should be determined on the basis of environmental monitoring data by the use of a simple calculation model which takes account of the origin and consumption rate of particular food products as well as seasonal variations in relevant parameters.

II-20. Persons consuming substantial amounts of locally produced food comprise the most exposed group of a population with regard to radiation exposure via the ingestion pathway. The monitoring data that are regularly obtained on radionuclide concentrations in locally produced agricultural foodstuffs can be used directly to assess the annual intake and the associated committed dose. In regions where the inhabitants normally consume substantial amounts of wild food products (e.g. game, freshwater fish, forest mushrooms and berries) with elevated radionuclide concentrations, available data from measurements should also be used for the estimation of intakes of radionuclides.

II-21. If data from measurements on food are unavailable or poor, the concentrations of radionuclides in foodstuffs can be roughly estimated from data on soil deposition or water concentrations by using known coefficients of radionuclide transfer from soil or water to plants and animals. When transfer coefficients are selected, attention should be paid to the use of appropriate natural and climatic conditions, including the soil type and the mineral content of fresh water.

II-22. The ingestion model should include the major groups of foodstuffs and drinking water as consumed by the representative person. The estimations of consumption rate of locally produced foodstuffs should be based on official production and trade statistics (for the general public) or should be obtained by means of personal interviews (for the representative person). The culinary losses of food mass and the associated reductions in intakes of radionuclides can additionally be used in estimating the ingestion of radionuclides.

II-23. The uncertainties in the modelling of internal doses can be substantially reduced when some crucial parameters are evaluated by measurement and some site-specific corrections are introduced. The most reliable method of validation of an ingestion model is by comparing its predictions with internal dose assessments made on the basis of data from individual measurements of radionuclide contents in the human body performed by whole body counting or by analysis of the concentrations of radionuclides in excreta.

Inhalation

II-24. The contribution of inhalation to the internal doses to the representative person is substantial for radioactive gases and vapours (e.g. radon or tritium oxide) and for radionuclides with low solubility and low mobility in food chains (e.g. actinides and transuranics), especially for persons working in the open air and in dusty conditions. The special case is that of long term residence in areas with elevated concentrations of natural uranium and radium resulting in the emanation of radon.

II-25. The inhalation dose to the critical population group in existing exposure situations should be determined on the basis of data from the monitoring of radionuclide concentrations in the near-surface air with the use of a model in which account is taken of the breathing rate of persons of various ages in conditions of performing various physical activities as well as for seasonal variations in the relevant parameters.

II-26. The set of regularly obtained data on radionuclide concentrations in air can be directly used to assess the annual intake and the associated committed dose. If monitoring data are unavailable or insufficient, radionuclide concentrations in air can be roughly estimated from soil deposition rates by using a resuspension model.

PROJECTED VERSUS RESIDUAL DOSE

II-27. The radiological contribution to the process of remediation optimization includes the selection of a reference level of dose between projected and residual doses determined as annual effective doses of the representative person.

II-28. The projected dose (${}^{\text{proj}}E$) is defined as the dose that would be expected to be received if planned remedial actions were not taken. It should be determined as the sum of external (${}^{\text{proj}}E_{\text{ext}}$) and internal (${}^{\text{proj}}E_{\text{int}}$) doses assessed without consideration of short-term countermeasures (action time less than 1 year) but with consideration of long-term remedial actions implemented at an early stage (e.g., decontamination of settlements, radical improvement of pastures, etc.). The projected dose assessment should be based on radiation measurements (radionuclide deposition, ambient dose rate, activity concentration in foods, etc.) and non-conservative modelling of each significant exposure pathway of the public.

II-29. The residual dose is the estimation of future doses after remedial actions have been terminated. The residual dose should be estimated using the projected dose to account for the expected effectiveness of possible remedial actions, as part of the process to select appropriate options.

II-30. The residual dose of external exposure of a representative person (${}^{\text{res}}E_{\text{ext}}$) is assessed by division of the projected external dose and by the reduction of the dose through the application of remedial actions. The residual dose of internal exposure of a representative person (${}^{\text{res}}E_{\text{int}}$) should be assessed as follows:

- (a) Assessment of the contributions of ingestion and inhalation to the total internal projected dose;
- (b) Identification of the major foods contributing to the ingestion dose;
- (c) Estimation of the internal dose through the food items taking into account the reduction of the dose through the application of remedial actions.

II-31. The internal residual dose can be estimated as the sum of residual doses from inhalation and ingestion of drinking water and food.

II-32. The total residual dose can be assessed as the sum of residual external and internal doses. Both the projected and residual doses should not include the dose from background radiation and medical irradiation.

Relationship between deposition per unit area and long-term annual effective dose

II-33. The most important radionuclide for the long-term exposure of the public in affected areas after the Chernobyl and Fukushima accidents is Cs-137.

II-34. The deposition of Cs-137 causes both internal and external exposure. The contributions of these two pathways depend on many factors such as:

- (a) The shielding characteristics of buildings;
- (b) The time people spent indoors and outdoors;
- (c) The level of Cs-137 in crops, which is controlled by the soil characteristics (organic matter, pH-value, clay content, exchangeable potassium in soil) in an affected area and the agricultural practice (e.g. use of potassium fertilizer);
- (d) The fraction of food consumed which was produced on areas which were affected by the deposition.

II-35. After the Chernobyl accident, Cs-137 caused both internal and external exposure. The relative importance of internal and external exposure depends on the local conditions. Typically, the contributions of ingestion to the total dose tend to increase under the following circumstances:

- (a) High fractions of acid soils, which are high in organic matter, low in clay contents and with low contents in potassium;
- (b) Little or no application of potassium fertilizer;
- (c) Proximity of settlements to forest areas, which allow collecting of mushrooms and berries, which are known to take up Cs-137 at higher rates;
- (d) Predominantly intake of locally produced foodstuffs.

II-36. After the Chernobyl accident, comprehensive investigations were going on to estimate doses to people through modelling and individual monitoring (whole-body counting, personal dosimeters). These studies cover a wide range of environmental conditions; the results give an overview of the spectrum of annual effective doses per unit deposition and allow an orientation on the order of magnitude of external and internal doses to be expected. Results of these studies are summarized for external and internal exposure in Table II-1 and Table II-2, respectively.

II-37. The variation of the dose per unit deposition for external exposure is generally lower than for internal exposure. The values based on individual dosimetry are lower, since model calculations usually apply purposely conservative assumptions.

II-38. The values for internal dose per unit deposition vary more widely, reflecting the influence of the environmental conditions.

II-39. In contrast to the situation following the Chernobyl accident, where both external and internal pathways contributed significantly to the total dose, in the aftermath of the Fukushima Daiichi accident the external dose was substantially more important [II-4]. Internal doses have been largely prevented by widespread restrictions on sale and distribution of contaminated food, supported by a comprehensive monitoring of food items. Agricultural products were intensively inspected, and food items containing contamination above permissible levels were automatically removed from the food market.

TABLE II-1. ORIENTATION VALUES FOR ANNUAL EFFECTIVE EXTERNAL DOSES PER UNIT Cs-137 DEPOSITION IN RURAL SETTLEMENTS OF RUSSIA, BELARUS AND THE RUSSIAN FEDERATION

Country	Year	Radio-nuclide	Annual effective external dose per unit deposition ($\mu\text{Sv a}^{-1}$ per kBq m^{-2})	Remark	Reference
Belarus	1995	Cs-137	3.5 (3.3-3.9)	Rural, official estimation, results of 24 settlements	[II-5]
Ukraine	1996	Cs-137	2.1 (2.0-2.2)	Rural, Official estimation results of 24 settlements	[II-5]
Russian Federation	1996	Cs-137	1.4 (0.7-2.7)	Rural, official estimation results from 26 settlements	[II-5]
	1996	Cs-137	0.8 (0.3-1.7)	Rural, individual dosimetry, 5 settlements	[II-6]
Joint model for Belarus/ Russia Federation / Ukraine	1990	Cs-137	1.4	Indoor worker, rural, brick house	[II-7]
	1995	Cs-137	1.1	Indoor worker, rural, brick house	[II-7]
	2000	Cs-137	0.9	Indoor worker, rural, brick house	[II-7]
Model calculation, based on Chernobyl experience, fresh deposit	1st year after deposition	Cs-134	5.1	Rural, indoor worker (27% outdoors)	[II-7]
		Cs-134	3	Urban, indoor worker (18% outdoors)	[II-7]
		Cs-137	2.3	Rural, indoor worker (27% outdoors)	[II-7]
		Cs-137	1.3	Urban, indoor worker (18% outdoors)	[II-7]

TABLE II-1. ORIENTATION VALUES FOR ANNUAL EFFECTIVE INGESTION DOSES PER UNIT CS-137 DEPOSITION IN RURAL SETTLEMENTS OF RUSSIA, BELARUS AND THE RUSSIAN FEDERATION

Country/ location	Year	Annual effective internal dose per unit deposition ($\mu\text{Sv a}^{-1}$ per kBq m^{-2})	Remark	Reference
Belarus	1995	0.8 (0.2-2.59)	Rural, official estimation, results of 24 settlements, predominantly consumption of local foodstuffs	[II-5]
Ukraine (without Rovno region) ^a	1996	2.3 (0.7-7.1)	Rural, official estimation, results of 24 settlements predominantly consumption of local foodstuffs	
Ukraine (Rovno region) ^a		9.8 (0.7-49)	Rural, official estimation, results of 24 settlements predominantly consumption of local food stuffs	
Russian Federation	1996	1.2 (0.1-4.3)	Rural, official estimation, results of 24 settlements predominantly consumption of local foodstuffs	

^a The Rovno region is characterized by factors that all cause high intake of Cs-137 through ingestion as high fraction of acid organic soils and little potassium supply, proximity to forests, therefore, this region is considered separately.

FLORA AND FAUNA

II-40. In the context of existing exposure situations, consideration should be given to the likely consequences of radiation exposure to biota (flora and fauna). The aim is that the overall outcome does more good than harm – for example, destroying a habitat to reduce radiation exposure usually does not provide a justified outcome. These decisions should be made in the more inclusive and holistic context of benefits and impacts, as the and that radiation exposure is often not the dominant impact to biota from proposed actions [II-8].

II-41. The concepts of Reference Animals and Plants (RAPs) [II-9] and derived consideration reference levels (DCRLs) describing biological effects for each RAP should be used under circumstances where this is, or may be, an environmental exposure above the natural background of significance to biota populations.

II-42. The impact on the environment should be considered as one of the elements in the process of optimization of protection and safety. It will be of particular importance to give consideration to the physical impacts on the environment from remedial actions proposed to be taken to reduce the exposure of members of the public relative to the benefits gained from the remediation. All such impacts should be considered in the justification and optimization of remediation [II-10].

REFERENCES TO ANNEX II

- [II-1] INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental and Source Monitoring for Purposes of Radiation Protection, IAEA Safety Standards Series No. RS-G-1.8, IAEA, Vienna (2005).
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- [II-10] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection of the Public and Protection of the Environment, IAEA Safety Standards Series, IAEA, Vienna (in preparation, DS432).

Annex III

OPTIMIZATION OF SITE REMEDIATION: PRACTICAL ASPECTS AND EXAMPLE

OPTIMISATION OF PROTECTION AND SAFETY

- III-1. Remedial actions should protect people and the environment (including flora and fauna) from harmful effects of ionizing radiation with the objective being optimal dose reduction ALARA. When assessing possible remedial actions, a wide range of options should be considered. The implementation of remediation strategies should be a dynamic process which changes with the evolution of the radiological situation. For example, the remedial action plan may include measures to reduce possible hazards or risks associated with the remediation or the situation, in general. This may include the development of interim remedial actions for containment of contamination, for example, to establish erosion barriers and long-term engineered drainage systems and surface barriers.
- III-2. Reductions in the doses to individuals and reduced environmental impacts should be achieved by means of remedial actions to remove the existing sources of contamination, to modify the pathways of exposure or to reduce the numbers of individuals or other receptors exposed to radiation from the source.
- III-3. Wide selection of remedial methods developed and tested in field conditions aimed at urban decontamination and environmental remediation, including long-term agricultural, forest and aquatic countermeasures, are presented in IAEA publications [III-1 – III-4] and some other relevant publications [III-5 – III-7].
- III-4. Remedial actions can have a variety of positive and negative environmental and societal side effects. While the outcome of remediation may restore land to productive use, the period during remediation may cause people to be displaced. These societal issues, along with other non-radiological aspects should be carefully considered throughout the process.
- III-5. The optimization of site remediation is the selection of remedial actions (methods, their combination, sequence and magnitude of their application) based on ALARA principle. Optimisation of remediation for a particular affected site, area or event should be carried out as part of remediation planning after remediation has been deemed justified.
- III-6. The radiological criterion for optimisation of remediation of a particular affected site, area or event is the reference level of residual annual dose of the public selected in the range of 1 to 20 mSv. It is not appropriate to plan for remediation that will not provide for residual doses below the selected reference level.

III-7. In addition to considerations regarding the radiation exposure of people and workers living or working in the contaminated territories with respect to optimisation of remediation, wide spectrum of non-radiological issues like social (public perception, interested party involvement, etc.) and economic (trade of materials, food, commodities, etc.) treatment of residual materials and waste as well as environmental protection and management should be taken into account.

III-8. The optimal remedial actions or their combination, the sequence and magnitude of their application should be selected by means of minimisation of adverse radiological, social and economic consequences of both radiation exposure and planned remediation. To this effect, appropriate methods of quantitative and qualitative decision-support analysis should be used, e.g. cost-benefit analysis or multi-attribute utility analysis [III-8].

III-9. Priority measures should be taken to reduce doses to people that are above the reference levels to levels below the reference levels. Then, the optimized remediation strategies are intended to keep doses below the reference level. Optimization process is to be applied, even if the doses initially received are below the reference level.

III-10. Involvement of interested parties and public communication will be important throughout the whole of the planning and decision making process, including optimisation stage. But the type of engagement, the roles of different parties, including other regulatory bodies and authorities, and the communication challenges will vary throughout the remediation process. Engagement should be implemented as early as practicable and will need to be tailored to the case and the stage of remediation, as well as cultural and national characteristics [III-9].

REFERENCE LEVEL OF DOSE

III-11. Reference levels are established for optimization of protection and safety under existing exposure situations, taking account of the site-specific environmental, social and economic conditions and the radiological situation. The reference level represents the level of dose or risk above which it is judged to be inappropriate to plan to allow exposures to occur, and below which the optimization of protection and safety is implemented [III-10].

III-12. The reference level serves as a boundary condition in defining the range of options for the purposes of optimization in implementing remediation. The reference level is the starting point for the optimisation of the protection. For particular existing exposure situation, it should be selected in such a way that during reasonable period of time (some years) the residual dose of the public in all the considered areas would decrease below the reference level.

III-13. The reference level of public exposure under existing exposure situations is typically expressed as a residual annual effective dose to the representative person in the range of 1 - 20 mSv or other corresponding quantity, the actual value depending on the feasibility of controlling the situation

and on experience in managing similar situations in the past (see paragraph 5.8 of GSR Part 3 [III-10]). At the lower end of this range, the reference level represents a moderate increase, of up to about 1 mSv, over the dose received in a year from exposure due to naturally occurring radiation sources. The annual dose of 1 mSv is traditionally viewed as safe being equal to dose limit for the general public in planned exposure situations.

III-14. Reference levels of annual dose within the range 1-20 mSv are used as basis for a protection system against public exposure under existing exposure situations because local residents are considered to benefit from this system. This benefit is for people to continue living in their present area and their home and not need to relocate to another area.

III-15. The reference dose is used both prospectively, for planning of remediation, and retrospectively as a benchmark for judging the effectiveness of an implemented remedial action plan. For operational remediation management, specific reference levels are calculated by means of realistic (non-conservative) dosimetric models for a representative person residing in existing exposure situation. These specific reference levels are measurable quantities, such as ambient dose rate, activity concentration in staple foods, or activity concentrations in other environmental compartments.

III-16. The reference level of dose and derived reference levels should be viewed as regulatory quantities and their selected values should be rounded to one or two significant digits and not provided with any uncertainty.

III-17. The selection of reference dose and specific reference levels depends on a number of radiation characteristics (radionuclide composition, physical and chemical properties and deposition density of radioactive material, size of contaminated area, etc.), environmental peculiarities of the affected area (soil types, relief, climate, presence of forests and water bodies, etc.), land use and agricultural technologies, social and demographic characteristics (settlement type, food habits, etc.). For that reason, site-specific and event-specific reference levels should be established for conditions of a particular affected area and concrete radioactive contamination event.

III-18. Factors that immediately influence the selection of the reference level are:

- (a) The prevailing circumstances of the exposure situation and, in particular, its origin, isotopic composition, exposure pathways, the projected and residual doses, the spatial extent, and the number of people exposed;
- (b) Evaluation of remedial actions in terms of public dose reduction, worker doses, public acceptability, time, cost, composition and potential volume of residual material and waste (including transportation), environmental impact, etc.;
- (c) The extent to which the exposure situation (as opposed to the exposure itself) benefits individuals and the societal disruption that would be produced by remediation;

- (d) Likely effectiveness of self-help measures and the practicability of further controlling dose by constraining certain human activities in specific geographical areas e.g. residence, agriculture, excavation, collection of natural foodstuffs, forestry etc;
- (e) Outcomes achieved when managing similar situations internationally;
- (f) Availability of financial, technological, and human resources;
- (g) Interested parties views and risk perception.

III-19. In considering all of the above it is important to allow for the uncertainties and heterogeneities in the modelling, sampling, distribution of doses to the affected public, and in the effectiveness of the proposed technologies. These uncertainties need to be considered when selecting the reference level because of their ability to affect a successful remediation and thereby maintain public confidence in the remediation process.

III-20. Selecting the reference level involves judgement of qualitative and quantitative factors and requires wide and informed consultation; it may be aided by techniques such as multi-attribute decision analysis. In any event, care should be taken to avoid setting the reference level at too low a value, recognizing that it may be difficult to increase it in the future.

III-21. The numerical value of the reference dose reference level for a particular affected area should be selected in the range between the projected dose, i.e. dose that would be expected to be received if planned protective actions were not taken, and residual one to be incurred in the future after the intensive application of feasible remedial actions have been terminated.

III-22. Given that the major benefit from remedial actions is partial prevention of the future dose to the public, both the projected and residual dose should be assessed for the period of time that begins from time when planned or factual remedial actions will start and for the forthcoming year. Those doses will allow for the settling the reference level value and its further application as a benchmark for optimization.

III-23. The procedure of determination of a numerical reference level value of annual dose for an existing exposure situation with uniform radioactive contamination of the area and corresponding public exposure conditions includes the following steps:

- (a) For the area under consideration, assess projected external (${}^{\text{proj}}E_{\text{ext}}$) and internal (${}^{\text{proj}}E_{\text{int}}$) doses of a representative person and the total dose as their sum (${}^{\text{proj}}E = {}^{\text{proj}}E_{\text{ext}} + {}^{\text{proj}}E_{\text{int}}$) based on radiation measurements (radionuclide deposition density, dose rate, activity concentration in foods, etc) and modelling of each significant exposure pathway, see Annex II;
- (b) For the same area, assess the residual dose of external exposure ${}^{\text{res}}E_{\text{ext}}$ and of internal exposure ${}^{\text{res}}E_{\text{int}}$ for a representative person, see Annex II. Assess the total residual dose for conditions of

intensive application of feasible remedial actions as sum of residual external and internal doses as follows: ${}^{\text{res}}E = {}^{\text{res}}E_{\text{ext}} + {}^{\text{res}}E_{\text{int}}$.

- (c) Select the reference level RL_{ext} of annual external dose in the range between the projected (${}^{\text{proj}}E_{\text{ext}}$) and residual (${}^{\text{res}}E_{\text{ext}}$) external doses. Within that range, select particular RL_{ext} value based on prevailing social and economic conditions, i.e., availability of funds, public perception, etc. Select the reference level RL_{int} of annual internal dose in a similar way. If ${}^{\text{res}}E_{\text{int}}$ exceeds 1 mSv, establish RL_{int} not more than 1 mSv in accordance with ICRP recommendations [III-9, III-11] and IAEA safety requirements [III-10]. Use both RL_{ext} and RL_{int} for calculation of respective specific reference level in measurable quantities.
- (d) Define the reference level value for the total annual dose as sum of selected RL_{ext} and RL_{int} values and use it for optimization of remediation planning in the area under consideration.

III-24. If the doses of the public in a considered settlement or area are characterized by frequency distribution, the reference level values should be selected in the range between 95% quantiles of the projected and residual doses. For the members of public whose residual doses belong to the upper tail of the statistical distribution, authorities may decide on appropriate specific measures to avoid excessive exposures.

III-25. The procedure of determination of reference level value for an existing exposure situation with non-uniform radioactive contamination of the area and corresponding public exposure conditions in different settlements is similar. The projected and residual doses should be assessed for each settlement under consideration, see Annex II. Then, distribution of the settlement number by respective doses should be parameterized and 95% percentiles defined. The reference level value for the area under consideration should be selected in the range between 95% percentiles of the projected and residual doses based on prevailing social and economic conditions.

III-26. If the number of residents in various settlements of the area under consideration is substantially different from each other, similar procedure can be applied to population-weighted number of settlements.

III-27. Radiation conditions and doses of the public change with time due to natural reasons (radionuclide decay, migration and fixation in environmental media) and human activities (traffic, production activities, countermeasures, etc.) and also change of social, economic and demographic characteristics (land use, population composition, etc.). For those reasons, reference levels should be reviewed every 1-10 years depending on velocity of aforementioned processes.

III-28. In cases of severe contamination, or lack of resources to comply with a full remediation, it may be considered advantageous to select an intermediate reference level and then, in light of experience and resources availability, revise it downwards so as to improve the situation progressively.

SPECIFIC REFERENCE LEVELS

III-29. For operational remediation management, some specific reference levels in terms of measurable physical quantities relevant to basic exposure pathways of the public, such as ambient dose rate, activity concentration in staple foods, etc., are calculated by means of realistic (non-conservative) dosimetric models for a representative person residing in existing exposure situation.

III-30. The specific reference level values should be selected in such a way that compliance with specific reference levels should with high probability provide for compliance with established reference annual dose, too.

III-31. Specific reference levels for external exposure with gamma-radiation of residents of an area contaminated with radionuclides should be established as ambient dose rate at the height of 1 m in a location where people collect substantial fraction of their external dose and where dose rate will change due to remediation. For urban area, the rooms in 1-2-floor residential houses can be used for this purpose. Specific reference levels for ambient dose rate should be established for measured values after background rate has been deducted.

III-32. For radionuclides in commodities (food, fodder, construction materials, etc.), specific reference levels should be established based on the special reference annual dose of 1 mSv recommended by ICRP [III-11] and IAEA [III-10].

III-33. In order to define specific reference levels for ingestion of radionuclides with foods, i.e. reference radionuclide activity concentration in food, those values should be calculated for various ICRP age groups by simple model with account for special reference annual dose (1 mSv), age-dependent food consumption rates and ICRP dose coefficients for ingestion of locally produced and imported foods. The minimum value of the derived radionuclide activity concentrations in food for various age groups is selected as a specific reference level.

III-34. In the case of area contamination with caesium radionuclides that tend to concentrate in wild foods (fungi, berries, game, etc.), specific reference levels for those foods can be established about one order of magnitude higher than specific reference level for agricultural foods because of low consumption rate of wild foods.

III-35. Specific reference levels for inhalation of radionuclides with air should be calculated in a similar way.

HISTORICAL EXAMPLE (CHERNOBYL)

III-36. The procedure of determination of a numerical reference level value for an existing exposure situation of the public residing in the Bryansk region, Russia, severely contaminated with radionuclides after the Chernobyl accident (1986) will be illustrated with dosimetric data assessed

from both extensive monitoring and modelling data conducted in 2001 when radiation protection of the public was topical [III-5].

III-37. The Handbook contains lists of the affected settlements and estimates of the projected annual doses for each of them that are similar to the dose of representative person, i.e. projected external (${}^{\text{proj}}E_{\text{ext}}$) and internal (${}^{\text{proj}}E_{\text{int}}$) doses and the total dose as their sum (${}^{\text{proj}}E = {}^{\text{proj}}E_{\text{ext}} + {}^{\text{proj}}E_{\text{int}}$). The internal exposure was caused predominantly by the consumption of local agricultural and wild foods containing Cs-137. In 2001, the projected total dose exceeded 1 mSv in 445 settlements and 5 mSv in 55 of them. The maximum dose was 11 mSv in the village of Sankovo, Zlynka district [III-5]. As the area contamination with Cs-137 was substantially non-uniform, dose distribution is presented below for a number of settlements.

III-38. For the selection of the reference level of dose and specific reference levels, both the projected and residual doses of external and internal exposure of the representative person for each settlement, where projected total dose in 2001 exceeded 1 mSv, are needed. The projected doses were directly taken from [III-5], and the residual doses were calculated as described in Annex II. For conditions of the Bryansk region, the reduction factor for external dose due to potential decontamination was taken equal to 1.2 for the settlements, which were earlier decontaminated, and 1.5 for the rest of settlements [III-6]. The reduction factor for internal dose due to potential application of efficient agricultural countermeasures (radical improvement of meadows and pastures, etc.) is in the range of 1.5 to 9, depending on the soil type, countermeasure technologies, etc. [III-6]. For conditions of the Bryansk region, based on the post-Chernobyl experience, the reduction factor for internal dose was selected equal to 3.

III-39. The distribution of the 445 settlements of the Bryansk region with projected dose in 2001 equal to or more than 1 mSv by the values of external, internal and total projected and residual dose is presented in Fig. III-1. Table III-1 presents statistical parameters of the six distributions under consideration, i.e. means, medians and 95% quantiles.

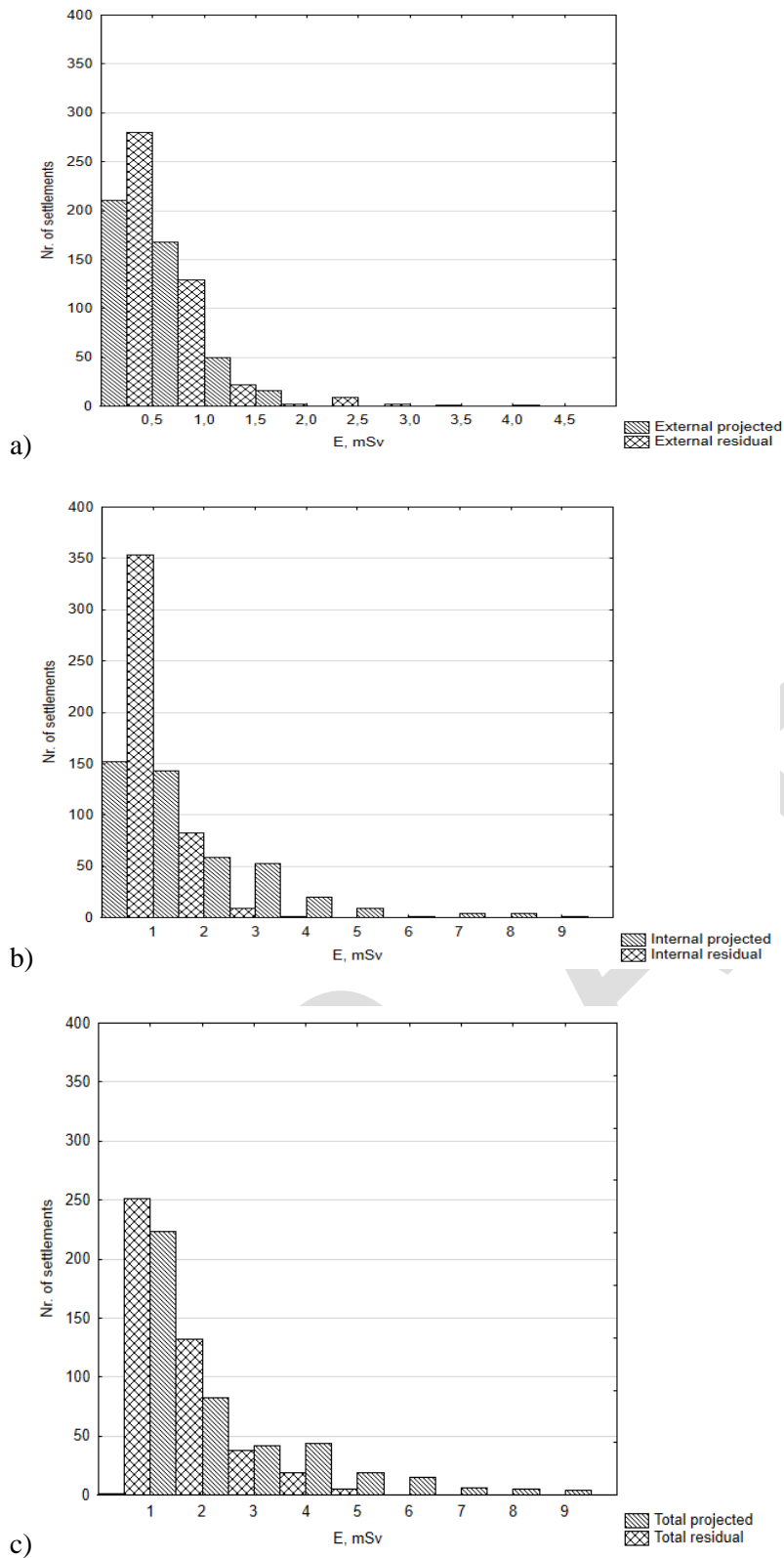


FIG III-1. Distribution of the number of the Bryansk region settlements with projected effective dose in 2001 equal to or more than 1mSv by the projected and residual annual dose (mSv):
 a) – for external dose; b) – for internal dose; c) – for total (external+internal) dose.

TABLE III-1. THE STATISTICAL PARAMETERS OF DISTRIBUTIONS OF THE NUMBER OF SETTLEMENTS OF THE BRYANSK REGION BY THE PROJECTED AND RESIDUAL EFFECTIVE DOSES (MSV) IN 2001.

Radiation exposure	Dose	Dose parameter, mSv			Reference Level range
		Mean	Median	95% quantile	
External	Projected	0.77	0.61	1.70	1.1 to 1.7
	Residual	0.52	0.41	1.13	
Internal	Projected	1.95	1.32	4.74	1.0
	Residual	0.65	0.44	1.6	
Total	Projected	2.73	2.00	6.80	2.1 to 2.7
	Residual	1.17	0.88	3.2	

III-40. In the right column of Table III-1, there are ranges of reference levels for the total annual effective dose and its components, external and internal doses. The reference level range for the external dose (1.1 to 1.7 mSv) is derived from the relevant dose distributions. The reference level for internal exposure (1 mSv) has been recommended by ICRP [III-9, III-11] and IAEA [III-10], because the 95% quantile of the residual internal dose was substantially larger. Reference levels for external and internal exposure will be used as basis for determination of relevant specific reference levels.

III-41. Within the range of 2.1 to 2.7 mSv, the particular reference level value should be selected based on the prevailing social and economic conditions. Reference levels for total dose will be used for optimization of remediation planning in the area under consideration.

REFERENCES TO ANNEX III

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Annex IV

SELF HELP ACTIONS

IV-1. Paragraph 5.17 of GSR Part 3 [IV-1] states that: “For those areas with long lasting residual radioactive material, in which the government has decided to allow habitation and the resumption of social and economic activities, the government, in consultation with interested parties, shall ensure that arrangements are in place, as necessary, for the continuing control of exposure with the aim of establishing conditions for sustainable living, ...”. Worldwide experience following nuclear and non-nuclear accidents shows that individuals are very unwilling to leave affected areas. In general, while authorities may require individuals to leave the affected areas for health reasons in case of excessive residual levels of exposure, wherever possible, they will aim to rehabilitate these areas to allow further human activities.

IV-2. The involvement of the affected communities in the recovery and remedial actions is a specific example of interested parties engagement and another remedial action option. Referred to as “Self-help”, these actions are defined as those that the public can initiate themselves (e.g. dietary changes, monitoring, and decontamination), following advice by the responsible party, the regulatory body or other relevant authority, or the government. Such actions may increase personal control over the radiological situation and may make an important contribution to the success of remediation. These may be connected to situations where lifestyle is a key driver of exposure levels, for example limiting ones time in certain physical areas, or no longer consuming certain local foodstuffs. There are a number of approaches that can help promote this, including: 1) development of situation-specific strategies for providing information on how people can control or reduce their own exposures; 2) providing access to personal dosimeters or other monitoring equipment; and 3) including the public in decision-making and remediation.

IV-3. While these can facilitate a degree of personal control over the situation, self-help protective actions may incur disturbances to everyday life, and their implementation supposes that affected individuals are fully aware of the situation and well informed. This necessitates an ongoing evaluation of the effectiveness of protective actions carried out at local or individual levels, in order to provide adequate support on how to further improve the situation (see paragraph 5.17(b) of GSR Part 3 [IV-1]).

IV-4. In existing exposure situations, justification should be considered for all remedial or mitigating actions that may be included in a remediation strategy: those implemented centrally and locally by authorities, experts, and professionals; and those directly implemented by the exposed individuals as self-help mitigating actions with the support of the authorities. The remediation strategy defined by the authorities should take into account both categories of actions, and should enable affected individuals to take self-help initiatives. However, as self-help mitigating actions are implemented by the inhabitants themselves, they need to be properly informed and, if relevant, trained

(to use the means and equipment provided by the authorities) in order to take informed decisions concerning their own protection, with a net benefit. The balance to be considered by the individuals includes, on one side, their desire to improve the situation and, on the other side, the ‘burden’ induced by the implementation of protective actions.

IV-5. The self-help actions also need co-ordination, human resource support, and available experts to help people understand the measurements and to provide suitable training and information about protection. Self-help thus requires resources to ensure adequate information, dialogue and community support.

IV-6. Of course not all people wish to be involved in measurement and remedial actions. Many simply want to be informed and reassured that everything is under control. This highlights the need for multiple channels and levels of communication.

REFERENCES TO ANNEX IV

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Annex V

RELEVANT LITERATURE

RADIATION AND ENVIRONMENTAL PROTECTION:

EUROPEAN COMMISSION, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3, IAEA, Vienna (2014).

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(more references to be added, as appropriate)

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