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Management of Residues Containing Naturally Occurring Radioactive Material from Uranium Production and Other Activities

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MANAGEMENT OF RESIDUES CONTAINING NATURALLY OCCURRING RADIOACTIVE MATERIAL FROM URANIUM PRODUCTION AND OTHER ACTIVITIES

CONTENTS

1. INTRODUCTION

BACKGROUND

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

1.2. Radioactive material is defined as material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity [1]. Naturally occurring radioactive material (NORM) is defined as radioactive material containing no significant amounts of radionuclides other than naturally occurring radionuclides: the exact definition of 'significant amounts' would be a regulatory decision [1]. Material in which the activity concentrations of the naturally occurring radionuclides have been changed by a process is also considered NORM [1]. A NORM residue is defined as material that remains from a process and comprises or is contaminated by NORM. NORM waste is defined as NORM for which no further use if foreseen [1]. For the purpose of this Safety Guide, NORM residues and NORM waste can be in solid or liquid form and might emit radioactive gases. The term 'NORM activity' is used in this Safety Guide to describe those processes or situations that involve NORM residues.

1.3. NORM residues can have a radiological impact on workers, members of the public, and the environment. The fundamental safety objective established in IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [2], is "to protect people and the environment from harmful effects of ionizing radiation". Consequently, a governmental, legal and regulatory framework, as described in IAEA Safety Standards Series No. GSR Part 1 (Rev. 1), Governmental, Legal and Regulatory Framework for Safety [3] for control of NORM residues may sometimes be necessary.

1.4. Uranium production activities have typically been subject to regulatory control, generally as part of the nuclear fuel cycle. Unlike uranium production, the residues arising from other NORM activities (which

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

may have been recycled, used in other applications or disposed of as waste) have not always been subject to appropriate regulatory control in the past, even though they might have contained radionuclides at levels that would now raise radiation safety concerns.

1.5. NORM residues, particularly those generated in mining and mineral processing, differ from radioactive residues generated at, for example, nuclear power plants or medical facilities. Such NORM residues can be generated in very large volumes, but tend to contain radionuclides at relatively low activity concentrations. This has important implications for the management of NORM residues, including siting and engineering options. In some cases, NORM residues contain radionuclides at higher activity concentrations, but normally in smaller volumes[2]. In such cases, a residue management strategy similar to that for the management of radioactive waste containing artificial radionuclides might be suitable.

1.6. Various IAEA Safety Standards and other IAEA publications have some relevance to NORM and to NORM residues, including the following:

- GSR Part 1 (Rev. 1) Governmental, Legal and Regulatory Framework for Safety [3];
- IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [4];
- IAEA Safety Standards Series No RS-G-1.7, Application of the Concepts of Exclusion, Exemption and Clearance [5];
- IAEA Safety Standards Series No. GSG-7, Occupational Radiation Protection [6];
- IAEA Safety Standards Series No. GSG-9, Regulatory Control of Radioactive Discharges to the Environment [7];
- IAEA Safety Standards Series No. GSR Part 5, Predisposal Management of Radioactive Waste [8];
- IAEA Safety Standards Series No. SSG-32, Protection of the public against Exposure Indoors due to Radon and Other Natural Sources of Radiation [9];
- IAEA Safety Standards Series No. WS-G-3.1, Remediation Process for Areas Affected by Past Activities and Accidents [10];
- IAEA Safety Standards Series No.SSR-6 (Rev. 1) Regulations for the Safe Transport of Radioactive Material, 2018 Edition [11];

[2] The volume of NORM residues can range from less than one cubic metre up to millions of cubic metres.

- IAEA Safety Standards Series No. GSR Part 7, Preparedness and Response for a Nuclear or Radiological Emergency [12];
- IAEA Safety Report Series No. 49, Assessing the Need for Radiation Protection Measures in Work involving Minerals and Raw Materials [13].

A series of Safety Reports containing practical information on NORM residues from specific industries (oil and gas, zircon and zirconia, rare earth processing, titanium dioxide and related industries, and the phosphate industry) have also been published [14–18]. Further information on publications that are relevant to the management of NORM residues can be found in the bibliography provided in Annex V.

1.7. This Safety Guide supersedes the Safety Guide on Management of Radioactive Waste from the Mining and Milling of Ores, IAEA Safety Standards Series No. WS-G-1.2, issued in 2002[3].

1.8. The terms used in this Safety Guide are to be understood as defined and explained in the IAEA Safety Glossary [1].

OBJECTIVE

1.9. The objective of this Safety Guide is to provide recommendations to regulatory bodies, operating organizations, technical support organizations and other interested parties on approaches for the safe management of NORM residues arising from uranium production and other NORM activities, in accordance with a graded approach. These recommendations are aimed at meeting the relevant requirements established in GSR Part 3 [4] for the protection of people and the environment, both now and in the future.

SCOPE

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

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

1.11. This Safety Guide covers the entire lifetime of facilities and activities relating to NORM residue management; including siting, construction, operation, decommissioning, closure, post-closure and a period of institutional control, as appropriate to the facility. A NORM residue management facility can be a facility for processing, storage and/or long term management of NORM residues, including the permanent disposal of NORM waste.

1.12. This Safety Guide identifies organizational and regulatory requirements (including for exemption and clearance, reuse, recycling and other uses). It includes recommendations on the conduct of screening assessments and, where necessary, safety assessments for facilities and activities involving NORM residues, including those facilities and activities for which a formal safety case is appropriate (for example, the management of uranium production tailings).

1.13. This Safety Guide provides recommendations for regulatory bodies to determine which facilities and activities carrying out NORM residue management should be considered for regulatory control.

1.14. This Safety Guide is principally directed towards the management of NORM residues as a planned exposure situation, i.e. including the generation, reuse and recycling, long term management and disposal of residues. It also applies to residues arising from decommissioning of NORM facilities.

1.15. This Safety Guide does not address the remediation of areas contaminated by residual radioactive materials arising from past practices. The requirements for the remediation of such areas are established in GSR Part 3 [4], and further recommendations are provided in WS-G-3.1 [10].

1.16. This Safety Guide is intended to address new facilities; however, it is also relevant in terms of the review and upgrading of existing facilities. It might not be practical to apply all of the recommendations to existing facilities; in such cases, the regulatory body should decide the extent to which these recommendations should be applied. In accordance with national policies, appropriate steps should be taken to review existing facilities and, where reasonably practicable, to upgrade the provisions for protection and safety in accordance with the recommendations provided in this Safety Guide.

1.17. The radionuclides contained in NORM residues are not the only potential hazard. The chemical constituents within many NORM residues are also capable of causing harm to people and the environment and it might be necessary to apply controls through environmental regulations or occupational health and safety regulations. These chemical constituents include heavy metals, inorganic elements (e.g. arsenic), acids and various organic compounds. The potential for such substances to cause harmful effects needs to be considered when planning the management of NORM residues. Although outside the scope of this Safety Guide, there is a particular need for regulatory bodies to take account of non-radiological hazards, which in many cases represent the primary risk to people and the environment. Achieving a consistent regulatory and integrated approach to protect against these different hazards is a challenge for regulatory bodies.

STRUCTURE

1.18. Section 2 provides an overview of NORM residues. Recommendations on the governmental, legal and regulatory framework for the safe management of NORM residues are provided in Section 3, and recommendations on the protection of people and the environment are provided in Section 4. Recommendations on the regulatory control process are provided in Section 5, while Section 6 provides recommendations on strategies for NORM residue management. Section 7 provides recommendations on the development of a safety case and supporting safety assessment. Section 8 addresses the full lifetime of facilities for the long term management of NORM residues, from siting through to long term institutional controls.

1.19. Three appendices and five supporting annexes complete the publication. Appendix I provides information on special consideration for managing residues from uranium production. Appendix II recommends a residue management plan for uranium production. Recommendation on closure plan for a tailings management facility at a uranium production site is provided in Appendix III. Annex I provides examples of NORM residues to be assessed for possible regulatory control. Annex II provides information on sampling NORM residues and determining radionuclide activity concentrations. Examples of the application of the graded approach in the management of NORM residues are provided in Annex III. Annex IV provides information on reuse and recycling of NORM residues. Annex V provides a list of publications that are relevant to the management of NORM residues.

2. OVERVIEW OF NORM ACTIVITIES AND NORM RESIDUES

2.1. Paragraph 3.4 of GSR Part 3 [4] states that the relevant requirements for planned exposure situations apply to:

> "(a) Exposure due to material in any practice … where the activity concentration of any radionuclide in the uranium decay chain or the thorium decay chain is greater than 1 Bq/g, or the activity concentration of ^{40}K is greater than 10 Bq/g;
>
> "(b) Public exposure due to discharges or due to the management of radioactive waste arising from a practice involving material as specified in (a) above".

2.2. The requirement stated in para. 2.1 does not apply to NORM residues in fertilizers, soil amendments or construction materials (or components of such), or NORM residues that exist as residual radioactive material in the environment. In all such cases, the requirements for existing exposure situations apply irrespective of the activity concentrations (para. 5.1 of GSR Part 3 [4]). However, in terms of the planning of a facility for recycling NORM residues (including recycling into construction materials), the optimum protection strategy might include treating the operation of the residue management facility as a planned exposure situation.

2.3. In addition to uranium production, other NORM activities also generate residues that might be of regulatory concern. This includes the following industry sectors[4] [13]:

(1) Extraction of rare earth elements;

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

(3) Production of tantalum, niobium and ferro-niobium;

(4) Mining of ores other than uranium ore;

(5) Production of oil and gas;

(6) Manufacture of titanium dioxide pigments;

(7) The phosphate and potash industries;

(8) The zircon and zirconia industries;

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

(10) Combustion of coal;

(11) Water treatment.

2.4. Table 1 provides a general overview of the NORM residues arising from uranium production and other industrial activities. Annex I provides more details of the typical characteristics of the NORM residues that might be of regulatory concern. Residues of different origins can vary significantly with respect to their radiological, chemical and physical characteristics. The information in Table 1 and Annex I includes the majority of industry sectors and NORM residues that need to be considered; however, NORM residues might also occur in other industrial activities that are yet to be identified.

2.5. Of the different residues generated by NORM activities, those residues that are generated in bulk amounts (of the order of millions of tons) represent the greatest challenge in terms of safe management. Although such residues contain radionuclides at relatively low activity concentrations, they are generated in very large volumes, they contain long lived radionuclides and (often) other hazardous substances, such as heavy metals. Such bulk

[4] The list is not exhaustive. NORM residues that might be of regulatory concern can also arise from other sectors, such as geothermal power, limestone processing and shale gas production.

residues include waste rock from uranium mining, mineral process tailings, phosphogypsum, red mud from alumina processing and metalliferous tailings.

2.6. Some residues might be of a relatively small volume but have a relatively high activity concentration, for example:

(a) Scales and sludge that accumulate in pipes or process vessels in oil and gas production, coal production with radium rich inflow water, geothermal energy production and in rare earth production;
(b) Anode slimes from electrowinning processes;
(c) Precipitated smelting dusts;
(d) Rare earth extraction residues (e.g. thorium hydroxide);
(e) Residues from decontamination processes;
(f) Contaminated equipment and process filters.

2.7. Plant and equipment used for handling or processing of NORM, such as pipes, valves, process vessels, pumps and machinery, can become contaminated with NORM residues, which can be a concern during the operation, and particularly during the decommissioning, of relevant facilities. These residues are often associated with scrap metals, which also require appropriate management: see Annex IV.

2.8. Liquid residues of various origin are also generated, in some cases in large volumes, including the following:

(a) Process water;
(b) Leaching fluids;
(c) Rainfall runoff (from the process plant area, residue management area, residue and ore stockpiles);
(d) Seepage from process tailings, stockpiles and waste rock management areas;
(e) Mine water (for example, groundwater that has entered open pits or underground mines).

Table 1: Types of NORM residue arising from different industrial activities

Industrial activities	Bulk amounts of residues			Moderate to small amounts of residues				
	Tailings	Waste rock	Liquids	Slags	Scale	Sludge/ Filter	Precipitator dust	Intermediate products
Conventional uranium production	X	X	X		X	X	X	
Heap leaching for uranium	X	X	X		X	X		
In-situ leaching for uranium			X		X	X		
Extraction of rare earth elements	X		X		X	X	X	
Production and use of thorium and its components	X				X	X		Thorium compound and concentrate
Production of tantalum, niobium and ferro-niobium	X			X		X	X	Pyrochlore concentrate
Mining of ores other than uranium ore	X	X	X		X	X		
Production of oil and gas			X		X	X		
Manufacture of titanium dioxide pigments	X		X		X	X		
The phosphate and potash industries	Phosphogypsum			Thermal production	X	X	X	
The zircon and zirconia industries							X	Fused zirconia
Production of tin, copper, aluminium, zinc, lead, and iron and steel	Red mud			Tin and copper smelting		X	X	
Combustion of coal	Fly ash				X			
Water treatment and geothermal energy production						X		

3. GOVERNMENTAL, LEGAL AND REGULATORY FRAMEWORK FOR SAFETY

RESPONSIBILITIES OF THE GOVERNMENT

3.1. Requirement 1 of GSR Part 1 [3] 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 the radiation risks associated with facilities and activities, to achieve the fundamental safety objective and to apply the fundamental safety principles established in the Safety Fundamentals."

3.2. For the safe management of NORM residues, the government should establish a policy and strategy that is appropriate to the national situation. The policy and strategy should acknowledge existing governmental, legal and regulatory frameworks, promote a graded approach to regulation, identify further industries that might need oversight, and coordinate the overall approach to the management of NORM residues. The policy and strategy should reflect, and be consistent with, the principles as set out in SF-1 [2] and the recommendations provided in Sections 4–8 of this Safety Guide.

3.3. The policy and strategy for management of NORM residues should be consistent with the national policy and strategy for development of activities that generate NORM residues. Together, these policies and strategies should address controls on the generation of NORM residues, and encourage the reuse and recycling of NORM residues, where it is safe and appropriate to do so. Recycling and reuse of NORM residues are described further in Section 6 (i.e. as options for residue management), and more information on the application of these options is given in Annex IV.

3.4. The policy and strategy for management of NORM residues should also take into account the national policies and strategies for safety, for management of non-radioactive waste and for radioactive waste management. States may choose to integrate key elements of the strategy for NORM residue management into their national policy, legal framework and regulatory instruments. In such cases, a separate national strategy for NORM residue management might not be necessary.

3.5. The government should consider the need for, and the extent of, public involvement and coordination among relevant governmental organizations during the development and implementation of the policy and strategy, including the establishment of a system for regulatory control. Increasing consultation with the public is a feature of the authorization process in many States; however, the responsibility for regulatory decisions remains with the regulatory body.

3.6. To enable oversight of NORM facilities and activities, the government should first identify which industries within the State process NORM and/or generate NORM residues. The government should then identify the regulatory body, or other authorities appropriate to these industries, to oversee NORM activities. If there are multiple activities or industries, there might be more than one regulatory body or authority involved.

3.7. In accordance with Requirements 3 and 4 of GSR Part 1 (Rev. 1) [3], the government is required to establish and maintain a regulatory body that is effectively independent and has the authority and sufficient resources (staff and financial) to properly oversee the safety of facilities and activities. For regulatory bodies that historically have not been involved in regulating radiation sources, this is likely to require cooperation with other agencies or organizations with relevant radiation protection expertise.

3.8. The government should coordinate the establishment of an appropriate national inventory of significant NORM residues arising from new and existing NORM activities. Where possible, residues identified from past practices (i.e. which need to be considered as part of the national strategy for residue management) should also be included in the inventory.

3.9. The government should establish legislation that allows the regulatory body to maintain effective oversight of NORM activities, where such legislation does not already exist. Such legislation should address the relevant requirements of GSR Part 3 [4], and should include provision for authorization of facilities and activities, and for establishing financial resources by the operating organization, where these are required. Financial resources are explained in more detail in Section 5.

3.10. For activities such as uranium production, effective legislation will:

(a) Establish requirements and/or safety criteria for management of residues, including for long term safety and the disposal of mill tailings and other residues as waste when no further use is foreseen.

(b) Prohibit the generation or storage of residues and waste unless these activities have been licensed by the regulatory body;

(c) Enable the regulatory body to specify conditions to be attached to licences;

(d) Make the failure to comply with licence conditions an offence subject to enforcement action;

(e) Require information and any associated fees to be provided with the licence application(s);

(f) Require that the operating organization prepare plans for the management of residues and waste;

(g) Require financial resources for the purposes of decommissioning, remediation, closure and institutional controls, as relevant;

(h) Require regulatory approval for significant changes to operations;

(i) Require regulatory approval before any licence is relinquished or is transferred to another party;

For other NORM activities, the legislation and the regulatory effort should be commensurate with the risks and should take into account existing legislation and systems of control. In some cases, existing regulations for workplace health and safety and for environmental protection may already provide adequate protection against radiation and hence further legislation specific to radiation protection might not be necessary for such NORM activities.

3.11. Given the range of industries concerned, it is possible that several different parts of government will have responsibilities relating to NORM facilities and activities, and it is likely that several pieces of legislation will apply. For effective and efficient regulation, it is important that responsibilities are defined and formally coordinated through instruments such as administrative agreements or memoranda of understanding between different agencies. This coordination can be achieved by one regulatory body acting for the government to coordinate regulatory oversight across multiple industries. More commonly, there will be multiple regulatory bodies. In the case of multiple regulatory bodies, it should be ensured that regulatory requirements and any authorization conditions are suitably aligned.

RESPONSIBILITIES OF THE REGULATORY BODY

3.12. For planned exposure situations involving NORM, as stated in Requirement 12 of GSR Part 3 [4]:

> "The government or regulatory body shall establish dose limits for occupational exposure and public exposure, and [operating organizations] shall apply these limits."

3.13. In addition, as stated in para. 3.22 of GSR Part 3:

> "The government or the regulatory body … [s]hall establish or approve constraints on dose and on risk, as appropriate, or shall establish or approve a process for establishing such constraints, to be used in the optimization of protection and safety."

3.14. The regulatory body is also required to oversee compliance with conditions specified in licences, and review and assess the results of inspection and enforcement activities, as appropriate, in accordance with Requirements 25, 27 and 31 of GSR Part 1 (Rev. 1) [2].

3.15. The regulatory body should establish regulations and/or guides for the exemption of practices and sources, for the clearance of material and for the release of sites from regulatory control, and establish end state criteria for such sites. The regulatory body should oversee the implementation of the operating organization's plans for decommissioning, the management of NORM residues and waste and, where appropriate, for closure (including any institutional controls or long term monitoring), to verify that progress to meet the end state criteria is being made.

3.16. The regulatory body is also responsible for establishing guidance on the implementation of regulatory requirements and on the authorization process: see paras 2.5(9) and 4.34 of GSR Part 1 [3]. The regulatory body should also establish guidance on regulatory review and assessment, operational oversight, and overseeing the closure or decommissioning of a facility. The process for making regulatory decisions should be transparent, independent and justifiable, such that if a decision is challenged the regulatory body can explain how it was reached.

3.17. Through the implementation of regulatory criteria that are based on the established national policy, strategy and legislation, the regulatory body should determine those facilities or processes that require formal regulatory control and those for which guidance on best practice is more appropriate. A key role of the regulatory body is to identify which industries, facilities and activities involving NORM or NORM residues are likely to be subject to the requirements of legislation, and to provide guidance to industry on the scope and application of regulations. This will then lead to the notification and assessment processes described in Section 5 of this Safety Guide. Uranium production facilities are likely to already know the regulatory framework, but for other NORM industries this guidance will be important.

3.18. The regulatory body should consider an outreach programme to communicate with industries involved with NORM residues, to make these industries aware of the potential need for regulation and radiation protection. The outreach programme should also encourage the sharing of data between the operating organization and the regulatory body, and should include communications with workers and, where appropriate, the public.

3.19. The regulatory body should encourage the reuse and recycling of NORM residues (i.e. rather than these residues being managed as waste), where relevant safety criteria can be met and residues can be cleared from further regulatory control.

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

3.21. The regulatory body should ensure that the operating organization keeps relevant records concerning any facility that generates, handles, processes, and/or stores NORM residues, in particular where residues are held for long term management. The regulatory body should request that the operating organization provide it with these records (or a summary of these records) on a defined schedule.

RESPONSIBILITIES OF THE OPERATING ORGANIZATION

3.22. The operating organization is responsible for all aspects of safety of the NORM activity, including protection of workers, members of the public, and the environment against any hazards associated with NORM residues throughout the lifetime of a NORM facility or activity, including decommissioning or closure.

3.23. The operating organization is required to notify the regulatory body of an intention to undertake a NORM activity, in accordance with Requirement 7 of GSR Part 3 [4].

3.24. The operating organization is required to provide the regulatory body with access to the facility and to safety related information, in accordance with para. 2.13 of GSR Part 1 (Rev. 1) [2] and para. 2.45 of GSR Part 3 [4].

3.25. In accordance with Requirement 6 of GSR Part 1 (Rev. 1), the operating organization is required to comply with all legal and regulatory requirements: for some facilities and activities that require a licence (see Section 5), these requirements will include collecting baseline data prior to site development and preparing a safety case and supporting safety assessment (see Section 7) associated with siting, design, construction, commissioning, operation, decommissioning or closure and post-closure.

3.26. The operating organization is responsible for developing a plan for the management of NORM residues.

3.27. The operating organization is responsible for establishing and implementing an appropriate management system that incorporates radiation protection requirements to a degree that is commensurate with the complexity and risk of the facilities and activities relating to NORM residues. The management system should meet the requirements of IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [19].

3.28. By means of design measures, procedures and processes, the operating organization should identify and implement measures to minimize the amount of NORM residues and the amount of NORM waste. This could be achieved, for example, by increasing the efficiency of processes, or through the reuse and recycling of NORM residues.

3.29. Where applicable, the operating organization should maintain up to date plans for the decommissioning and the closure of facilities, as appropriate. These plans should take account of the financial provision throughout the lifetime of the facility, including how it will meet the end state criteria, which also will provide the basis for any financial resources mechanism that is necessary.

4. PROTECTION OF PEOPLE AND THE ENVIRONMENT

GENERAL

4.1. The fundamental safety objective is to protect people and the environment from harmful effects of ionizing radiation [2]; this is to be achieved through compliance with the requirements established in GSR Part 3 [4]. Given the broad spectrum of NORM residues arising from a wide range of NORM activities, it is important that a graded approach to protection and safety in the management of NORM residues is adopted. That is, the protection measures adopted should be commensurate with the magnitude and likelihood of exposures and level of risk.

4.2. The regulatory framework for NORM residue management is based on requirements laid out in GSR Part 3 [4]. Practices or sources may be exempted from some or all of the requirements of GSR Part 3 [4]: with regard to NORM, para. I.4 of GSR Part 3 [4] states:

> "For radionuclides of natural origin, exemption of bulk amounts of material is necessarily considered on a case by case basis by using a dose criterion of the order of 1 mSv in a year, commensurate with typical doses due to natural background levels of radiation."

4.3. The management of NORM residues is an example of the management of facilities and activities, as defined in GSR Part 3 [4]. Radiation protection considerations are therefore governed by the principles of justification, optimization and (for planned exposure situations) dose limitation. The justification principle should be applied in respect of proposed new NORM activities, before making modifications to processes that would affect the generation of NORM residues, and during licence renewal.

4.4. In the management of NORM residues, a safety culture that encourages continuous improvement and a questioning and learning attitude to protection and safety, should be fostered and sustained: see Requirement 12 of GSR Part 2 [19].

4.5. Radioactive discharges to the environment from NORM facilities and activities that are subject to authorization should be controlled in accordance with a licence issued by the regulatory body. Recommendations on the regulatory control of discharges are provided in GSG-9 [7].

PLANNED EXPOSURE SITUATIONS

Occupational exposure

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

(a) External exposure to radiation (primarily gamma radiation);

(b) Intakes of radionuclides directly through dust inhalation and ingestion, and/or indirectly through ingestion of contaminated water or food;

(c) Exposure due to radon (and sometimes thoron) released from residues into the air[5].

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

Workers might be exposed during the generation of NORM residues, during operations to process, reuse or recycle the residues, or during the long term management of such residues.

4.7. Where NORM residues are subject to regulatory control, the operating organization is required to prepare and implement a radiation protection programme (Requirement 24 of GSR Part 3 [4]). The radiation protection programme should describe the measures taken to ensure that the protection of workers is optimized. Recommendations on the scope and content of the radiation protection programme are provided in GSG-7 [6], which also includes special considerations for mineral processing involving NORM (in paras 9.66–9.72).

4.8. Occupational radiation protection in the generation of NORM residues is usually managed as part of the radiation protection programme for the overall process that is generating the residues. For example, radiation protection in the generation and handling of uranium mill tailings will be a part of the overall radiation protection programme for the mill. In other cases, a single NORM residue might be the only material in the whole process where the concentration of radionuclides is sufficient to lead to exposures that warrant control: in such cases, the radiation protection programme will be specific to the NORM residue. For example, for a rare earth facility, the main residue of interest might be thorium hydroxide, which presents a significant radiological risk that needs to be managed through the radiation protection programme. Another example is NORM scale in oil and gas production facilities.

4.9. The radiation protection programme is required to include arrangements for the designation of controlled and supervised areas (paras 3.88–9-92 of GSR Part 3 [4]). Controlled areas are likely to be unnecessary where only materials with low activity concentrations are handled, such as is the case in many industrial activities involving NORM (see para. 3.79 of GSG-7 [6]).

Public exposure

4.10. As NORM radionuclides are present in the environment, and contribute to natural background radiation, it is important that care be taken to distinguish between exposures arising as a result of NORM activities and NORM residues, and those arising from natural background. Establishing baseline information on natural radiation levels[6] is therefore important (see also para. 8.48 (d)).

4.11. For public exposure, the dose limit is an effective dose of 1 mSv in a year[7], (Schedule III of GSR Part 3 [4]). NORM activities are also subject to the radiation protection principle of optimization, for which (for

[6] For facilities and sites where NORM industries have been operating for a long time, the monitoring program for establishing natural radiation levels may need to focus on representative locations away from the immediate vicinity of the site.

[7] In special circumstances a higher value of effective dose could apply in a single year, providing that the average effective dose over five consecutive years does not exceed 1 mSv per year.

planned exposure situations) the government or the regulatory body is required to establish or approve dose constraints (para. 3.120 of GSR Part 3 [4]).

4.12. Dose limits and dose constraints for public exposure apply both during operations involving NORM residues— such as generation, reuse or recycling, storage or disposal of NORM residues — and after the cessation of such operations. During operation, public exposure can be assessed, for example, through monitoring of radionuclides in ambient air or foodstuffs, or indirectly through the monitoring of discharges and then modelling the transfer of radionuclides through the environment to estimate the subsequent intakes and doses to members of the public. After the cessation of operations, the end state criteria, in conjunction with institutional control, where appropriate, should ensure that public exposures are below the established dose constraint.

4.13. If several facilities and activities are located at the same site, the dose constraints for public exposure should apply to all sources of planned exposure to which a member of the public could be exposed, leaving an appropriate margin for foreseeable future activities at the site that could give rise to additional exposure. As described in para. 4.11, the regulatory body is required to either establish dose constraints, or else approve dose constraints, for example that have been proposed by the operating organizations of the facilities and activities on the site.

4.14. There should be reasonable assurance by the operating organization that any control measures implemented will remain effective for a specified period agreed with regulatory body, and that during this period the dose constraint established or approved by the regulatory body will continue to be met.

4.15. The potential for public exposures in excess of the dose constraint due to possible future redevelopment of, or unplanned intrusion into, closed facilities for NORM residue management, should be considered in the planning and design as well as in the safety assessment, and appropriate institutional controls should be planned and implemented.

EMERGENCY EXPOSURE SITUATIONS

4.16. For the management of NORM residues, there are very few, if any, credible accident scenarios[8] that could lead to an emergency exposure situation. Consequently, arrangements for emergency preparedness and response, as described in GSR Part 7 [12], are unlikely to be required.

4.17. Engineering controls (such as the surface cover of a tailings dam) could fail because of natural processes (such as erosion), or other incidents might occur that result in the release of increased amounts of radionuclides to the environment. These might have some radiation exposure implications; however, other

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[8] The term 'scenario' is defined as a postulated or assumed set of conditions and/or events [1].

(non-radiological) risks will generally dominate. Due consideration should be given to the probability of failure of such controls and to the likely impact in terms of the overall integrity of the facility and any public exposure or environmental consequences. Such events, however, generally do not fall within the definition of a radiological emergency. The management of non-radiological emergencies is outside the scope of this Safety Guide.

4.18. If the results of the safety assessment demonstrate that an emergency exposure situation could occur in a NORM facility or activity, an adequate level of emergency preparedness and response is required, in accordance with the requirements established in GSR Part 7 [12]. Recommendation and guidance supporting the implementation of GSR Part 7 are provided in IAEA Safety Standards Series No. GS-G-2.1, Arrangements for Preparedness for a Nuclear or Radiological Emergency [20], and IAEA Safety Standards Series No. GSG-2, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency [21].

4.19. In most cases, any deviations from normal operations and small scale incidents should be managed within the framework established for planned exposure situations. In the event of such circumstances, some arrangements might be needed for dealing with public concerns (e.g. the provision of information) and for the management of non-radiological hazards (e.g. chemicals) present at the site; however, the establishment of either on-site or off-site emergency plans, in accordance with GSR Part 7 [12], is not warranted.

EXISTING EXPOSURE SITUATIONS

4.20. There are three categories of existing exposures situation involving NORM residues that can potentially give rise to public exposures and/or occupational exposures (para 5.1 of GSR Part 3 [4]), as follows:

(a) Contaminated areas containing NORM residues from past activities that were never subject to regulatory control or that were subject to regulatory control but not in accordance with the requirements of the Safety Standards. Where persons have access to sites containing residual NORM contamination, exposure can arise directly from those residues. More commonly, exposures occur in the area surrounding the site due to radionuclides being dispersed by airborne or waterborne pathways, and by the emanation of radon.

(b) Where NORM (irrespective of the activity concentration) occurs in commodities, including fertilizers, soil amendments and construction materials, or as residual radioactive material in the environment.

(c) Where NORM occurs in other materials and the activity concentration of radionuclides in either the uranium decay chain or the thorium decay chain does not exceed 1 Bq/g and the activity concentration of ^{40}K does not exceed 10 Bq/g.”

4.21. For existing exposure situations involving NORM residues in which doses are less than 1 mSv in a year, further action with respect to radiological controls would not normally be warranted. Where annual effective doses exceed 1 mSv, then a protection strategy should be developed and implemented to ensure that any remedial action is justified and that protection and safety is optimized, in accordance with Requirement 48 of GSR Part 3 [4]. Recommendations on the remediation of contaminated sites from past practices are provided in WS-G-3.1 [10].

4.22. The management of NORM residues in existing exposure situations is generally out of the scope of this Safety Guide (see para. 1.14). However, there might be circumstances where the regulatory body determines that the most appropriate protection strategy (see paras 5.4 and 5.5 of GSR Part 3 [4]) in a particular existing exposure situation is to utilize the system of regulatory control that is applied to planned exposure situations. This guidance is not intended to preclude such actions on the part of the regulatory body.

PROTECTION OF THE ENVIRONMENT

4.23. As defined in GSR Part 3 [4]:

> “Protection of the environment includes the 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.”

4.24. In many cases, the standard of radiation protection to protect people from harmful effects means that specific consideration of effects in the environment might not be necessary: see para. 1.21 of IAEA Safety Standards Series No. GSG-10, Prospective Radiological Environmental Impact Assessment for Facilities and Activities [22]. Furthermore, in many cases, protection of the environment from the non-radiological (i.e. chemical and physical) impacts (see paras 4.25–4.26) of NORM activities is likely to dominate the decision making process. Nevertheless, there is a need to be able to demonstrate that the environment is protected from harmful effects of ionizing radiation in situations in which NORM residues are released into the environment. The radiological environmental impact assessment should assess such impacts and, where necessary, identify additional control measures. Recommendations on assessing the radiological environmental impact for facilities and activities are provided in GSG-10 [22].

NON-RADIOLOGICAL CONSIDERATIONS

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

4.26. In many cases, non-radiological risks are of greater concern than the radiation risks. Arrangements are necessary between the involved regulatory bodies in order to have a consistent approach to the management of all hazards and to clearly assign the tasks and responsibilities of each regulatory body.

5. SYSTEM FOR REGULATORY CONTROL

GENERAL

5.1. The number of facilities involved in the processing of minerals and raw materials is very large, but relatively few processes result in significant radiological hazards due to NORM [13]. The selection and application of regulatory controls should be commensurate with the associated hazards and risk. While the criteria for applying regulatory controls should be based on reasonable and prudent precautions to ensure safety, it should be recognized that an inappropriate application of regulatory controls could result in many facilities and activities being regulated without any net benefit. For this reason, the concept of a graded approach is especially important in defining the scope of regulatory control. Before introducing regulatory controls for the purpose of radiation protection, the regulatory body should consider the regulations and controls that are already in place (i.e. for non-radiological purposes) and aim to integrate with these existing controls.

5.2. NORM residues arising from uranium production should always be under regulatory control. In order to determine the optimum regulatory approach for other NORM residues, the regulatory body should understand how, when and where natural radionuclides could occur in the NORM activities listed in Section 2. The regulatory body should therefore consider the processes, the materials and the residues in more detail

— including an initial estimate of occupational exposures and public exposures — and consider the costs of regulation in comparison to the benefits achievable.

INVENTORY OF NORM FACILITIES AND ACTIVITIES FOR REGULATORY CONSIDERATION

5.3. Creating a list of the NORM activities that are potentially of regulatory concern is the first step in the regulatory control process. These activities can be identified by operating organizations and by the regulatory body. The list can be developed based on the information in Section 2 and Annex I adjusted to take account of national circumstances.

5.4. A detailed understanding of NORM industrial activities is essential for the proper implementation of the graded approach. Therefore, the regulatory body should compile an inventory of the NORM facilities and activities that generate or manage NORM residues, including a description of the processes and materials, and the associated occupational exposures and public exposures. Information on sampling NORM residues and determining the radioactive content is provided in Annex II.

5.5. The list of NORM activities for consideration of regulatory control should not be just limited to those activities that generate NORM residues. Attention should also be paid to activities involving reuse and recycling, disposal in landfill, and other long term management options.

5.6. With regard to the residues from uranium mining, especially bulk waste rock materials, the activity concentrations of radionuclides in the uranium and thorium decay chains are, in most cases, less than 1 Bq/g. As indicated in para. 4.20, the requirements for existing exposure situations normally apply to such materials; however, a safety assessment is generally considered to be mandatory for these residues from uranium mining, which are managed in accordance with the requirements for planned exposure situations.

GRADED APPROACH TO REGULATION

5.7. For NORM activities subject to the requirements for planned exposure situations, a graded approach to regulatory control is required to be adopted, in accordance with Requirement 6 of GSR Part 3 [4]. As such, the application of the requirements for planned exposure situations to NORM activities need to be commensurate with the characteristics of the NORM activity, and with the magnitude and likelihood of the exposures. As stated in Section 4, where an existing formal regulatory process (e.g. licensing) is already in place for managing residues, then that process should be followed. An example of the application of the graded approach to NORM residues is given in Annex III.

5.8. Important features of the graded approach in planned exposure situations are provisions for exemption and clearance based on established criteria (see Schedule I of GSR Part 3 [4]), and the application of different levels of regulatory control, as follows:

(a) Exemption (from some or all regulatory requirements);

(b) Notification;

(c) Authorization in the form of registration;

(d) Authorization in the form of licensing.

5.9. A stepwise and graded approach to the regulatory control of NORM residues in accordance with GSR Part 3 [4] is shown in Figure 1.

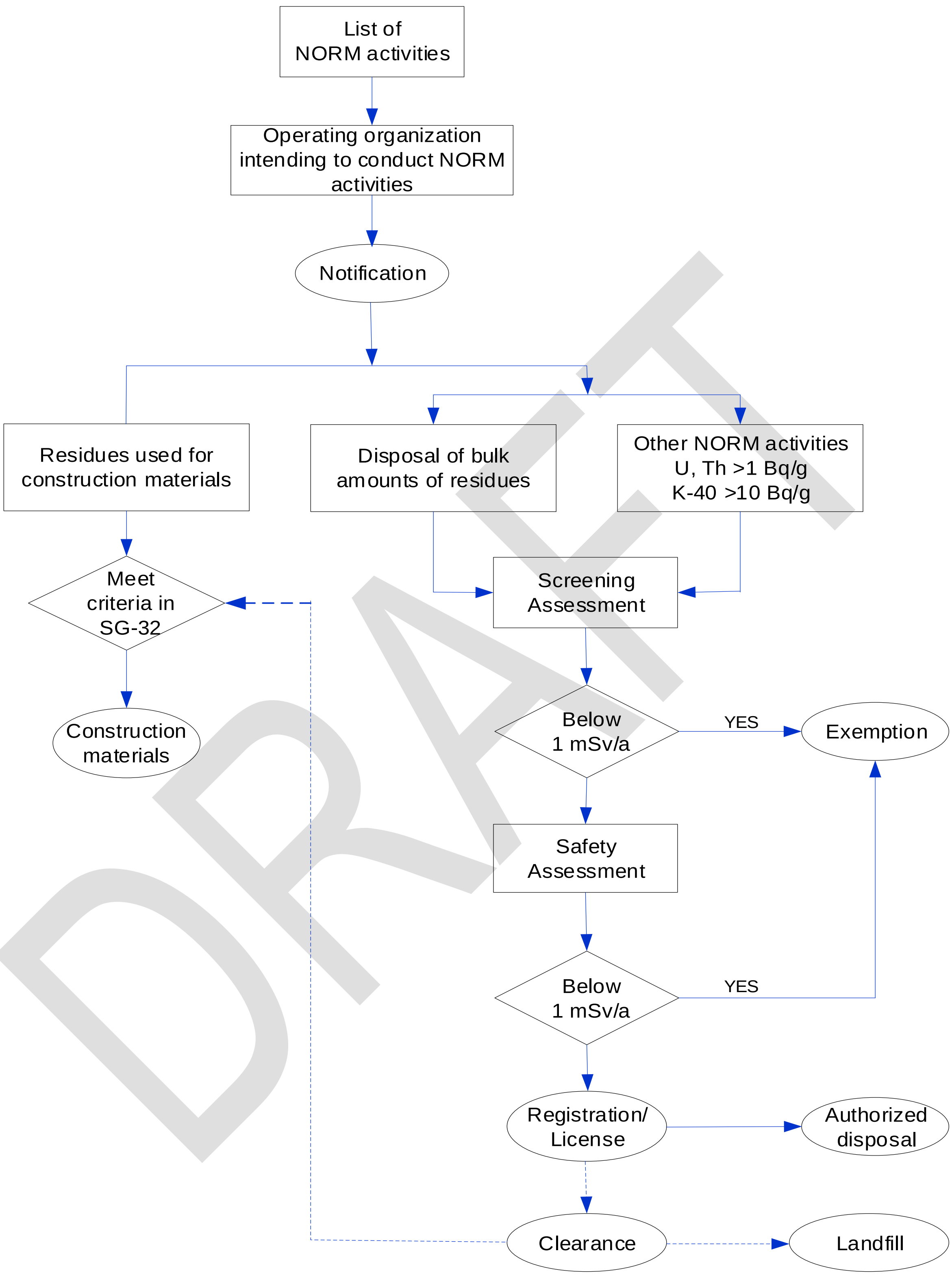

FIG 1. Stepwise and graded approach to the regulatory control of NORM residues in accordance with GSR Part 3 [4]

Notification

5.10. Requirement 7 of GSR Part 3 [4] states that: “Any person or organization intending to operate a facility or conduct and activity shall submit to the regulatory body a notification…” This notification should be made when it is intended to carry out the practice or when it is intended to make any modifications with implications for radiation protection. In this way, the regulatory body remains informed of operations and important changes.

5.11. An operating organization that intends to start an activity that is on the list of identified NORM activities within the State, should formally inform the regulatory body of its plans, including the following information:

(a) The type of intended activity and contact information;

(b) The location of the facility or activity, and details of the surrounding environment;

(c) The process and the processing capacity, including raw materials, discharges and the generation of solid residues;

(d) The radiological characteristics of raw materials, by-products and residues;

(e) The plan for managing NORM residues.

5.12. As stated in para. 3.7 of GSR Part 3 [4]:

> “Notification alone is sufficient provided that the exposures expected to be associated with the practice or action are unlikely to exceed a small fraction, as specified by the regulatory body, of the relevant limits, and that the likelihood and magnitude of potential exposures and any other potential detrimental consequences are negligible.”

In such cases, there may be no need for any further action by the operating organization or the regulatory body. Nevertheless, the recommendations provided in this Safety Guide can still be used as guidance to encourage best practice in the management of NORM residues.

5.13. For reuse and recycling of NORM residues into construction materials, reference levels are required to be established by the regulatory body or other relevant authority, in accordance with Requirement 51 of GSR Part 3 [4]. In addition, manufacturers and suppliers should provide the relevant authority with information on the activity concentration of radionuclides in construction materials: see para. 4.14 of SSG-32 [9].

5.14. If the NORM activity involves disposal of bulk amounts of residues, a screening assessment (see paras. 5.16–5.19) is very likely to be necessary, and a further detailed safety assessment might also be necessary (see Section 7).

5.15. For other NORM residues (i.e. not recycled into construction materials or disposed of in bulk amounts), if the activity concentration of any radionuclide in the uranium decay chain or the thorium decay chain exceeds 1 Bq/g (or 10 Bq/g for ^{40}K), a screening assessment should be carried out for decision making on exemption from any further regulatory requirements.

Screening assessment

5.16. Upon receiving notification from the operating organization (or if the regulatory body has identified an industry belonging to the list that has been complied as described in paras 5.3–5.6) the regulatory body may request that the operating organization undertakes a screening assessment that includes the following:

(a) The baseline radiological conditions on the site and in the surrounding environment (see para. 4.10);

(b) The activity concentrations in the raw materials, in processed materials, and in residues, and where these occur in the facility;

(c) The estimated magnitude of the doses to workers and to members of the public arising from the NORM residues, including the impact on these estimated doses from implementing alternative options for the long term management, reuse and recycling of NORM residues;

(d) The protection measures that have been implemented for workers and for members of the public.

5.17. The screening assessment should be specific to a particular facility or activity, where specific information is available, and the assessment method should be agreed with the regulatory body. The assessment could be based on existing information relating to the facility or activity and its processes and residue management methods. Alternatively, the assessment might be based on an agreed monitoring programme that is designed to provide more data. In some cases, the screening assessment could be based on assessments undertaken for other similar facilities, activities or processes that involve similar materials.

5.18. Possible outcomes of the screening assessment include exemption, authorization by registration (including a periodic review) or authorization by licensing. If the estimated effective dose, excluding the contribution from the emanation of radon, to workers or to the public exceeds 1 mSv in a year, a more detailed safety assessment should be undertaken (see paras 5.27–5.30) and the facility or activity may need be authorized.

5.19. In the event of a significant change in the process, or where external events (e.g. flooding, fire, land slippage, subsidence) have affected the facility or activity, a new screening assessment might be necessary. The operating organization and the regulatory body should review the situation after a mutually agreed period to check whether the conclusions of the screening assessment are still valid.

Exemption

5.20. The regulatory body may decide that the optimum regulatory option is to not apply regulatory requirements to the operating organization. The mechanism for implementing such a decision is the granting of an exemption for some or all aspects of the facility or activity and from some or all of the regulatory requirements. As stated in para. I.1 of GSR Part 3 [4]:

> "The general criteria for exemption of a practice or a source within a practice from some or all requirements of [GSR Part 3] are that:
>
> (a) Radiation risks … are sufficiently low as not to warrant regulatory control…, or
>
> (b) Regulatory control … would yield no net benefit, in that no reasonable control measures would achieve a worthwhile return in terms of reduction of individual doses or of health risks."

5.21. For NORM activities, the general criteria for exemption are deemed to have been met if the doses to workers and the public (as determined in the screening assessment) from the activity are 1 mSv per year or less. As stated in para. I.4 of GSR Part 3 [4]:

> "Exemption of bulk amounts of material is necessarily considered on a case by case basis by using a dose criterion of the order of 1 mSv in a year, commensurate with typical doses due to natural background levels of radiation."

5.22. In granting an exemption, the regulatory body may choose to exempt the operating organization from some or all or of the regulatory requirements, including liability. The regulatory body should choose to grant a partial exemption in cases where certain specific control measures are considered to achieve a net benefit.

Registration

5.23. Registration is the appropriate form of authorization in cases where the operating organization has only limited obligations to meet to ensure that workers, the public and the environment are adequately protected. These obligations would typically involve measures to keep exposures under review and to ensure that the management of NORM residues, the impacts of discharges to the environment and working conditions are such that protection and safety are optimized, with doses not approaching or exceeding the established dose constraints or the authorized limits for discharges.

5.24. As stated in footnote 19 to para. 3.8 of GSR Part 3 [4]:

> "Typical practices that are suitable for registration are those for which: (i) safety can largely be ensured by the design of the facilities and equipment; (ii) the operating procedures are simple to follow; (iii) the training requirements for safety are minimal; and (iv) there is a history of few problems relating to safety in operations. Registration is best suited to those practices for which operations do not vary significantly."

5.25. For NORM activities authorized by registration a graded approach to other regulatory processes, including review and assessment and inspection of facilities and activities, should also be applied. The facility or activity will not need a complex radiation protection programme for managing NORM residues; instead, this might be integrated with overall programme for health and safety. Such facilities and activities will require a safety assessment and a radiological environmental impact assessment; however, generic assumptions and simple calculations are likely to be more appropriate than the more complex safety assessments set out in Section 7.

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

Safety assessment

5.27. If the screening assessment indicates that doses might exceed 1 mSv in a year, a more detailed safety assessment should be conducted. As described in Section 7 of this document, this might include:

(a) A detailed baseline survey of the site and its surrounding environment;

(b) The use of assumptions and exposure scenarios that are more realistic than those used in the screening assessment;

(c) The collection of more specific data to improve the estimation of the source of exposure, the exposure pathways and the resulting doses;

(d) More complex models to estimate exposures.

5.28. If the safety assessment demonstrates that the expected doses are of the order of 1 mSv per year, the regulatory body can still grant a partial exemption, subject to certain conditions, such as enhanced monitoring by the operating organization and/or by the regulatory body and regulatory inspections.

5.29. If the expected doses are of the order of 1 mSv per year and have the potential to slightly exceed 1 mSv in a year, they regulatory body may authorize the practice by registration.

5.30. Where the safety assessment demonstrates that doses will exceed 1 mSv in a year, regulatory authorization incorporating further regulatory controls is needed and appropriate, and these controls should be placed on the operating organization through the granting of a licence by the regulatory body.

Licensing

5.31. Licensing is the appropriate form of authorization for NORM activities in which an acceptable level of protection can only be ensured only through the enforcement of more stringent measures to control radiation exposures. This is the highest level of the graded approach to regulation and is normally used for practices involving exposure to the following residues:

- Residues that are generated in very substantial quantities (e.g. by uranium production facilities);
- Low volume residues containing radionuclides with a high activity concentration;
- Residues that are discharged to the environment in significant quantities.

5.32. Licensed facilities and activities should undertake a radiological environmental impact assessment and ensure that the safety assessment addresses the recommendations provided in Section 7. A specific programme for the management of NORM should be developed and fully documented, and should be made available for regulatory review. Licensed facilities and activities should be subject to regular regulatory supervision.

5.33. For facilities and activities subject to licensing, the strategies for NORM residue management set out in Section 6, and the safety considerations for long term management set out in Section 8, represent the general expectations in terms of the control measures that should be implemented. The regulatory body should specify in the licence conditions the measures necessary to effectively manage the risks.

Clearance

5.34. Clearance is defined as the removal of regulatory control by the regulatory body from radioactive material or radioactive objects within notified or authorized facilities and activities [1], thus allowing the material or objects to be removed from the site without any further restrictions. As stated in para. I.10 of GSR Part 3 [4]:

> "The general criteria for clearance are that:
>
> (a) Radiation risks arising from the cleared material are sufficiently low as not to warrant regulatory control, and there is no appreciable likelihood of occurrence for scenarios that could lead to a failure to meet the general criterion for clearance; or
>
> (b) Continued regulatory control of the material would yield no net benefit, in that no reasonable control measures would achieve a worthwhile return in terms of reduction of individual doses or of health risks."

5.35. As stated in para. I.12(c) of GSR Part 3 [4]:

> "Radioactive material may be cleared without further consideration provided that:
>
> (c) For radionuclides of natural origin in residues that might be recycled into construction materials, or the disposal of which is liable to cause the contamination of drinking water supplies, the activity concentration in the residues does not exceed specific values derived so

as to meet a dose criterion of the order of 1 mSv in a year, which is commensurate with typical doses due to natural background levels of radiation."

5.36. As stated in para. I.13 of GSR Part 3 [4]:

"Clearance may be granted by the regulatory body for specific situations, on the basis of the criteria of paras 1.10 and 1.11 [of GSR Part 3], with account taken of the physical or chemical form of the radioactive material, and its use or the means of its disposal[65]. Such clearance levels may be specified in terms of activity per unit mass or per unit surface area.

"[65]For example, specific clearance levels may be developed for metals, rubble from buildings and waste for management in landfill sites."

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

5.37. In accordance with para. I.12(b) of GSR Part 3 [4], NORM residues may be cleared without further consideration provided that the activity concentration of each radionuclide in the uranium decay chain or the thorium decay chain is below 1 Bq/g and the activity concentration of ^{40}K is below 10 Bq/g. The clearance of NORM residues containing activity concentrations above these values may be appropriate in certain situations, providing the regulatory body is satisfied that future exposures from such residues will not require the reinstatement of controls.

FINANCIAL PROVISIONS

5.38. The objective of the provision of financial resource is to protect the government and society from liabilities arising from the operating organization failing to adequately construct, operate, decommission or ensure the effective closure of a site containing NORM residues.

5.39. As described in para. 3.9, the government should establish a regulatory framework that allows the regulator body to require financial resources from the operating organization to cover all costs (including any extra costs incurred due to the existence of NORM residues) associated with decommissioning or long term institutional control of a site containing NORM residues. These finances should be accessible only for the purpose of decommissioning or closure and any long term institutional control.

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

5.41. With regard to disposal facilities, the regulatory body should require the operating organization to establish a mechanism to ensure that adequate funds are available for closure and for any ongoing institutional control. The amount of funding that is needed will vary with time as liabilities increase due to the impact of operations, and decrease with any progressive decommissioning, where applicable. Funding estimates should become more accurate as the scheduled final decommissioning approaches. Operating organizations could become insolvent at any time; therefore, the funds need to be in place prior to the creation of liabilities. For many NORM residues the liability and the financial resources should address both the radiological and non-radiological aspects.

5.42. The regulatory framework should include the condition that the requirement for financial resources cannot be terminated without regulatory approval. The amount of financial resources should be reviewed at a frequency that is commensurate with the liabilities incurred by the NORM residue.

INTERESTED PARTIES

5.43. The regulatory body and the operating organization are required to consult with interested parties: see, for example, Requirement 36 of GSR Part 1 (Rev. 1) [3], Requirement 5 of GSR Part 2 [19] and Requirement 3 of GSR Part 3 [4]. For facilities and activities involving the management of NORM residues, the regulatory body should ensure that the operating organization undertakes a consultation process with interested parties, when deemed necessary by the regulatory body. This consultation should also be consistent with the graded approach to regulation; for activities subject to authorization this should be a condition of licensing. Radioactive material attracts a high amount of public scrutiny, even when the associated radiation risk is low. Consultation with affected interested parties is required to be an open and inclusive process (para. 4.67 of GSR Part 1 (Rev. 1) [3]).

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

(a) Residents and landowners;

(b) Indigenous people;

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

(d) Government agencies including the regulatory body.

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

5.46. A government that is setting up a new NORM regulatory framework should consider, where appropriate, undertaking a public engagement and education programme. It should promote awareness among NORM industries and promote education and training activities for operating organizations and workers involved in NORM activities.

THE MANAGEMENT SYSTEM

5.47. Requirement 5 of GSR Part 3 [4] requires that protection and safety are effectively integrated into the overall management system, and that:

> "the management system is designed and applied to enhance protection and safety by ... describing the planned and systematic actions necessary to provide confidence that the requirements for protection and safety are fulfilled".

5.48. Requirements for the management systems are established in GSR Part 2 [19]. Recommendations relevant to establishing a management system for NORM residues are provided in the following publications:

- IAEA Safety Standards Series, No. GS-G-3.1, Application of the Management System for Facilities and Activities [23];
- IAEA Safety Standards Series No. GS-G-3.3, The Management System for the Processing, Handling and Storage of Radioactive Waste [24];
- IAEA Safety Standards Series No. GS-G-3.4, The Management System for the Disposal of Radioactive Waste [25].

5.49. With respect to facilities and activities relating to the management of NORM residues, the management system will need to address the life cycle of the residues, from their generation until their reuse, long term management and/or disposal, and the life cycle of the facilities, including siting, design, construction, commissioning, operation, decommissioning or closure and, as appropriate, long term institutional control.

5.50. The management system will need to address the impacts and controls identified in the safety assessment and in the radiological environmental impact assessment. Residue management plans should be established. For uranium production these plans should cover residue management, radiation protection, environmental management, emergency preparedness and response, decommissioning and closure (as appropriate), monitoring and evaluation, engagement of interested parties, and transport of radioactive material. The recommended contents of a residue management plan and a decommissioning plan applicable to uranium production are provided in Appendix II and Appendix III, respectively. The information in

Appendix II and Appendix III might also be applicable, to some extent, to NORM residues of other origin with similar characteristics. Plans for the management of residues from other NORM facilities and activities should be developed, commensurate with the scale of the operation and nature of the risks.

5.51. As stated in Requirement 6 of GSR Part 2 [19]:

> "The management system shall integrate its elements, including safety, health, environmental, security, quality, human-and-organizational-factor, societal and economic elements, so that safety is not compromised."

Radiation protection should be integrated with and incorporated into management systems for quality assurance, environment and workplace safety. With regard to the management of NORM residues, it is important that radiation safety is not allowed to compromise protection from more significant workplace hazards or environmental impacts.

5.52. The management system should include measurable performance indicators for radiation protection, including for occupational exposure and public exposure, and in terms of workplace monitoring results.

5.53. As part of the management system, operational limits and conditions[9] should be developed on the basis of the following:

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

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

(c) The key factors and components that are important to safety;

(d) The consequences of events following the failure of equipment;

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

5.54. The plans for the management of residues should be reviewed by the operating organization, as follows:

(a) At a frequency agreed with the regulatory body;

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

(c) As part of the process of periodically reviewing the safety case (see Section 7) for the facility;

[9] Operational limits and conditions are a set of rules setting forth parameter limits, the functional capability and the performance levels of equipment and personnel approved by the regulatory body for safe operation of an authorized facility [1].

(d) Following incidents or near misses[10];

(e) If there are changes in relevant regulatory requirements.

Any consequent changes that are made to the plans for managing NORM residues as a result of these reviews should be subject to regulatory approval.

6. STRATEGIES FOR NORM RESIDUE MANAGEMENT

GENERAL

6.1. This section provides recommendations on the general approach to NORM residue management in facilities and activities for which authorization by licensing is appropriate, including the application of the graded approach to implement the requirements established in GSR Part 5 [8]. It covers options for residue management through processing[11], reuse and recycling, storage and retrieval and long term management of NORM residues. Approaches to controlling the generation of NORM residues are also described. More information on the long term management of NORM residues is given in Section 8. For other facilities and activities (i.e. for which licensing is not appropriate), the recommendations in this section can also be useful in terms of continuous improvement and the application of good practices.

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

(a) Assessment of the potential for generating different types of residue, based on the design and operation of similar facilities;

(b) Measures to control the generation of residues;

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

(d) Clearance, if applicable;

(e) Reuse and recycling;

(f) Discharge to the environment;

(g) Long term management, including disposal where appropriate.

[10] A 'near miss' is defined as a potential significant event that could have occurred as the consequence of a sequence of actual occurrences but did not occur owing to the conditions prevailing at the time [1].

[11] Processing is considered to be any operation that changes the characteristics of residues, including pretreatment, treatment and conditioning

6.3. Facilities that generate NORM residues should be designed such that exposures arising from the management of such residues are optimized. The design should address the principle of preventing an undue burden on future generations, for example by minimizing waste to be disposed of; minimizing the use of fresh water; minimizing the project footprint and its potential impacts; and by maximizing the reuse and recycling of materials, with due consideration of radiation safety issues and regulatory requirements.

6.4. To avoid the need for long term management of residues, the options of clearance, discharge to the environment, reuse and recycling, and authorized disposal (including disposal at existing landfills and other waste disposal facilities), should be used to the maximum extent possible, subject to meeting relevant regulatory requirements. The segregation of NORM residues can reduce the volume of material for which long term management is necessary and, as a result, can reduce the amount of land or surface area needed for this purpose. Segregation facilitates the clearance, reuse and recycling of residues, as well as the conditioning and packaging of other NORM residues for transport and long term management off the site.

6.5. The design, construction, operation, decommissioning and/or closure of facilities for the processing, storage and disposal of residues from NORM activities should be undertaken in accordance with the management system outlined in paras 5.47–5.54. In particular, licenced facilities for the management of NORM residues should be constructed, operated and decommissioned or closed in accordance with plans and procedures approved by the regulatory body. Appendix I provides special considerations for residues arising from uranium production.

6.6. The siting and design of the long term management facility should aim to avoid the need to relocate large quantities of residues when the NORM activities on the site cease. Siting and design are an essential part of the overall project development, and should be addressed from the earliest stages of project development, as described in Section 8.

6.7. The decommissioning and/or closure of a residue management facility should be considered in all phases of the NORM activity, that is, during siting, design, construction and operation. Planning for the management of NORM residues should already have been addressed in the siting and design phase, and not be delayed until the decommissioning or closure stage. For example, taking measures at an early stage to reduce the migration of water-borne and airborne contamination to the surrounding environment will facilitate the subsequent management of the closure stage. During design and operation, attention should be given to the prevention and management of contamination of the plant and pieces of equipment. Consideration should also be given to potential events that may result in unexpectedly spreading of contamination.

6.8. Section 8 of this Safety Guide outlines the important characteristics and desirable features of the options that should be considered for the long term management of residues from NORM activities that require authorization through licensing, including considerations in the design, construction, operation, decommissioning or closure of facilities, the release of materials from regulatory control, and the factors to be considered for institutional control of disposal facilities.

DEVELOPMENT AND IMPLEMENTATION OF A RESIDUE MANAGEMENT PLAN

6.9. A residue management plan should be developed, implemented and updated, as necessary, by the operating organization, in compliance with relevant regulatory requirements and in accordance with the operating organization’s policy and strategy for protection and safety, environmental management and waste management. The residue management plan should address the various streams of residues, with account taken of their respective characteristics, and address the full life cycle, from the generation of the residue until clearance, discharge, reuse and recycling or long term management including final disposal, as appropriate. Further information on a residue management plan for uranium production is given in Appendix II.

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

6.11. The characterization of residues is an important factor in determining appropriate controls. Characterization helps in developing a complete understanding of the physical, chemical and radiological characteristics of the residue(s) for classification and segregation, transport, processing, reuse and recycling, and for long term management, including final disposal.

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

(a) Sources and quantities of NORM residues;

(b) Physical, chemical and radiological characteristics;

(c) Significant exposure pathways and exposure scenarios;

(d) Predicted radiation exposures and radiological environmental impact from the residues considered;

(e) Predicted impacts and risks from non-radiological components that might affect the radiological characteristics (for example the acidic nature of residue might lead to the mobilisation of radionuclides);

(f) The measures that may be taken to control exposures, environmental impacts and other risks, including any measures to mitigate the consequences of accidents.

6.13. The development of a cost effective residue management plan can be complex. The process involves evaluating options for siting, design and construction, operation, management of residues streams (e.g. processing, storage, recycling), decommissioning or closure and long term institutional control. Factors to be taken into account include benefits, costs, detriments, the national policy and strategy, and any regulatory limits and constraints. The process is also iterative as different options are evaluated. For many NORM residues, non-radiological environmental considerations will dominate the radiological considerations.

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

CONTROL OF RESIDUE GENERATION

6.15. NORM facilities and activities should be designed to reduce, as far as practicable, the volume and radioactivity content of residues and waste to be managed. This can be accomplished through the choice of appropriate processes that generate less NORM residues, and the reuse and recycling of equipment, materials and residues.

6.16. With regard to design features and operational procedures for controlling the generation of residues, the operating organization should consider the following aspects:

(a) The selection of design options, processes and materials, construction methods, commissioning, and operating procedures that facilitate the control of the generation of residues throughout the entire life cycle of the facility, including decommissioning;

(b) The implementation of measures to avoid spills and the classification and designation of areas to prevent the spread of contamination;

(c) Appropriate segregation of the various streams of residues to facilitate subsequent processing and reuse and recycling, where appropriate.

6.17. The quantities of residue that need long term management should be kept to the minimum practicable. Viable options for the safe reuse or recycling of NORM residues should be sought by the operating organization before designating such residues as NORM waste. Information on the reuse and recycling of NORM residues is given in Annex IV.

PROCESSING

Pretreatment

6.18. Pretreatment generally consists of collection, characterization, segregation, chemical adjustment and/or treatment of residues and decontamination of equipment contaminated with residues, including interim storage, as necessary.

6.19. The characterization step is important because it provides an opportunity to segregate residues in terms of their physical, chemical and radiological features, and so facilitate the subsequent management of the residues, including treatment, storage, clearance and reuse and recycling.

6.20. Residues should be segregated on the basis of their physical, chemical and radiological characteristics, with account taken of subsequent options for treatment and the potential for generating further (secondary) residues. Segregation should be designed and implemented to reduce the volume of residues and/or waste that will need long term management. Segregation should facilitate the reuse and recycling of residues. In mining and mineral processing, the segregation of non-mineralized or clean waste rock from mineralized waste rock is a pretreatment activity.

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

Treatment

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

6.23. Other options for liquid residue management include:

(a) Diversion of clean water away from sources of contamination;

(b) Reuse of residue water in the process or for dust suppression;

(c) Treatment to separate any solid NORM residues that are suspended in liquids;

(d) Treatment of residual liquid to make it suitable for discharge to the environment;

(e) Optimised processes to reduce the volume.

6.24. Unless the practice or source is exempt, or the residue meets the criteria established for release from regulatory control (see paras 5.34–5.37), authorization for discharges is required: see paras 3.4, 3.123, 3.124 and 3.132–3.134 of GSR Part 3 [4]. Further recommendations are provided in GSG-9 [7].

Conditioning

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

6.26. Residues containing hazardous constituents that can become mobile in the environment, or constituents that can enhance the mobility of radionuclides in the environment, should be immobilized, stabilized or otherwise properly controlled. This is particularly important for large volumes of mining and processing tailings and for stockpiles of NORM residues from processed raw materials, such as phosphogypsum and red mud, and in acid mine drainage.

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

REUSE AND RECYCLING

6.28. The implementation of reuse and recycling options should be subject to suitable criteria, especially clearance criteria (including, as appropriate, clearance for specific situations: see paras 5.36 and 5.37). More information on reuse and recycling of NORM residues is given in Annex IV.

6.29. As described in para. 5.35, for radionuclides of natural origin in residues that might be recycled into construction materials, the activity concentration in the residues should not exceed specific values derived to meet a dose criterion of the order of 1 mSv in a year. Further recommendations on the use of NORM residues in the manufacture of construction materials are provided in SSG-32 [9]. The reference level of about 1 mSv in a year applies to the dose received from exposure to gamma radiation from the building materials only, i.e. excluding any additional dose from ^{222}Rn or ^{220}Rn released from building materials into indoor air: see paras 4.17–4.27 of SSG-32 [9].

STORAGE AND RETRIEVAL OF RESIDUES

6.30. Storage refers to the placement of the NORM residues in a facility where appropriate containment is provided, and with the intention of retrieval of these residues [1]. Storage may take place between and/or within different residue management steps. In some cases, storage may be used to facilitate the next step in the residue management, for example to act as a buffer within and between residue management steps, or to provide time for the decay of radionuclides until authorized discharge, authorized reuse and recycling or clearance can be allowed. For example, some residues might be suitable for storage to allow for decay of short lived radionuclides such as ^{210}Po.

6.31. Storage might be appropriate for materials that are currently uneconomic to process but that might be subsequently retrieved. In such cases, it is important that the management plan adequately manages the risks and liabilities associated with stockpiled residues.

OPTIONS FOR LONG TERM MANAGEMENT OF NORM RESIDUES

6.32. The preferred option for long term management will depend on the conditions at the facility or the site where the activity is undertaken, and on the characteristics of the ore body or the process materials, the mining and/or processing operation and the residues generated. When no future use of the NORM residues is foreseen, the residues should be processed or otherwise prepared so as to meet acceptance criteria for long term management established with the approval of the regulatory body. These criteria are required to specify the radiological, mechanical, physical, chemical and biological properties of the residues (para. 4.24 of GSR Part 5 [8]).

Bulk amounts of residues

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

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

6.35. The relocation of large quantities of material is an expensive option and can affect the viability of a project. Relocating bulk amounts of NORM residues when a site is shut down would not normally be the optimum strategy for residue management because of the very large volumes and costs involved. In considering the relocation of bulk amounts of residues, the radiological, non-radiological and environmental impacts introduced by the relocation itself should be taken into account.

6.36. Subject to authorization by the regulatory body, some residues may be suitable for reincorporation into the environment from which they were originally removed, possibly including blending or selective mixing to reduce activity concentrations, where allowed by the regulatory body. An example would be monazite sands being reincorporated uniformly into the remediated workings of a minerals sands extraction operation.

Medium quantities of residues

6.37. A possible option for medium quantities of residues that can be transported is taking such residues to existing management facilities, or co-locating the residues with other wastes, for example in landfills. If on-site management is still considered to be the best option, siting and design are important considerations, as described in Section 8.

Low volume residues with higher activity concentrations

6.38. Residues that arise in small quantities can be managed at off-site facilities, using a graded approach based on risk evaluation and regulatory approval.

6.39. Small volumes of unmodified residues might be sealed into suitable containers and deposited together with radioactive waste or other hazardous waste in a designated waste facility or special landfills, or possibly placed deep within tailings management facilities that are destined for long term management. Possible options for some liquid residues, such as those from in situ leaching of uranium, are injection into suitable geological formations or pretreatment followed by land application.

6.40. After an appropriate treatment, some low volume, high activity residues might be suitable for dispersion throughout a large volume of low activity residues, provided this is addressed in the safety case and meets regulatory requirements. For instance, scales with a significant activity concentration are often removed by water jetting techniques; the secondary waste from this decontamination process might be suitable for mixing with low activity residues.

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

GENERAL

7.1. Paragraph 3.15 of SF-1 [2] states that:

> "Safety has to be assessed for all facilities and activities, consistent with a graded approach. A safety assessment involves the systematic analysis of normal operation and its effects, of the ways in which failures might occur and the consequences of such failures."

7.2. The safety assessment is required to address risks in the present and in the long term, in accordance with para. 4.11 of IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Facilities and Activities [26]. Requirements for the safety assessment for predisposal management of radioactive waste are established in GSR Part 5 [8],

7.3. A safety case is defined as a collection of arguments and evidence in support of the safety of a facility or activity, and will normally include the findings of a safety assessment and a statement of confidence in these findings [1]. Recommendations on the safety case and safety assessment specific to the predisposal management and disposal of radioactive waste are provided in IAEA Safety Standards Series No. GSG-3, The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste [27], and in IAEA Safety Standards Series No. SSG-23, The Safety Case and Safety Assessment for the Disposal of Radioactive Waste [28].

7.4. The recommendations in this section apply to NORM residues associated with facilities and activities for which licensing is the appropriate form of authorization, i.e. where an acceptable level of protection and safety can be ensured only through the enforcement of more stringent measures to control radiation exposures. This is the highest level of regulation described in Section 5, which should be applied to those practices listed in para. 5.31. For uranium production and other significant NORM facilities and activities, a safety case and a supporting safety assessment will be required, in accordance with para. 4.1 of GSR Part 4 (Rev. 1) [26].

7.5. For facilities and activities relating to the long term management (including disposal) of NORM residues (see Section 8), a safety case and safety assessment should be prepared before the facility is constructed or the activity is commenced. SSG-23 [28] provides further recommendations on the safety case and safety assessment. As stated in para. 1.9 of GSR Part 4 (Rev. 1) [26]:

"For many facilities and activities, environmental impact assessments and non-radiological risk assessments will be required before construction or implementation can commence. The assessment of these aspects will, in general, have many commonalities with the safety assessment that is carried out to address associated radiation risk. The different assessments may be combined to save resources and to increase the credibility and acceptability of their results."

7.6. A safety assessment is required to be undertaken in conjunction with the planning and design of a proposed facility or activity (para. 1.8 of GSR Part 4 (Rev. 1) [26]). When planning a NORM residue facility and/or activity, the operating organization should start to prepare and develop a safety assessment that demonstrates the safety of the proposed facilities or activities and that these facilities or activities will be in compliance with regulatory requirements.

7.7. The safety assessment should primarily address the radiological impact on people and the environment in terms of radiation doses and radiation risks. In cases in which non-radiological risks dominate the radiation risks, arrangements between the regulatory bodies involved are necessary in order to have a consistent approach to all hazards and to clearly assign the tasks and responsibilities of each regulatory body.

7.8. A radiological environmental impact assessment should form part of the safety assessment. GSG-10 [22] provides recommendations on a general framework for performing prospective assessments for facilities and activities, to estimate the radiological impact on the public and on the environment.

7.9. The key points to consider in conducting a safety assessment are as follows:

(a) A graded approach is required in terms of the scope and level of detail of the safety assessment that is carried out for different facilities and activities relating to NORM residue management (Requirement 1 of GSR Part 4 (Rev. 1) [26]).
(b) The safety assessment is required to be carried out at the design stage or as early as possible for an existing facility or activity (para. 4.6 of GSR Part 4 (Rev. 1) [26]). The safety assessment is required to cover the full lifetime of the facility or activity, including decommissioning or closure and post-closure, as appropriate (para. 1.8 of GSR Part 4 (Rev. 1) [26]).
(c) The safety assessment should identify and assess the impacts of the various streams of NORM residues through all potential exposure pathways. The effects of temporal variations (e.g. groundwater levels, diurnal radon fluctuations) should also be considered, including possible long term effects.
(d) The safety assessment is required to be documented and show how the assessment has led to improvements in design or operation (Requirement 20 and para. 4.15 of GSR Part 4 (Rev. 1) [26]).
(e) The safety assessment is required to be updated as necessary to reflect material changes in operation or regulatory requirements (para. 4.6 of GSR Part 4 (Rev. 1) [26]).

7.10. The operating organization is required to use the safety assessment as an input to establish operational limits and conditions, as well as a monitoring programme and administrative controls (Requirement 24 of GSR Part 4 (Rev. 1) [26]). The safety assessment should also inform the plan and design criteria for NORM residue management.

7.11. The safety assessment is the primary documentation for the operating organization to submit to the regulatory body when applying for an authorization for a facility or activity. Therefore, it should demonstrate compliance with regulatory requirements, with consideration of the whole life cycle of NORM residue management. An important outcome of the safety assessment is the facilitation of communication between interested parties on issues relating to the facility or activity (see also para. 5.9 of GSR Part 4 (Rev. 1) [26]).

7.12. The various stages in the lifetime of NORM residue facilities (i.e. siting, design, construction, operation, decommissioning or closure and post-closure) and NORM residue activities (residue generation, processing, reuse and recycling, storage and disposal) should be taken into account in the safety assessment.

7.13. The government should ensure that the regulatory framework (see Section 3) includes provisions for the regulatory review and approval of safety cases, in accordance with the graded approach.

SCOPE OF THE SAFETY ASSESSMENT

7.14. As noted in paras 7.1–7.4, the scope and extent of the safety assessment should be commensurate with the site-specific issues relating to NORM residue management to be addressed. The results of the initial safety assessment should be factored into the selection of the site and the design of the facility for NORM residue management. The assessment should consider all significant scenarios and exposure pathways by which workers, the public and the environment might be subject to a radiological impact. The scope and depth of the safety assessment should be sufficient to identify and evaluate relevant risk components over the lifetime of the facility or activity. The models or methods used should allow the effects of the various hazards associated with different options for NORM residue management to be compared in a consistent manner.

7.15. Both radiological and non-radiological components should be assessed in order to determine the optimization of protection and safety. The assessment of non-radiological impacts will also be subject to environmental protection legislation and health and safety legislation, as appropriate. While the assessment of non-radiological hazards lies outside the scope of this Safety Guide, the approaches to assessment described here might also be of use in the assessment of hazards and risk posed by non-radioactive components of NORM residues. Equally, existing systems to assess and manage environmental impacts and general health and safety (e.g. for workers) might be valuable in terms of managing radiological risks. This is especially true for NORM facilities and activities for which licensing is not considered appropriate.

7.16. The safety assessment should include aspects such as the following:

(a) A description of the site and the facility and/or activity, including relevant structures, systems and components and the characteristics of items important to the safety of facility or activity.
(b) The maximum expected inventory of radioactivity in raw materials, process equipment, products and NORM residues, together with any associated acceptance criteria.
(c) A description of operations and procedures (inside and outside the facility), including the associated inventories and characteristics of residues.
(d) A description of the management system for protection and safety in relation to NORM residue management.
(e) The systematic identification of hazards for scenarios associated with operational states and accident conditions.
(f) An evaluation of different scenarios, including combinations, which might result in a failure of containment that leads to a release of radioactive material, to eliminate from further consideration those scenarios of low likelihood or with low potential consequences.
(g) Assessment of doses to workers and the public, including exposure due to radon and/or thoron where applicable.
(h) Assessment of the likelihood and potential consequences of the release(s) of radioactive material and comparison of the results of the assessment with regulatory limits and constraints.
(i) The establishment of operational limits and conditions and administrative controls. If necessary, the designs for the management of NORM residue should be modified and the safety assessment should be updated.
(j) Procedures and operational manuals for activities with significant safety implications.
(k) A programme for periodic maintenance, inspection and testing of plant and/or equipment.
(l) A description of the monitoring and surveillance programmes.
(m) The training programme for staff.
(n) The emergency plan, if appropriate.
(o) Provisions for occupational radiation protection and for protection of the public and the environment.
(p) Provisions for decommissioning or closure including financial resources requirements, if applicable.

CONDUCTING A SAFETY ASSESSMENT

7.17. In addition to those aspects listed in para. 7.16, a safety assessment should include:

(a) The context for the assessment, including the assessment criteria;

(b) Development and justification of the operational scenarios to be assessed;

(c) Formulation and implementation of models used to calculate radiological impacts;

(d) An analysis of results and a comparison with the assessment criteria;

(e) A description of any revisions to the project or processes;

(f) A description of any reiterations of the assessment undertaken to achieve compliance with the assessment criteria and an optimized level of protection and safety.

7.18. The context for the assessment includes the purpose and scope of the assessment, the philosophy underlying the assessment, the regulatory framework, the assessment criteria and endpoints, and the time frame for the assessment. As noted in para. 7.9, the assessment is required to cover the full lifetime of the facility, including decommissioning or closure and post-closure, as appropriate.

7.19. The description of the site, facility and the operational activities should be sufficiently detailed to support the development of operational scenarios and the subsequent safety assessment of these scenarios. The scenarios should be specific, where practicable: specific site and facility features, facility specific operational arrangement and characteristics of NORM residues should be considered and selected. The scenario should cover features, events and processes during operation, closure and post-closure. For example, any factors that affect the stability of a tailings management facility, including natural and human activities, should be sufficiently addressed. It is required that the features, events and processes considered in the safety assessment are addressed systematically (see para. 7.1) and that the identification of scenarios relevant to safety is justified (para 4.51 of GSR Part 4 (Rev. 1) [26]).

7.20. Once the scenarios have been developed, the corresponding assessments should be carried out, with account taken of the application of the graded approach. This is commonly undertaken using assessment models. A useful approach is a site model that considers the potential pathways by which radioactivity might move through the environment. This site model should consider the inventories of NORM residues and their physical and chemical characteristics, the location of any NORM, including raw materials, residues and waste, together with a description of any non-radiological hazards. The assessment model may be developed from one or more of the following components: specialist knowledge, conceptual site models, mathematical modelling, and computer simulations. Often specific models may need to be developed, for example to consider particular processes. For the purposes of safety assessment, any individual components need to be linked in such a way that it is possible to assess the potential radiological impacts of the facility or activity as a whole.

7.21. The safety assessment should also consider the following:

(a) The endpoints for the assessment, together with a justification for their selection;
(b) If several facilities and/or activities exist or are planned for the same site, the cumulative impact of all such facilities and activities;
(c) Initiating events, including internal events, external events and human induced events (see paras 4.5 and 4.22 of GSR Part 4 (Rev. 1) [26]);
(d) The use of both conservative and realistic calculations in completing the assessment;
(e) For disposal facilities, the need for any ongoing institutional control after closure and the duration of any such controls;
(f) In relation to disposal facilities, the loss of institutional control after closure, including the possibility of inadvertent human intrusion;
(g) The use of sensitivity analyses and the approach to uncertainties in the safety assessment (see Requirement 17 of GSR Part 4 (Rev. 1) [26]).

7.22. Upon completion of the assessment, the radiation risks associated with each scenario should be quantified, screened and ranked in such a manner so as to direct resources towards the most significant hazards associated with the facility or activity. Any scenarios lacking the potential to cause any significant harm to people or the environment can be removed from further consideration in the safety assessment. In the re-evaluation of a safety assessment, any such decisions should be reviewed to check that they remain valid.

7.23. The safety assessment is required to be submitted by the operating organization to the regulatory body as part of the authorization process (para. 1.2 of GSR Part 4 (Rev. 1) [26]). The output from the safety assessment will also form part of the safety case that is required for certain facilities and activities: see Requirements 13–16 of GSR Part 5 [8].

7.24. If the results of the safety assessment do not demonstrate compliance with regulatory requirements, the project components should be revisited and revised as necessary to achieve the necessary level of compliance. It is not sufficient that the calculated doses are below dose constraints; the project should be re-assessed in order to demonstrate that protection and safety is optimized. This step should be repeated, as necessary, to "provide the highest level of safety that can reasonably be achieved throughout the lifetime of the facility or activity…" (para. 3.21 of SF-1 [2]). The safety case should not be finalized until this iterative process is completed.

7.25. The operating organization should ensure that any calculations undertaken as part of the safety assessment are sufficient to enable comparisons with the assessment endpoints and with any additional safety or performance criteria specified by the regulatory body. Guidance on the application of the safety assessment results should be provided by the operating organization when applying for a licence. For example, it should be explained how the safety assessment results (endpoints) demonstrate compliance with regulatory criteria (e.g. safety targets).

GRADED APPROACH TO SAFETY ASSESSMENT

7.26. It is important that a graded approach to conducting safety assessment is applied, and that existing occupational health, safety and environmental control measures are taken into account. For NORM residues, in many cases very simple assumptions and calculations may be more appropriate than undertaking a detailed and complicated safety assessment. Furthermore, additional controls should be applied to the management of NORM residues only where these controls are necessary to reach an optimum level of radiation protection.

7.27. Safety assessment is a systematic process (para. 3.15 of SF-1 [2]), and the resources devoted to safety assessment are required to be proportionate to the risks that need be managed (para. 3.2 of GSR Part 4 (Rev. 1) [26]). For more complex projects, the safety assessment should be iterative, and with each iteration contributing to the optimization of protection and safety.

7.28. Due account needs to be taken of social and economic factors when determining the optimum level of protection, and also when determining the optimum level of regulatory intervention (paras 3.23–3.24 of SF-1 [2]). As such, while the safety principles are the same for managing any radioactive residues, regardless of origin, there are likely to be significant differences in the practical focus of individual programmes for NORM residue management in order to optimize protection.

7.29. Paragraph 3.3 of GSR Part 4 (Rev. 1) [26] states:

> "The main factor to be taken into consideration in the application of a graded approach is that the safety assessment has to be consistent with the magnitude of the possible radiation risks arising from the facility or activity. The approach also takes into account any releases of radioactive material in normal operation, the potential consequences of anticipated operational occurrences and possible accident conditions, and the possibility of the occurrence of very low probability events with potentially high consequences."

7.30. Three aspects to be considered in the application of a graded approach (paras 3.3–3.4 of GSR Part 4 (Rev. 1) [26] are:

(a) The magnitude of the possible radiation risks;

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

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

7.31. The application of the graded approach should be reassessed as the safety assessment progresses and a better understanding is obtained of the radiation risks arising from the facility or activity. The regulatory body should consider granting exemption from specific regulatory requirements if the safety assessment demonstrates that such requirements will not be effective in terms of the optimization of protection and safety.

DOCUMENTATION OF THE SAFETY CASE AND THE SAFETY ASSESSMENT

7.32. As stated in Requirement 15 of GSR Part 5 [8] in respect of predisposal radioactive waste management facilities and activities:

> "The safety case and its supporting safety assessment shall be documented at a level of detail and to a quality sufficient to demonstrate safety, to support the decision at each stage and to allow for the independent review and approval of the safety case and safety assessment. The documentation shall be clearly written and shall include arguments justifying the approaches taken in the safety case on the basis of information that is traceable"

7.33. Any assumptions made, or generic information used, in the safety case are required to be justified in the documentation (para. 5.9 of GSR Part 5 [8]). For facilities or activities that involve long time frames, a plan for adequate record keeping over the expected project life should be provided as part of the safety case.

7.34. Some regulatory bodies might not have in-depth experience and expertise in the regulation of facilities and activities involving NORM residues. In such cases, the regulatory body may need to seek cooperation and advice from relevant expert agencies and staff when reviewing and assessing the safety case and the safety assessment.

PERIODIC SAFETY REVIEWS

7.35. The safety assessment is required to be periodically reviewed (Requirement 24 of GSR Part 4 [26]) at predefined intervals in accordance with regulatory requirements (para. 5.12 of GSR Part 5 [8]). In accordance with Requirement 16 of GSR Part 5 [8], the safety case and supporting safety assessment is expected to be reviewed and updated:

(a) When there is any material change to the facility or activity, or a change in the radionuclide inventory that might affect safety;

(b) When changes occur to the site, which might impact on the facility or activity, such as encroaching industrial or municipal development;

(c) When significant changes in knowledge and understanding occur, for example from new research data or from monitoring and operating experience;

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

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

8. SAFETY CONSIDERATIONS FOR LONG TERM MANAGEMENT OF NORM RESIDUES

GENERAL

8.1. This section applies to facilities for long term management of NORM residues for which authorization by licensing is appropriate, as described in Section 5. This is the highest level of regulation described in Section 5, which should be applied to those practices listed in para. 5.31, and includes uranium production and other significant NORM facilities and activities for which a safety case and a supporting safety assessment is required, as described in Section 7.

8.2. The siting, design, construction, operation and decommissioning or closure of residue management facilities should meet the requirements established by the regulatory body, including any licensing conditions, through all of these phases. When residues have no foreseen further use, and are neither exempted nor cleared from regulatory control, the requirements for disposal of radioactive waste established in IAEA Safety Standards Series No. SSR-5, Disposal of Radioactive Wastes [29] will apply.

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

8.4. The construction of a facility for managing large volumes of NORM residues, such as uranium mine or process tailings, is generally a long term project involving significant costs; therefore, any issues in terms of siting, design or construction should be identified before work begins —or as early in the process as possible — to avoid unexpected costs. Repairs or other remedial measures on completed constructions will most likely be economically prohibitive, time consuming, and in some cases impractical.

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

SITING

8.6. In selecting a site for large volumes of residues, an important consideration is to minimize the dependence on active institutional controls. The final optimized choice of site, obtained using the conceptual design for residue management, should be assessed and the resulting safety assessment, which includes the environmental impact assessment, should be submitted to the regulatory body for review and approval. The choice of the location of a facility for the management of residues should take into consideration long term stability and the need to optimize protection and safety for people and the environment for the expected lifetime of the facility during normal operation and possible accident conditions. In selecting a site, consideration should be given to features that might help control the further generation of residues, for example features that minimize secondary contamination of environmental matrices, such as soil or seepage water. For uranium production and other NORM facilities, non-radiological environmental protection issues will usually dominate the decision making.

8.7. The long term management facility for bulk amounts of residues is usually near the site where the residues are generated. It is, however, essential to identify the optimum site through a step-wise site selection programme and site characterization programme: see also Requirement 15 of SSR-5 [29] in relation to site characterization for a disposal facility. A preliminary evaluation of site characteristics should be made to identify any restrictions, in terms of radiological and environmental factors, at each proposed location, and to allow the selection of a small number of locations and possible preliminary design concepts for which the impacts can then be evaluated in detail.

8.8. Characterization of the site is especially important when selecting a location for long term management of bulk residues. Understanding the site, including temporal fluctuations, before design decisions for long term management are made is very important. The site characterization information that is needed to support design decisions includes the following:

(a) Local climate and meteorology;

(b) Geography and geomorphology;

(c) Structural geology and seismology;

(d) Geochemistry (of natural and process materials);

(e) Mineralogy;

(f) Surface water and groundwater hydrology;

(g) Flora and fauna, including any protected and endangered species;

(h) Local land management;

(i) Population distribution and local land use;

(j) Archaeological and heritage issues;

(k) Socioeconomic issues.

DESIGN AND CONSTRUCTION

8.9. A long term management facility for NORM residues and/or NORM waste should be designed and constructed to:

(a) Minimize water infiltration;

(b) Maintain long term stability and integrity of containment;

(c) Maximize the use of inert and stable materials as containment barriers;

(d) Placing residues and/or waste below ground level to minimize the effects of potential surface erosion that could lead to the failure of the facility and/or accidental release of contaminated material;

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

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

(g) Minimize the potential for groundwater contamination;

(h) Minimize the need to retrieve or relocate residues before the closure of a disposal facility;

(i) Minimize the possibility of inadvertent intrusion;

(j) Facilitate the implementation of surveillance, maintenance and controls during operations and, where appropriate, post-closure;

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

8.10. The design of a long term residue management facility should follow good practice (and best practice, to the extent practicable) and meet the applicable regulatory requirements for protection and safety. Factors that should be considered in the design process include the following, as appropriate:

(a) Site characteristics (see para. 8.8);

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

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

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

(e) The potential for retrieval of residues for relocation, re-use or recycling (including processing for further resource extraction);

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

(g) The acid generating potential of the residues;

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

(i) Site access control and control of access to controlled areas;

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

(k) Ventilation of facilities including the filtration of exhaust air discharged to the atmosphere;

(l) The permeability of any cover and base, and the permeability criteria that are acceptable considering the site and residue characteristics, including those relating to intrusion, the leaking of liquids and the emanation of radon;

(m) Provisions for environmental monitoring, including groundwater well installations, and water and air sampling stations for effluent discharges or airborne releases;

(n) Provisions to facilitate maintenance work and eventual decommissioning or closure;

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

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

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

8.12. The detailed design should be supported by the safety assessment (see Section 7) and, where appropriate, by fieldwork and laboratory and/or pilot plant studies. The design should take account of plans for the management of residues and/or waste. Such plans will include, for example, the management of tailings and waste rock, proposals for effluent treatment, seepage controls and operational monitoring and a consideration of closure and post-closure management

8.13. A quality control programme for construction should be established at an early stage in the design process: this programme should be clearly defined and documented, and reassessed periodically. The effective implementation of a robust quality control programme involves well-trained and dedicated staff. The quality control programme should specify the tests to be carried out, including the test objectives and the design criteria to be met, and any other measures that are necessary to ensure completion of the construction in accordance with the detailed design.

8.14. During the conceptual design stage for a disposal facility, a preliminary closure plan should be prepared, which identifies and ranks the available options for closure according to the results of the safety assessment and the optimization of protection. The preliminary closure plan should also specify the financial resources necessary for the preferred option and take into account the post-closure land use options. The preliminary closure plan should be submitted to the regulatory body for approval.

OPERATION

8.15. Facilities for the long term management of NORM residues and/or waste should be operated in accordance with the residue and/or waste management plan that was developed and modified in a manner consistent with the safety assessment, and in accordance with the authorization issued by the regulatory body. This plan should describe in detail all aspects of the management of the residues and/or waste. The plan should be consistent with the quality assurance programme and should include provisions for:

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

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

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

(d) The designation of controlled and supervised areas, as appropriate (see Requirement 24 of GSR Part 3 [4])

(e) Procedures for clearance of materials removed from the site;

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

(g) The development of emergency plans, where appropriate (see paras 4.16–4.19).

8.16. The operating organization should ensure that the residue management plan and operating procedures are followed. The management plans should be modified and updated to take account of feedback and lessons learned from the operation of the facility. This is important for maintaining the desired level of protection and safety during operation and, where appropriate, after closure.

8.17. The regulatory body should review and approve the residue management plan and verify that operating procedures are followed by the operating organization during operation and decommissioning or closure. The regulatory body should implement a suitable system to audit and inspect the operating organization's compliance with the approved residue management plan. If the operating organization fails to satisfactorily follow the approved residue management plan, the regulatory body should take appropriate action to address the non-compliance.

8.18. As with other aspects of NORM residue management, the regulatory body should take a graded approach to regulatory oversight, commensurate with the scale of the risks under normal operation and from foreseeable incident scenarios.

8.19. The operating organization should take measures, on the basis of the safety assessment, to limit the release of radionuclides to the environment in liquid and airborne effluents. Measures should be taken to ensure that solid residues and waste remain under proper control so that the misuse of tailings and other NORM residues is avoided. Releases of radon or radioactive dusts into the atmosphere, and of radium and other radionuclides into surface water and groundwater by surface runoff or leaching from solid residues or waste, should be minimized.

8.20. In specific cases, a confined water covering over tailings placed in a pit may be used as a radon barrier, and thereby obviate the need to perform dewatering to any significant degree. Plans for the closure of facilities that rely on water coverings should consider the placement of the tailings (above ground or below ground), the local climate and the likelihood of the water cover being passively maintained over the long term. Water covers are generally used only as temporary or interim radon barriers for residues placed above ground or, in the case of residues placed below ground, where conditions do not support a permanent water cover.

DECOMMISSIONING OF FACILITIES AND CLOSURE OF FACILITIES

8.21. Requirements for the closure of disposal facilities are established in SSR-5 [29] and requirements for decommissioning of facilities are established in IAEA Safety Standards Series GSR Part 6, Decommissioning of Facilities [30]. Recommendations on decommissioning are provided in IAEA Safety Standards Series No. WS-G-5.1, Release of Sites from Regulatory Control on Termination of Practices [31] and IAEA Safety Standards Series No.WS-G-5.2, Safety Assessment for the Decommissioning of Facilities Using Radioactive Material [32].

8.22. When a facility for the long term management of NORM residues and waste is shut down, both decommissioning (i.e. of buildings and services used for then management of residues) and closure (i.e. of the part of the site in which waste has been disposed) might be necessary. In such case, the process would comprise of the following steps:

(a) Design considerations and early planning;

(b) Preparation and approval of the final plans for decommissioning and for closure;

(c) Decommissioning of buildings and other structures;

(d) The management of residues and waste resulting from decommissioning activities;

(e) Closure of the disposal facility;

(f) Final radiation survey;

(g) Implementation of institutional controls, if necessary;

(h) Consideration of final land use and infrastructure use.

8.23. A preliminary plan for decommissioning and/or closure should be prepared during the design phase prior to construction of the facility. The preliminary decommissioning and/or closure plan should identify and rank the available options for safety managing residues and waste according to the safety assessment and the end state criteria, with the goal of selecting a preferred option in which protection and safety is optimized. The preliminary plan should also specify the provision of financial resources necessary for the preferred option. The preliminary plan for decommissioning and/or closure should be subject to regulatory review and approval.

8.24. Long term protection and safety in the management of residues and waste relies primarily on passive means to minimize the need for significant and ongoing maintenance. The passive safety features that are used depends on the amount and type of residues or waste. For example, uranium process tailings should be stabilized and covered by soil or water to limit radon emissions, and liners are often used and necessary to reduce the chance of ground water contamination.

8.25. Prior to decommissioning or closure, regulatory criteria should be established for the clearance, reuse and recycling of materials: see paras 6.28 and 6.29. Criteria should also be established, as appropriate for, equipment, structures and the site, for example, in terms of the following:

(a) Removal of equipment and structures from regulatory control;

(b) Reuse and recycling of equipment, structures and material;

(c) Release of the site for unrestricted or restricted use.

8.26. Progressive closure and decommissioning in stages should be undertaken to the extent reasonably practicable during operation.

8.27. The plan for decommissioning and/or closure should be subject to review on the following basis:

(a) Periodically, to take into account ongoing operations, the results of monitoring and any measures implemented for contamination control;
(b) Following modifications made to the facility or the types or quantities of NORM residue being managed;
(c) If there are changes in regulatory requirements or anticipated future uses of the land.

8.28. Recommendations on financial provisions are provided in paras 5.38–5.42. The operating organization should periodically review the financial resources and the plan for decommissioning and/or closure during operation of the facility to ensure that adequate funds are available to cover the full costs of meeting the end state criteria.

8.29. The final decommissioning and/or closure plan is required to be approved by the regulatory body (Requirement 11 of GSR Part 6 [30] and Requirement 19 of SSR-5 [29]) prior to the initiation of decommissioning and/or closure activities. The final decommissioning and/or closure plan should address at least the following elements:

(a) An assessment of the post-decommissioning and/or post-closure risks to people and the environment.
(b) Land ownership and future land use.
(c) End state criteria – radiological, environmental and landform – and how they are to be met.
(d) Decommissioning and decontamination procedures and techniques, including:
    - The reuse and recycling of residues and plant structures, equipment and items containing or contaminated by NORM;
    - The management of NORM residues arising from decontamination and decommissioning of the facility.
(d) The need for any remediation of any land areas.
(e) The final radiation survey of the site.
(f) The need for any long term institutional control including monitoring and surveillance.

8.30. NORM residues that arise from operation and from decommissioning can potentially use the same long term facilities for the management of NORM residues. The decommissioning plan should consider the effects of mixing of materials from various waste streams, and its implications on consolidation and differential settlement.

8.31. Both decommissioning and closure will involve a consideration of the non-radiological constituents of NORM residues and waste, and in many cases these non-radiological considerations will be the dominant factors.

8.32. A decommissioning and/or closure report needs to be prepared by the operating organization to confirm that the end state of the facility and/or site has been achieved, as specified in the approved final decommissioning and/or closure plan. The report should be subject to review and approval by the regulatory body.

8.33. Based on the review of the final decommissioning and or closure report and any other verification measures deemed necessary, the regulatory body will decide on the termination of the authorization for a facility following decommissioning and/or closure, and on the release of the facility with or without restrictions (see Requirement 15 of GSR Part 6 [30] and paras 5.10 and 5.14 of SSR-5 [29]).

8.34. A system is required be established to ensure that all safety related records relevant to the decommissioning and/or closure of a facility are maintained (para. 9.7 of GSR Part 6 [30] and paras 3.15 and 5.13 of SSR-5 [29]). This system should involve the operating organization, the regulatory body, the government, and any other entity responsible for implementing long term management and institutional control. The system should be designed to ensure that any persons wishing to access the site are informed about the previous presence of a facility on the site, and about the nature of the activities that were conducted at the site.

LONG TERM MANAGEMENT AND INSTITUTIONAL CONTROLS

8.35. If a site cannot be released for unrestricted use, the use of the site should be restricted and appropriate institutional controls will be necessary to ensure protection of people and the environment over the long term. As stated para. 1.22 (iii) of SSR-5 [29]: "institutional controls are put in place to prevent intrusion into facilities and to confirm that the disposal system is performing as expected by means of monitoring and surveillance." Control may be active (e.g. by means of monitoring, surveillance, remedial work, water diversion and treatment, and fences) or passive (e.g. by means of land use controls, markers, records).

8.36. The long term management period begins when operational buildings and supporting services have been decommissioned, all engineered containment and isolation features have been put in place, and any remaining facilities are in the final configuration. In accordance with Requirement 22 of SSR-5 [29], after decommissioning actions and closure are complete, the safety of the long term management facility is required to be provided for primarily by means of passive features including the characteristics of the site and the final covering that has been put in place, together with institutional control measures, such as markers.

8.37. Where institutional controls are considered necessary, a custodian organization for these controls will be necessary; this custodian can be the government (usually an agency other than the regulatory body) or a qualified private entity. The custodian should provide periodic reports to the regulatory body or government on the situation at the site.

8.38. If active controls are warranted, the operating organization should provide sufficient funds to implement and maintain monitoring, surveillance and control of the facility throughout the necessary time period. The site and any residues therein should not become a financial burden on the government or the public.

8.39. The operating organization is responsible for preparing a proposed programme for long term management of the site, for review and approval by the regulatory body: see Requirement 22 of SSR-5 [29]. The design of the programme should be based on safety assessments as described in Section 7, in which impacts on people and the environment over an appropriate period into the future have been considered.

8.40. The safety case prepared by the operating organization should state the period over which institutional controls are planned to remain in force, and this should be subject to approval by the regulatory body. Scenarios postulating human intrusion, failure of engineered structures and changes in environmental conditions should be considered in the safety assessment (see Section 7).

8.41. As part of a long term management programme, all relevant records of the characteristics of closed residue management facilities and of restrictions on land use and ongoing monitoring and/or surveillance measures should be maintained in accordance with applicable legal requirements. Such records should be made available to interested parties, upon request (see also paras 3.16 and 5.13 of SSR-5 [29]).

8.42. For some sites currently in operation, or some sites resulting from past practices, the goal of using primarily a passive approach might not be fully achievable (paras 6.3 of SSR-5 [29]). In such cases, efforts have to be made to minimize the amount of active controls (paras 3.48, and 5.9 of SSR-5 [29]).

MONITORING AND SURVEILLANCE

8.43. Requirements 10 and 21 of SSR-5 [29] address monitoring and surveillance programmes for disposal facilities: more detailed recommendations are provided in IAEA Safety Standards Series No. SSG-31, Monitoring and Surveillance of Radioactive Waste Disposal Facilities [33]. Further guidance on monitoring and surveillance programmes at uranium production facilities is given in Ref. [34].

8.44. The operating organization is required to develop and implement a monitoring and surveillance programme (Requirements 10 and 21 of SSR-5 [29]): this programme should be subject to regulatory approval. The programme should be conducted and reviewed periodically by the operating organization prior to, during and after operation, decommissioning and closure. The regulatory body should inspect and verify monitoring results throughout the lifetime of the facility and the period of long term management. The institutional controls custodian (see para. 8.37) should ensure that the monitoring and surveillance programme is robust and continues, as necessary, following closure.

8.45. The monitoring and surveillance programme consists of continuous or periodic observations and measurements to evaluate and verify the behaviour of the residue management facility. The programme includes the measurement of radiological, environmental and engineering parameters. The results from this programme should be used to evaluate the impact of the facility on people and the environment and support decision making at various stages in the lifetime of the facility.

8.46. The types, duration and frequency of monitoring should be adapted to each period in the lifetime of a facility, i.e. the pre-operational period, operational period (including decommissioning operations) and post-closure period (see para. 1.22 of SSR-5 [29]).

8.47. A graded approach should be taken to adapt the level of detail (e.g. duration, frequency, locations for sampling, parameters to be monitored) in the monitoring programme so that it is commensurate with the level of risk associated with the facility.

Pre-operational phase

8.48. The pre-operational period includes site evaluation (selection, verification and confirmation) and safety assessment and design studies. The objectives of the monitoring and surveillance programme during the pre-operational period are:

(a) To contribute to the characterization of the site and the evaluation of the suitability of the site;

(b) To provide input for the design and construction of the facility;

(c) To provide input necessary for the operational and post-closure safety cases;

(d) To establish baseline conditions, including a determination of the existing level of natural radioactivity at the site, for comparison with later monitoring results. This is especially important in respect of NORM residues, because the same radionuclides are already present in nature;

(e) To aid in designing the monitoring programme for the operational period.

Operational period

8.49. The objectives of the monitoring and surveillance programme during the operational period are:

(a) To demonstrate the protection of workers;

(b) To provide data to confirm the performance of the long term management facility;

(c) To check the performance of systems for effluent treatment and control and abatement systems for airborne releases, as appropriate;

(d) To provide early warning of any deviations from normal operation;

(e) To provide data on the discharge of radionuclides (e.g. rates, concentrations, and composition) to the environment, for use in predictive modelling and determination of exposures to the public;

(f) To evaluate of compliance with regulatory requirements;

(g) To provide information and support communication with interested parties.

Post-decommissioning and post-closure phase

8.50. The monitoring and surveillance programme for the period after decommissioning and closure should be conducted to demonstrate that the facility is performing as predicted and should be used to:

(a) Detect abnormal concentrations of radionuclides in the environment that could be attributable to the long term management facility;

(b) Verify the performance and integrity of barriers;

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

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

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

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

(g) Evaluate compliance with regulatory requirements.

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

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

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

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

8.52. Annex I of Ref. [34] provides an example of the typical content of a long term surveillance plan for a uranium mill tailings site in the post-closure phase. This can also be adapted to the surveillance of facilities for other NORM residues with similar characteristics, with account taken of the graded approach.

APPENDIX I. SPECIAL CONSIDERATIONS FOR RESIDUES FROM URANIUM PRODUCTION

I.1. Uranium production generates various residue streams, including mill tailings, waste rock, mineralized waste rock and process water, including leaching solutions. Rainfall, snowmelt runoff and seepage from stockpiles and areas of uranium process plants should also be managed. In addition, the residue management programme should also take into account used pipes, process vessels, filters and mine waters.

URANIUM MINING WASTE ROCK

I.2. Bulk waste rock from uranium mining warrants long term management because of the large volumes generated, the presence of long lived radionuclides and heavy metals, and the potential to generate acidic drainage.

I.3. Bulk waste rock from uranium mining contains all the radionuclides in the original ore in secular equilibrium, but at lower activity concentrations. The concentrations of the radionuclides in the uranium decay chain are mostly below 1Bq/g however, this can still result in public exposure above 1 mSv in a year. Some options for reusing waste rock materials exist, for example for road construction or as backfilling material.

I.4. In most cases, waste rock is heaped up close to the mine on ground with a low permeability. Seepage water is collected by a drainage system to prevent or reduce the migration of radionuclides into groundwater.

I.5. After closure of the mine (or progressively during operation) waste rock heaps are covered to reduce the infiltration of rainwater. In general, there are two types of cover that are utilized, depending on the potential for acidification of the waste rock material. In particular, different designs should be considered when dealing with alkaline waste rock and pyritic waste rock. Thicker and multilayer cover might be necessary to avoid acidification due to pyrite oxidation and consequently the leaching of radionuclides.

I.6. Options for managing waste rock and mineralized waste rock include use as backfill materials in open pits and underground mines, and for construction at the mine site. Covering mineralized waste rock with inert waste rock should be considered. As with bulk amounts of mineral processing residues, the stability of piles of waste rock, and their resistance to erosion and rainwater infiltration, should be considered, to ensure that these piles do not result in unacceptable environmental impacts on the water catchment area (e.g. acid mine drainage).

I.7. Co-placement of waste rock with tailings is a concept that can be considered for both underground and above ground management options in mining situations. Appropriate cover should be put in place to both inhibit the release of radon to the air and to and prevent potential human intrusion. However, the chemical and mechanical compatibility of the combined material should be considered.

URANIUM MILL TAILINGS

I.8. Uranium mill tailings represent a challenge in terms of long term management because of the large volumes generated, the presence of long lived radionuclides, heavy metals and chemical hazards, and the potential to generate acidic drainage.

I.9. Tailings contain all the radionuclides in the original ore, at concentrations near their concentration in ore, with the exception of the uranium isotopes and their immediate short lived decay products. Approximately 75% of the original radioactivity present in the uranium ore is retained in the tailings. Tailings are usually discharged as slurry containing about 20–50% solids into a purpose-built water-retaining structure or impoundment, either above or below ground level.

I.10. There are few options for reusing tailings. Tailings, particularly the coarser size fractions, might be of use as a component of mine fill; however, engineering considerations can make this problematic as tailings slimes do not consolidate well on their own. Uranium can be produced by processing of this material; however, the radiological implications of any such reuse would need to be considered.

I.11. The key issues that should be considered in the design of a tailings management facility include:

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

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

I.12. The option of relocating tailings to a more favourable site for closure would not normally be expected to be the optimum residue management strategy because of the large volumes of waste involved. However, if relocation of the waste is being considered, care should be taken to take into account the optimization of all significant radiological and non-radiological impacts that might be introduced by the relocation itself, including issues relating to the transport of large volumes of waste.

I.13. The design of a facility for the management of tailings should incorporate drainage systems to consolidate tailings before closure and to reduce excess pore water pressure. In the case of a surface impoundment or a pit, this could be achieved by the installation of a drainage system prior to or during the emplacement of tailings, or by the use of wicks driven into the tailings after emplacement. The base and cap of the impoundment should be built to minimize the release of contaminants, if possible using material of natural origin. The addition of a stabilizing agent (such as cement) to the tailings immediately prior to their deposition has the potential to reduce significantly the permeability of the tailings mass, thus retarding the transport of contaminants and binding any pore water. However, in certain cases, a confined water covering in a pit can possess excellent characteristics as a radon barrier, thereby obviating the need to perform dewatering to any significant degree.

I.14. To avoid undue burden on future generations, a passive approach to design for closure is preferable to a design that needs significant and ongoing maintenance. Such a passive approach is generally best achieved by disposal in pits excavated specifically for this purpose, in mined out pits, in underground mine voids, or in natural water bodies, where appropriate. This option might eliminate or significantly reduce the need for surface disposal of tailings.

I.15. The decision on which approach to take should be optimized so as to match barrier characteristics with available site conditions. Mine or process residues disposed of below ground level are less susceptible to surface erosion and to intrusion. Subsurface placement generally necessitates less maintenance than surface tailings impoundments and eliminates the risk of a dam or dyke structural failure. Closure entails sealing the openings to the underground disposal facility, thereby isolating it from the surface. While buried tailings are less vulnerable to erosion, they might be more vulnerable to groundwater fluctuation if the water level is not deep; or might be closer to the water table in event of liner failure.

I.16. In the case of long term management of tailings in underground mines, the increase in structural integrity gained by using concrete with the tailings mass might allow mining to be continued nearby. Prior to adopting this strategy, possible chemical interactions between the stabilizing agent, the tailings and the host rock should be carefully investigated to ensure that the transport of contaminants would not be enhanced at some time in the future, or impact the active mine workings or the workers.

I.17. For the disposal of tailings underground, provided that the probabilities of geological disturbance to the site and of human intrusion into the site are deemed to be sufficiently low, no further controls might be necessary, other than archiving details of the location and characteristics of the waste and monitoring the site for a limited period.

I.18. Practical engineering solutions can be identified for some site specific problems associated with below ground tailings disposal facilities. For example, if the hydraulic conductivity of the tailings mass is greater than that of the surrounding host rock, the use of a highly permeable envelope surrounding the tailings should be considered as a means of diverting water around the tailings. In the case of a small and confined aquifer intersecting a pit or underground mine wall, localized grouting should be considered.

I.19. It is possible that the below ground disposal of mine tailings at a particular site might not be feasible, owing either to site specific problems for which no engineering solutions can be identified (e.g. when placement is likely to result in contamination of groundwater) or due to prohibitive costs. In such cases, the use of engineered surface impoundments might be the only viable option and should be considered.

I.20. For options involving the management of tailings in above ground impoundments, the tailings should be contained within low permeability engineered structures so as to reduce seepage. An above ground closure option would usually necessitate having greater institutional control than an underground option. Monitoring and maintenance programmes should be implemented during the operational, closure and post-closure periods. This approach would entail lower initial costs but higher continuing costs.

I.21. A cover system that is designed to limit infiltration and radon emissions is necessary for bulk amounts of residues placed above ground. Cover materials that have been effective in reducing radon emissions include water, earthen materials, geosynthetics such as geomembranes and geosynthetic clay liners, and evapotranspirative barriers. Simple covers might contain one type of material; however, robust combinations of different materials are often necessary.

I.22. Cover systems designed to limit infiltration and radon emissions might comprise a lateral drainage layer consisting of either coarse sand or gravel above a low permeability clay layer, and a top layer of durable rock for erosion protection. Depending on the climate and environment, a vegetative cover for erosion control, stabilization and limiting infiltration might be employed.

I.23. For placement of waste in a pit, the necessary degree of passive control can be achieved either by backfilling and capping with natural materials or by the establishment of a permanent water pond over the tailings. The latter option might also involve the application of a low permeability cover for the waste to reduce contact with the pond water. The subsurface conditions should be fully investigated in order to gain sufficient understanding to be able to ensure that the hydraulic pressure over the backfilled pit will not result in problems with groundwater contamination in the future.

I.24. The diffusion coefficient for radon in a saturated soil can be several orders of magnitude lower than that for a dry soil. A water covering or saturated cover layer might therefore serve as an effective radon barrier, although in dry environments a different approach is necessary.

I.25. Depending on the risk of contamination, a groundwater monitoring programme should be considered, to avoid creating areas that will require remediation in the future.

I.26. In addition to the emplacement of tailings in above ground impoundments, open pits and underground mine voids, there are other options for tailings management, such as the deposition of tailings in lakes. Monitoring and/or geochemical modelling should be undertaken, where appropriate, to show that a reducing environment has been established. However, some of these alternative options might not be acceptable to the regulatory body or the public, and would need further study and evaluation.

I.27. Other disposal strategies for mill tailings may be appropriate and they should be evaluated on a case by case basis. For example, small quantities of mill tailings might be accepted for disposal in a facility designed for low level radioactive waste, provided that the waste acceptance criteria of the facility are complied with.

HEAP LEACH RESIDUES

I.28. Heap leaching is a method used for processing low-grade uranium ore and typically involves the treatment of crushed or pelletized ore grade material with acid or alkali (or bacteria) on large engineered pads on the surface. Stope leaching or block leaching of uranium ore underground is also conducted. Most heap leaching operations generate medium quantities of residues; however, some operations are quite large and generate residues in bulk quantities.

I.29. Surface heap leach facilities require efficient containment and liquid collection systems, base liners and leak detection systems to protect the surface environment and groundwater resources.

I.30. Heap leach residues consist of process liquids generated during operation, the leached ore and potentially, a continuing release of solutions due to infiltration of the closed facility. During operation, waste process solutions can be collected, treated and sent to adjacent evaporation ponds and/or injected into deep injection wells. In some cases, a separate residue storage dam might be necessary with characteristics similar to those of a tailings dam.

I.31. An important consideration is locating the heap leach pad to facilitate decommissioning and isolation of the resulting residues without relocation. Heap flushing and neutralization might be conducted at the same time as decommissioning. Following decommissioning, long term management of the NORM residues might still be necessary.

RESIDUES FROM IN-SITU LEACHING OF URANIUM

I.32. In-situ leaching is carried out by drilling a pattern of injection and extraction wells into the ore body and then circulating a leach liquor that is either acid or alkali depending on the host sediments and ores. The uranium is extracted from the resulting ‘pregnant solution’ by conventional solvent extraction or ion exchange methods and the now ‘barren solution’ is reconstituted and re-injected into the leaching field. No conventional tailings are generated, but large volumes of liquid and small to medium amounts of solid residues can be generated.

I.33. A small fraction (0.5–2%) of the leach liquor is bled off and this bleed stream constitutes the largest volume of liquid residues from the process. Large volumes of liquid residues can also be generated where reconstitution of the ore body aquifer is undertaken following completion of the operation, for example from flushing of the aquifer. Smaller volumes of liquid water are generated from normal facility operation, including from the wash down of equipment and from spillages.

I.34. If the bleed stream is evaporated, elevated concentrations of radionuclides can remain, and if the bleed is treated chemically to remove radionuclides, these will usually be recovered in solid or slurry form.

I.35. In some cases, selenium and radium are removed prior to land application or re-injection of the resulting water. In these cases, small amounts of residues need to be managed and ultimately disposed of.

I.36. The ore body aquifer might need pretreatment prior to mining, commonly to remove calcium, and the resulting precipitates can contain elevated radium concentrations.

I.37. Liquid residues can be reduced or eliminated by evaporation, or discharged into aquifers or surface water bodies in accordance with the relevant discharge conditions approved by the regulatory body. Injection to deep (and preferably well-confined) aquifers is a possible solution, as is injection to shallower aquifers, typically the mining aquifer itself.

I.38. In cases of injection of liquid residues into aquifers, an environmental impact assessment involving detailed hydrogeological modelling of the situation should be undertaken. Techniques for restoration of groundwater can include natural attenuation, groundwater flushing to accelerate natural attenuation, injection of reducing agents or groundwater sweep and reverse osmosis. The more intensive restoration techniques should progressively be used, as necessary (i.e. if the effect of restoration is not proving adequate), to achieve the agreed end state criteria for closure of the facility in a reasonable timescale. More intensive methods require more energy and surface infrastructure, generate waste streams, and incur additional costs. Best practice is therefore to use the restoration technique that will achieve the end state criteria for closure in an agreed timescale with the minimum environmental impact.

I.39. Solid radioactive residues generated by an in situ leaching facility can include used pipes, pumps, filters and other equipment, contaminated soil and sludge from ponds and from evaporation of waste liquids. These might be managed in a purpose built management facility that is usually on the site, or else such residues are taken to an off-site residue management facility.

APPENDIX II. RESIDUE MANAGEMENT PLAN FOR URANIUM PRODUCTION

II.1. The content of a residue and waste management plan for a uranium production facility could include the following:

(a) A description of the processes in which the residues and waste are generated by the facility;

(b) A description of each of the residue streams and waste streams and the measures taken to prevent these streams arising or else to minimize these streams;

(c) The limits and conditions necessary for the waste to be managed safely;

(d) A comprehensive list of the current and anticipated residues and waste arising and inventories for the facility;

(e) Definition of the waste management principles and objectives at the facility;

(f) Identification of residue and waste management options and associated steps, as well as interdependences between these steps;

(g) Justification of the selection of appropriate management options based on the information above and on international good practices;

(h) Demonstration that the residue and waste management plan is compatible with the national policy and strategy;

(i) Demonstration, if necessary, of how the safety case is affected by the residue and waste management plan (e.g. a modification of the plan to incorporate longer storage than the building was originally designed for would impact the safety case).

II.2. The plan should include provisions for the following:

(j) Keeping the generation of residues and waste to the minimum practicable, in terms of type, activity and volume, by using suitable technologies;

(k) Possible reuse and recycling of materials;

(l) Appropriate classification and segregation of waste, and maintenance of an accurate inventory for each residue stream and waste stream, with account taken of the available options for clearance or disposal;

(m) Collection, characterization and safe storage of residues and waste;

(n) Adequate storage capacity for the residues and waste that are expected to be generated (conditioned and unconditioned) and an additional reserve storage capacity;

(o) Ensuring that stored residues and waste can be retrieved at any time within the anticipated storage period;

(p) Techniques and suitable procedures available for the retrieval of stored residues and waste;

(q) Processing radioactive waste to comply with waste acceptance requirements and to ensure safe storage and long term management including disposal of residues for which no further use is foreseen;

(r) Safe handling and transport of residues and waste, if necessary;

(s) Adequate control of discharges of effluents to the environment.

APPENDIX III. CLOSURE PLAN FOR A TAILINGS MANAGEMENT FACILITY AT A URANIUM PRODUCTION SITE

III.1. A closure plan for a tailings management facility at a uranium production site could include the following:

- Introduction, including site location and history:
  - Amounts and types of material produced;
  - Activities undertaken;
  - Previous site assessments;
  - Applicable regulatory end state criteria to be met;
  - Current environmental and radiological conditions.
- Geology and seismology:
  - Stratigraphic features;
  - Structural and tectonic features;
  - Geomorphic features;
  - Seismicity and ground motion estimates.
- Geotechnical stability:
  - Site and uranium mill tailings characteristics;
  - Slope stability;
  - Settlement;
  - Liquefaction potential;
  - Engineering design of the disposal cell cover;
  - Construction considerations;
  - Hydraulic conductivity of the disposal cell.
- Surface water hydrology and erosion protection;
  - Hydrologic description of site;
  - Flooding determinations;
  - Water surface profiles, channel velocities, and shear stresses;
  - Design of erosion protection;
  - Design of erosion protection covers;
  - Protecting water resources.
- Groundwater protection:
  - Standards for groundwater quality;
  - Monitoring results (baseline, during operation and post-operational);
  - Environmental impact assessment;

- Corrective action assessment;
  - Groundwater corrective action and compliance monitoring plans.
- Air quality
  - Standards for air quality;
  - Monitoring results (baseline, during operation and post-operational).
- Radiation protection:
  - Engineered cover of the tailing facility (type of material, thickness, ability to prevent radon emissions in the long term)
  - Attenuation of radon releases;
  - Attenuation of gamma radiation;
  - Radioactivity content of the cover.
- Closure plan for the site;
  - Types of restriction to the site for long term access control;
  - Site access and the need for institutional controls;
  - Discussion of the long term stability and containment of residues and waste;
  - The proposed types of engagement with interested parties;
  - A description of the final form of land features, including demographics and possible receptors;
  - Schedule and budget.

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ANNEX I. EXAMPLES OF RESIDUES TO BE ASSESSED FOR POSSIBLE REGULATORY CONTROL

I-1. Table I-1 provides a list of residues that might need regulatory consideration. It is based on table 1 of Ref. [I-1].

TABLE I-1. RESIDUES TO BE ASSESSED FOR POSSIBLE REGULATORY CONTROL

Category	**Material (operation)**	**Radionuclide(s) with highest activity concentration**	**Typical activity concentration (Bq/g)**
By products	Red mud (alumina production)	U-238, Th-232	0.1–3
	Phosphogypsum (H_2SO_4 process)	Ra-226	0.015–3
Slags	Niobium extraction	Th-232	20–120
	Tin smelting	Th-232	0.07–15
	Copper smelting	Ra-226	0.4–2
	Thermal phosphorus production	U-238	0.3–2
Scales, sludge sediments and other residues	Scale (oil and gas production)	Ra-226	0.1–15 000
	Scale (phosphoric acid production)	Ra-226	0.003–4000
	Residue (rare earth extraction)	Ra-228	20–3000
	Scale (TiO_2 pigment production)	Ra-228, Ra-226	<1–1600
	Scale (rare earth extraction)	Ra-226, Th-228	1000
	Sludge (oil and gas production)	Ra-226	0.05–800
	Residue (niobium extraction)	Ra-228	200–500
	Scale (coal mines with Ra rich inflow water)	Ra-226, Ra-228	Up to 200
	Scale (iron smelting)	Pb-210, Po-210	Up to 200
	Scale (coal combustion)	Pb-210	>100
	Sludge (iron smelting)	Pb-210	12–100
	Residue (TiO_2 pigment production)	Th-232, Ra-228	<1–20
	Sludge (water treatment)	Ra-226	0.1–14
Precipitator dust	Thermal phosphorus production	Pb-210	Up to 1000
	Fused zirconia production	Po-210	Up to 600
	Niobium extraction	Pb-210, Po-210	100–500
	Metal smelting	Pb-210, Po-210	Up to 200

REFERENCES TO ANNEX I

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ANNEX II. SAMPLING NORM RESIDUES AND DETERMINING RADIONUCLIDE ACTIVITY CONCENTRATIONS

INTRODUCTION

V-1. For NORM industries, it is useful to conduct an initial screening assessment that is designed to eliminate from further regulatory consideration a facility or activity that poses a low level hazard. This will normally involve the sampling and analysis of NORM materials, residues and waste to determine the radionuclide activity concentrations. Further information can be found in References [II-1 and II-2].

V-2. The most probable radionuclides of interest for which the activity concentrations need to be determined are:

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

SAMPLING OF MATERIAL

V-3. Collecting representative samples is a prerequisite for obtaining reliable results. Sampling positions and numbers of samples are also important. The quantities of material containing NORM can be very large, and exhibit a significant range of activity concentrations due to the inhomogeneous distribution of radionuclides. The activity concentration might also vary over time. To the extent practicable, both of these variations need to be taken into account when developing a suitable material sampling strategy.

V-4. The number of samples collected for analysis is important for obtaining a reasonable estimate of the average activity concentration: the greater the number of samples collected and analysed, the greater the confidence in the results that are obtained. A point is reached, however, where any further gain in accuracy is minimal compared to the additional time and resources needed to analyse more samples. The accuracy of results is also affected by other factors such as the degree to which the samples are representative of the material as a whole.

MEASUREMENT ACCURACY AND QUALITY ASSURANCE

V-5. Adequate confidence in the results of analyses is ensured if the samples are analysed at a suitably accredited laboratory and if the level of accuracy of the analytical technique is commensurate with the activity concentration criterion against which the material is being compared. If an accredited laboratory is not available, the analytical techniques can at least be validated against appropriate reference materials. Problems due to cross-contamination between samples and contamination of equipment can be avoided by exercising an appropriate level of care during sampling and at the laboratory.

V-6. The distribution of activity concentrations in a material might span an order of magnitude or more. The lower limit of detection of the analysis needs to be well below the activity concentration level against which the measurements are being compared. For instance, when a material is being compared against a value of 1 Bq/g for radionuclides in the uranium decay chain and thorium decay chain (or 10 Bq/g for ^{40}K), a lower limit of detection of 0.1 Bq/g (1 Bq/g for ^{40}K) would be appropriate.

ANALYTICAL TECHNIQUES [II-1]

V-7. Having defined the main radionuclides of interest (e.g. on the basis of knowledge of the process or from a search of relevant literature) and the necessary measurement sensitivity, appropriate analytical protocols can be considered. Analysis techniques for determining activity concentrations of individual radionuclides in solid materials can be time-consuming and expensive. The techniques employed for a particular sample therefore need to be chosen carefully.

V-8. For a general screening of the total radioactivity it might be adequate to perform gross alpha–beta counting, applying suitable corrections for self-absorption, where appropriate. This technique is a relatively quick and inexpensive method for determining the total activities (or activity concentrations) of alpha emitting and beta emitting radionuclides, from which the ratio of the two can be obtained. This technique does not give information on individual radionuclides; however, the alpha–beta ratio can provide some indication of the radionuclide composition, which can be useful in deciding upon subsequent analysis steps. If the total activity concentration is less than the activity concentration criterion for individual radionuclides, then no further analysis is necessary. Counting times are selected to obtain the necessary lower limit of detection for the materials concerned.

V-9. For analysis of individual radionuclides of interest, the following analytical techniques can be applied:

(a) X ray fluorescence spectrometry

This method is widely used to measure the elemental composition of materials, and is suitable for the rapid determination of uranium and thorium. There are two types of spectrometer, both of which can be used for this application:

(i). Wavelength dispersive spectrometers, in which photons are separated by diffraction on an analysing crystal before being detected;

(ii). Energy dispersive spectrometers, in which the energy of the photon is determined when it is detected; these spectrometers are smaller and cheaper than wavelength dispersive spectrometers, and the measurement is faster; however, the resolution and the limit of detection are not as good.

(b) Inductively coupled plasma atomic emission spectroscopy

This method is used for the chemical analysis of aqueous solutions of rocks and other materials, and is suitable for the determination of a wide range of major elements and a limited number of trace elements.

Sample preparation involves the digestion of the powdered material with 40% (v/v) hydrofluoric acid mixed with either perchloric or nitric acid. Some minerals such as chromite, zircon, rutile and tourmaline will not completely dissolve using this digestion procedure. For samples containing substantial amounts of these minerals, X ray fluorescence analysis is probably more appropriate.

(c) Inductively coupled plasma mass spectroscopy:

This method is used to determine trace elements in aqueous solutions. The technique is suitable for the determination of uranium and thorium. The sample preparation procedure is the same as that for inductively coupled plasma atomic emission spectroscopy.

(d) High energy gamma spectrometry (high purity germanium crystal detector):

This technique provides a quantification of radionuclides such as ^{226}Ra, ^{228}Ra, ^{228}Th and (if needed) ^{40}K. The method can also be used to quantify the ^{238}U concentration, although the lower limit of detection is relatively poor.

(e) Low energy gamma spectrometry (high purity germanium crystal or lithium drifted silicon crystal detector):

This technique provides a quantification of ^{238}U and ^{210}Pb (as well as ^{235}U). The technique can also provide a determination of ^{226}Ra (as well as other radionuclides such as ^{227}Ac, ^{231}Pa and ^{230}Th) but with a poorer lower limit of detection.

(f) Alpha spectrometry:

Sample digestion followed by various chemical separation techniques and then alpha spectrometry can be used to determine each of the NORM alpha emitters. This technique is commonly used for the quantification of ^{210}Po.

V-10. The application of the techniques described in para II-9 is summarized in Table II-1. The minimum sample size needed is in each case about 10g, although for techniques involving high energy gamma spectrometry larger samples (up to 1 kg) are preferred. When undertaking analyses for elemental uranium or thorium the following conversions from ppm to Bq/g can be used:

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

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

V-11. For material associated with most NORM industrial processes it is adequate to have a basic analytical infrastructure consisting of X ray fluorescence spectrometry in combination with a background shielded thin-window high purity germanium crystal gamma spectrometry system. Only in those processes where ^{210}Po is of concern will radiochemical techniques in combination with alpha spectrometry be necessary.

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

Radionuclide	Suitable technique	Comments
U-238, Th-232	XRF[a], ICP-AES[b], ICP-MS[c]	Sensitivity of 1 ppm uranium or thorium achievable with any of these techniques (equivalent to about 0.01 Bq/g U-238 and 0.004 Bq/g Th-232)
Ra-226, Ra-228, Th-228 (and K-40)	High energy gamma spectrometry	The presence of uranium can interfere with the direct determination of Ra-226 For indirect determination of Ra-226, gas-tight sealing of the sample for 3 weeks is needed to ensure equilibrium with progeny (Pb-214, Bi-214) To achieve a lower limit of detection of 0.1 Bq/g, the detector needs to be shielded from background radiation High relative efficiency (>25%) and high resolution HPGe[d] detectors are needed Counting times of a few hours per sample will be adequate Self-absorption corrections are necessary for high density materials (>2.5 g/cm^3)
Pb-210	Low energy gamma spectrometry	Self-absorption corrections are necessary To achieve a lower limit of detection of 0.1 Bq/g, the detector needs to be shielded from background radiation Counting times of a few hours per sample will be adequate
Po-210	Sample digestion + alpha spectrometry	Microwave acid digestion might be necessary Validated radiochemical separation techniques are needed Counting times of a few hours per sample will be adequate to achieve a lower limit of detection of 0.1 Bq/g

[a] X ray fluorescence spectrometry

[b] Inductively coupled plasma atomic emission spectroscopy

[c] Inductively coupled plasma mass spectroscopy

[d] High purity germanium

REFERENCES TO ANNEX II

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ANNEX III: EXAMPLE OF APPLICATION OF THE GRADED APPROACH IN THE MANAGEMENT OF NORM RESIDUES

GENERAL

III-1. This Annex provides further information on various aspects for which the graded approach can be applied, and includes an example of the application of the graded approach to NORM residues management.

III-2. Applying the graded approach is intended to ensure that the level of effort applied to achieving protection and safety is optimized, i.e. the level of effort is commensurate with the magnitude of the radiation risks and their amenability to control.

III-3. For NORM, the ideal regulatory infrastructure has flexibility in terms of the control measures needed for different conditions, based on specific criteria. These different levels could be accommodated through suitable regulations or a system for authorization that explicitly accommodates different levels of control based on NORM residue characteristics and the associated levels of risk.

III-4. The first step to establish a regulatory framework for the management of NORM residues is to determine a list of activities that need to be considered for regulatory control. The list provides the opportunity for the national authorities to proactively investigate particular sectors and, on the basis of an initial assessment, exclude those that do not warrant further investigation. A periodic review of the list is advisable.

III-5. Classification of residues into different categories may provide a framework to readily apply a graded approach to the way these residues are processed or disposed (exemption, unconditional clearance, specific clearance, disposal in conventional landfill, disposal in a facility for NORM residues, or a radioactive waste disposal facility). The development of a graded system of control based on categories of NORM residues will be based on knowledge of the NORM residues, including their radiological and chemical characteristics, and the control measures (regulatory or otherwise) that are already in place.

III-6. As noted in Section 5 of this Safety Guide, the graded approach will also define the authorization process in terms of registration or licensing. This can be taken further with a graded approach being applied in the form of different categories of licence, or else by adapting the authorization conditions to the specific characteristics of the NORM residues.

III-7. The graded approach will also influence the strategy that is applied to the radiological and chemical characterization of residues, including the level of detail needed, for example in terms of the dose rate from the NORM residues, the activity concentrations of radionuclides, the doses received by workers and by member of the public, and the impact on the environment.

III-8. The graded approach is also applied to the degree of detail contained in the safety assessment. In many cases, the application of a generic approach, or the use of simple and pragmatic rules or models, will be sufficient to estimate occupational and public exposures. If a specific assessment is performed, the complexity of the assessment and the effort involved are expected to be commensurate with the magnitude of the risks.

EXAMPLE FROM BELGIUM OF THE GRADED APPROACH

III-9. The Belgian Federal Agency for Nuclear Control (FANC), and regional environmental authorities authorize operating organizations that generate, process and dispose of NORM residues.

III-10. The list of activities that require regulatory control was derived from Ref. [III-1]. The list is reviewed and amended through the Royal Decree on radiation protection [Ref. III-2] to include any additional activities that are newly identified. Up to now, the majority of NORM residues have arisen from the phosphate industry (gypsum and $CaCl_2$ sludge) and the titanium dioxide industry (TiO_2 filter cake).

III-11. According to the Belgian radiation protection regulations [III-2], NORM residues are subject to regulatory control when they contain radionuclides of natural origin with an activity concentration exceeding the exemption levels described in Ref. [III-3], (i.e. 0.5 Bq/g for U-238 and Th-232 in secular equilibrium with their progeny). If the activity concentration exceeds these levels, any operating organization that processes or disposes of the residues is required to notify FANC. These levels are thus applied to determine exemption from notification; they are not intended to define what is “radioactive” and “non-radioactive” waste.

III-12. If the notification level is exceeded, the residue may be accepted by treatment facilities for non-radioactive waste, subject to a set of generic conditions. On basis of the information provided in the notification by the operating organization, FANC imposes waste acceptance criteria on the treatment facility, derived from a generic safety assessment. These acceptance criteria consist of limits on the maximum activity concentration per batch of NORM residues as well as a limit on the total quantities of NORM waste that can be annually disposed to landfill. Other limits are applied to the activity concentration of the end product and/or on the residues from the processing operations. These generic acceptance criteria, shown in Table III-1, are imposed on the waste facility in the form of conditions attached to an authorization by registration.

TABLE III-1: GENERIC ACCEPTANCE CRITERIA FOR DISPOSAL TO LANDFILLS AND TO INCINERATORS

Type of processing	Maximum activity concentration (Bq/g)	
	Input (single batch of residues)	Output (average activity concentration after processing)
Disposal on landfill for hazardous waste	50	< 0.2 Bq/g
Disposal on landfill for non- hazardous waste	10	< 0.2 Bq/g
Incineration	10	Residues from incineration < 0.5 Bq/g

III-13. If these generic acceptance criteria are not met, the waste facility (or the facility that generates the NORM residue) needs to submit a detailed safety assessment demonstrating that the impact to the public of the waste disposal or processing is less than 0.3 mSv in a year.

III-14. The level of detail needed in the safety assessment is defined by FANC on a case-by-case basis. In some cases (e.g. a phosphogypsum stack), the operating organization is allowed to refer to an assessment performed for facilities with similar characteristics. The conclusions of the environmental impact assessment performed for the environmental permit will also be taken into consideration.

III-15. If it is demonstrated that public exposures are lower than 0.3 mSv in a year, FANC imposes specific conditions in the form of a registration or a licence, such as a monitoring programme for the relevant radionuclides.

III-16. If the detailed safety assessment indicates that public exposure can exceed 0.3 mSv in a year, the NORM residue is treated as radioactive waste and managed by the Belgian National Waste Agency.

REFERENCES TO ANNEX III

[III-1] EUROPEAN COMMISSION, Laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, Council Directive 2013/59/EURATOM.

[III-2] Royal Decree of 20 July 2001 Setting forth the general regulation for the protection of the population, the workers and the environment against the danger of ionizing radiation, Moniteur Belge, (2001).

[III-3] European Commission, Practical Use of the Concepts of Clearance and Exemption – Part II Application of the Concepts of Exemption and Clearance to Natural Radiation Sources, Radiation protection 122 (2001).

ANNEX IV. REUSE AND RECYCLING OF NORM RESIDUES

IV-1. Reuse can be defined as the reutilization of materials for their original purpose, either in their original form or in a recovered state. Recycling is the utilization of materials, tools and equipment for other than the original purpose, with or without treatment. The reuse and recycling options are attractive in cases in which there is a strong economic incentive to use the large volume of NORM residues, and to avoid the costs associated with long term management. The decision of whether or not to reuse and recycle residues depends on many factors that are specific to the type of residue, the industries concerned and the situation in the State. Implementation of reuse and recycling options requires the establishment of suitable criteria, together with a suitable measurement methodology and suitable instrumentation.

IV-2. Mixing of NORM residues with other materials might be considered as means to facilitate reuse and recycling. Although the Euratom Basic Safety Standards [IV-1] prohibit the deliberate dilution of radioactive materials for the purpose of them being released from regulatory control, the mixing of materials that takes place in normal operations (i.e. where radioactivity is not a consideration) is not subject to this prohibition. The competent authority might authorize, in specific circumstances, the mixing of radioactive and non-radioactive materials for the purpose of reuse or recycling.

IV-3. Some examples of reuse and recycling of NORM residues are described in the following paragraphs.

SCRAP METAL

IV-4. Contaminated scrap metal from NORM industries can, in many cases, be decontaminated by various methods. Details of decontamination methods for equipment in the oil and gas industry, as well as information on measurements principles and instrumentation, are given in Ref. [IV-2]. The decontaminated metals can be recycled.

IV-5. The contaminated scrap might also be melted in dedicated furnaces: natural radionuclides normally transfer to the slag, leaving the metal clean for reuse. Depending on the activity concentration, the slag can also be reused if regulatory requirements can be met.

IV-6. Melting of contaminated scrap is generally a regulated practice, and complies with requirements established by the regulatory body. The transport of contaminated items is subject to the requirements of Safety Standards Series No. SSR-6 (Rev. 1), Regulations for the Safe Transport of Radioactive Material, 2018 Edition [IV-3], when the activity concentration limits for exempt material and activity limits for exempt consignments are exceeded.

SLAG

IV-7. Slag from NORM industries can be used as landfill or in road construction. An example of the latter is the use of slag from the thermal phosphorus production industry in road construction in the United States of America and in the Netherlands [IV-4].

FLY ASH

IV-8. In many cases, fly ash from coal-fired stations is recycled in building materials, for instance, as additives to concrete or in lightweight building materials. The use of fly ash in concrete blocks for building construction is not of concern in States where the activity concentration is well below 1 Bq/g. In other States, regulations specify the maximum permissible activity concentrations in concrete and in imported building materials such as cement.

PHOSPHOGYPSUM

IV-9. There are several options for the recycling of phosphogypsum, such as use as a fertilizer additive, and use in road construction and in building materials: detailed information can be found in Ref. [IV-4]. Treatments to improve soils for agricultural use often employ natural gypsum, but phosphogypsum might also be recycled for use in soils. However, as well as the radiological issues associated with this option, non-radiological contaminants, such as cadmium and fluorine, also have an impact on the suitability of recycling this residue in agriculture.

IV-10. Phosphogypsum, when subjected to compaction, can be transformed into a solid of valuable strength. In tests, it has been shown to be effective as a binder to stabilize soil and as a replacement for shell and clay in road and parking lot construction. This results in significant savings in cost, compared to the traditional method of construction. Radiation monitoring during road construction indicated no significant radiological hazards, either to the construction workers or to members of the public living in the area.

REFERENCES TO ANNEX IV

[IV-1] EUROPEAN COMMISSION, Laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, Council Directive 2013/59/EURATOM.

[IV-2] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection and the Management of Radioactive Waste in the Oil and Gas Industry, Safety Reports Series, No 34, IAEA, Vienna (2003).

[IV-3] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Material, 2018 Edition, IAEA Safety Standards Series No. SSR-6 (Rev. 1), IAEA,

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