IAEA Safety Standards
for protecting people and the environment

Predisposal Management of Radioactive Waste from Nuclear Fuel Cycle Facilities

Specific Safety Guide
No. SSG-41

IAEA
International Atomic Energy Agency

IAEA SAFETY STANDARDS AND RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish or adopt standards of safety for protection of health and minimization of danger to life and property, and to provide for the application of these standards.

The publications by means of which the IAEA establishes standards are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety. The publication categories in the series are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides**.

Information on the IAEA's safety standards programme is available on the IAEA Internet site

http://www-ns.iaea.org/standards/

The site provides the texts in English of published and draft safety standards. The texts of safety standards issued in Arabic, Chinese, French, Russian and Spanish, the IAEA Safety Glossary and a status report for safety standards under development are also available. For further information, please contact the IAEA at: Vienna International Centre, PO Box 100, 1400 Vienna, Austria.

All users of IAEA safety standards are invited to inform the IAEA of experience in their use (e.g. as a basis for national regulations, for safety reviews and for training courses) for the purpose of ensuring that they continue to meet users' needs. Information may be provided via the IAEA Internet site or by post, as above, or by email to Official.Mail@iaea.org.

RELATED PUBLICATIONS

The IAEA provides for the application of the standards and, under the terms of Articles III and VIII.C of its Statute, makes available and fosters the exchange of information relating to peaceful nuclear activities and serves as an intermediary among its Member States for this purpose.

Reports on safety in nuclear activities are issued as **Safety Reports**, which provide practical examples and detailed methods that can be used in support of the safety standards.

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Security related publications are issued in the **IAEA Nuclear Security Series**.

The **IAEA Nuclear Energy Series** comprises informational publications to encourage and assist research on, and the development and practical application of, nuclear energy for peaceful purposes. It includes reports and guides on the status of and advances in technology, and on experience, good practices and practical examples in the areas of nuclear power, the nuclear fuel cycle, radioactive waste management and decommissioning.

PREDISPOSAL MANAGEMENT OF RADIOACTIVE WASTE FROM NUCLEAR FUEL CYCLE FACILITIES

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The Agency’s Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is “to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world’’.

IAEA SAFETY STANDARDS SERIES No. SSG-41

PREDISPOSAL MANAGEMENT OF RADIOACTIVE WASTE FROM NUCLEAR FUEL CYCLE FACILITIES

SPECIFIC SAFETY GUIDE

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FOREWORD

by Yukiya Amano
Director General

The IAEA's Statute authorizes the Agency to "establish or adopt… standards of safety for protection of health and minimization of danger to life and property" — standards that the IAEA must use in its own operations, and which States can apply by means of their regulatory provisions for nuclear and radiation safety. The IAEA does this in consultation with the competent organs of the United Nations and with the specialized agencies concerned. A comprehensive set of high quality standards under regular review is a key element of a stable and sustainable global safety regime, as is the IAEA's assistance in their application.

The IAEA commenced its safety standards programme in 1958. The emphasis placed on quality, fitness for purpose and continuous improvement has led to the widespread use of the IAEA standards throughout the world. The Safety Standards Series now includes unified Fundamental Safety Principles, which represent an international consensus on what must constitute a high level of protection and safety. With the strong support of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its standards.

Standards are only effective if they are properly applied in practice. The IAEA's safety services encompass design, siting and engineering safety, operational safety, radiation safety, safe transport of radioactive material and safe management of radioactive waste, as well as governmental organization, regulatory matters and safety culture in organizations. These safety services assist Member States in the application of the standards and enable valuable experience and insights to be shared.

Regulating safety is a national responsibility, and many States have decided to adopt the IAEA's standards for use in their national regulations. For parties to the various international safety conventions, IAEA standards provide a consistent, reliable means of ensuring the effective fulfilment of obligations under the conventions. The standards are also applied by regulatory bodies and operators around the world to enhance safety in nuclear power generation and in nuclear applications in medicine, industry, agriculture and research.

Safety is not an end in itself but a prerequisite for the purpose of the protection of people in all States and of the environment — now and in the future. The risks associated with ionizing radiation must be assessed and controlled without unduly limiting the contribution of nuclear energy to equitable and sustainable development. Governments, regulatory bodies and operators everywhere must ensure that nuclear material and radiation sources are used beneficially, safely and ethically. The IAEA safety standards are designed to facilitate this, and I encourage all Member States to make use of them.

THE IAEA SAFETY STANDARDS

BACKGROUND

Radioactivity is a natural phenomenon and natural sources of radiation are features of the environment. Radiation and radioactive substances have many beneficial applications, ranging from power generation to uses in medicine, industry and agriculture. The radiation risks to workers and the public and to the environment that may arise from these applications have to be assessed and, if necessary, controlled.

Activities such as the medical uses of radiation, the operation of nuclear installations, the production, transport and use of radioactive material, and the management of radioactive waste must therefore be subject to standards of safety.

Regulating safety is a national responsibility. However, radiation risks may transcend national borders, and international cooperation serves to promote and enhance safety globally by exchanging experience and by improving capabilities to control hazards, to prevent accidents, to respond to emergencies and to mitigate any harmful consequences.

States have an obligation of diligence and duty of care, and are expected to fulfil their national and international undertakings and obligations.

International safety standards provide support for States in meeting their obligations under general principles of international law, such as those relating to environmental protection. International safety standards also promote and assure confidence in safety and facilitate international commerce and trade.

A global nuclear safety regime is in place and is being continuously improved. IAEA safety standards, which support the implementation of binding international instruments and national safety infrastructures, are a cornerstone of this global regime. The IAEA safety standards constitute a useful tool for contracting parties to assess their performance under these international conventions.

THE IAEA SAFETY STANDARDS

The status of the IAEA safety standards derives from the IAEA's Statute, which authorizes the IAEA to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property, and to provide for their application.

With a view to ensuring the protection of people and the environment from harmful effects of ionizing radiation, the IAEA safety standards establish fundamental safety principles, requirements and measures to control the radiation exposure of people and the release of radioactive material to the environment, to restrict the likelihood of events that might lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation, and to mitigate the consequences of such events if they were to occur. The standards apply to facilities and activities that give rise to radiation risks, including nuclear installations, the use of radiation and radioactive sources, the transport of radioactive material and the management of radioactive waste.

Safety measures and security measures[1] have in common the aim of protecting human life and health and the environment. Safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation. They are issued in the IAEA Safety Standards Series, which has three categories (see Fig. 1).

Safety Fundamentals

Safety Fundamentals present the fundamental safety objective and principles of protection and safety, and provide the basis for the safety requirements.

Safety Requirements

An integrated and consistent set of Safety Requirements establishes the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objective and principles of the Safety Fundamentals. If the requirements are not met, measures must be taken to reach or restore the required level of safety. The format and style of the requirements facilitate their use for the establishment, in a harmonized manner, of a national regulatory framework. Requirements, including numbered ‘overarching’ requirements, are expressed as ‘shall’ statements. Many requirements are not addressed to a specific party, the implication being that the appropriate parties are responsible for fulfilling them.

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[1] See also publications issued in the IAEA Nuclear Security Series.

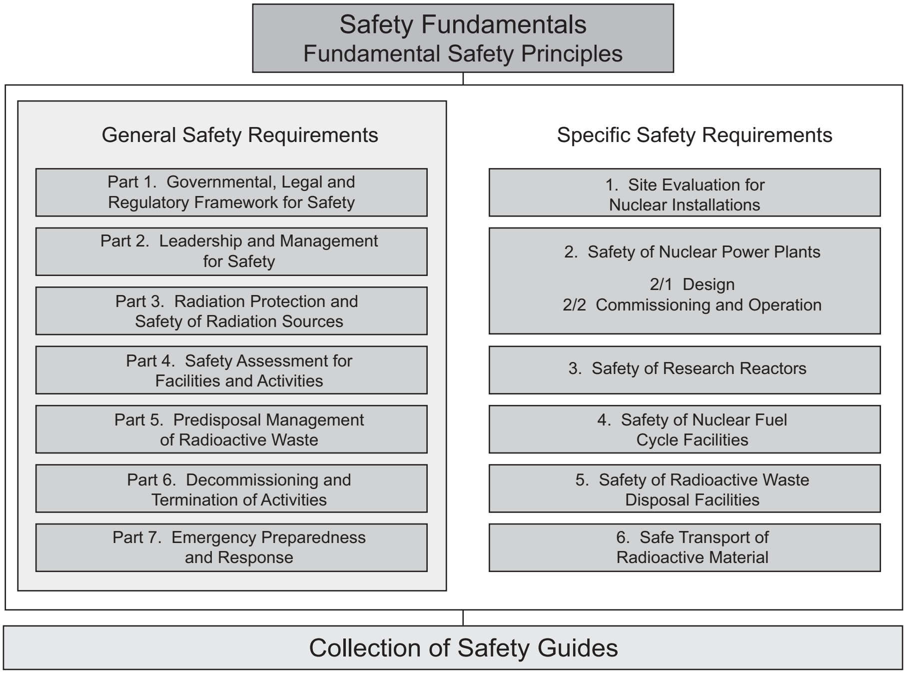

FIG. 1. The long term structure of the IAEA Safety Standards Series.

Safety Guides

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures). The Safety Guides present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as 'should' statements.

APPLICATION OF THE IAEA SAFETY STANDARDS

The principal users of safety standards in IAEA Member States are regulatory bodies and other relevant national authorities. The IAEA safety standards are also used by co-sponsoring organizations and by many organizations that design, construct and operate nuclear facilities, as well as organizations involved in the use of radiation and radioactive sources.

The IAEA safety standards are applicable, as relevant, throughout the entire lifetime of all facilities and activities — existing and new — utilized for peaceful purposes and to protective actions to reduce existing radiation risks. They can be used by States as a reference for their national regulations in respect of facilities and activities.

The IAEA's Statute makes the safety standards binding on the IAEA in relation to its own operations and also on States in relation to IAEA assisted operations.

The IAEA safety standards also form the basis for the IAEA's safety review services, and they are used by the IAEA in support of competence building, including the development of educational curricula and training courses.

International conventions contain requirements similar to those in the IAEA safety standards and make them binding on contracting parties. The IAEA safety standards, supplemented by international conventions, industry standards and detailed national requirements, establish a consistent basis for protecting people and the environment. There will also be some special aspects of safety that need to be assessed at the national level. For example, many of the IAEA safety standards, in particular those addressing aspects of safety in planning or design, are intended to apply primarily to new facilities and activities. The requirements established in the IAEA safety standards might not be fully met at some existing facilities that were built to earlier standards. The way in which IAEA safety standards are to be applied to such facilities is a decision for individual States.

The scientific considerations underlying the IAEA safety standards provide an objective basis for decisions concerning safety; however, decision makers must also make informed judgements and must determine how best to balance the benefits of an action or an activity against the associated radiation risks and any other detrimental impacts to which it gives rise.

DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

The preparation and review of the safety standards involves the IAEA Secretariat and five safety standards committees, for emergency preparedness and response (EPReSC) (as of 2016), nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on Safety Standards (CSS) which oversees the IAEA safety standards programme (see Fig. 2).

All IAEA Member States may nominate experts for the safety standards committees and may provide comments on draft standards. The membership of

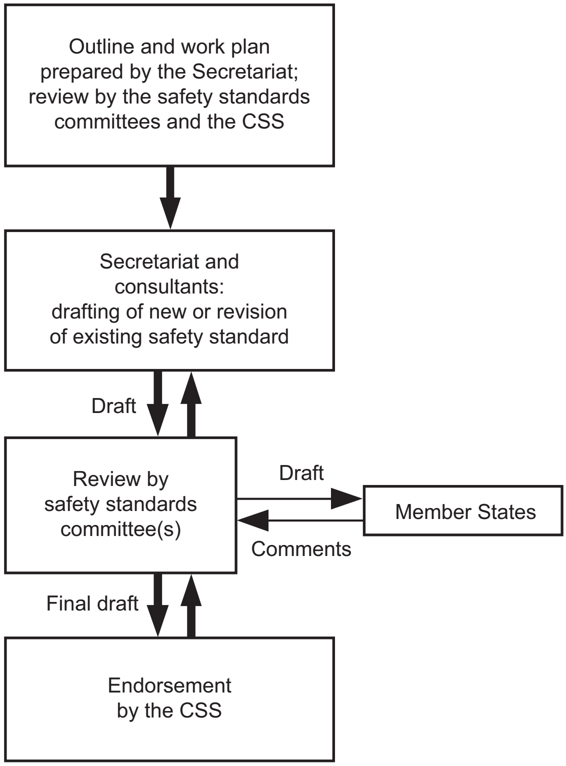

FIG. 2. The process for developing a new safety standard or revising an existing standard.

the Commission on Safety Standards is appointed by the Director General and includes senior governmental officials having responsibility for establishing national standards.

A management system has been established for the processes of planning, developing, reviewing, revising and establishing the IAEA safety standards. It articulates the mandate of the IAEA, the vision for the future application of the safety standards, policies and strategies, and corresponding functions and responsibilities.

INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

The findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the recommendations of international expert bodies, notably the International Commission on Radiological Protection (ICRP), are taken into account in developing the IAEA safety standards. Some safety standards are developed in cooperation with other bodies in the United Nations system or other specialized agencies, including the Food and Agriculture Organization of the United Nations, the United Nations Environment Programme, the International Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization.

INTERPRETATION OF THE TEXT

Safety related terms are to be understood as defined in the IAEA Safety Glossary (see http://www-ns.iaea.org/standards/safety-glossary.htm). Otherwise, words are used with the spellings and meanings assigned to them in the latest edition of The Concise Oxford Dictionary. For Safety Guides, the English version of the text is the authoritative version.

The background and context of each standard in the IAEA Safety Standards Series and its objective, scope and structure are explained in Section 1, Introduction, of each publication.

Material for which there is no appropriate place in the body text (e.g. material that is subsidiary to or separate from the body text, is included in support of statements in the body text, or describes methods of calculation, procedures or limits and conditions) may be presented in appendices or annexes.

An appendix, if included, is considered to form an integral part of the safety standard. Material in an appendix has the same status as the body text, and the IAEA assumes authorship of it. Annexes and footnotes to the main text, if included, are used to provide practical examples or additional information or explanation. Annexes and footnotes are not integral parts of the main text. Annex material published by the IAEA is not necessarily issued under its authorship; material under other authorship may be presented in annexes to the safety standards. Extraneous material presented in annexes is excerpted and adapted as necessary to be generally useful.

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. Radioactive waste (radioactive material for which no further use is foreseen, and with characteristics that make it unsuitable for authorized discharge, authorized use or clearance from regulatory control) arises from a number of activities involving the use of radioactive material. The nuclear fuel cycle produces a wide range of radioactive waste, including: high level waste (e.g. vitrified waste from spent fuel reprocessing), intermediate level waste that typically contains longer lived radionuclides, and low level waste that typically contains short lived radionuclides and limited quantities of long lived radionuclides. The approach to treating liquid and gaseous waste streams influences the amount of effluent generated for discharge, and the approach to clearance from regulatory control and recycling influences the amount of waste for storage and disposal; therefore, optimization of the overall radioactive waste management process (predisposal waste management and disposal) is very important. Thus, a key feature of the predisposal management of radioactive waste from nuclear fuel cycle facilities is the interdependence between the steps in the processes of predisposal management and disposal within a national framework for waste management.

1.2. The principles that govern the safety of the management of radioactive waste are presented in IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [1], and the requirements to be met are established in the following IAEA Safety Requirements publications: IAEA Safety Standards Series Nos GSR Part 1 (Rev. 1), Governmental, Legal and Regulatory Framework for Safety [2], GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [3] and GSR Part 5, Predisposal Management of Radioactive Waste [4]. Similar safety aspects and expectations for good practice have been set down in international legal instruments, such as the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (Joint Convention) [5].

1.3. GSR Part 5 [4] and IAEA Safety Standards Series No. NS-R-5 (Rev. 1), Safety of Nuclear Fuel Cycle Facilities [6], require that measures to prevent or restrict the generation of radioactive waste are considered in the design of nuclear facilities and in the planning of activities that have the potential to generate radioactive waste. This recognizes that the proper management of the materials and processes that result in radioactive waste is key to avoiding or minimizing the quantities of waste generated, thereby minimizing the overall environmental impact.

1.4. Predisposal management of radioactive waste, as the term is used in GSR Part 5 [4], covers all steps in the management of radioactive waste from its generation up to (but not including) its disposal, including waste processing (pretreatment, treatment and conditioning), storage and transport. While the generation of radioactive waste at nuclear fuel cycle facilities is considered part of normal operations, it is important to address the interdependences between the operational demands of each of the various steps in waste management.

1.5. These steps include the following:

— Pretreatment, which may include waste assay and characterization, waste collection, waste segregation, chemical adjustment and decontamination;
— Treatment, which may include volume reduction, removal of radionuclides and changing the composition of the waste;
— Conditioning, which involves those operations that transform radioactive waste into a form suitable for subsequent activities such as handling, transport, storage and disposal; conditioning may include immobilization of the waste, placing of the waste into containers and provision of additional packaging;
— Storage, which refers to the temporary placement of radioactive waste in a facility where appropriate isolation and monitoring are provided; storage is an interim activity performed with the intent to retrieve the waste at a later date for clearance from regulatory control, for authorized use (e.g. subsequent to a decay period), for processing and/or for disposal, or in the case of effluent, for authorized discharge.

1.6. The generation of radioactive waste cannot be prevented entirely but is required to be kept to the minimum practicable (‘waste minimization’) (Requirement 8, GSR Part 5 [4]). Waste minimization should form an essential element of a radioactive waste management strategy. Waste minimization relates to the type, volume and activity of the waste. Measures to prevent or minimize the generation of radioactive waste have to be put in place at the beginning, in the design of facilities and in the planning of activities that have the potential to generate radioactive waste [4]. This recognizes that the proper planning of the activities that generate radioactive waste is key to minimizing the quantities generated.

1.7. It may be that not all processing steps are necessary for particular categories of radioactive waste. The type of processing necessary will depend on the particular category of waste, its form and characteristics, and the overall approach to its management, including consideration of the generation of secondary waste. Where appropriate, material resulting from the pretreatment and treatment of waste may be reused or recycled, or cleared from regulatory control in accordance with national regulations. Such activities serve to reduce the eventual challenge associated with waste management. The remaining radioactive waste from all sources that is not cleared, discharged or reused needs to be managed safely over its entire lifetime. Lifetimes of certain waste streams are such that the operating organization[1] may not be capable of their management or their management may be dictated by the availability in the State of appropriate disposal facilities (e.g. a deep geological repository).

1.8. GSR Part 1 (Rev. 1) [2] requires the government to make provision for the safe management and disposal of radioactive waste arising from facilities and activities. Such provisions should be included as essential elements of governmental policy and of the corresponding strategies over the lifetime of facilities and for the duration of activities. Furthermore, the government is also required to enforce continuity of responsibility between successive authorized parties.

1.9. In some instances, the solution for predisposal management of waste has to be found by optimizing conflicting demands, e.g. balancing exposures of workers and/or those of members of the public, the short term and long term risk implications of different waste management strategies, the technological options available and the costs [4].

1.10. "To select the most appropriate type of pretreatment, treatment and conditioning for the radioactive waste when no disposal facility has been established, assumptions have to be made about the likely disposal option", including likely waste acceptance criteria (GSR Part 5 [4], para. 1.8). In cases where waste is to be stored for extended periods, conservative assumptions should be made, for example, about the timescale within which a disposal facility will become available and, thus, about the behaviour and stability of the waste during the anticipated storage period. All assumptions made that impact the selection of options for the predisposal management of waste should be properly

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[1] Operating organizations include generators of waste, organizations that carry out decommissioning activities and operators of facilities for the predisposal management of radioactive waste [4].

justified. “It is necessary to address the interdependences and the potential conflicts between the operational demands of each of the various steps in waste management, while ensuring that the waste is contained and stored in a passive, safe condition. In striking a balance between choosing an option and retaining flexibility, it is necessary to ensure that conflicts between operational demands that might compromise safety are avoided” (GSR Part 5 [4], para. 1.8).

OBJECTIVE

1.11. The objective of this Safety Guide is to provide operating organizations that generate and manage radioactive waste (including spent nuclear fuel declared as waste and high level radioactive waste), as well as regulatory bodies and government bodies, with recommendations on how to meet the requirements for the predisposal management of radioactive waste generated at nuclear fuel cycle facilities, excluding nuclear power plants, research reactors and facilities for the mining or processing of uranium ores or thorium ores. The waste may be managed either within larger nuclear fuel cycle facilities or at separate, dedicated waste management facilities, including centralized waste management facilities.

1.12. This Safety Guide provides recommendations and guidance on how to meet the requirements established in GSR Part 5 [4], as well as in GSR Part 1 (Rev. 1) [2] and GSR Part 3 [3], NS-R-5 (Rev. 1) [6] and IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [7].

1.13. This Safety Guide supersedes IAEA Safety Standards Series Nos WS-G-2.5, Predisposal Management of Low and Intermediate Level Radioactive Waste[2] and WS-G-2.6, Predisposal Management of High Level Radioactive Waste[3], both of which were issued in 2003.

1.14. Guidance on the predisposal management of waste from nuclear power plants and research reactors (including subcritical assemblies and critical assemblies) is provided in IAEA Safety Standards Series No. SSG-40, Predisposal Management of Radioactive Waste from Nuclear Power Plants and Research Reactors [8].

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[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Predisposal Management of Low and Intermediate Level Radioactive Waste, IAEA Safety Standards Series No. WS-G-2.5, IAEA, Vienna (2003).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Predisposal Management of High Level Radioactive Waste, IAEA Safety Standards Series No. WS-G-2.6, IAEA, Vienna (2003).

SCOPE

1.15. This Safety Guide provides guidance on the predisposal management of all types of radioactive waste (including spent nuclear fuel declared as waste and high level waste) generated at nuclear fuel cycle facilities. The waste may be managed at waste management facilities located within larger facilities or at separate, dedicated waste management facilities (including centralized waste management facilities). This Safety Guide covers all stages in the lifetime of a waste management facility, including its siting, design, construction, commissioning, operation, shutdown and decommissioning. It covers all steps carried out in the management of radioactive waste following its generation up to (but not including) disposal, including its processing (pretreatment, treatment and conditioning), storage and transport. It covers radioactive waste generated during normal operation and in accident conditions. While the recommendations of this Safety Guide are applicable to the generation and predisposal management of radioactive waste throughout the entire lifetime of the nuclear fuel cycle facility, other operational activities at nuclear fuel cycle facilities are outside the scope of this Safety Guide. A classification scheme for radioactive waste and recommendations on its application to the various types of radioactive waste are provided in IAEA Safety Standards Series No. GSG-1, Classification of Radioactive Waste [9].

1.16. While storage and transport are included in the definition of predisposal management of radioactive waste, they are not dealt with in detail in this Safety Guide. Recommendations on storage of radioactive waste and spent fuel are provided in IAEA Safety Standards Series Nos WS-G-6.1, Storage of Radioactive Waste [10] and SSG-15, Storage of Spent Nuclear Fuel [11]. Transport of radioactive waste is subject to the requirements of IAEA Safety Standards Series No. SSR-6, Regulations for the Safe Transport of Radioactive Material [12]. Spent fuel that is transferred to or destined for reprocessing facilities is not considered radioactive waste.

1.17. This Safety Guide primarily addresses the situations that are typical at facilities for the predisposal management of radioactive waste arising from the nuclear fuel cycle and from facilities that produce medical isotopes from irradiation of nuclear material. The operating organization and the regulatory body should adopt a graded approach, taking account of the hazards, the complexity and stage in the lifetime of the facilities and activities, and the characteristics of the waste (see Section 3).

1.18. Although this Safety Guide does not specifically address non-radiological hazards or conventional industrial health and safety issues, these issues also have to be considered by national authorities, both in their own right and in as much as they may affect radiological consequences [4].

1.19. This Safety Guide does not provide recommendations on the nuclear security of nuclear material, nuclear facilities or radioactive material. Fundamentals, recommendations for and guidance on nuclear security at nuclear facilities and for radioactive material are provided in Refs [13–15] and in other publications in the IAEA Nuclear Security Series.

STRUCTURE

1.20. Section 2 of this Safety Guide provides recommendations on the protection of human health and protection of the environment. Section 3 addresses the roles and responsibilities of the government, the regulatory body and the operating organization. Section 4 provides recommendations on the integrated approach to safety. Section 5 provides recommendations on development of the safety case and supporting safety assessment, while Section 6 outlines general safety considerations over the lifetime of a waste management facility. Seven appendices are included, which set out examples relevant for the predisposal management of waste from nuclear fuel cycle facilities.

2. PROTECTION OF HUMAN HEALTH AND PROTECTION OF THE ENVIRONMENT

RADIOACTIVE WASTE MANAGEMENT

2.1. The safety objective and the fundamental safety principles established in SF-1 [1] apply to all facilities and activities in which radioactive waste is generated, processed or stored, for the entire lifetime of facilities, including their planning, siting, design, construction, commissioning, operation, shutdown and decommissioning. This includes the associated transport of radioactive waste.

2.2. GSR Part 1 (Rev. 1) [2], GSR Part 5 [4], NS-R-5 (Rev. 1) [6] and GSR Part 2 [7] establish requirements for a management system that integrates, among other things, all elements of management including safety, health, environmental, nuclear security, quality and economic elements, so that the implications of all actions are considered with regard to safety as a whole and safety is not compromised. A key component of such a system in an organization is a robust safety culture.

2.3. In nuclear fuel cycle facilities, the control of events initiated by chemical hazards can have a significant bearing on achieving the fundamental safety objective. Events initiated by chemical hazards are required to be considered in the design, commissioning, operation and decommissioning of such facilities. Activities at nuclear fuel cycle facilities may also include industrial processes that pose additional hazards to site personnel and to the environment.

2.4. In controlling the radiological and non-radiological hazards associated with radioactive waste, the following aspects are also required to be considered: conventional health and safety issues, environmental impacts, radiation risks that may transcend national borders, and potential impacts and burdens on future generations [1].

RADIATION PROTECTION

2.5. The three general principles of radiation protection, which concern justification, optimization of protection and application of dose limits, are expressed in safety principles 4, 5, 6 and 10 of SF-1 [1], and related requirements are established in GSR Part 3 [3].

2.6. Requirements for radiation protection have to be established at the national level, with due regard to GSR Part 3 [3]. In particular, GSR Part 3 [3] requires radiation protection to be optimized for any persons who are exposed as a result of activities, with due regard to dose constraints, and requires the exposures of individuals to be kept within specified dose limits.

2.7. National regulations will prescribe dose limits for the exposure of workers and members of the public under normal conditions. Internationally accepted values for these limits are contained in schedule III of GSR Part 3 [3]. In addition to the provision for protection against the exposures that will arise from normal operations, provision has to be made for preventing and limiting the likelihood and magnitude of exposures in anticipated operational occurrences and accident conditions. Requirements for preventing and limiting the likelihood and magnitude of exposures in anticipated operational occurrences and accident conditions are also established in GSR Part 3 [3]. They include management requirements and technical requirements for preventing the occurrence of accidents and provisions for mitigating their consequences if they do occur.

2.8. In choosing options for the predisposal management of radioactive waste, consideration has to be given to both the short term and the long term radiological impacts on workers and the public [1, 16, 17].

2.9. Doses and risks associated with the transport of radioactive waste have to be managed in accordance with the requirements established in SSR-6 [12].

PROTECTION OF THE ENVIRONMENT

2.10. Requirements for protection of the environment that are associated with the predisposal management of radioactive waste have to be established by the relevant national regulatory bodies, with all potential environmental impacts that could reasonably be expected taken into consideration [1, 3].

2.11. In accordance with para. 2.1 of SF-1 [1], to achieve the fundamental safety objective of protecting people and the environment from harmful effects of ionizing radiation,

> "measures have to be taken:
>
> (a) To control the radiation exposure of people and the release of radioactive material to the environment;
> (b) To restrict the likelihood of events that might lead to a loss of control over…source[s] of radiation;
> (c) To mitigate the consequences of such events if they were to occur."

2.12. NS-R-5 (Rev. 1) [6] states that the operating organization is required to take measures to avoid or to optimize the generation of radioactive waste, including consideration of requirements related to disposal, with the aim of minimizing the overall environmental impact. This includes ensuring that gaseous and liquid radioactive releases to the environment are in compliance with authorized limits and reducing doses to the public and effects on the environment to levels that are as low as reasonably achievable (optimization of protection).

2.13. Clearance (the removal of radioactive material within authorized practices from any further regulatory control) and the control of discharges (planned and controlled releases of gaseous or liquid radioactive material to the environment) are addressed in IAEA Safety Standards Series Nos RS-G-1.7, Application of the Concepts of Exclusion, Exemption and Clearance [18] and WS-G-2.3, Regulatory Control of Radioactive Discharges to the Environment [19], respectively.

3. ROLES AND RESPONSIBILITIES

LEGAL AND ORGANIZATIONAL FRAMEWORK

Requirement 1 of GSR Part 5 [4]: Legal and regulatory framework

"The government shall provide for an appropriate national legal and regulatory framework within which radioactive waste management activities can be planned and safely carried out. This shall include the clear and unequivocal allocation of responsibilities, the securing of financial and other resources, and the provision of independent regulatory functions. Protection shall also be provided beyond national borders as appropriate and necessary for neighbouring States that may be affected."

Requirement 2 of GSR Part 5 [4]: National policy and strategy on radioactive waste management

"To ensure the effective management and control of radioactive waste, the government shall ensure that a national policy and a strategy for radioactive waste management are established. The policy and strategy shall be appropriate for the nature and the amount of the radioactive waste in the State, shall indicate the regulatory control required, and shall consider relevant societal factors. The policy and strategy shall be compatible with the fundamental safety principles and with international instruments, conventions and codes that have been ratified by the State. The national policy and strategy shall form the basis for decision making with respect to the management of radioactive waste."

3.1. The government is responsible for ensuring that a national policy and strategy are established for the management of radioactive waste [1, 2]. The policy and strategy, and the legal framework, should cover all types and volumes of radioactive waste generated in the State, all waste processing and storage facilities located in the State, and all waste imported into it or exported from it, with due account taken of the interdependences between the various steps of radioactive waste management, the time periods involved and the long term management (including disposal) options available.

3.2. The management of radioactive waste should be undertaken within an appropriate national legal and regulatory framework that provides for a clear allocation of duties and responsibilities, and that ensures the effective regulatory control of the facilities and activities concerned [1, 2]. Measures should be established within the legal framework to ensure compliance with other relevant international legal instruments, such as the Joint Convention [5], the Convention on Nuclear Safety [20], the Code of Conduct on the Safety and Security of Radioactive Sources [21], the Convention on Assistance in the Case of a Nuclear Accident [22], and the Convention on Early Notification of a Nuclear Accident or Radiological Emergency [23].

3.3. If more than one governmental body is charged with implementation of the national policy and strategy, effective arrangements should be put in place to ensure that the responsibilities and functions of each body are clearly defined and coordinated, in order to avoid any omissions or unnecessary duplication. This should be organized in such a way as to achieve consistency and to enable the necessary feedback and exchange of information.

3.4. In relation to the predisposal management of radioactive waste, where nuclear safety, environmental protection, industrial safety and occupational health aspects are separately regulated, the regulatory framework should recognize that safety as a whole is affected by the interdependences between radiological, industrial, chemical and toxic hazards. This should be taken into account in the regulatory framework, so that it delivers effective control.

3.5. It should be ensured within the legal framework that the construction of facilities for the predisposal management of radioactive waste adjacent to an existing facility that could affect the safety of either facility is monitored and controlled by means of planning requirements or other legal instruments.

3.6. The management of radioactive waste may entail the transfer of the waste from one operating organization to another, or from one State to another. Such transfers create interdependences in legal responsibilities as well as physical interdependences in the various steps in the management of radioactive waste. The legal framework should include provisions to ensure a clear allocation of responsibility for safety throughout the entire waste management process (including provisions for regulatory control and authorization), in particular with respect to the long term storage of radioactive waste and with respect to its transfer between operating organizations.

3.7. The government is responsible for establishing a regulatory body independent from the owner of the radioactive waste and the operating organization managing the radioactive waste, with adequate authority, power, staffing and financial resources to discharge its assigned responsibilities [2, 4].

3.8. Responsibility for safety should be ensured by means of a system of authorization established by the regulatory body. For transfers of radioactive waste between one State and another, authorizations from the relevant national regulatory bodies of both States are required [2, 4].

3.9. A mechanism for providing adequate financial resources is required to be established to cover future costs, in particular, the costs associated with the decommissioning of the nuclear fuel cycle facility and its associated waste management facilities, and also the costs of long term management of radioactive waste (including its storage and disposal) [4, 24]. The organizational and financial arrangements are required to be updated at each stage of licensing. Consideration is also required to be given to the use of these financial resources in the event of a sudden shutdown of the predisposal radioactive waste management facility or early dispatch of the waste to a disposal facility.

3.10. In order to facilitate the establishment of a national policy and strategy, the government should establish a national inventory of the radioactive waste (both current waste and anticipated waste, including waste expected to be generated during the decommissioning and dismantling of nuclear fuel cycle facilities and associated waste management facilities) and should update it at regular time intervals. This inventory should address the various waste classes as defined in GSG-1 [9] or in the national waste classification scheme. In establishing the national policy and strategy, account should be taken of the long term management of the waste including its disposal, both from a technical point of view and from the point of view of ensuring adequate human resources and financial resources.

3.11. There should be sufficient capacity to process all waste generated, and storage capacity should be sufficient to take account of uncertainties in the availability of facilities for the processing and disposal of waste. In judging the sufficiency of capacity, account should be taken of uncertainties in processes, reliability and availability of systems and the possible need for redundancy.

3.12. The government should consult interested parties (i.e. those who are involved in or are affected by radioactive waste management activities) on matters relating to the development of national policies and strategies that affect the management of radioactive waste, and should take due account of the concerns of the public in decision making [2].

RESPONSIBILITIES OF THE REGULATORY BODY

Requirement 3 of GSR Part 5 [4]: Responsibilities of the regulatory body

"The regulatory body shall establish the requirements for the development of radioactive waste management facilities and activities and shall set out procedures for meeting the requirements for the various stages of the licensing process. The regulatory body shall review and assess the safety case[3] and the environmental impact assessment for radioactive waste management facilities and activities, as prepared by the operator both prior to authorization and periodically during operation. The regulatory body shall provide for the issuing, amending, suspension or revoking of licences, subject to any necessary conditions. The regulatory body shall carry out activities to verify that the operator meets these conditions. Enforcement actions shall be taken as necessary by the regulatory body in the event of deviations from, or noncompliance with, requirements and conditions."

[3] "The safety case is a collection of arguments and evidence in support of the safety of a facility or activity. The safety case will normally include the findings of a safety assessment, and will typically include information (including supporting evidence and reasoning) on the robustness and reliability of the safety assessment and the assumptions made therein."

3.13. The main responsibilities of the regulatory body relating to the safe management of radioactive waste include the development of regulatory requirements, of procedures for licensing, compliance verification and enforcement, and of guidance to be followed by licensees. Responsibilities of the regulatory body may also include contributing to the technical basis and inputs for the establishment of policies, safety principles and associated criteria, and establishing requirements or conditions to serve as the basis for regulatory decisions. The regulatory body should also provide specific guidance on how to meet requirements for the safe management of radioactive waste.

3.14. The scope and level of detail of the regulatory review of the licensing documentation (safety case[4]) for the predisposal management of radioactive waste from nuclear fuel cycle facilities should follow a graded approach commensurate with the safety significance, complexity, and maturity of the facility or activity, as well as the characteristics of the waste, with consideration given to the stage in the lifetime of the nuclear fuel cycle facility or predisposal radioactive waste management facility. The safety case and supporting safety assessment should be reviewed and updated periodically as necessary by the operating organization and subsequently reviewed by the regulatory body.

3.15. General recommendations for regulatory inspection and enforcement actions relating to radioactive waste management facilities are provided in IAEA Safety Standards Series No. GS-G-1.3, Regulatory Inspection of Nuclear Facilities and Enforcement by the Regulatory Body [25]. The regulatory body should periodically verify that the operation of the radioactive waste management facility meets national requirements and the facility's licence conditions, including requirements relating to the keeping of records on inventories and material transfers; requirements for processing, storage, maintenance, inspection, testing and surveillance; operational limits and conditions; requirements for modifications to the facility; and requirements relating to emergency preparedness and response. Such verification may be carried out, for example, by means of routine inspections of the radioactive waste management facility and audits of the operating organization. The regulatory body should verify that the necessary records are prepared and that they are maintained for an appropriate period of time. A suggested list of records is included in IAEA Safety Standards Series No. GS-G-1.4, Documentation for Use in Regulating Nuclear Facilities [26].

3.16. The regulatory body should establish a process for informing interested parties about the safety aspects (including health and environmental aspects) of the radioactive waste management facility and about regulatory processes, and should consult these parties, as appropriate, in an open and inclusive manner. The need for confidentiality, for example for purposes of nuclear security, should be respected.

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[4] The safety case may be known by different names (such as safety report, safety dossier, safety file) in different States and may be presented in a single document or a series of documents (see Section 5).

3.17. The regulatory body should establish and clarify to the operator the licensing strategy to be adopted for each waste management facility (in accordance with the national legal and governmental framework), for example:

(a) A licence issued for an indefinite period of time (e.g. the entire lifetime of the predisposal waste management facility), covering the generation and processing of waste and/or the storage system, and encompassing the entire anticipated operating period of the nuclear fuel cycle facility generating the waste, including periodic review of the safety case and safety assessments (see Section 5); or
(b) A licence issued for a specified time period, or for a specific stage of the lifetime of the predisposal waste management facility, with the possibility of its renewal on or prior to expiration; or
(c) A licence issued for a specific activity or condition, e.g. long term storage of radioactive waste after the nuclear fuel cycle facility has been permanently shut down and decommissioned.

3.18. If the regulatory body consists of more than one authority, effective arrangements are required to be put in place through the establishment of clear communication and operational protocols to ensure that regulatory responsibilities and functions are clearly defined, agreed and effectively coordinated. Communication and operational protocols should clearly identify the responsibilities and functions of each authority, should spell out the objectives and actions or agreements, and should be periodically reviewed in order to avoid any omissions or unnecessary duplication and to prevent conflicting requirements being placed on the operating organization (Requirement 7, GSR Part 1 (Rev. 1) [2]).

RESPONSIBILITIES OF THE OPERATING ORGANIZATION

Requirement 4 of GSR Part 5 [4]: Responsibilities of the operator

"Operators shall be responsible for the safety of predisposal radioactive waste management facilities or activities. The operator shall carry out safety assessments and shall develop a safety case, and shall ensure that the necessary activities for siting, design, construction, commissioning, operation, shutdown and decommissioning are carried out in compliance with legal and regulatory requirements."

3.19. The operating organization is responsible for the safety of all activities undertaken at its facilities associated with the management of radioactive waste (including activities undertaken by contractors) in compliance with the principles contained in SF-1 [1]. The operating organization is responsible for the demonstration of safety by means of a safety case and periodic safety reviews, and is responsible for ensuring that activities are carried out in compliance with the safety case and with national legal and regulatory requirements. The operating organization is responsible for the establishment and implementation of a management system, including the related programmes and procedures necessary to ensure safety. The operating organization is required to maintain a strong safety culture, to take measures to review and assess its safety culture periodically, and to adopt and apply the necessary principles and processes in order to strengthen the safety culture [7].

3.20. In some instances the operating organization may be the owner of the radioactive waste, while in other cases the owner may be a separate organization or operating unit. If the owner and the operating organization are separate, the interface between responsibilities of the owner and those of the operating organization should be clearly defined, agreed on and documented. Ownership of the waste should be clearly specified; in cases of centralized reprocessing facilities that collect and mix waste streams arising from multiple sources, ownership of the conditioned waste should be clearly identified. Information on any change in ownership of the radioactive waste or in the relationship between the owner and the operating organization of the waste management facility should be provided to the regulatory body and, as required, to governmental bodies.

3.21. The responsibilities of the operating organization of a radioactive waste management facility typically include the following:

(a) Application to the regulatory body, including submission of an acceptable safety case, to obtain regulatory approval for the radioactive waste management facility or activity.
(b) The conduct of appropriate radiological impact assessments and non-radiological environmental impact assessments in support of the application for a licence, and the conduct of periodic safety reviews.
(c) The development of operational limits and conditions and controls, including waste acceptance criteria of the waste management facility consistent with the safety case, for approval by the regulatory body.
(d) The conduct of all activities in accordance with the requirements of the safety case, the licence conditions and the applicable regulations.

(e) The development and application of procedures for the receipt, storage and processing of radioactive waste.
(f) Planning for the possible long term storage of radioactive waste after the nuclear fuel cycle facility has been decommissioned.
(g) Ensuring that the information recorded at a particular step in the waste management process is sufficient to demonstrate compliance with the downstream waste acceptance criteria (e.g. the safety case for disposal of the waste).
(h) Management of the information required either to support the later disposition or storage of the radioactive waste or to support the decommissioning of that waste management facility, especially where such decommissioning may take place many decades after operations have ceased.
(i) The provision of periodic reports as required by the regulatory body (e.g. information on the actual inventory of radioactive waste, on any transfers of radioactive waste into and out of the facility, including material cleared from regulatory control, and on any events that occur at the facility and which have to be reported to the regulatory body) and communication with relevant interested parties and the public.
(j) The development and implementation of measures that will control the generation of radioactive waste, in terms of its volume and activity content, to the minimum practicable.
(k) Ensuring that radioactive waste is processed in a manner that complies with the acceptance criteria for storage and disposal as well as with transport requirements. In situations where acceptance criteria for disposal are not yet available, ensuring that the management of radioactive waste is based on reasonable assumptions for the anticipated disposal option, including provisions for waste characterization in order to supply data for future decisions with respect to disposal, and making provisions for relocating the radioactive waste for storage and/or disposal.
(l) Ensuring that spent nuclear fuel declared as waste is managed appropriately with account taken of its high activity, heat generation and potential for criticality [27]. Appendix I provides a listing of the typical properties and characteristics that should be considered for waste packages and spent nuclear fuel declared as waste.
(m) Due consideration and decision making in the following cases:
    (i) The management of waste if no disposal option is available;
    (ii) The management of waste that would need to be stored over long periods of time prior to its disposal;

(iii) The management of waste in the case of storage for radioactive decay with the objective of clearance of the waste from regulatory control or reclassification of the waste.

3.22. The operating organization is responsible for establishing an overall waste management strategy consistent with the national waste management policy. The operating organization should develop a waste management programme that is consistent with the overall waste management strategy, that is facility specific, and that is consistent with other relevant programmes on the site (e.g. on multi-facility sites). The waste management programme:

(a) Should implement the national waste management policy and strategy, as far as applicable;
(b) Should take into account the connections between the sources of radioactive waste and the eventual discharge, disposal or onward disposition of the waste from that facility;
(c) Should take into account the following hierarchy of strategic options for the predisposal management of radioactive waste:
    (1) Keeping the generation of radioactive waste to the minimum practicable, in terms of its type, activity and volume, by using suitable technologies;
    (2) Reuse and recycling of materials;
    (3) Processing of radioactive waste to ensure its safe storage and disposal.

More detailed guidance on facility specific waste management programmes is provided in Appendix II.

3.23. At the design stage, the operating organization is required to prepare an initial decommissioning plan, and to update it as necessary and as required [24]. The final decommissioning plan is required to consider the possible long term storage and disposal of radioactive waste after permanent shutdown of the facility[5]. For new facilities, features that will facilitate decommissioning are required to be included in the design; such features should be included in the initial decommissioning plan, together with information on arrangements for how the availability of the necessary financial resources will be ensured.

[5] The term 'permanent shutdown', as used in this Safety Guide, means that the nuclear fuel cycle facility has ceased operation, i.e. it will no longer be used for its intended purpose. Permanent shutdown differs from a planned shutdown (e.g. due to maintenance, inspection or modification) or an unplanned shutdown (e.g. due to an incident or accident).

3.24. For existing facilities without a decommissioning plan, such a plan is required to be prepared by the operating organization as soon as possible. The decommissioning plan is reviewed and updated at each stage and periodically throughout the lifetime of the facility. Requirements on decommissioning are established in IAEA Safety Standards Series No. GSR Part 6, Decommissioning of Facilities [24], and recommendations are provided in IAEA Safety Standards Series No. WS-G-2.4, Decommissioning of Nuclear Fuel Cycle Facilities [28].

3.25. The operating organization should establish the requirements for training and qualification of its staff and contractors, including for initial training and periodic refresher training. The operating organization should ensure that all staff members concerned understand the nature of the radioactive waste being managed, the objectives of the radioactive waste management processes, the safety case, potential hazards associated with the waste and the relevant operating and safety procedures to the extent required by their responsibilities. Supervisory staff should be competent to perform their activities and should therefore be selected, trained, qualified and authorized for that purpose. Trained and qualified radiation protection officers should be appointed to oversee the application of the radiation protection requirements.

3.26. The operating organization should carry out pre-operational tests and commissioning tests to demonstrate compliance of the radioactive waste management facility and its activities with the requirements of the safety case and supporting safety assessment and with the safety requirements established by the regulatory body. A report summarizing the results of the pre-operational and commissioning tests before the introduction of radioactive material (i.e. inactive commissioning or ‘cold processing’) should be prepared and should be submitted to the regulatory body for review and acceptance.

3.27. The operating organization should ensure that the clearance of radioactive material within authorized practices from any further regulatory control and the control of discharges of radioactive material and other potentially hazardous materials to the environment are in accordance with the conditions of the licence or authorization, and should limit on-site contamination and occupational exposure, with account taken of the need for optimization of protection and safety.

3.28. Records should be maintained for discharges, the clearance of radioactive material from regulatory control, the reuse or recycling of materials, and the delivery of radioactive waste to an authorized disposal facility or its transfer to other facilities. Such records should be retained until the facility has been fully decommissioned, or alternatively for a period of time after decommissioning as agreed with the regulatory body.

3.29. The operating organization should develop and maintain a records system on the generation, processing, storage and transfer of radioactive waste (e.g. for further processing, storage or disposal), which should cover, among other aspects, the radioactive inventory, the location and characteristics of the radioactive waste, and information on its ownership, origin and place of transfer [29]. Such records should be preserved and updated, to enable the implementation of the facility specific radioactive waste management programme. The records system should be managed by the operating organization in accordance with regulatory requirements.

3.30. The operating organization should prepare plans and implement programmes for personnel monitoring, area monitoring and environmental monitoring. Such programmes should be evaluated periodically.

3.31. The operating organization should establish a process for authorization of modifications that includes the evaluation of modifications to the radioactive waste management facility and activities, to the operational limits and conditions, and to the radioactive waste to be processed or stored. The evaluation should use a graded approach that is commensurate with the safety significance of the modifications. The evaluation of the potential consequences of such modifications should also consider potential consequences for the safety of other facilities and for the subsequent storage, further processing or disposal of radioactive waste.

3.32. As stated in GSR Part 5 [4], the operating organization is required to put in place appropriate mechanisms for ensuring that sufficient resources, including financial resources, are available to undertake all necessary tasks throughout the lifetime of the facility, including for its decommissioning, for possible long term storage of radioactive waste at the site after the facility has been permanently shut down, and for the disposal of radioactive waste (even when a disposal option is not yet available). In certain circumstances, financial resources may need to be provided by the waste owner.

3.33. The operating organization should develop on-site emergency arrangements, including an on-site emergency response plan for preparedness for and response to a nuclear or radiological emergency on the basis of the hazards associated with the facility and activities within the site and the potential consequences of an emergency [30–32]. In assessing the hazards associated with nuclear fuel cycle facility sites on which radioactive waste processing or storage facilities are also located, the hazards and potential consequences associated with these facilities and the mutual interactions between these facilities should be considered.

4. INTEGRATED APPROACH TO SAFETY

SAFETY AND SECURITY

Requirement 5 of GSR Part 5 [4]: Requirements in respect of security measures

"Measures shall be implemented to ensure an integrated approach to safety and security in the predisposal management of radioactive waste."

Requirement 21 of GSR Part 5 [4]: System of accounting for and control of nuclear material

"For facilities subject to agreements on nuclear material accounting, in the design and operation of predisposal radioactive waste management facilities the system of accounting for and control of nuclear material shall be implemented in such a way as not to compromise the safety of the facility."

4.1. For a new facility, the site selection and design should take nuclear security into account as early as possible and should also address the interface between nuclear security, safety and nuclear material accounting and control, in order to avoid any conflicts and to ensure that all three elements support one another and that neither safety nor security is compromised.

4.2. The operating organization should assess and manage the interfaces between nuclear security, safety and nuclear material accounting and control activities appropriately, to ensure that they do not adversely affect one another and that, to the extent possible, they are mutually supportive.

4.3. When material needs to be accessed for purposes of waste management or for IAEA nuclear safeguards activities, all the requirements for nuclear safety, radiation protection, waste management and nuclear security should be taken into account. Fundamentals and specific recommendations on nuclear security in the management of radioactive waste are provided in the IAEA Nuclear Security Series [13–15].

INTERDEPENDENCES

Requirement 6 of GSR Part 5 [4]: Interdependences

“Interdependences among all steps in the predisposal management of radioactive waste, as well as the impact of the anticipated disposal option, shall be appropriately taken into account.”

4.4. Interdependences exist among all steps in the management of radioactive waste, from the generation of the waste up to its disposal, discharge or clearance from regulatory control. Planning should be carried out in advance for all the various steps so that a balanced approach to safety is taken in the overall waste management programme and conflicts between the safety requirements and the operational requirements are avoided. There are various alternatives for each step in the management of radioactive waste. For example, treatment and conditioning options are influenced by the established or anticipated acceptance criteria for storage and disposal. At all times, due consideration should also be given to the interdependence between safety and environmental protection as described in Section 2.

4.5. The following aspects in particular should be addressed:

(a) The identification of interfaces between each step and the definition of the responsibilities of the various organizations involved;
(b) The establishment of acceptance criteria and the confirmation of conformance with the acceptance criteria.

4.6. Compliance of the waste packages with the waste acceptance criteria for the chosen disposal option (or next step of the waste management process) should be demonstrated; however, if a disposal option has not been identified, reasonable assumptions should be made about the likely disposal options, including likely waste acceptance criteria, and these should be set down clearly.

4.7. For many programmes for the predisposal management of radioactive waste, decisions have to be made before the waste acceptance criteria for disposal are finalized. Decisions on the predisposal management of radioactive waste should be made and implemented so as ultimately to ensure compliance with the waste acceptance criteria for the selected or anticipated disposal option. In addition, in the design and preparation of waste packages for the disposal of radioactive waste, consideration should be given to the suitability of the packages for transport and storage, including for possible retrieval, and to their suitability for handling and emplacement in a disposal facility on the basis of the anticipated waste acceptance criteria.

4.8. Given that disposal is the final step in the management of radioactive waste that cannot be otherwise cleared from regulatory control, discharged or reused, the selected or anticipated disposal option also needs to be taken into account when any other radioactive waste management activity is being considered. However, in many States, disposal facilities are not yet available in general or are available only for specific types of waste. In this case, proper determination and documentation of the characteristics of the waste form and the waste container should be ensured to provide data for future decisions. Independent of the availability of a disposal facility, all radioactive waste arisings are required to be managed. This means that decisions need to be taken on the waste forms to be produced and the waste containers to be used. Such decisions will have to be taken before all radioactive waste management activities are finally established.

4.9. If no disposal facility is yet available or no future disposal facility has yet been defined, then an interim position should be taken such that either options are not prematurely excluded from consideration or all practicable steps will be taken to prepare the waste for the most probable disposal option. The interdependences between the waste generator, the predisposal radioactive waste management facility and the (existing or anticipated) disposal facility should also be defined.

MANAGEMENT SYSTEM

Requirement 7 of GSR Part 5 [4]: Management systems

"Management systems shall be applied for all steps and elements of the predisposal management of radioactive waste."

4.10. The requirements on the management system (which should cover safety, health, environmental, nuclear security, quality and economic elements) for all stages in the lifetime of a predisposal radioactive waste management facility are established in GSR Part 2 [7]. General guidance on the management system for facilities and activities is given in IAEA Safety Standards Series No. GS-G-3.1, Application of the Management System for Facilities and Activities [33], while specific guidance on the management system for the processing, handling and storage of radioactive waste is provided in IAEA Safety Standards Series No. GS-G-3.3, Management System for the Processing, Handling and Storage of Radioactive Waste [29].

4.11. The management of radioactive waste involves a variety of activities that may extend over a very long period of time. This presents a series of challenges to the development and implementation of effective management systems for a waste management programme, and gives rise to the need for an integrated management system to deal with all matters that might affect the management of radioactive waste, including the financial provisions to carry it out.

4.12. As stated in GSR Part 2 [7], an integrated management system is required to be established, implemented, assessed and continually improved by the operating organization. The management system should be applied to all steps of the predisposal management of radioactive waste. The management system covers all aspects of management, including arrangements for quality assurance and quality control. The management system should foster a safety culture that is aligned with the goals of the operating organization and should contribute to their achievement. The management system should make provision for the siting, design, construction, commissioning, operation, maintenance and decommissioning of the predisposal radioactive waste management facility. Examples of key planning activities relevant to the lifetime of a predisposal radioactive waste management facility are provided in Appendix III.

4.13. For establishing and maintaining an integrated management system, the following long term aspects should be considered (with account taken of the duration of waste processing and storage periods):

(a) The preservation of technology and knowledge and the transfer of such knowledge to individuals joining the operating organization in the future;
(b) The retention or transfer of ownership of the radioactive waste and of the waste management facility;
(c) Succession planning for technical human resources and managerial human resources;
(d) The continuation of arrangements for interacting with interested parties;
(e) The provision of adequate financial resources (the adequacy of resources for maintenance and eventual decommissioning of facilities and equipment may need to be periodically reviewed over operational periods that may extend over decades);

(f) The preservation and quality of records and information (e.g. details of radioactive waste inventories; records relating to siting, design, commissioning, operation and decommissioning of the facility; and records relating to the development of the safety case);
(g) Provision for review to ensure that the goals of the management system can still be met.

RESOURCE MANAGEMENT

4.14. Radioactive waste management activities will require financial and human resources and the necessary infrastructure. Senior management of any facility involved in the generation or management of radioactive waste should make arrangements to provide adequate resources for radioactive waste management activities, to satisfy the demands imposed by the safety, health, environmental, nuclear security, quality and economic aspects of the full range of radioactive waste management activities and by the potentially long duration of such activities.

4.15. The management of radioactive waste can take place over long timescales. Therefore, the government, the regulatory body, the waste owner and the operating organization should ensure the sustainability of all the required resources to maintain safety and environmental protection in appropriate policies, strategies and plans.

PROCESS IMPLEMENTATION

4.16. For long term radioactive waste management activities, future infrastructure requirements should be specified to the extent possible, and plans should be made to ensure that these will be met. In such planning, consideration should be given to the continuing need for support services, spare parts for equipment that may eventually no longer be manufactured and equipment upgrades to meet new regulations, and operational improvements, and to the evolution and inevitable obsolescence of software. Consideration should also be given to the need to develop monitoring programmes and inspection techniques for use during extended periods of storage.

4.17. Consideration should be given to the possible need to relocate radioactive waste if problems arise after it has been placed in long term storage (e.g. threats to the integrity of containers or problems associated with criticality or decay heat). The availability of any specialized equipment that may be necessary over a long time period while radioactive waste is in storage, or that may become necessary in the future, should be assessed.

4.18. Records concerning the radioactive waste that need to be retained for an extended period should be stored such that the likelihood and consequences of loss, damage or deterioration due to unpredictable events such as fire, flooding or other natural or human induced hazards are minimized (e.g. by applying the principle of redundancy). Storage arrangements for records should meet regulatory requirements and the status of the records should be periodically assessed.

5. THE SAFETY CASE AND SAFETY ASSESSMENT

Requirement 13 of GSR Part 5 [4]: Preparation of the safety case and supporting safety assessment

"The operator shall prepare a safety case and a supporting safety assessment. In the case of a step by step development, or in the event of modification of the facility or activity, the safety case and its supporting safety assessment shall be reviewed and updated as necessary."

Requirement 14 of GSR Part 5 [4]: Scope of the safety case and supporting safety assessment

"The safety case for a predisposal radioactive waste management facility shall include a description of how all the safety aspects of the site, the design, operation, shutdown and decommissioning of the facility, and the managerial controls satisfy the regulatory requirements. The safety case and its supporting safety assessment shall demonstrate the level of protection provided and shall provide assurance to the regulatory body that safety requirements will be met."

Requirement 15 of GSR Part 5 [4]: Documentation of the safety case and supporting safety assessment

"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."

Requirement 16 of GSR Part 5 [4]: Periodic safety reviews

"The operator shall carry out periodic safety reviews and shall implement any safety upgrades required by the regulatory body following this review. The results of the periodic safety review shall be reflected in the updated version of the safety case for the facility."

Requirement 22 of GSR Part 5 [4]: Existing facilities

"The safety at existing facilities shall be reviewed to verify compliance with requirements. Safety related upgrades shall be made by the operator in line with national policies and as required by the regulatory body."

5.1. Requirements on the safety case and supporting safety assessment for the predisposal management of radioactive waste are established in GSR Part 5 [4] and guidance is provided in IAEA Safety Standards Series No. GSG-3, The Safety Case and Safety Assessment for Predisposal Management of Radioactive Waste [34]. Requirements on the safety case and periodic safety reviews of nuclear fuel cycle facilities are established in NS-R-5 (Rev. 1) [6] and guidance is provided in IAEA Safety Standards Series Nos SSG-5, Safety of Conversion Facilities and Uranium Enrichment Facilities [35], SSG-6, Safety of Uranium Fuel Fabrication Facilities [36] and SSG-7, Safety of Uranium and Plutonium Mixed Oxide Fuel Fabrication Facilities [37]. Requirements on safety assessment for all facilities and activities are established in IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Facilities and Activities [38].

5.2. The safety case and supporting safety assessment for a nuclear fuel cycle facility typically address the management of radioactive waste as follows:

(a) The safety principles and criteria for the protection of operating personnel and the public and protection of the environment;
(b) A description of the design and operation of structures, systems and components for radioactive waste management (waste generation and control, waste pretreatment, treatment and conditioning, and waste storage);

(c) A description of the main sources of solid, liquid and gaseous waste and estimates of their generation rate in compliance with the design requirements;
(d) An analysis of the hazards associated with the operation of the facility and an assessment of accidents;
(e) Demonstration of compliance with the regulatory requirements and criteria;
(f) Management system and organizational responsibilities;
(g) Identification of structures, systems and components important to safety.

5.3. As stated in GSG-3 [34], compliance with the requirements for documentation of the safety case for the predisposal management of radioactive waste presents a number of challenges, owing to the wide scope of safety concerns at different nuclear fuel cycle facilities, such as hazards associated with the management of large quantities of toxic and reactive chemicals. GSG-3 [34] provides guidance on the use of criteria (e.g. the safety significance, complexity and maturity of the facility or activity) in the application of a graded approach and in informing decisions on the amount of effort that should be applied. Greater consideration should be given to facilities and processes involving significant chemical and physical processing, material transfer and human intervention.

5.4. The safety case for the waste management facilities and activities at a nuclear fuel cycle facility should identify interfaces between the radioactive waste management facility and the operational limits and conditions of the nuclear fuel cycle facility. If the waste is to be managed at a dedicated (centralized) waste management facility, the safety case and supporting safety assessment should demonstrate that consideration has been given to all steps in the generation and processing of the waste up to its disposal, including the clearance of radioactive material from regulatory control and the authorized discharge of effluents, and to the overall compatibility of all steps. Thus, operational aspects and long term safety aspects of waste management should be considered, as well as the possible need for future handling, processing and storage of the waste and the risks and doses that may be associated with these activities.

5.5. As the management of radioactive waste within a nuclear fuel cycle facility is often a flow process in which material moves directly from step to step, the interdependences of these steps should be taken into account when considering data and models and their inputs and outputs.

5.6. The safety case and supporting safety assessment should include the identification of uncertainties in the characteristics of the waste at the waste management facility and uncertainties in the performance of activities, an analysis of the significance of such uncertainties, and the specification of approaches for the management of significant uncertainties. Such uncertainties should be subject to examination by the regulatory body in its review of the inputs into the safety case and of the interdependences between safety cases of different facilities. Guidance on the management of uncertainties is provided in GSG-3 [34].

5.7. Variation and uncertainty in the form and composition of the waste is a particular challenge for some types of legacy waste for which the accuracy and completeness of historical records may be limited. Therefore, safety assessments for the predisposal management of legacy waste should be performed in a comprehensive and detailed manner.

5.8. A description of the specific structures, systems and components and activities associated with the generation and processing of radioactive waste at a nuclear fuel cycle facility is the basis from which the hazards can be identified, characterized and quantified (e.g. management of natural uranium versus irradiated materials). As described in GSG-3 [34], this description should include the following:

(a) A description of the facilities and equipment used for processing and storing radioactive waste, including their location in relation to collocated or nearby facilities or activities or equipment, relevant design features, and their expected lifetimes;
(b) A description of the radioactive waste that is generated and processed, including data on the radioactive waste streams (e.g. the origin of the waste; the volume, mass and form of the waste; radionuclides of concern; the radioactive content of the waste; the presence of fissile materials; and other physical, chemical and pathogenic properties); this should include data on secondary waste streams and on radioactive material that is cleared from regulatory control or discharged.

5.9. A description of the waste quantities and the chemical and radiological characteristics of the waste is important in characterizing and assessing hazards associated with specific waste generation and processing activities. Such characteristics should be considered within the framework of the decision making process, using a graded approach. The description should take into consideration additional hazards (e.g. fissile, thermal, physical, reactive hazards) arising from activities or processes for management of the waste, and should identify where initiating events (e.g. operational events, external events or natural phenomena) could create the potential for harm to human health and/or the environment.

5.10. In the case of a centralized waste management facility where one or more waste streams are received from separate sources, the assessment:

(a) Should be carried out for all waste categories received and for all activities relating to their specific processing;
(b) Should have regard to areas within the facility where there is a potential for waste from different waste streams to interact;
(c) Should identify safety measures and engineering aspects for each waste category;
(d) Should review the safety measures to determine the optimum safety measures and engineering aspects for the safety case for the overall facility such that no conflicts or duplications occur;
(e) Should identify consolidated operational limits and conditions as a basis for safe operation and to ensure compliance with the safety criteria.

5.11. Appendix IV provides examples of hazards associated with typical activities for the predisposal management of radioactive waste in nuclear fuel cycle facilities. Appendix V provides examples of hazards associated with the management of waste in dedicated waste management facilities. Appendix VI identifies hazards associated with, or that could affect waste management at, different types of nuclear fuel cycle facility. These examples are not exhaustive; rather, they are intended to assist in the identification and subsequent assessment of hazards. Annex I of GSG-3 [34] provides further information on the identification and assessment of hazards and postulated initiating events relevant to typical waste management activities.

5.12. Facilities that were not constructed to present safety standards may not meet all the safety requirements. In assessing the safety of such facilities, there may be indications that safety criteria are not met. In such circumstances, practicable measures should be taken to ensure the safety of the facility.

5.13. Non-radiological hazards (e.g. chemo-toxic hazards, industrial hazards) should also be addressed as specified in national requirements or as they may affect radiological safety (e.g. fires). Non-radiological hazards for which safety criteria exist can be assessed and modelled along with radiological hazards (e.g. hazards associated with the lifting and handling of waste containers).

6. GENERAL SAFETY CONSIDERATIONS

GENERAL

6.1. The steps involved in the predisposal management of radioactive waste are the following:

- — Assessment of potential and actual waste arisings and evaluation of options for their subsequent management;
- — Waste generation and control;
- — Processing, which comprises:
  - Pretreatment;
  - Treatment;
  - Conditioning;
- — Storage;
- — Transport.

6.2. Waste management options such as clearance from regulatory control (including for recycling or reuse) and the control of discharges, and authorized disposal, in compliance with the conditions and criteria established by the regulatory body, should be used as far as practicable, with preference given to recycling, reuse and clearance from regulatory control. The limits and controls for clearance from regulatory control and for discharges should be established by the regulatory body [18, 19].

6.3. As part of the management of radioactive waste, it should be verified that the waste complies with acceptance criteria. Therefore, the radioactive waste should be characterized and classified at the various steps in its management, as necessary. Waste packages should have a system of identification that is unique, that enables the packages to be linked to their associated records and that takes account of the need to be readable in the long term future, up to disposal of the waste.

6.4. The ultimate goal of predisposal management of radioactive waste that is not to be cleared, discharged, recycled or reused is to make the waste suitable for disposal (or for storage if no disposal facility is available). This implies that each waste package, i.e. the final waste form and the waste container, has to comply with the waste acceptance criteria of the disposal facility (or with the operational safety requirements of the storage facility). In situations where acceptance requirements for disposal are not yet available, waste acceptance criteria should be specified on the basis of reasonable assumptions about the anticipated disposal option.

6.5. Radioactive waste will need to be handled and transported between and within the various steps involved in its predisposal management. Requirements for the safe transport of radioactive waste are established in SSR-6 [12] and guidance is provided in IAEA Safety Standards Series No. SSG-26, Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition) [39].

6.6. The transport of radioactive waste within the site of a waste management facility may not need to meet all the requirements for off-site transport [12], because transport remains, at all times, under the control of the operating organization, which is responsible for the safety of on-site operations.

WASTE GENERATION AND CONTROL

Requirement 8 of GSR Part 5 [4]: Radioactive waste generation and control

"All radioactive waste shall be identified and controlled. Radioactive waste arisings shall be kept to the minimum practicable."

6.7. Design features and operational procedures for waste generation and control at nuclear fuel cycle facilities should include the following aspects [6, 35–37]:

(a) The appropriate selection of processes, design options, materials, and structures, systems and components for the facility;
(b) The selection of construction methods, commissioning procedures and operating procedures that facilitate waste minimization throughout the entire lifetime of the facility, including its decommissioning;
(c) The use of effective and reliable techniques and equipment;
(d) The containment and packaging of radioactive waste so as to maintain its integrity;
(e) Adequate zoning to prevent the spread of contamination;
(f) Provision for the decontamination of zones and the provision of equipment to prevent the spread of radioactive contamination.

6.8. The requirement for minimization and control of waste generation should also be taken into account in the selection of approaches to storage and processing, in order to minimize the generation of secondary radioactive waste. Examples of processing steps for which this requirement should be taken into account include the selection of conditioning processes and the testing programme used to verify treatment and conditioning processes. The programme for qualification of a conditioning process should be designed in such a way that the number of test specimens using actual radioactive waste is minimized. For a conditioning process in which components become contaminated, equipment of proven longevity should be used.

6.9. Pretreatment operations, including segregation of waste, should be carried out so as to minimize the amount of radioactive waste to be further treated, conditioned, stored and disposed of. Decontamination and/or a sufficiently long period of storage to allow for radioactive decay should be used, where appropriate, to allow reclassification of the waste at a lower level or to enable the waste to be cleared from regulatory control.

CHARACTERIZATION AND CLASSIFICATION OF WASTE

Requirement 9 of GSR Part 5 [4]: Characterization and classification of radioactive waste

"At various steps in the predisposal management of radioactive waste, the radioactive waste shall be characterized and classified in accordance with requirements established or approved by the regulatory body."

6.10. As stated in GSR Part 5 [4], radioactive waste is required to be characterized at various stages in its predisposal management in order to provide information on its properties for use in controlling the quality of the waste or waste package, verifying the process and thus facilitating the subsequent steps for safely processing and finally disposing of the radioactive waste.

6.11. In order to determine appropriate arrangements for the handling, processing and storage of radioactive waste, consideration should be given to the following:

(a) The origin of the waste, the waste type and the physical state of the raw waste (solid, liquid or gaseous);
(b) The criticality risk [27];
(c) The radiological properties of the waste (e.g. half-life, activity and concentration of radionuclides, dose rates from the waste, heat generation);
(d) Other physical properties (e.g. size, mass, compactibility);

(e) Chemical properties (e.g. the composition of raw waste, water content, solubility, corrosiveness, combustibility, gas generation properties, chemical toxicity);
(f) Biological properties (e.g. biological hazards associated with the waste);
(g) Intended methods of processing, storage and disposal.

6.12. The characterization process should include the measurement of physical and chemical parameters, the identification of radionuclides and the measurement of activity content. Such measurements are necessary for tracking the radioactive waste or waste packages through the stages of processing, storage and disposal and for maintaining records for the future, particularly with respect to decommissioning of the waste management facility. Priority should be given to characterization of raw waste at the point of its generation.

6.13. The data requirements for characterization of the waste and the methods for collecting data will differ depending on the type and form of the radioactive waste. When waste streams are processed, characterization may be performed by sampling and analysis of the chemical, physical and radiological properties of the waste. The quality of waste packages may be investigated by non-destructive methods and, infrequently, also by destructive methods. However, it may be possible to apply indirect methods of characterization that are based on process control and process knowledge, including modelling. Such methods may be applied instead of or in addition to the sampling and the inspection of waste packages in order to avoid undue occupational exposure. The methods of characterization in the processing of waste should be acceptable to the regulatory body, as part of the authorization process.

6.14. To ensure the acceptance of waste packages for disposal, a programme should be established to develop a process for conditioning that is acceptable to the regulatory body. The features adopted for waste characterization and process control should contribute to enhancing confidence in the quality of the characterization data and to ensuring that the properties of the waste packages will be as envisaged (so as to ensure the fulfilment of the waste acceptance criteria).

6.15. The categorization and classification of radioactive waste contributes to the development of management strategies and the operational management of the waste. Segregation of waste with different properties will also be helpful at any stage between the arising of the raw waste and its processing, storage, transport and disposal. In order to properly segregate the waste, it is necessary to know its properties and, hence, it is necessary to characterize the waste at various stages of its processing. Documented procedures should be followed for the characterization of radioactive waste and its segregation, and for assigning the waste to a particular class.

6.16. Details of the purpose, methods and approaches to the classification of radioactive waste are provided in GSG-1 [9]; annex III of GSG-1 [9] also provides information on the origin and types of radioactive waste. The classification scheme set out in GSG-1 [9] is based on the long term management (disposal) of the radioactive waste.

6.17. Most radioactive waste from nuclear fuel cycle facilities contains alpha emitting radionuclides. Flammable, pyrophoric, corrosive or other hazardous materials should also be given special attention. Care should be taken to avoid mixing waste with such properties.

6.18. Liquid radioactive waste should be characterized for processing purposes in accordance with its activity concentration and its content of chemical substances. For instance, radioactive waste containing organic matter may need special treatment. Non-aqueous radioactive waste, such as oil, should be segregated for separate treatment. If liquid radioactive waste is immobilized or solidified in a suitable matrix, chemical compatibility between the liquid waste and the matrix material should be ensured.

6.19. Solid radioactive waste should be classified in accordance with its radionuclide content (type and half-life of radionuclides) and its activity concentration, with account taken of the existing or likely disposal options, and should be segregated in accordance with the intended treatment and conditioning processes. For instance, sludge, cartridge filters, contaminated equipment and components, ventilation filters and miscellaneous items (such as paper, plastic or towels) may be segregated in accordance with the type of treatment and conditioning process, such as compaction, incineration or immobilization.

PROCESSING OF RADIOACTIVE WASTE

Requirement 10 of GSR Part 5 [4]: Processing of radioactive waste

“Radioactive material for which no further use is foreseen, and with characteristics that make it unsuitable for authorized discharge, authorized use or clearance from regulatory control, shall be processed as radioactive waste. The processing of radioactive waste shall be

based on appropriate consideration of the characteristics of the waste and of the demands imposed by the different steps in its management (pretreatment, treatment, conditioning, transport, storage and disposal). Waste packages shall be designed and produced so that the radioactive material is appropriately contained both during normal operation and in accident conditions that could occur in the handling, storage, transport and disposal of waste."

6.20. The predisposal management of radioactive waste may include one or more steps, e.g. pretreatment, treatment and conditioning (see Appendix VII). These steps may take place in stationary facilities or mobile facilities. Handling, storage and transport of the waste may be necessary within, between and after such steps.

6.21. The processing of radioactive waste can either facilitate the recycling and reuse of waste items, or produce conditioned waste suitable for subsequent handling, storage, transport and disposal. If reuse or recycling is not feasible, and no disposal facility is available, reasonable assumptions should be made about the requirements for the acceptance of the waste for disposal, in order to provide guidance for its processing, which may include provisions for its long term storage.

6.22. Radioactive waste should be processed as close to the point of generation as practicable, with account taken of different aspects, such as safety, security, exposure and financial aspects, in order to convert it into a passively safe waste form and to prevent its dispersal during storage and disposal. Consideration should be given to the need for a balance between potential mobility of the waste, ALARA considerations and operational impact.

6.23. Thermal processing (processes which, by the assistance of heat, break down or destroy the organic components of the wastes, or involve the assistance or application of heat at temperatures in excess of 600°C) is used in the processing of both solid and liquid radioactive waste. The most commonly used technology is incineration [40].

Pretreatment

6.24. Pretreatment includes operations such as waste collection, segregation, chemical adjustment and decontamination, and is performed to reduce the amount of waste needing further treatment and conditioning, storage and disposal, to adjust the characteristics of the waste, to make the waste more amenable to further processing, and to reduce or eliminate certain hazards posed by the waste owing to its radiological, physical and chemical properties.

6.25. The first operation in the pretreatment of radioactive waste is generally the collection of waste, and segregation as necessary on the basis of its radiological, physical and chemical properties. The segregation of radioactive waste into appropriate categories should be carried out as near to the point of generation of the waste as practicable. Written procedures should be drawn up for the segregation of the waste. Radioactive waste containing predominantly short lived radionuclides should not be mixed with waste containing long lived radionuclides. In the segregation of waste, it should be taken into account whether the waste can be cleared from regulatory control or whether it can be recycled or discharged, either directly or after allowing for a period of storage for radioactive decay.

6.26. To facilitate further treatment and to enhance safety, solid waste should be segregated in accordance with the waste management programme at the facility and the means available. Segregation should be carried out on the basis of consideration of the following properties of the waste:

(a) Combustible or non-combustible, if thermal treatment (e.g. incineration) is a viable option;
(b) Compressible or non-compressible, if compaction is a viable option;
(c) Metallic or non-metallic, if melting is a viable option;
(d) Fixed surface contamination or non-fixed surface contamination, if decontamination is a viable option.

6.27. Spent sealed sources should be segregated from other waste.

6.28. Special care should be taken in the segregation of materials and objects that are fissile, pyrophoric, explosive, chemically reactive or otherwise hazardous, or that contain free liquids or pressurized gases.

6.29. Liquid waste should be segregated, with account taken of the following waste properties:

(a) The radionuclide half-life (e.g. very short lived radionuclides and not very short lived radionuclides);
(b) The specific activity;
(c) The composition (e.g. organic and aqueous waste, low and high salt-containing aqueous waste);
(d) The phase status (e.g. ion exchange resins, sludge).

6.30. A number of decontamination processes remove surface contamination using a combination of mechanical, chemical and electrochemical methods. Care should be taken to limit the amount of secondary waste generated and to ensure that the characteristics of secondary waste are compatible with subsequent steps in the waste management process.

6.31. Mixing of waste (e.g. for purposes of concentration averaging) at the point of generation may be allowed in certain States in order to achieve specific waste acceptance criteria. Mixing of waste streams should be limited to those streams that are radiologically and chemically compatible. Mixed waste streams should be compatible with the waste acceptance criteria of the waste management facility (e.g. for processing, storage or disposal). If the mixing of chemically different waste streams is considered, an evaluation of the chemical reactions that could occur should be carried out, especially any exothermic reactions, in order to avoid uncontrolled or unexpected reactions that could cause the unplanned release of volatile radionuclides or radioactive aerosols. Organic liquid waste needs different treatment owing to its chemical nature and should be segregated from aqueous waste streams. Organic liquid waste may also be flammable and so its collection and storage should incorporate provisions for adequate ventilation and fire protection.

Treatment

6.32. The treatment of radioactive waste may include the following:

(a) Reduction in the volume of the waste (e.g. by incineration of combustible waste, compaction of solid waste and segmentation or disassembly of bulky waste components or equipment);
(b) Removal of radionuclides (e.g. by evaporation or ion exchange for liquid waste streams and filtration of gaseous waste streams);
(c) Change of the form or composition of the waste (e.g. by means of chemical processes such as precipitation, flocculation and acid digestion, as well as by chemical or thermal oxidation);
(d) Change of the form or physical properties of the waste (e.g. solidification, sorption or encapsulation; common immobilization matrices include cement, bitumen and glass).

Solid waste

6.33. Solid radioactive waste may be heterogeneous. Particular consideration should be given to representative sampling before processing so as to confirm compatibility of the waste with the intended process, and appropriate arrangements should be made for such sampling as far as practicable. Arrangements should be made for the systematic control of the final treatment products to verify compliance with established requirements.

6.34. A great number of processes are available for producing acceptable waste forms. The processes to be employed should be selected on the basis of the characteristics of the waste concerned. If possible, processes that achieve high volume reduction factors and that use proven techniques, such as compaction or incineration, should be employed.

6.35. Incineration of combustible solid waste normally achieves the highest reduction in volume as well as yielding a stable waste form. After combustion, radionuclides from the waste will be distributed between the ash, the products from cleaning the exhaust gases and the stack discharges. The distribution will depend on the design and operating parameters of the incinerator used and the nature of the radionuclides in the waste. Incineration will result in an increase of the activity concentration levels in the ash, which might result in a change of the waste class. In addition, other constituents in the waste may yield acidic gases and corrosive combustion products, which could lead to corrosion of the incinerator's components and acid releases to the atmosphere. Off-gas scrubbing to prevent the discharge of radioactive material and non-radioactive hazardous materials may be necessary and should be considered. Consideration should be given to the possibility of radionuclides accumulating in residues of the gas cleaning system and of radionuclides remaining in the ash, and to the need for further conditioning.

6.36. Releases of radionuclides to the environment are largely determined by the operating conditions of the incinerator, in particular by control of the temperature and the types and amounts of waste treated and the radionuclide content. For incinerators processing significant amounts of radioactive waste, the operating organization should monitor the radionuclides in the stack discharge by appropriate means to ensure that the concentrations and amounts discharged are within the limits specified by the regulatory body and are consistent with the parameters modelled in the safety assessment. Certain products of incineration (acids, polychlorinated biphenyls and various other materials) present non-radiological hazards.

6.37. Compaction is a suitable method for reducing the volume of certain types of waste. It may include the compaction of ash resulting from the incineration of waste. The characteristics of the material to be compacted and the desired volume reduction should be well defined and controlled. Consequences of compaction that should be given consideration in selecting or designing and operating a compactor include the following:

(a) The possible release of volatile radionuclides and other airborne radioactive contaminants during compaction;
(b) The possible release of contaminated liquid during compaction;
(c) The chemical reactivity of the material during and after compaction;
(d) Potential fire and explosion hazards due to pyrophoric or explosive materials or pressurized components;
(e) Criticality hazards when waste that contains fissile material is compacted into a single waste package.

6.38. Segmentation or disassembly and other size reduction techniques may be applied before the conditioning of waste that is bulky or oversized in relation to the intended processing (e.g. worn out components or structures). Processes for segmentation or disassembly typically use cutters with high temperature flames, various sawing methods, hydraulic shearing, abrasive cutting and plasma arc cutting. The need for means of preventing the spread of particulate contamination and for fire protection in case of pyrophoric waste should be considered in the selection of the method and in the operation of the equipment.

6.39. For non-combustible and non-compressible solid waste, for which ‘delay and decay’ or decontamination is not a viable option, direct conditioning without prior treatment should be considered. Melting of metal scrap, with resultant homogenization of the radioactive material and its accumulation in the slag, may be considered as a means of achieving material that can be reused or cleared from regulatory control.

Liquid waste and discharges

6.40. Prior to discharging liquids to the environment, the operating organization is required to submit an environmental impact assessment to the regulatory body and conduct a process of optimization of protection of the public. The regulatory body is required to use these submissions as a basis for establishing or approving authorized limits on discharges and conditions for their implementation [3, 19].[6]

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[6] A Safety Guide on radiological environmental impact assessment is in preparation.

6.41. Methods for the treatment of aqueous waste include evaporation, chemical precipitation, ion exchange, filtration, centrifugation, ultrafiltration, thermal treatment and reverse osmosis. In each case, limitations on processes that may be associated with corrosion, scaling, foaming and the risk of fire or explosion in the presence of organic material, should be carefully considered, especially with regard to the safety implications of operation and maintenance. If the waste contains fissile material, the potential for criticality should be evaluated and eliminated to the extent practicable by means of design features and administrative safety measures [27].

6.42. Spent ion exchange resins may be flushed out as slurry, although some operating organizations retain resins as a dry solid [41, 42]. When resins are flushed out as slurry, care should be taken to prevent blockages of the flow as these may cause radiation hot spots and may necessitate special maintenance. Special care should also be taken with the prolonged storage of resins that are awaiting conditioning, because of the potential for radiolysis or chemical reactions generating combustible gases or causing physical degradation or exothermic reactions.

6.43. Liquids for discharge may be produced in the treatment of waste. To the extent possible, liquid waste should be characterized on the basis of its radiological and chemical properties to facilitate collection and segregation. With proper characterization, it may be possible to discharge the liquid within authorized limits, provided that the non-radiological characteristics of the liquid are appropriate.

6.44. All discharged liquids should be readily water soluble or readily dispersible in water. If the liquid contains suspended materials, it may need to be filtered prior to discharge. Waste that is immiscible with water should be completely excluded from discharge. Acidic or alkaline liquids should be neutralized prior to discharge. If the liquid also contains toxic material or other chemicals that could adversely affect the environment or the treatment of sewage, it should be treated prior to discharge in accordance with regulations for protection of workers, the public and the environment.

6.45. For routine discharges of liquids to the environment, the main options for control are provided either by storage systems that allow for the decay of short lived radionuclides before the liquid is released to the environment, or by treatment systems that remove radionuclides from the effluent stream for disposal by other means. Within these two broad categories, there may be a number of different options available. The limits and controls for discharges are established or approved by the regulatory body [3, 19].

6.46. While the volume of organic liquid waste is generally small relative to that of aqueous waste, the risk associated with its incorrect management may be high. Organic waste requires management steps that take account not only of its radioactivity, but also of its chemical organic content, since this can also have detrimental effects on the environment. Treatment of large amounts of organic liquid waste is technologically intensive as well as costly. The treatment steps for organic liquid waste that should be considered include incineration, emulsification to facilitate encapsulation into cement, absorption into a matrix, distillation and wet oxidation.

Gaseous waste and discharges

6.47. As with liquid discharges to the environment, prior to discharging gases to the environment, the operating organization is required to submit an environmental impact assessment to the regulatory body and conduct a process of optimization of protection of the public. The regulatory body is required to use these submissions to establish or approve authorized limits on discharges and conditions for their implementation [3, 19].

6.48. In the operation of treatment systems for gaseous radioactive waste, consideration should be given to: the amount of gas to be treated; its activity; the radionuclides contained in the gas; the concentrations of particulates; the chemical composition; the humidity; the toxicity; and the possible presence of corrosive or explosive substances. As far as reasonably achievable, noble gases with short half-lives should be retained in holdup tanks or other delay systems that allow the radionuclides to decay to an acceptable activity content or activity concentration level before discharge in accordance with the authorized limits established or approved by the regulatory body.

6.49. Radioactive particulates and aerosols in gaseous effluents may be removed by filtration using high efficiency particulate air (HEPA) filters. Iodine can be removed by charcoal filters and noble gases can be delayed by means of sorption beds charged with activated carbon. The use of scrubbers for the removal of gaseous chemicals, particulates and aerosols from off-gases should be considered. Where required by the regulatory body, or if reliability is essential to ensuring safety, redundant systems, such as two filters in sequence, should be used. Additional components of the off-gas system that should be considered for detecting problems include components that ensure proper operation of the filters, such as pre-filters or roughing filters, and temperature and humidity control systems, as well as monitoring equipment such as gauges that show pressure differentials.

6.50. For both liquid and gaseous discharges, the operator is required to review and modify the discharge control measures, as appropriate and in agreement with the regulatory body, taking into account operating experience and any changes in exposure pathways or in the characteristics of the representative person that could affect the assessment of doses due to the discharges [3].

Conditioning

6.51. Conditioning of radioactive waste consists of operations that produce a waste package suitable for safe handling, transport, storage and disposal. Conditioning may include the immobilization of liquid waste or dispersible waste, the enclosure of the waste form in a container and the provision of an overpack as necessary.

6.52. Waste packages produced by conditioning should satisfy the respective acceptance criteria. Therefore, the regulatory body and organizations operating or planning to operate transport services, storage facilities and disposal facilities should be consulted in deciding which types of pretreatment, treatment and conditioning will be necessary.

6.53. Liquid waste is often converted into a solid form by solidifying it in a suitable matrix, such as cement, bitumen or polymer for low level and intermediate level waste, or glass for high level waste, in accordance with the waste acceptance criteria. Solidification may also be achieved without a matrix material, for example, by drying. The product is then enclosed in a container.

6.54. To the extent practicable, the solidification process for liquid waste should produce a waste form with the following characteristics and properties:

(a) Physical and chemical compatibility of the waste with any matrix materials and with the container;
(b) Homogeneity;
(c) Low voidage;
(d) Low permeability and leachability;
(e) Chemical, thermal, structural, mechanical and radiation stability for the required period of time;
(f) Resistance to chemical substances and microorganisms.

6.55. The required characteristics of the form of the solid waste should be considered on a case by case basis. The characteristics of the waste form as listed in para. 6.54 apply to many types of solid waste. Some of the characteristics (in particular homogeneity and low voidage) do not apply for certain types of solid waste.

6.56. It should be taken into account that certain processes (e.g. bituminization) are exothermic and may present a fire and/or explosion hazard, depending on the material in the mix. It should also be taken into account that certain metals, such as aluminium, magnesium and zirconium, could react with, for example, the alkaline water of cement slurry or water diffused from a concrete matrix, to produce hydrogen. In addition, some metal particles, such as zirconium, can become flammable when the ratio of the particle size to surface area and the environment are favourable. The behaviour of chelating agents, organic liquids or oil and salt content in liquid waste may also be of concern in the conditioning process.

6.57. Depending on the waste characteristics and the methods of handling, transport and storage, the container may also need to provide shielding against direct radiation. In selecting materials for the container and its outer surface finish, consideration should be given to their ease of decontamination. If a waste package is not initially designed to meet the relevant acceptance criteria for transport, storage or disposal, an additional container or an overpack will be necessary to meet the acceptance criteria. Care should be taken to ensure the compatibility of the waste package and the overpack with the waste acceptance criteria and transport requirements.

6.58. The conditioned waste package should provide integrity during the anticipated storage period prior to disposal and should be capable of allowing for the following:

(a) Retrieval at the end of the storage period;
(b) Enclosure in an overpack, if necessary;
(c) Transport to and handling at a disposal facility;
(d) Meeting the waste acceptance criteria of the disposal facility.

STORAGE OF RADIOACTIVE WASTE

Requirement 11 of GSR Part 5 [4]: Storage of radioactive waste

"Waste shall be stored in such a manner that it can be inspected, monitored, retrieved and preserved in a condition suitable for its subsequent management. Due account shall be taken of the expected period of storage, and, to the extent possible, passive safety features shall be applied. For long term storage in particular, measures shall be taken to prevent degradation of the waste containment."

General

6.59. Storage is an option that should be considered in the waste management strategy for a nuclear fuel cycle facility. Proper storage should be provided at all stages in waste processing, to ensure isolation and for environmental protection; storage should also facilitate retrieval for subsequent steps. Recommendations on the storage of radioactive waste and on the storage of spent fuel are provided in WS-G-6.1 [10] and SSG-15 [11].

6.60. The design of storage facilities should take into consideration the type of radioactive waste, its characteristics and associated hazards, the radioactive inventory, and the anticipated period of storage. Provision should be made for regular monitoring, inspection and maintenance of the waste and of the storage facility to ensure their continued integrity. Means should also be provided for maintaining the performance parameters of such facilities within acceptable operational and regulatory limits.

6.61. Where necessary, provision should be made for containment in areas where radioactive effluent or radioactive waste is stored prior to its treatment and discharge. The need for provisions for the storage of waste in transit and for the transfer of waste out of storage areas should also be considered.

6.62. The design of storage facilities and waste packages should take account of the waste form (i.e. solid, liquid or gaseous), the radionuclide content and half-lives, activity concentration levels, the total radioactive inventory, non-radiological characteristics and the expected duration of storage. The design features and facility operations should be such as to ensure that the waste can be received, handled, stored and retrieved without undue occupational exposure, exposure of the public or environmental impact.

6.63. Sufficient storage capacity should be provided for radioactive waste generated in normal operation, with a reserve capacity for waste generated in any incidents or abnormal events. Extension of this capacity may be necessary in the event that the waste cannot be transferred off the site because, for example, a disposal facility is not available.

6.64. To the extent practicable, radioactive waste should be stored in a passive condition (e.g. the radioactive material is immobile, the waste form and container are both physically and chemically stable and are resistant to degradation, containment is provided that uses a multi-barrier approach, safety functions are provided by passive systems and the need for active systems or maintenance is minimized and the storage environment optimizes the lifetime of the waste container). The operating organization should ensure that the integrity of the structures, equipment, waste forms and containers is maintained over the expected duration of storage. Consideration should be given to interactions between the waste, the containers and the environment (e.g. corrosion processes due to chemical reactions or galvanic reactions). For certain types of waste (e.g. corrosive liquid waste), special precautions should be taken, such as the use of double walled containers and impervious liners.

6.65. In facilities in which significant volumes of liquid waste are generated, collecting tanks should be the preferred container for liquid waste. Such tanks should be constructed from chemically resistant material, such as stainless steel, plastic, rubber lined carbon steel or fibreglass. Secondary containment should be provided around the tank to prevent the spread of contamination in the event of leakage. The provision of adequate shielding should also be considered.

6.66. Radioactive waste containing short lived radionuclides may be collected and stored to allow its activity to decay to levels that permit authorized discharge, authorized use or clearance of the waste from regulatory control. Storage may also be necessary for operational reasons, for example, to permit off-site transfer of the waste after a specified time.

6.67. Radioactive waste should be stored in a segregated manner such that it can be retrieved for further treatment, conditioning, transfer to another storage facility or disposal. Radioactive waste should be stored separately from non-radioactive, industrial waste to avoid contamination of industrial waste, loss of control over the radioactive material, or increased exposure of workers or the public. Special attention may need to be given to the storage of fissile materials, to avoid storage configurations that could lead to criticality concerns.

6.68. A tracking system for waste packages should be developed and implemented. The system should provide for the identification of waste packages and their locations and an inventory of the waste stored. The sophistication of the waste tracking system required (e.g. labelling and bar coding) should be defined on the basis of overall national obligation and of final disposal needs. Further technical information on the development of waste tracking systems is provided in Ref. [43].

Storage of liquid high level waste

6.69. In the storage of liquid high level waste, surveillance should be provided to confirm the operability of safety related systems such as systems for ventilation, cooling and fluid level detection. Consideration should be given to providing redundant capabilities for the monitoring and indication of the measured values. In addition, means should be provided to monitor the key physical and chemical parameters of the waste (e.g. temperature and pressure, subcriticality and the concentrations of key constituents, the degree of the radiolytic decomposition of aqueous solutions and amounts of flammable or explosive substances). Means should also be provided for maintaining these parameters within acceptable operational and regulatory limits, as well as for maintaining the discharge of airborne and liquid effluents within the regulatory limits.

6.70. Care should be taken to ensure that liquid high level waste is chemically compatible with the process chemistry used for its conditioning and with the construction materials of vessels, pipes and other structures and components. Design features should include double walled pipes and vessels, containment bunds and sumps for waste holding tanks, and active ventilation systems that ensure that air flows from areas of lower contamination to areas of higher contamination. Collection and recovery systems for leaks or spills, such as cell lining and sump systems and liquid recycling systems, should be provided. Measures should also be put in place to maintain solids in suspension in order to promote adequate cooling and to prevent their buildup on cooling surfaces.

6.71. Protection against the hazards associated with the storage of liquid high level waste should be provided by engineered safety features that make use of redundant active or passive safety systems. Such features should include, as a minimum, shielding and containment as well as provisions to prevent the uncontrolled generation of explosive gases or rises in temperature and pressure, by cooling of the liquid high level waste and ventilation of the gases that may be generated.

6.72. Storage facilities for liquid high level waste should be provided with off-gas systems that employ appropriate filtration systems to control the release of airborne effluents and ensure they remain within the regulatory limits.

RADIOACTIVE WASTE ACCEPTANCE CRITERIA

Requirement 12 of GSR Part 5 [4]: Radioactive waste acceptance criteria

"Waste packages and unpackaged waste that are accepted for processing, storage and/or disposal shall conform to criteria that are consistent with the safety case."

6.73. Criteria are required to be developed for the acceptance of radioactive waste at facilities for the predisposal management of radioactive waste [4]. Account should be taken of all relevant operational limits and conditions of the nuclear fuel cycle facility and the waste management facility (consistent with the safety case) and also of the future disposal facility. An important objective of the predisposal management of radioactive waste is to produce waste packages that can be handled, transported, stored and disposed of safely. In particular, waste should be conditioned to meet the acceptance criteria for its disposal. In order to provide reasonable assurance that the conditioned waste can be accepted for disposal, although specific requirements may not yet have been established, options for the future disposal of the waste and the associated waste acceptance criteria should be anticipated as far as possible. Waste acceptance criteria may be met by providing an overpack that is tailored to the specific conditions for disposal and to the characteristics of the waste and the engineered components of the disposal facility. Such an overpack could also be a solution to comply with transport requirements.

6.74. Appendix I provides a listing of the typical properties and characteristics that should be considered for the management of waste packages. To ensure the acceptance of waste packages for disposal, a programme should be established, as an element of the management system, to develop a process for conditioning. The conditioning programme should be made subject to approval by the regulatory body. A programme for quality assurance and control of waste packages should be developed and included in the management system. After approval of the quality assurance programme by the regulatory body, it should be implemented as a means of justifying compliance with the waste acceptance criteria of the disposal facility.

6.75. The operating organization should ensure that the radioactive waste accepted in the facility (and installations) complies with the established acceptance criteria. Procedures for determining whether acceptance criteria are met should be included in the management system.

6.76. Establishment of waste acceptance criteria enables the effective interlinking of facilities and processes in which material is transferred, held for storage or transported to a disposal facility.

6.77. Adequate techniques should be put in place to identify the characteristics of the waste in order to demonstrate that it is consistent with the safety case and that it meets the waste acceptance criteria for the subsequent steps in the waste management process.

6.78. The operating organization should put contingency measures in place in the event that waste packages are received whose characteristics do not comply with the acceptance criteria. Such measures may include placing the waste package into a safe and secure isolation area, returning the waste package to the facility that generated the waste or sending it to an alternative treatment facility.

SAFETY CONSIDERATIONS OVER THE LIFETIME OF THE WASTE MANAGEMENT FACILITY

Siting and design

> **Requirement 17 of GSR Part 5 [4]: Location and design of facilities**
>
> **"Predisposal radioactive waste management facilities shall be located and designed so as to ensure safety for the expected operating lifetime under both normal and possible accident conditions, and for their decommissioning."**

6.79. Requirements for site evaluation for nuclear installations are established in IAEA Safety Standards Series No. NS-R-3 (Rev. 1), Site Evaluation for Nuclear Installations [44] and recommendations on the application of a graded approach in siting and site evaluation are provided in IAEA Safety Standards Series Nos SSG-9, Seismic Hazards in Site Evaluation for Nuclear Installations [45], SSG-18, Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations [46], SSG-21, Volcanic Hazards in Site Evaluation for Nuclear

Installations [47] and SSG-35, Site Survey and Site Selection for Nuclear Installations [48].

6.80. Facilities for the predisposal management of radioactive waste on any particular site should be located in the same area, to the extent practicable, to reduce the need to transport waste between locations for processing and for storage.

6.81. Facilities for the predisposal management of radioactive waste should be designed with the following objectives:

(a) To prevent dispersion of radioactive material (e.g. by means of confinement, cooling or measures against accumulation of explosive gas mixtures);
(b) To prevent external radiation exposure (by means of shielding);
(c) To prevent criticality.

The design assessment should consider internal and external hazards (see annex I of NS-R-5 (Rev. 1) [6]).

6.82. In the design of the nuclear fuel cycle facility and its associated waste management facilities, due consideration should be given to the following:

(a) Criticality safety (if relevant);
(b) The control of access to areas for waste processing and storage and the control of movement between radiation zones and contamination control zones;
(c) The need for retrieval of stored waste (including waste generated during operation);
(d) Waste characterization and inventory control;
(e) The inspection of the waste and its containment;
(f) Means for dealing with waste and waste packages that do not meet specifications;
(g) The control of liquid and gaseous effluents;
(h) The management of waste giving rise to non-radiological hazards;
(i) Maintenance work and eventual decommissioning.

6.83. Measures to be considered in the design of the nuclear fuel cycle facility for the management of gaseous radioactive waste and gaseous effluents should include the following:

(a) Provisions for radioactive gases to be channelled through proper ducting as appropriate and brought to monitored release points;
(b) Provision of means for the authorized discharge of gaseous radioactive waste, such as stacks, and of methods for sampling and monitoring of those discharges.

6.84. Measures to be considered in the design of the nuclear fuel cycle facility for the management of liquid radioactive waste and liquid effluents should include the following:

(a) The collection of radioactive liquid effluents in a common point such as a holding tank, either for reuse (e.g. treatment using resins or solidification) or because the activity levels are too high for their immediate release to the environment;
(b) Means for monitoring of releases of liquid radioactive waste with low levels of activity for potential increases in the concentrations of radionuclides downstream from the release site;
(c) The management and control of liquid radioactive waste with high levels of activity;
(d) Provisions for storage for radioactive decay to minimize releases of radioactive material;
(e) Provisions for sampling from and monitoring of retention tanks prior to the release of liquid content, preferably at the point of release;
(f) Provisions for segregation of liquid waste by radioactivity (radionuclide half-life, specific activity), composition (organic and aqueous waste, low and high salt-containing aqueous waste) and phase status (ion exchange resins, sludge);
(g) Provisions for treating liquid radioactive waste, either for reuse (e.g. treatment using resins) or because activity levels are too high for its discharge to the environment;
(h) Provisions, as necessary, for storage of spent ion exchange resins and dehydration of liquid waste;
(i) Provisions for filtration in liquid waste collection lines to prevent the release of solids.

6.85. Measures to be considered in the design of the nuclear fuel cycle facility for the management of solid radioactive waste should include, as far as applicable, the following:

(a) Provisions for segregation of waste by type (i.e. by physical form, volume, mass, isotopic composition and activity concentration) or in accordance with its area of origin;
(b) Means for the handling, packaging and storage of solid low level radioactive waste and very low level radioactive waste (e.g. contaminated cleaning equipment, clothing, paper and tools);
(c) Means for the handling, packaging and storage of solid intermediate level radioactive waste (e.g. waste arising from ion exchange resins, ventilation filters and charcoal beds);
(d) Areas and tools for handling, temporary storage and loading of waste;
(e) Equipment and tools for radiation protection;
(f) Provisions as necessary for handling and storage of filters, resins and residues from the evaporation of liquid waste;
(g) Provisions for ensuring that the clearance of radioactive material from regulatory control and the control of discharges are conducted within authorized limits.

6.86. Facilities should be designed to prevent interactions between different materials that may compromise the containment of the waste or compromise safety at the facility.

6.87. The predisposal management of radioactive waste may also entail the management of non-radioactive hazardous material. Measures should be taken to ensure that its management is in compliance with the applicable regulations relating to hazardous material and to take account of potential interactions between radioactive and non-radioactive constituents.

6.88. For the conditioning of waste, all relevant characteristics of the waste form should be considered and provided for in the design of the waste package. The waste package should provide adequate containment and shielding and should have adequate heat removal properties.

6.89. The design and operation of predisposal radioactive waste management facilities should be carried out in such a way as to ensure subcriticality both in operational states (normal operation and anticipated operational occurrences) and in accident conditions, by means of safe geometrical configurations, limitations on concentrations and inventories of fissile material or the use of neutron poisons.

Conditions of optimum moderation and reflection should be considered in the determination of safe configurations of radioactive waste and the development of operating procedures. An appropriate limiting neutron multiplication factor, with suitable safety factors for mass, concentration and other characteristics taken into account, should be selected in the design. The need for additional organizational and administrative arrangements that may be necessary in the operation of such a facility to ensure subcritical conditions should be considered [27].

6.90. The design of a facility for the predisposal management of high level (heat generating) radioactive waste should incorporate systems that are capable of maintaining the temperature of the waste or the waste form within acceptable limits in all stages of predisposal management of radioactive waste, both in operational states and in accident conditions. Such temperature limits should be based on the properties of the waste and waste packages, with account taken of the material properties of the container, the containment structures and the waste form in all steps of management, including storage. To the extent practicable, the cooling systems for storage facilities for conditioned high level waste should be passive and should need minimal maintenance. If the forced circulation of coolant is used, the system should be highly reliable. Examples of features that enhance the reliability of the cooling system are capabilities for dealing with the settling of solids and with buildup on surfaces that affects the efficiency of heat removal. The storage facility itself should be designed to be capable of enduring events involving temporary loss of cooling without damage to the stored waste. In addition, means of mitigation should be put in place to deal with such contingencies.

Construction and commissioning

Requirement 18 of GSR Part 5 [4]: Construction and commissioning of the facilities

"Predisposal radioactive waste management facilities shall be constructed in accordance with the design as described in the safety case and approved by the regulatory body. Commissioning of the facility shall be carried out to verify that the equipment, structures, systems and components, and the facility as a whole, perform as planned."

6.91. Guidance for the construction of nuclear installations is provided in IAEA Safety Standards Series No. SSG-38, Construction for Nuclear Installations [49].

6.92. For modular storage systems, most of the commissioning will be completed on loading of the first storage module. Some of the commissioning processes may become a part of regular operation as new modules are brought into service. However, a change in module design may require some of the commissioning steps to be repeated for the new design [11].

Facility operation

> **Requirement 19 of GSR Part 5 [4]: Facility operation**
>
> **"Predisposal radioactive waste management facilities shall be operated in accordance with national regulations and with the conditions imposed by the regulatory body. Operations shall be based on documented procedures. Due consideration shall be given to the maintenance of the facility to ensure its safe performance. Emergency preparedness and response plans, if developed by the operator, are subject to the approval of the regulatory body [30]."**

Operating instructions

6.93. Instructions and procedures should be prepared for normal operation at the waste management facility and for accident conditions. Instructions and procedures should be prepared in order to be readily available when needed by the designated responsible person.

6.94. Measures for limiting or preventing exposure associated with radioactive waste generated in normal operation should include the following:

(a) Provisions for the isolation of radioactive waste from site personnel and the public, including access control, for example, adequate zoning to prevent the spread of contamination;
(b) Provisions for radiation monitoring and visual inspection whenever waste is handled or moved (placed into storage, retrieved or transported off the site);
(c) Provisions for detection, collection and treatment of liquid spills;
(d) Provisions for the decontamination of personnel and equipment;
(e) Provisions for the handling of radioactive waste arising from decontamination activities.

6.95. The operating organization should ensure that operating procedures relating to the maintaining of subcriticality are subjected to rigorous review and are compared with the safety requirements of the design. This may include confirmatory analysis and review by the regulatory body. Some of the factors that should be considered in this review include the following:

(a) The type and class of the waste to be stored;
(b) Geometries necessary to ensure subcriticality;
(c) The dependence of subcriticality on neutron absorbers;
(d) Conditions of optimum moderation and reflection;
(e) The waste form and waste packages;
(f) Handling operations;
(g) The potential for abnormal operation;
(h) Analysis of the measures relied upon to provide defence in depth.

6.96. Protection and safety considerations that should be taken into account in the development of operating procedures and contingency arrangements and emergency arrangements are addressed in IAEA Safety Standards Series Nos GS-G-2.1, Arrangements for Preparedness for a Nuclear or Radiological Emergency [31] and GSG-2, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency [32]. When developing emergency arrangements, the operating organization should consider events such as the following:

(a) The failure of handling systems, including severe crane failure, dropping of loads, or falling waste packages;
(b) The loss of safety related facility process systems, such as supplies of electricity, process water, compressed air and ventilation;
(c) Explosions (e.g. due to the buildup of gases generated by radiolysis);
(d) Fires, which could damage items important to safety;
(e) External natural hazards, such as extreme weather conditions and earthquakes;
(f) External human induced hazards, such as aircraft crashes or sabotage and other malicious acts.

Operational limits and conditions

6.97. Operational limits and conditions should be developed on the basis of the following:

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

(b) The sensitivity of items important to safety and the consideration of scenarios involving the failure of items, the occurrence of specific events or variations in operating parameters;
(c) The accuracy and calibration of instrumentation equipment for measuring safety related operating parameters;
(d) Consideration of the technical specifications for each item important to safety and the need to ensure that such items will continue to function in the event of any specified fault occurring or recurring;
(e) The need for items important to safety to be available to ensure safety in operational states, including during maintenance;
(f) Specification of the equipment that needs to be available to enable a full and proper response to postulated initiating events or accident conditions;
(g) The minimum staffing levels needed to operate the waste management facility safely.

6.98. Operational limits and conditions should be kept under review and may also have to be revised as necessary, in accordance with the national regulatory framework, for the following reasons:

(a) In the light of operating experience;
(b) Following modifications made to the facility and/or to the type of radioactive waste;
(c) As part of the process of periodically reviewing the safety case (including as part of periodic safety review) for the facility;
(d) In case of relevant changes in legal or regulatory conditions.

Feedback of operating experience

6.99. Operating experience and events at the facility and reported by similar facilities should be collected, screened and analysed and/or reviewed in a systematic way. Conclusions should be drawn and communicated by means of an appropriate feedback procedure. Any new standards, regulations or regulatory guidance should also be reviewed to check their applicability for safety at the facility. Such feedback processes should be applied for enhancing both design and operation.

Maintenance

6.100. In general, the maintenance schedule should be derived from the requirements of the safety assessment and should take into account the following:

(a) Analysis of maintenance requirements on the basis of previous experience or other applicable data (such as manufacturers' recommendations);
(b) Work planning in relation to the availability of skilled personnel, tools and materials (including spare parts);
(c) The monitoring programme for radiation protection and industrial safety;
(d) The potential for a loss of confinement function;
(e) The impact on other operating facilities on the site.

6.101. Approval and implementation of the maintenance, inspection and testing programme, and approval of associated working procedures and acceptance criteria, should be carried out by suitably qualified and experienced operating personnel.

Radiation protection programme

6.102. A radiation protection programme should be put in place that ensures that areas of the waste management facility are classified according to the radiation levels and the potential for contamination. The programme should include the monitoring and control of all relevant radiation risks at the facility and should include provisions for ensuring that exposures of personnel working in the facility are assessed, recorded, optimized and kept below dose limits. A programme of work planning should also be put in place to ensure that doses are kept as low as reasonably achievable.

Arrangements for emergency preparedness and response

6.103. Emergency plans and procedures should be developed and documented, and should be made available to the personnel concerned. Such plans and procedures should be subject to periodic review and revision as necessary in light of past experience and following any changes that may impact emergency arrangements. Personnel concerned should be qualified and trained in the implementation of these plans and procedures. Emergency arrangements should be tested in exercises on a regular basis and feedback obtained should be incorporated into the emergency arrangements as necessary. The management system in place should ensure that equipment, supplies, communication systems and other resources necessary for response to an emergency are available and in working order when they are needed [30, 31].

Decommissioning

> **Requirement 20 of GSR Part 5 [4]: Shutdown and decommissioning of facilities**
>
> **"The operator shall develop, in the design stage, an initial plan for the shutdown and decommissioning of the predisposal radioactive waste management facility and shall periodically update it throughout the operational period. The decommissioning of the facility shall be carried out on the basis of the final decommissioning plan, as approved by the regulatory body. In addition, assurance shall be provided that sufficient funds will be available to carry out shutdown and decommissioning."**

6.104. Requirements on decommissioning are established in GSR Part 6 [24] and recommendations are provided in WS-G-2.4 [28]. The key elements to be considered in planning for the decommissioning of waste management facilities, as specified in GSR Part 6 [24], include the following:

(a) Selecting a decommissioning strategy that:
   - (i) Is consistent with the national policy for the management of radioactive waste;
   - (ii) Considers the optimization of protection and safety;
   - (iii) Applies a graded approach;
   - (iv) Ensures that interdependences are taken into account in the planning for individual facilities (for sites with multiple facilities);
   - (v) Is supported by a safety assessment and environmental impact assessment;

(b) Preparing and submitting to the regulatory body for approval an initial decommissioning plan in order to identify decommissioning options, demonstrate their feasibility, ensure that sufficient financial resources will be available, and identify categories and estimate quantities of waste that will be generated;

(c) Establishing and implementing an integrated management system that covers all aspects of decommissioning, fosters a safety culture, and provides a single framework for the arrangements and processes necessary to address the goals of the operating organization;

(d) Estimating the cost of decommissioning actions and establishing a mechanism for providing adequate financial resources to cover the

associated costs, including the management of the resulting radioactive waste;
(e) Performing radiological surveys and obtaining information on radiological conditions in support of providing baseline data;
(f) Preparing and retaining appropriate records and reports that are relevant to decommissioning (e.g. records and reports of events).

6.105. The decommissioning plan for a nuclear fuel cycle facility should address potential hazards that could lead to high external or internal doses to the workers or could lead to criticality accidents, as well as non-radiological hazards. An initial version of the decommissioning plan is required to be prepared during the design of the waste management facility [24].

6.106. During the operation of the facility, the initial decommissioning plan should be periodically reviewed and updated and should be made more comprehensive with respect to the following:

(a) Technological developments in decommissioning;
(b) Possible external natural and human induced hazards;
(c) Modifications to systems and structures affecting the decommissioning plan;
(d) Amendments to regulations and changes in government policy;
(e) Possible long term storage and disposal of radioactive waste at the site once the nuclear fuel cycle facility has been permanently shut down, or delivery of radioactive waste to an authorized facility for storage or disposal in compliance with the transport requirements;
(f) Availability of disposal options and waste acceptance criteria for disposal;
(g) Cost estimates, financial provisions, and update of decommissioning funds on the basis of updates to characterization data and the safety case;
(h) Ensuring that properly trained, qualified and competent staff are available for the decommissioning project.

Appendix I

DEVELOPMENT OF SPECIFICATIONS FOR WASTE PACKAGES

I.1. Specifications for conditioned radioactive waste should be established to ensure that the waste package satisfies the relevant acceptance criteria for storage or disposal, and the transport requirements. The radiological characteristics of the waste should be identified at an early stage. Other specifications of the waste package may be divided into four main topics: chemical and physical properties, mechanical properties, containment capability, and stability or robustness. Stability or robustness concerns the capability of the waste package to retain radionuclides over extended periods of time.

RADIOLOGICAL CHARACTERISTICS

I.2. The radiological characteristics of the waste include the following:

(a) Radionuclide specific activities and half-lives;
(b) Total activity content (alpha, beta and gamma) and activity concentration levels;
(c) Dose rate;
(d) Heat output.

CHEMICAL AND PHYSICAL PROPERTIES

I.3. The chemical and physical properties of the waste form include the following:

(a) Chemical composition;
(b) Density, porosity, permeability to water and permeability to gases;
(c) Homogeneity and the compatibility of the waste with the matrix;
(d) Thermal stability;
(e) Percentage of water incorporated, exudation of water under compressive stress, shrinkage and curing;
(f) Leachability and corrosion rate.

I.4. The chemical and physical properties of the container include the following:

(a) Materials and composition (e.g. metal alloy, glass, ceramic);
(b) Porosity, permeability to water and permeability to gases;
(c) Thermal conductivity;
(d) Solubility and corrosion in corrosive atmospheres or liquids such as water or brines.

I.5. The physical properties of the waste package include the following:

(a) Number of voids in the container (which are to be minimized);
(b) Characteristics of the lidding and sealing arrangements;
(c) Sensitivity to changes in temperature.

MECHANICAL PROPERTIES

I.6. The mechanical properties of the waste form include its tensile strength, compressive strength and dimensional stability.

I.7. The mechanical properties of the waste package include its behaviour under mechanical loads (static loads and impact loads) or thermal loads.

CONTAINMENT CAPABILITY

I.8. The containment capability of the waste package concerns the following:

(a) The potential for diffusion and leaching of radionuclides in an aqueous medium;
(b) The potential for the release of gas under standard atmospheric conditions or conditions in a repository;
(c) The potential for the diffusion of tritium under standard atmospheric conditions or conditions in a repository;
(d) The capability of the waste package to retain radionuclides;
(e) Water tightness and gastightness of the package sealing device.

STABILITY OR ROBUSTNESS

I.9. The stability or robustness of the waste package (i.e. its long term performance and durability) concerns the following:

(a) Behaviour under temperature cycling;
(b) Sensitivity to elevated temperatures and behaviour in a fire;
(c) Behaviour under conditions of prolonged radiation exposure;
(d) Sensitivity of the matrix to water contact;
(e) Resistance to the action of microorganisms;
(f) Corrosion resistance in a wet medium (for metal containers);
(g) Porosity and degree of gastightness;
(h) The potential for swelling due to the internal buildup of gases.

Appendix II

FACILITY SPECIFIC WASTE MANAGEMENT PROGRAMME

II.1. The content of a facility specific waste management programme should include the following:

(a) A description of the processes in which radioactive waste is generated at the facility;
(b) A description of the radioactive waste streams and the efforts to be made to avoid and minimize them;
(c) The limits and conditions necessary for the waste to be managed safely;
(d) A comprehensive list of the waste categories and anticipated waste arisings and inventories for the facility;
(e) Definition of the waste management principles and objectives specific to the facility;
(f) Identification of waste management options and associated steps, as well as identification of interdependences between waste management steps;
(g) Identification of funding to implement the waste management programme throughout the lifetime of the facility, including its decommissioning, and the possible long term storage of radioactive waste;
(h) Justification of the selection of appropriate management options on the basis of elements (a) to (g), above, and international good practices;
(i) Demonstration that the facility specific waste management programme is compatible with national policy and strategy for radioactive waste management;
(j) Demonstration, if necessary, of how the safety case is affected by the waste management programme, e.g. how a decision to store waste for longer periods than the building was originally designed for would impact the safety case.

II.2. The waste management programme should include provisions for the following:

(a) Keeping the generation of radioactive waste to the minimum practicable, in terms of type, activity and volume, by using suitable technologies;
(b) The possible reuse and recycling of materials;
(c) The appropriate classification and segregation of waste, and maintenance of an accurate inventory for each radioactive waste stream, with account taken of the available options for clearance, storage and disposal;

(d) The collection, characterization and safe storage of radioactive waste;
(e) Adequate storage capacity for the radioactive waste expected to be generated (conditioned and unconditioned), and an additional reserve storage capacity;
(f) Ensuring that the radioactive waste can be retrieved at any time within the anticipated storage period;
(g) Techniques and suitable procedures for the retrieval of stored radioactive waste;
(h) The processing of radioactive waste to comply with waste acceptance criteria and to ensure safe storage, transport and disposal;
(i) The safe handling and transport of radioactive waste;
(j) Adequate control of discharges of effluents to the environment;
(k) Monitoring of sources (of discharges of effluents) and of the environment, for the demonstration of regulatory compliance;
(l) Maintaining facilities and equipment for the processing and storage of waste to ensure safe and reliable operation;
(m) Monitoring the status of the containment for radioactive waste in the storage location;
(n) Monitoring changes in the characteristics of radioactive waste by means of inspection and regular analysis, in particular if storage is continued for extended periods;
(o) Initiation, as necessary, of research and development activities for improving existing methods for processing radioactive waste or for developing new methods and techniques;
(p) Conducting, recording and reporting on a systematic evaluation of operating experience and events at the facility;
(q) Adoption and implementation of corrective actions on the basis of the results of monitoring and operating experience feedback;
(r) Emergency preparedness and response[7];
(s) Addressing the main risks and uncertainties associated with the programme development and evaluation of their influence on its implementation.

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[7] Although emergency preparedness and response is mentioned specifically under the waste management programme, such arrangements may be part of the overall emergency arrangements for the entire facility. In this case, the waste management programme should make reference to the overall emergency arrangements.

Appendix III

EXAMPLES OF KEY PLANNING ACTIVITIES RELEVANT TO THE LIFETIME OF A PREDISPOSAL RADIOACTIVE WASTE MANAGEMENT FACILITY

ACTIVITIES IN THE DESIGN STAGE

III.1. The following activities should be carried out by the design organization or operating organization when a decision is made to carry out operations involving the management of radioactive materials:

(a) A review of government policies to establish national expectations with respect to the national strategic waste strategy;
(b) Establishment of the location of the facility, to take into account safety and radioactive waste management aspects, i.e. the distance from population centres and availability of transport links from the facility to waste treatment or disposal facilities, with recognition that decommissioning of the facility will also impact the population;
(c) Establishment of a waste management programme and strategy;
(d) Establishment or upgrading of a waste management inventory;
(e) Establishment of the steps in the management of the radioactive waste;
(f) Further development of the waste management inventory to incorporate potential secondary waste;
(g) Establishment of initial waste disposal criteria, onward disposition criteria and storage criteria;
(h) Establishment of links with upstream and downstream waste management facilities;
(i) Application of the waste management hierarchy to ensure an optimal waste management strategy;
(j) Building of additional requirements into the design of the facility and the records management;
(k) Setting down of research and development requirements to determine the gaps in knowledge that need to be filled to achieve optimal waste management;
(l) Repetition of all activities through the conception, development, detailed design and building sub-stages of design, in order to expand the database of information, develop future requirements for information and establish an auditable trail of decisions.

ACTIVITIES IN THE OPERATIONAL STAGE

III.2. The following functions should be carried out by the operating organization when radioactive material is introduced into the waste management facility:

(a) A review of government policies to establish how operational needs and experience are influenced by national expectations and the overall waste strategy as well as the national strategic waste strategy;
(b) Establishment or upgrading of waste management inventory with operational data;
(c) Registration and recording of all normal waste arisings as well as those outside the normal arisings;
(d) Ascertaining and monitoring the behaviour of radioactive waste in the steps in the management of the radioactive waste;
(e) Further development of the waste management inventory to incorporate all waste identified;
(f) Further development of waste disposal criteria, onward disposition criteria and storage criteria;
(g) Improvement and addition of detail to the waste strategy and application of the waste management hierarchy to develop optimal waste management as information from the facility evolves;
(h) Building of additional requirements into the operation of the facility and the records management;
(i) Development of the design of the facility as it is modified during the operational stage to deal, where possible, with gaps in knowledge that need to be filled to achieve optimal waste management;
(j) Communication with the regulatory body and the government;
(k) Repetition of all activities through the commissioning, operation and shutdown stages, in order to expand the database of information, develop future requirements for information and establish an auditable trail of decisions.

ACTIVITIES IN THE DECOMMISSIONING STAGE

III.3. The following functions should be carried out by the operating organization when all radioactive material has been removed from the waste management facility:

(a) A review of government policies to establish national expectations and the national strategic waste strategy;

(b) Establishment or upgrading of the waste management inventory, by means of techniques such as monitoring;
(c) Use of the waste management inventory to establish the scope and condition of the waste remaining within the facility;
(d) Ascertaining and monitoring the behaviour of radioactive waste in the steps in the management of the radioactive waste, by selection of appropriate methods and equipment that deliver optimal waste minimization;
(e) Further development of the waste management inventory to incorporate all waste identified;
(f) Further development of the waste disposal criteria, onward disposition criteria and storage criteria;
(g) Improvement and addition of detail to the waste strategy and application of the waste management hierarchy to develop optimal waste management as information from the facility evolves;
(h) Building of additional requirements into the decommissioning process and the records management;
(i) Communication with the regulatory body and the government;
(j) Repetition of all activities through the decommissioning and interim storage stages, in order to expand the database of information, develop future requirements for information and establish an auditable trail of decisions.

Appendix IV

EXAMPLES OF HAZARDS ASSOCIATED WITH WASTE MANAGEMENT ACTIVITIES AT NUCLEAR FUEL CYCLE FACILITIES

TABLE 1. HAZARDS ASSOCIATED WITH WASTE MANAGEMENT ACTIVITIES AT NUCLEAR FUEL CYCLE FACILITIES

Waste management activities	Waste materials	Characteristics	Hazards (radiological)	Hazards (non-radiological)
Uranium conversion (natural): • Treatment of insoluble solids post-dissolution; • Management of effluent from solvent washing; • Scrubbing of gaseous fluorides; • Particulate scrubbing; • Particulate filtration; • Management of liquid scrubber effluent;	• Insoluble uranium oxide concentrate.	• Uranium concentration and concentration of radioactive material of natural origin; • Properties of uranium compounds; • Impurities (e.g. vanadium, chromium).	• Alpha emitting material; • Internal and/or external exposure.	• Heavy metal toxicity.

TABLE 1. HAZARDS ASSOCIATED WITH WASTE MANAGEMENT ACTIVITIES AT NUCLEAR FUEL CYCLE FACILITIES (cont.)

Waste management activities	Waste materials	Characteristics	Hazards (radiological)	Hazards (non-radiological)
• General management of solid waste, including collection, size reduction and packaging.	• Uranium excess (fluoride ash).	• Concentration of short lived progeny (thorium, protactinium); • Uranium concentration; • Properties of uranium compounds; • Fluorine content; • Particulate size and dispersibility; • Temperature and thermal capacity.	• Alpha emitting materials; • Internal and/or external exposure; • Additional beta dose rates from concentrations of short lived radionuclides.	• Fire; • Fluoride toxicity (with acute and/or chronic effects); • Heavy metal toxicity; • Thermal burns.
	• Potassium hydroxide liquors, including test liquors.	• Liquids containing uranium and fluorides and alkalis; • Low uranium concentration.	• Impact of uranium on the environment.	• Handling of alkalis and fluorides; • Chemical impact on the environment; • Chemical impact on workers.

TABLE 1. HAZARDS ASSOCIATED WITH WASTE MANAGEMENT ACTIVITIES AT NUCLEAR FUEL CYCLE FACILITIES (cont.)

Waste management activities	Waste materials	Characteristics	Hazards (radiological)	Hazards (non-radiological)
	• Carbonate and hydroxide liquors from solvent washing, including test liquors.	• Contamination with solvents; • Possible formation of colloids; • Properties of uranium compounds; • Impurities (e.g. vanadium, chromium); • Various concentrations of test chemicals and uranium and decay products.	• Impact of uranium and decay products on the environment.	• Handling of alkalis and fluorides; • Chemical impact on the environment; • Solvent impact on the environment; • Chemical impact on workers.
	• Personal protective equipment and other compressible solids.	• Various levels of surface contaminated materials.	• Alpha emitting materials; • Internal and/or external exposure.	• Heavy metal toxicity.
	• Contaminated filters.	• Various levels of activity; • Uranium; • Properties of uranium compounds.	• Alpha emitting materials; • Internal and/or external exposure.	• Heavy metal toxicity.

TABLE 1. HAZARDS ASSOCIATED WITH WASTE MANAGEMENT ACTIVITIES AT NUCLEAR FUEL CYCLE FACILITIES (cont.)

Waste management activities	Waste materials	Characteristics	Hazards (radiological)	Hazards (non-radiological)
	• Components manufactured from non-ferrous and ferrous metals.	• Various levels of activity; • Uranium; • Properties of uranium compounds.	• Alpha emitting materials; • Internal and/or external exposure.	• Heavy metal toxicity; • Environmental impact.
	• Components manufactured from organic or plastic materials (e.g. polytetrafluoroethylene (PTFE)).	• Various levels of activity; • Uranium; • Properties of uranium compounds; • Impurities in organic materials.	• Alpha emitting materials; • Internal and/or external exposure.	• Fire; • Heavy metal toxicity; • Hydrogen fluoride; • Fluorine.
	• Contaminated electrolytes.	• Uranium; • Properties of uranium compounds; • Hydrogen fluoride and/or potassium fluoride electrolytes in solid and liquid forms; • Gaseous hydrogen fluoride; • Fluorine; • Hydrogen.	• Alpha emitting materials; • Internal and/or external exposure.	• Fire and explosion; • Heavy metal toxicity; • Hydrogen fluoride; • Fluorine; • Fluoride toxicity (with acute and/or chronic effects); • Heavy metal toxicity; • Chemical burns.

TABLE 1. HAZARDS ASSOCIATED WITH WASTE MANAGEMENT ACTIVITIES AT NUCLEAR FUEL CYCLE FACILITIES (cont.)

Waste management activities	Waste materials	Characteristics	Hazards (radiological)	Hazards (non-radiological)
	• Non-compressible solids (e.g. building rubble).	• Various levels of activity concentration.	• Alpha emitting materials; • Internal and/or external exposure.	• Heavy metal toxicity.
	• Organic liquids (e.g. kerosene, tributyl phosphate).	• Various levels of activity; • Uranium; • Properties of uranium compounds; • Organic properties.	• Alpha emitting materials; • Internal and/or external exposure; • Environmental impact.	• Fire; • Heavy metal toxicity; • Environmental impact.
	• Gases and aerosols.	• Various levels of activity (e.g. uranium, uranium decay products and their compounds); • Various chemical compositions (e.g. UF_6, UO_2F_2, HF, F_2, NH_3).	• Alpha emitting materials; • Internal and/or external exposure; • Environmental impact.	• Heavy metal toxicity; • Environmental impact.

TABLE 1. HAZARDS ASSOCIATED WITH WASTE MANAGEMENT ACTIVITIES AT NUCLEAR FUEL CYCLE FACILITIES (cont.)

Waste management activities	Waste materials	Characteristics	Hazards (radiological)	Hazards (non-radiological)
Uranium conversion (irradiated): • Same processes as in conversion of natural uranium; • Additional considerations from irradiated feedstock.	• Feedstocks, products and wastes.	• Concentration of fission products (e.g. uranium-232 and plutonium isotopes); • Increase in the amount of daughter radionuclides during processing; • Elevated activity concentration levels.	• Alpha emitting materials; • Elevated dose rates.	

TABLE 1. HAZARDS ASSOCIATED WITH WASTE MANAGEMENT ACTIVITIES AT NUCLEAR FUEL CYCLE FACILITIES (cont.)

Waste management activities	Waste materials	Characteristics	Hazards (radiological)	Hazards (non-radiological)
Uranium enrichment (centrifuge): • Particulate filtration; • Cylinder decontamination; • Reduction in the size of waste cylinders; • General management of solid waste, including collection, size reduction and packaging; • General management of liquid waste (e.g. cooling water, disposal of steam condensates); • Disposal of refrigerants and glycol.	• Used cylinders including those requiring long term management prior to disposal.	• Various levels of activity from buildup of uranium and uranium decay products and impurities; • Potential for the presence of residual washings; • Potential for contents whose mass and composition are unknown; • Hydrogen; • Hydrogen fluoride.	• Alpha emitting materials; • Internal and/or external exposure; • Criticality; • Environmental impact.	• Heavy metal toxicity; • Corrosive chemicals; • Explosion; • Overpressurization; • Environmental impact.
	• Spent cylinder washings.	• Various levels of activity from buildup of uranium and uranium decay products and impurities; • Various chemical compositions, potentially unknown; • Hydrofluoric acid content.	• Alpha emitting materials; • Internal and/or external exposure; • Criticality; • Environmental impact.	• Heavy metal toxicity; • Corrosive chemicals; • Hydrofluoric acid; • Explosion; • Overpressurization; • Environmental impact.

TABLE 1. HAZARDS ASSOCIATED WITH WASTE MANAGEMENT ACTIVITIES AT NUCLEAR FUEL CYCLE FACILITIES (cont.)

Waste management activities	Waste materials	Characteristics	Hazards (radiological)	Hazards (non-radiological)
	• Cooling water and condensates.	• Possible uranium contamination.	• Alpha emitting materials; • Internal and/or external exposure.	• Heavy metal toxicity; • Environmental impact.
	• Ferrous and non-ferrous metals.	• Various levels of activity; • Uranium.	• Alpha emitting materials; • Internal and/or external exposure.	• Heavy metal toxicity; • Environmental impact.
	• Personal protective equipmentand other compressible solids.	• Materials with various levels of surface contamination.	• Alpha emitting materials; • Internal and/or external exposure.	• Heavy metal toxicity; • Environmental impact.
	• Gases and aerosols.	• Various levels of activity; • Various chemical compositions (e.g. UF_6, UO_2F_2, HF).	• Alpha emitting materials; • Internal and/or external exposure.	• Heavy metal toxicity; • Hydrogen fluoride; • Environmental impact.
	• Process filters.	• Various levels of activity; • Uranium.	• Alpha emitting materials; • Internal and/or external exposure.	• Heavy metal toxicity.

TABLE 1. HAZARDS ASSOCIATED WITH WASTE MANAGEMENT ACTIVITIES AT NUCLEAR FUEL CYCLE FACILITIES (cont.)

Waste management activities	Waste materials	Characteristics	Hazards (radiological)	Hazards (non-radiological)
	• Particulate filters.	• Various levels of activity; • Uranium.	• Alpha emitting materials; • Internal and/or external exposure.	• Heavy metal toxicity.
	• Non-compressible solids (e.g. building rubble).	• Various levels of activity concentration;	• Alpha emitting materials; • Internal and/or external exposure.	• Heavy metal toxicity.
Uranium fuel fabrication: • Dissolution and solvent extraction; • Treatment of liquid effluents and discharge to the environment.	• Liquid effluents.	• Concentrations of uranium compounds; • Characteristics of the uranium as UF_6, a soluble compound; • Characteristics of the uranium as UO_2, an insoluble compound.	• Criticality; • Alpha emitting materials; • Internal and/or external exposure; • Environmental impact.	• Hydrogen; • Hydrofluoric acid; • High temperature processes; • Concentrations of uranium as heavy metals; • Pyrophoric properties of uranium metal.

TABLE 1. HAZARDS ASSOCIATED WITH WASTE MANAGEMENT ACTIVITIES AT NUCLEAR FUEL CYCLE FACILITIES (cont.)

Waste management activities	Waste materials	Characteristics	Hazards (radiological)	Hazards (non-radiological)
Mixed oxide fuel fabrication: • Interim storage of waste; • Collection and transport of waste to a central waste management area; • Interim and long term storage; • Filtration and discharge of gaseous effluents.	• Solid waste: waste contaminated with plutonium, floor sweepings, waste and residues from decontamination.	• Concentrations of uranium and transuranics (e.g. increase in the daughter product americium); • Characteristics of the uranium and transuranic insoluble compounds; • Plutonium dust and contamination.	• Criticality; • Alpha emitting materials; • Internal and/or external exposure; • Environmental impact.	• Radiolytic properties of plutonium (generation of flammable gases and breakdown of materials); • Heat generation (from plutonium isotopes with even mass numbers and from americium); • Physical properties of plutonium (hardness and ability to act as a grinding medium); • High temperature processes.

TABLE 1. HAZARDS ASSOCIATED WITH WASTE MANAGEMENT ACTIVITIES AT NUCLEAR FUEL CYCLE FACILITIES (cont.)

Waste management activities	Waste materials	Characteristics	Hazards (radiological)	Hazards (non-radiological)
Spent fuel reprocessing: • Collection, segregation and management of process residues; • Treatment and conditioning of waste; • Vitrification of liquid high level waste; • Bituminization of process sludges and other materials; • Cementation or compaction of hulls and end caps.	• Cemented or compacted hulls and end caps.	• Residual concentrations of uranium and transuranics; • Characteristics of the uranium and transuranic insoluble compounds; • Concentration of fission products and minor actinides; • Chemical reagents and reaction products (including hydrogen and nitrogen oxides).	• Elevated dose rates; • Increase in the amount of daughter radionuclides during processing; • Elevated activity concentration levels; • Criticality (particularly in effluent precipitation processes and solvent washing).	• The possibility of an explosive reaction; • Chemical processes that generate effluents and gaseous emissions; • High temperature processes; • Chemically reactive metals (e.g. zirconium).
	• Waste containing magnesium and graphite.	• Reactive material.	• Alpha emitting materials; • Internal and/or external exposure; • Concentrations of carbon-14.	• Risk of fire or explosion from graphite dust.
	• Vitrified, separated fission products and minor actinides.	• High activity concentration; • Heat generation.	• Alpha emitting materials; • Internal and/or external exposure.	

TABLE 1. HAZARDS ASSOCIATED WITH WASTE MANAGEMENT ACTIVITIES AT NUCLEAR FUEL CYCLE FACILITIES (cont.)

Waste management activities	Waste materials	Characteristics	Hazards (radiological)	Hazards (non-radiological)
	• Contaminated equipment and waste from technical processes.	• Surface contamination.	• Alpha emitting materials; • Internal and/or external exposure.	
	• Bituminized process sludges.	• Potential for radiolysis.	• No direct radiological hazard.	• Hydrogen (risk of explosion or deflagration); • Risk of fire/explosion from bituminization process or products.
	• Personal protective equipment and other compressible solids.	• Various levels of surface contaminated materials.	• Alpha emitting materials; • Internal and/or external exposure.	• Heavy metal toxicity.
	• Gases and aerosols.	• Various levels of activity; • Various chemical compositions depending on process used.	• Alpha emitting materials; • Internal and/or external exposure; • Environmental impact.	• Heavy metal toxicity; • Environmental impact.

TABLE 1. HAZARDS ASSOCIATED WITH WASTE MANAGEMENT ACTIVITIES AT NUCLEAR FUEL CYCLE FACILITIES (cont.)

Waste management activities	Waste materials	Characteristics	Hazards (radiological)	Hazards (non-radiological)
	• Process filters.	• Various levels of activity.	• Alpha emitting materials; • Internal and/or external exposure.	• Heavy metal toxicity.

Appendix V

EXAMPLES OF HAZARDS ASSOCIATED WITH CENTRALIZED WASTE MANAGEMENT FACILITIES

TABLE 2. HAZARDS ASSOCIATED WITH CENTRALIZED WASTE MANAGEMENT FACILITIES

Facility description	Activities	Hazards (radiological)	Hazards (non-radiological)
Centralized facility that receives compactible, solid waste in drums from a medical isotope processing facility and produces waste packages for disposal; the waste received is low activity, alpha emitting waste.	• Receipt of waste and verification of waste acceptance criteria including sampling.	• External exposure; • Internal exposure (via contamination or release).	• Reactive and/or toxic hazards; • Industrial hazards including handling of sharps; • Chemical reactions of or between waste compounds; • Fragile materials.
	• Compaction of the drums received.	• External exposure; • Internal exposure (via contamination or release); • Release of radioactive liquids including oils; • Release of radioactive dust; • Release of radioactive gases.	• Generation of liquids; • Generation of dust; • Chemical reactions; • Pressure bursts; • Explosions; • Industrial hazards including handling of sharps.
	• Transfer, sorting and collection and drying of pucks.	• External exposure; • Internal exposure (via contamination or release).	• Industrial hazards including handling of sharps; • Chemical and/or toxic hazards.

TABLE 2. HAZARDS ASSOCIATED WITH CENTRALIZED WASTE MANAGEMENT FACILITIES (cont.)

Facility description	Activities	Hazards (radiological)	Hazards (non-radiological)
	• Placement of pucks into waste containers.	• External exposure; • Internal exposure (via contamination or release).	• Industrial hazards including handling of sharps; • Chemical and/or toxic hazards.
	• Waste containers grouted to produce waste packages.	• External exposure; • Internal exposure (via contamination or release).	• Industrial hazards; • Chemical hazards (e.g. from grout).
	• Cleaning, surveillance and monitoring of waste packages and transfer to interim storage location.	• External exposure; • Internal exposure (via contamination).	• Industrial hazards.

Appendix VI

SAFETY CONSIDERATIONS FOR WASTE MANAGEMENT AT NUCLEAR FUEL CYCLE FACILITIES

VI.1. The following is a list of hazards associated with, or that could affect, waste management at typical fuel cycle facilities. Where appropriate, certain features are highlighted that require specific consideration for radioactive waste management. This list is not exhaustive. Rather, it provides indicators for the safety assessor to produce the equivalents of Tables 1 and 2 in Appendices IV and V of this Safety Guide for the specific facility under consideration.

HAZARDS ASSOCIATED WITH CONVERSION OF NATURAL URANIUM

— Concentrations of uranium compounds and uranium decay products as radioactive materials in waste;
— Concentrations of uranium as heavy metals in waste;
— Characteristics of the uranium compounds (e.g. solubility);
— Concentrations of contaminants in the waste streams, including heavy metals such as chromium and vanadium;
— Corrosive materials (e.g. hydrogen fluoride, sulphuric acid);
— Toxic materials (e.g. ammonia);
— Fire risk from reagents including fluorine and hydrogen;
— Chemical processes that generate effluent and gaseous emissions.

HAZARDS ASSOCIATED WITH CONVERSION OF IRRADIATED URANIUM

— The same hazards as for conversion of natural uranium;
— Concentration of fission products (e.g. uranium-232 and plutonium isotopes);
— Elevated dose rates;
— Increase in the amount of daughter radionuclides during processing;
— Elevated activity concentration levels.

HAZARDS ASSOCIATED WITH URANIUM ENRICHMENT FACILITIES

— Concentrations of uranium compounds as radioactive materials in waste;
— Concentrations of uranium as heavy metals in waste;
— Characteristics of the uranium as UF_6, a soluble compound;
— Presence of hydrogen fluoride as a reaction product;
— Generation and accumulation of bulk depleted uranium as a corrosive fluoride;
— Criticality associated with techniques and chemical reactions such as precipitation;
— Failure of process equipment (which may occur if the replacement frequency of enrichment stages, where the enrichment stage is a contaminated waste metal, is not optimized).

HAZARDS ASSOCIATED WITH URANIUM FUEL FABRICATION FACILITIES

— Concentrations of uranium compounds as radioactive materials in waste;
— Concentrations of uranium as heavy metals in waste;
— Characteristics of the uranium as UF_6, a soluble compound;
— Characteristics of the uranium as UO_2, an insoluble compound;
— Pyrophoric properties of uranium metal;
— Criticality;
— Hydrogen;
— Hydrofluoric acid;
— High temperature processes;
— Maintenance of tight manufacturing tolerances (owing to inspection requirements on the operating organization or failures in fuel manufacturing generating unanticipated waste streams).

HAZARDS ASSOCIATED WITH MIXED OXIDE FUEL FABRICATION FACILITIES

- Concentrations of uranium and transuranics as radioactive materials in waste (e.g. increase in the daughter product americium);
- Characteristics of the uranium and transuranic insoluble compounds;
- Physical properties of plutonium (hardness and ability to act as a grinding medium);
- Radiolytic properties of plutonium (self-heating);
- Plutonium dust and contamination;
- Criticality;
- Hydrogen;
- High temperature processes;
- Maintenance of tight manufacturing tolerances (owing to inspection requirements on the operating organization or failures in fuel manufacturing generating unanticipated waste streams).

HAZARDS ASSOCIATED WITH REPROCESSING FACILITIES

- Radiological characteristics of spent fuel (burnup and cooling, effects on handling equipment);
- Physical characteristics of spent fuel (fragility);
- Concentrations of uranium and transuranics as radioactive materials in waste;
- Characteristics of the uranium and transuranic insoluble compounds;
- Concentration of fission and nuclear reaction products;
- Elevated dose rates;
- Increase in the amount of daughter radionuclides during processing;
- Elevated activity concentration levels;
- Criticality (particularly in effluent precipitation processes and solvent washing);
- Chemical reagents and reaction products (including hydrogen, nitrogen oxides and organic materials);
- High temperature processes;
- Chemically reactive metals (e.g. zirconium);
- Chemical processes that generate effluents and gaseous emissions;
- Chemical processes that generate explosive gaseous mixtures in the off-gas system.

HAZARDS ASSOCIATED WITH A CENTRALIZED WASTE MANAGEMENT FACILITY

Hazards associated with treatment of liquid waste

- — Presence of contaminants;
- — Presence of dissolved contaminants and particulates within liquid streams;
- — Physical concentration that generates precipitates of radioactive material including fissile material;
- — Chemical reactions that generate precipitates of radioactive material including fissile material;
- — Criticality;
- — Chemical reagent (non-radiological hazards and environmental impact);
- — Environmental impact of discharges;
- — Generation of secondary radioactive waste (e.g. accumulations of spent radioactive ion exchange media, giving rise to elevated external dose rate levels).

Hazards associated with treatment of gaseous waste

- — Presence of contaminants;
- — Presence of particulates and aerosols within gaseous effluent streams (from condensation or deposition within gaseous effluent lines);
- — Environmental impact of emissions and discharges;
- — Generation of secondary waste (e.g. accumulation of used HEPA filters, giving rise to elevated external dose rate levels, or generation of liquid waste);
- — Accumulation of short lived isotopes on adsorption media (e.g. presence of iodine-131 on activated carbon columns).

Hazards associated with evaporation and thermal treatment

- Concentration of radioactive material including fissile material within the waste, giving rise to:
  - Increased dose rates;
  - Criticality;
  - Challenges having to do with the ability to dispose of the waste;
- High temperatures;
- Fire;
- Chemical reagents;
- Chemical reactions of contaminants or unanticipated arisings of waste (e.g. solvents within aqueous waste streams);
- Presence of contaminants;
- Presence of particulates and aerosols within gaseous effluent streams (from condensation or deposition within gaseous effluent lines);
- Environmental impact of emissions and discharges;
- Generation of secondary waste (e.g. accumulation of used HEPA filters, giving rise to elevated external dose rate levels, or generation of liquid waste).

Hazards associated with vitrification

- Concentration of radioactive material including fissile material within the waste, giving rise to:
  - Increased dose rates;
  - Criticality;
  - Challenges having to do with the ability to dispose of the material;
- High temperatures;
- Corrosive liquids and vapours (e.g. nitric acid, nitrogen oxides);
- Chemical reactions of contaminants or unanticipated arisings of waste (e.g. solvents within aqueous waste streams);
- Presence of all contaminants;
- Presence of particulates and aerosols within gaseous effluent streams (from condensation or deposition within gaseous effluent lines);
- Environmental impact of emissions and discharges;
- Generation of secondary waste with significant activity levels (e.g. accumulation of used HEPA filters, liquid wastes and highly contaminated process equipment, resulting in elevated external dose rate levels);
- Corrosive effects of molten glass (giving rise to the generation of highly contaminated spent material).

Appendix VII

FLOW DIAGRAM FOR THE MANAGEMENT OF SOLID RADIOACTIVE WASTE

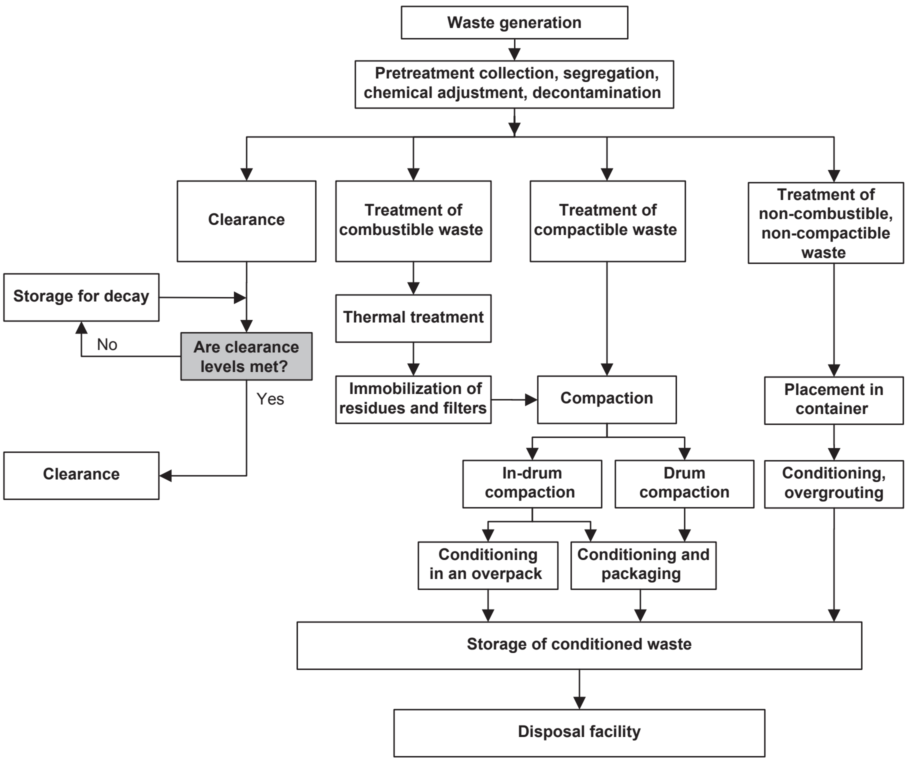

FIG. 1. Flow diagram for the management of solid radioactive waste.

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