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Predisposal Management of Radioactive Waste from Nuclear Reactors

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PREDISPOSAL MANAGEMENT OF

RADIOACTIVE WASTE FROM NUCLEAR REACTORS

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1 The production of electricity in nuclear power plants and the use of nuclear research reactors (including subcritical or critical assemblies) generate radioactive waste (radioactive material for which no further use is foreseen, and with characteristics that make it unsuitable for authorised discharge, authorised use or clearance from regulatory control.). Such radioactive waste arising from nuclear power plants and from research reactors is diverse and variable in nature and encompasses a broad range of radionuclides and levels of activity content. Typical waste from reactors includes, but is not limited to: spent ion exchange resins, filters, activated metals, liquid and gaseous effluents, irradiated experimental components, spent fuel declared as waste and waste from decommissioning. Because of the variability and diversity in the waste streams from these facilities, particular and constant attention has to be given to all steps of the management of the waste. Thus, a key feature of predisposal management of radioactive waste at reactors is the interdependence between the steps of predisposal radioactive waste management as well as disposal within a national framework of waste management.

1.2 The principles and requirements that govern the safety of the management of radioactive waste are presented in the Fundamental Safety Principles SF-1 [1], and in the following IAEA Safety Requirements publications: Governmental, Legal and Regulatory Framework for Safety (GSR Part 1) [2], Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards (GSR Part 3) [3] and Predisposal Management of Radioactive Waste (GSR Part 5) [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] establishes requirements for the safe management of radioactive waste prior to its disposal. These requirements are derived from the safety principles established in the Safety Fundamentals publication SF-1 [1] and include requirements for the protection of human health and the environment and associated responsibilities. Recommendations on the fulfilment of these requirements are provided in this Safety Guide and several associated Safety Guides.

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

1.5 These activities include;

- Pretreatment may include waste assay and characterisation, waste collection, segregation, chemical adjustment and decontamination.
- Treatment may include volume reduction, radionuclide removal and change of composition.
- Conditioning involves those operations that transform radioactive waste into a form suitable for subsequent activities such as handling, transport, storage and disposal; this may include immobilization of the waste, placing of the waste into containers and provision of additional packaging.
- Storage refers to the temporary placement of radioactive waste in a facility where appropriate isolation and monitoring are provided; it is an interim activity with the intent to retrieve the waste at a later date for clearance, processing and/or disposal at a later time, 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'). Waste minimization should form an essential component of a radioactive waste management strategy. Waste minimization relates to type, volume and activity. Measures to prevent or minimize the generation of radioactive waste have to be put in place at the beginning during the design of facilities and the planning of activities that have the potential to generate radioactive waste. This step recognizes that the management of the activities that generate radioactive waste is the key to avoiding or minimizing quantities produced.

1.7 Reactor waste management is further complicated by the problem of mixed waste. Reactor wastes commonly contain other hazards, in addition to radiological hazards, which require specific measures to address conventional health and safety and need to be regulated appropriately.

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

1.9 In some instances, the predisposal waste management solution has to be found optimizing conflicting demands. Such considerations include the balancing of 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.

1.10 To select the most appropriate type of pretreatment, treatment and conditioning for the radioactive waste when no disposal facility has been established, reasonable assumptions have to be made about the likely disposal option. In cases where waste are to be stored for extended periods, conservative assumptions need to be made e.g. the time scale in which a disposal facility will be available. All assumptions made that impact on the selection of pre-disposal management options should be properly 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 important to ensure that safety is not compromised.

OBJECTIVE

1.11 The objective of this Safety Guide is to provide operating organizations[1] that generate and manage 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 arising from nuclear power plants and research reactors (including subcritical or critical assemblies when declared as waste).

1.12 This Safety Guide presents recommendations and guidance on how to meet the requirements established in GSR Part 5 [4], as well as in GSR Part 1 [2] GSR Part 3 [3], and GS-R-3, The Management System for Facilities and Activities [6].

1.13 Once published, this Safety Guide will supersede Safety Guides 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.

SCOPE

1.14 This Safety Guide provides guidance on the predisposal management of radioactive waste of all types arising from nuclear power plants and research reactors (including subcritical and critical assemblies). It covers all phases in the lifecycle of the facilities, including siting, design, construction,

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[1] The operating organization is the generator of radioactive waste and includes inter alia, operators of facilities for the predisposal management of radioactive waste, and organizations carrying out decommissioning activities [4].

[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).

commissioning, operation, shutdown[4] and decommissioning. It covers all the 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 accident conditions. While it is recognized that the recommendations in this publication are applicable to the generation of radioactive waste at nuclear reactors; however, operation of nuclear reactors is 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 GSG-1 Classification of Radioactive Waste [7].

1.15 This Safety Guide is not specifically intended to cover the storage of spent nuclear fuel as long as it remains a part of the operational activities of a nuclear power plant or research reactor. Storage of spent nuclear fuel in facilities that are collocated with a nuclear power plant or research reactor is addressed in Safety Guide SSG-15, Storage of Spent Nuclear Fuel [8]. Spent fuel that is transferred to or destined for reprocessing facilities is not considered radioactive waste.

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 are provided in Safety Guide WS-G-6.1 [9]. Transport of radioactive waste is subject to the requirements of SSR-6 [10].

1.17 Although this publication 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.

1.18 The Safety Guide does not provide recommendations on the nuclear security of nuclear material, nuclear facilities or radioactive material. Recommendations and guidance on nuclear security at nuclear facilities and for radioactive material are provided in Nuclear Security Series No. 13 [11], No. 14 [12] and other publications in the IAEA Nuclear Security Series.

STRUCTURE

1.19 to be added later

[4] The term ‘permanent shutdown’, as used in this publication, means that the reactor has ceased operation and will not be restarted, i.e. it will no longer be used for its intended purpose. Permanent shutdown is a state that is different from a planned shutdown (e.g. due to refueling outage, maintenance, inspection or refurbishment) or an unplanned shutdown (e.g. due to a scram), during which the reactor is not in operation.

2. PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

RADIOACTIVE WASTE MANAGEMENT

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

2.2 The Safety Requirements GSR Part 5 [4] and GS-R-3 [6] provide requirements on management system that integrates, among others, all elements of management, including safety, health, environmental, nuclear security, quality and economic requirements so that safety is not compromised. A key component of such a system in an organization is a robust safety culture.

2.3 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 the potential impacts and burdens on future generations arising from long periods of storage of radioactive waste [1].

RADIATION PROTECTION

2.4 GSR Part 3 [3] states that 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 stated in [1].

2.5 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 require radiation protection to be optimized for any persons who are exposed as a result of activities, with due regard to dose constraints, and require the exposures of individuals to be kept within specified dose limits.

2.6 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 referred to in the preceding paragraphs, provision has to be made for protection against potential exposure from operations outside normal conditions, e.g. anticipated operational occurrences, incidents or accidents. Requirements for protection against potential exposure are also established in GSR Part 3 [3]. They include management and technical requirements to prevent the occurrence of incidents or accidents and provisions for mitigating their consequences if they do occur.

2.7 When 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 members of the public (SF-1, ICRP 77, ICRP 81) [1, 13, 14].

2.8 Doses and risks associated with the transport of radioactive waste have to be managed in the same way as those associated with the transport of any radioactive material. Safety in the transport of radioactive waste is ensured by complying with the requirements in [10].

PROTECTION OF THE ENVIRONMENT

2.9 Requirements for protection of the environment that are associated with 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 being taken into consideration [1, 3].

2.10 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; [and]

(c) To mitigate the consequences of such events if they were to occur.

2.11 The operator has a duty in the area of radioactive waste management to take measures to avoid or to minimize 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 to reduce doses to the public and effects on the environment to levels that are as low as reasonably achievable (optimization of protection).

2.12 Clearance (the removal of radioactive materials within authorized practices from any further regulatory control) and the control of discharges (on-going or anticipated releases to the environment within limits authorized by the regulatory body of or gaseous liquid radioactive material that originate from regulated nuclear facilities during normal operation) are addressed in IAEA Safety Standards Series Nos. RS-G-1.7 [15], WS-G-2.3 [16] and NS-G-3.2 [17], respectively.

3. ROLES AND RESPONSIBILITIES

LEGAL AND ORGANIZATIONAL FRAMEWORK

Requirement 1 (GSR Part 5, Ref. [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 (GSR Part 5, Ref. [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, as well as 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 waste imported 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 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]. The legal framework should also establish measures to ensure compliance with other relevant international legal instruments, such as the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [5], the Convention on Nuclear Safety [18], and other relevant Directives and Conventions.

3.3 In order to implement the national policy and strategy, some Government responsibilities can be placed on a government institution. If more than one government institution is involved, effective arrangements should be made to ensure that their responsibilities and functions 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, environmental, industrial safety and occupational health aspects are separately regulated the regulatory framework should recognize that the overall safety is affected by the interdependences between radiological, industrial, chemical and toxic hazards. It should be ensured that the regulatory framework takes this into account and delivers effective control.

3.5 The legal framework should ensure that the construction of facilities for the predisposal management of radioactive waste adjacent to an existing facility that could prejudice the safety of either facility are monitored and controlled by means of planning requirements or other legal instruments.

3.6 The management of radioactive waste may involve the transfer of radioactive waste from one operating organization to another or from one governmental region to another, or may even be processed in another State. 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 process (including provisions for regulatory control and authorization), in particular with respect to the interface with the storage of radioactive waste and its transfer between operating organizations.

3.7 The government is responsible for establishing a regulatory body independent from the owners of the radioactive waste or the operating organizations 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 by the regulatory body. For transboundary transfers of radioactive waste between States, authorizations from the relevant national regulatory bodies within the legal and regulatory frameworks of both States are required [2, 4].

3.9 A mechanism for providing adequate financial resources should be established to cover future costs; in particular, the costs associated decommissioning of the reactor and waste management facilities, and also the costs of long-term management of radioactive waste (including storage and disposal). The financial mechanism should be established at each stage of licensing and should be updated as necessary. Consideration should also be given to provision of the necessary financial resources in the event of a premature shutdown of the predisposal radioactive waste management facility or an 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 and anticipated, including waste generated during decommissioning and dismantling of facilities) and update it at regular time intervals. This inventory should address the various waste classes as identified in GSG-1[7] or in the national waste classification scheme, taking into account their long-term management including disposal, both from a technical point of view as well as from a human and financial resources point of view.

3.11 There should be sufficient capacity to process all waste generated and the storage capacity should be sufficient to account for uncertainties in the availability of facilities for processing and disposal. In judging the sufficiency of capacity, account should be taken of process uncertainties, system reliability and availability 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. Communication with and involvement of the public is very important for decision making.

RESPONSIBILITIES OF THE REGULATORY BODY

Requirement 3 (GSR Part 5, Ref. [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[5] **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 licenses, 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.**

3.13 Regulatory body main responsibilities as related to the safe management of radioactive waste include the development of regulatory requirements; procedures for licensing, compliance verification and enforcement; and guidance to be followed by licensees. Responsibilities may also include contributing to the technical basis and inputs for the establishment of policies, safety principles and associated criteria, and for 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 as related to the safe management of radioactive waste.

3.14 The regulatory review of the safety case for the predisposal management radioactive waste at reactors should follow a graded approach, particularly considering the phases in the lifetime of the predisposal radioactive waste management facility or activities. At each phase in the lifetime of these facilities or activities (including decommissioning), the safety case should be updated by the operator and reviewed by the regulatory body.

[5] The safety case is a collection of arguments and evidence in support of the safety of a facility or activity. This collection of arguments and evidence 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).

3.15 General recommendations for regulatory inspection and enforcement actions relating to radioactive waste management facilities are provided in Safety Guide GS-G-1.3, Regulatory Inspection of Nuclear Facilities and Enforcement by the Regulatory Body [19]. The regulatory body should periodically verify that the key aspects of the operation of the radioactive waste management facility meet the requirements of the national legal system and facility licence conditions, such as those relating to the keeping of records on inventories and material transfers, compliance with requirements for processing, storage, maintenance, inspection, testing and surveillance, operational limits and conditions, emergency preparedness and response. Such verification may be carried out, for example, by routine inspections of the radioactive waste management installations 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 Safety Guide GS-G-1.4, Documentation for Use in Regulating Nuclear Facilities [20].

3.16 The regulatory body should follow a graded approach in 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, e.g. for nuclear security reasons, should be respected.

3.17 The regulatory body should consider the licensing strategy to be adopted (in accordance with the national legal and governmental framework), for example:

(a) A licence issued for the entire lifetime of the generation, processing and/or storage system and/or installation, which encompasses the entire anticipated operating period, including periodic review of safety assessments; or

(b) A licence issued for a specified time period with the possibility for its renewal at or prior to expiration.

(c) Possible long-term storage of radioactive waste and spent fuel after the reactor has been shut down and decommissioned.

3.18 If the regulatory body consists of more than one authority, effective arrangements should be made to ensure that regulatory responsibilities and functions are clearly defined and coordinated in order to avoid any omissions or unnecessary duplication and to prevent conflicting requirements, as far as practicable, on the operating organization. The regulatory functions of authorization, review and assessment, inspection, enforcement and development of regulations and guides should be organized in such a way as to achieve consistency and to enable the necessary feedback and exchange of information.

RESPONSIBILITIES OF THE OPERATING ORGANIZATION

Requirement 4 (GSR Part 5, Ref. [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 developing site specific policies and strategies consistent with overall national policies and strategies. Furthermore, the operating organization retains its responsibility for the safety of facility and activities, and a continuous commitment by the organization remains a prerequisite to ensuring safety and the protection of human health and the environment.

3.20 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 [1], and for the identification and implementation of the programmes and procedures necessary to ensure safety. The operating organization should demonstrate safety and maintain a robust safety culture. The operating organization should take measures to review and assess the safety culture periodically, and adopt and implement the necessary principles and processes in order to strengthen the safety culture.

3.21 In some instances, the operating organization may be the owner of the radioactive waste and in other cases the owner may be a separate organization or operating unit. In the latter case, the interface between responsibilities of the owner and the operating organization should be clearly defined, agreed and documented. Ownership of the waste should always be clearly identified. Information about changes in ownership of the radioactive waste or changes in the relationship between the owner and the waste management organization should be provided to the regulatory body and, where required, to government institutions. For example, NPP operators who do not have complete responsibility for all aspects of predisposal management should coordinate and harmonize with the regulatory authority and waste management organization (where necessary) to ensure that the management of radioactive waste generated at their facility is appropriately planned and safely conducted.

3.22 The responsibilities of the operating organization of a radioactive waste management facility typically include:

(a) Application to the regulatory body for permission to site, obtain regulatory approval for the radioactive waste management facility or activity by providing an acceptable safety case;

(b) Conducting appropriate radiological safety and environmental assessments in support of the application for a license and conducting periodic safety reviews;

(c) Development of operational limits, conditions, and controls, including waste acceptance criteria consistent with the safety case for approval by the regulatory body;

(d) Development and application of procedures for the receipt, storage and processing of radioactive waste;

(e) Conducting all activities in accordance with the requirements of the safety case, the license conditions and the applicable regulations;

(f) Taking into consideration possible long-term storage of radioactive waste after the reactor has been decommissioned.

(g) Ensuring that the information recorded at a particular step in the predisposal radioactive waste management process is aligned with the information required to demonstrate compliance with the downstream waste acceptance criteria (e.g., safety case for disposal);

(h) Management of the information required either to support the onward disposition/storage of any radioactive waste or to support the decommissioning of that facility, especially where the latter may be many decades after operations have ceased;

(i) Providing periodic reports as required by the regulatory body (e.g. information on the actual inventory of radioactive waste, any transfers of radioactive waste into and out of the facility, including material cleared from regulatory control, and any events that occur at the facility and which have to be reported to the regulatory body) and communicating with relevant interested parties and the general public;

(j) Ensuring operations are in compliance with criteria for either the removal or discharge of radioactive material as approved or authorized by the regulatory body;

(k) Limiting onsite contamination and occupational exposure;

(l) Taking into consideration measures that will control the generation of radioactive waste, in terms of volume and radioactivity content, to the minimum practicable;

(m) Ensuring that radioactive waste is appropriately processed to comply with the acceptance criteria for storage and disposal as well as 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, and making provisions for relocating the radioactive waste for storage and/or disposal.

(n) Ensuring that high level waste including spent fuel declared as radioactive waste is managed appropriately taking into account its higher activity, heat generation and potential for nuclear criticality (SSG-27) [21]. Appendix 1 provides a listing of the typical properties and characteristics that should be considered for waste packages and spent nuclear fuel declared as waste.

(o) Due consideration and decision making in the following cases::

(1) management of waste if no disposal option is available,;

(2) management of waste that would need to be stored over long periods of time prior to disposal; or

(3) management of waste in case of decay storage with the purpose of clearance or reclassification.

3.23 The operating organization should develop a facility specific waste management programme, integrated with other relevant on site programmes (e.g. multi-facility sites), that:

(a) implements the national waste management policy and strategy, as far as applicable;

(b) recognizes the connections between the sources of radioactive waste and the eventual discharge, disposal or onward disposition from that facility;

(c) recognizes the hierarchy of the following strategic options, which are applicable to predisposal management of radioactive waste:

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

(2) Possible reuse and recycling of materials; and

(3) Processing of radioactive waste to ensure its safe storage and disposal.

More detailed guidance on facility-specific waste management programmes are provided in Appendix 2.

3.24 At the design stage, the operating organization is required to prepare an initial decommissioning plan. The decommissioning plan should consider possible long term storage and disposal of radioactive waste after permanent shut down of the facility6. For new facilities, features that will facilitate decommissioning should be taken into consideration at the design stage; such features should be included in the initial decommissioning plan together with information on arrangements for how the availability of the necessary human and financial resources and information will be assured. For existing facilities without a decommissioning plan, such a plan should be prepared as required by or

[6] The term ‘permanent shutdown’, as used in this publication, means that the reactor has ceased operation and will not be restarted, i.e. it will no longer be used for its intended purpose. Permanent shutdown is a state that is different from a planned shutdown (e.g. due to refuelling outage, maintenance, inspection or refurbishment) or an unplanned shutdown (e.g. due to a scram), during which the reactor is not in operation

agreed with the regulator. The decommissioning plan should be reviewed and updated at each phase in the lifetime of the facility. Requirements on decommissioning are established in GSR Part 6, Decommissioning of Facilities [22], and recommendations are provided in Safety Guide WS-G-2.1, Decommissioning of Nuclear Power Plants and Research Reactors [23].

3.25 For reactors decommissioning plans need to consider that spent fuel and high level waste may be present, the need to avoid high doses to the workers and to minimize the generation of radioactive waste during decommissioning options (e.g., immediate versus deferred dismantling), the availability of suitable processing and storage facilities, the potential for nuclear criticality, as well as non-radiological hazards.

3.26 The operating organization should establish the requirements for training and qualification of its staff and contractors, including for initial and periodic refresher training. The operating organization should ensure that all staff members concerned understand the safety case, the nature of the radioactive waste, its potential hazards 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 radiation protection requirements.

3.27 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 such these pre-operational and commissioning tests (inactive commissioning) should be prepared and submitted to the regulatory body for review and acceptance.

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

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

3.30 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 include among others the radioactive inventory, location and characteristics of the radioactive waste, information on ownership, origin and transfer location (Safety Guide GS-G-3.3, The Management System for the Processing, Handling and Storage of Radioactive Waste) [24]. Such records should be preserved and updated, to enable the implementation of the facility specific radioactive waste management programme. Such a records system should be managed by the operating organization as required by the national authority or regulatory body.The operating organization should prepare plans and implement monitoring programmes for personnel, area, and environmental. Such programmes should be evaluated periodically.

3.31 The operating organization should establish a process for authorization of modifications that includes evaluation of modifications to the radioactive waste management facility and activities, operational limits and conditions, or the radioactive waste to be processed or stored, using a graded approach that is commensurate with the safety significance of the modifications. The process of evaluating 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, are available to undertake all necessary tasks throughout the lifetime of the facility, including its decommissioning, possible long term storage of radioactive waste at the site after the reactor has been permanently shut down, and 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 onsite emergency arrangements, including onsite emergency response plan for preparedness and response for a nuclear or radiological emergency on the basis of the hazards associated with the facility and activities and the potential consequences of an emergency (GSR-2, GS-G-2.1, GSG-2) [25, 42, 44]. In assessing the hazards associated with reactor sites that contain radioactive waste processing or storage facilities, the hazards and potential consequences associated with these facilities and their mutual interactions should be considered.

4. INTEGRATED APPROACH TO SAFETY

SAFETY AND SECURITY

Requirement 5 (GSR Part 5, Ref. [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 (GSR Part 5, Ref. [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 also address the interface between nuclear security, safety and nuclear material accountancy and control to avoid any conflicts and to ensure that all three elements support each other and neither safety nor security is compromised.

4.2 The operator should assess and manage the interfaces between nuclear security, safety and nuclear material accountancy and control activities appropriately to ensure that they do not adversely affect each other and that, to the degree possible, they are mutually supportive.

4.3 When material needs to be accessed for waste management or safeguard purposes, all the requirements for radiation protection, waste management, and nuclear security should be taken into account. Specific recommendations on nuclear security in the management of radioactive waste are dealt with in the publications of the IAEA Nuclear Security Series [10, 11].

INTERDEPENDENCES

Requirement 6 (GSR Part 5, Ref. [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. In selecting strategies and activities for the predisposal management of radioactive waste, planning should be carried out for all the various steps so that a balanced approach to safety is taken in the overall management programme and conflicts between the safety requirements and 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 requirements for storage and disposal. At all times due consideration should also be given to the interdependency between safety and environmental protection as described in Chapter 2.

4.5 The following aspects in particular should be addressed:

(a) The identification of interfaces and the definition of the responsibilities of the various organizations involved at these interfaces;

(b) The establishment of and confirmation of conformance with acceptance criteria .

4.6 A key feature of predisposal radioactive waste management in respect of nuclear reactors is the nature of their interdependence and often their place within a national framework. Such interdependences create safety case interfaces, including waste acceptance criteria and operational limits and conditions and should be carefully managed along with any deviations that might occur for instance associated to those uncertainties. Thus it is important to highlight that the interdependences should be taken into consideration to ensure that an integrated approach to safety is adopted; and that safety (within a waste management framework that also considers waste minimization via adoption of the waste management hierarchy) is optimized as required by the ALARA principle. All secondary wastes produced in the facility should undergo an approval process for further specific actions.

4.7 Compliance of the waste packages with the waste acceptance requirements of the chosen disposal option (or next step in the management process) should be considered and demonstrated; however, in the case that a disposal option has not been identified at a certain stage, reasonable assumptions should be made about the likely disposal options and these should be set down clearly.

4.8 For many programmes for the predisposal management of radioactive waste, decisions have to be made before the waste acceptance requirements 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 requirements 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 retrieval, and to their suitability for handling and emplacement in a disposal facility on the basis of the anticipated waste acceptance requirements.

4.9 Given that disposal is the final step in the management of radioactive waste that cannot be otherwise cleared, 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 Member States disposal facilities are not yet available in general or only for specific types of waste. In this case, proper determination and documentation of the characteristics of waste form and waste package should be ensured. Independent of this, all radioactive waste arisings are required to be managed. This requires decisions on waste forms to be produced which, in this situation, have to be made before all radioactive waste management activities are finally established.

4.10 If there is no disposal facility yet available or defined, then an interim position should be defined such that either options are not foreclosed or all reasonably practicable steps have been taken to prepare waste for the anticipated disposal option. The interdependences between the waste generator, the radioactive waste management facility and the (existing or anticipated) disposal facility should also be defined.

MANAGEMENT SYSTEM

Requirement 7 (GSR Part 5, Ref. [4]): Management systems

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

4.11 The requirements on management systems (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 Ref. [6]. General guidance on the management systems for facilities and activities is given in Ref. [26], while specific guidance on a management system for the processing, handling and storage of radioactive waste is provided in GSG-3.3 [24].

4.12 Managing radioactive waste involves a variety of activities that may extend over a very long period of time. These characteristics present a series of challenges to the development and implementation of effective management systems for a waste management programme, and give 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.

4.13 As stated in GS-R-3 [6] an integrated management system is required to be established, implemented, assessed and continually improved by the operating organization and it should be applied to all steps of the predisposal management of radioactive waste. Such an integrated system covers all aspects of management including arrangements for quality assurance and control. The management system should foster a safety culture that should be aligned with the goals of the operating organization and should contribute to their achievement. Management systems should make provision for siting, design, construction, commissioning, operation, maintenance and decommissioning of the predisposal radioactive waste management facility.

4.14 For achieving and maintaining an integrated management system the following long term aspects (taking into account the duration of waste processing and storage periods) should be considered:

(a) Preservation of technology and knowledge and transfer of such knowledge to people joining the operating organization in the future;

(b) Retention or transfer of ownership of radioactive waste and predisposal management facilities;

(c) Succession planning for the technical and managerial human resources;

(d) Continuation of arrangements for interacting with interested parties;

(e) Provision of adequate financial resources (the adequacy of resources for maintenance and decommissioning of facilities and equipment may need to be periodically reviewed over operational periods that may extend over decades); and

(f) Preservation and quality of records and of information (e.g., details of radioactive waste inventories, facility siting, design, operation, and safety case development); and

(g) Provision for review to ensure that the goals of the management system can still be met.

RESOURCE MANAGEMENT

4.15 Radioactive waste management activities will require financial and human resources and the necessary infrastructure. Senior management of all the facilities involved in the generation and management of radioactive waste should be responsible for making 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 activities involved in the management of radioactive waste and the potentially long duration of such activities.

4.16 Management of radioactive wastes can take place over long timescales. In such circumstances the government, regulators, waste owners and site operators should address the sustainability of all the required resources to maintain safety and environmental protection in appropriate policies, strategies and plans.

PROCESS IMPLEMENTATION

3.34 In the design of predisposal radioactive waste management facilities to be operated over a long period (e.g., radioactive waste storage facilities that remain at the site once the reactor has been permanently shut down), consideration should be given to the incorporation of measures that will facilitate operation, maintenance of equipment and eventual decommissioning of the facility.

4.17 For long term radioactive waste management activities, future infrastructural 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.

4.18 Consideration should be given to the possible need to relocate radioactive waste if problems arise after it has been placed in long term storage or disposal (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 be necessary in the future should be assessed.

4.19 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., principle of redundancy. Storage arrangements for records should meet the requirements prescribed by the national authorities or the regulatory body and the status of the records should be periodically assessed.

5. SAFETY CASE AND SAFETY ASSESSMENT

Requirement 13 (GSR Part 5, Ref. [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 the modification of the facility or activity, the safety case and its supporting safety assessment shall be reviewed and updated as necessary.

Requirement 14 (GSR Part 5, Ref. [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 (GSR Part 5, Ref. [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 (GSR Part 5, Ref. [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 (GSR Part 5, Ref. [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 and guidance on the safety case for the predisposal management of radioactive waste at nuclear reactors are as follows:

(a) Requirements on the safety case and supporting safety assessment for predisposal management of radioactive waste are set in GSR Part 5 [5] and guidance is provided in GSG-3 [27];

(b) Requirements on the safety assessment for all facilities and activities are set in GSR Part 4 [28].

(c) Guidance on the safety assessment and periodic safety reviews of nuclear power plants are provided in GS-G-4.1 and SSG-25 [29, 30];

(d) Guidance on the safety assessment for research reactors are provided in SSG-20 [31];

5.2 The licensing documentation and periodic safety reviews of nuclear power plants and research reactors normally include the safety assessment and review of the radioactive waste management systems within the reactor facility (GS-G-4.1, SSG-25, SSG-20) [29, 30, 31]. This includes at a minimum a safety analysis report (SAR) and operational limits and conditions that typically include:

- Description of the design and operation of radioactive waste management structures, systems and components (SSCs) (waste generation and control, waste treatment and conditioning, storage)
- Measures taken to control discharges to the environment of solid, liquid and gaseous radioactive effluents
- Organizational responsibilities
- Assessment and management of safety and radiation protection, including operational limits and controls

5.3 The safety case and supporting safety assessment for the waste management facilities and activities at reactors should follow a graded approach. For example, the scope, extent and detail of the safety case for low power research reactors may be significantly less than is required for high power research reactors because certain accident scenarios may not apply or may need only a limited analysis.

5.4 For waste generated within a reactor, the safety case may need to cross-reference the sections of the SAR in which waste management and radiation protection issues for the plant are considered. At a minimum, the safety case should identify interfaces between the radioactive waste management SSCs and operational limits and conditions of the reactor. The safety case should also identify the instrumentation relied upon to monitor for possible leaks or escapes of radioactive waste.

5.5 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 clearance of materials from regulatory control and authorized discharge of effluents, and to their overall compatibility. Thus, operational and long term safety aspects of waste management should be considered, as well as the possible need for future handling and processing of the waste after the reactor has been decommissioned or permanently shut down and the risks and doses that may be associated with these activities.

5.6 The safety case and supporting safety assessment should address the compatibility of the waste packages and unpackaged waste with the existing or anticipated disposal option; however, in the event that a disposal option does not exist, reasonable assumptions should be made about the likely disposal options and these should be set down clearly.

5.7 The safety case and supporting safety assessment should include identification of uncertainties in the performance of the waste management SSCs and activities and inventories, analysis of the significance of the uncertainties, and identification of approaches for the management of significant uncertainties. Such uncertainties should be a focus of an examination of the interdependences by the regulator between the boundaries of interlinking safety cases. Guidance on the management of uncertainties is provided in GSG-3 [27].

5.8 Appendix 3 provides examples of hazards associated with typical activities for the predisposal management of radioactive waste from nuclear reactors. These examples are not exhaustive; rather, they are intended to assist in the identification and subsequent assessment of hazards. GSG-3 (Annex 1) [27] also provides examples of hazards and potential initiating events relevant to typical waste management activities.

5.9 Long term storage of radioactive waste at the reactor site e.g. after the reactor has been decommissioned or permanently shut down, requires special consideration in the safety case (GSR Part 4, WS-G-6.1, GSG-3) [28, 9, 27]. The safety case should take into consideration the establishment of an ageing management programme, the assessment of passive safety features, package and packaging requirements, retention of records, the establishment and maintenance of emergency arrangements, decommissioning plan, and monitoring and inspection. The safety case should also consider degradation of engineered features and availability of maintenance systems, changes to the stored waste and uncertainties in parameters and models used, including the anticipated timescales of storage.

5.10 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.

5.11 The safety case and supporting safety assessment are to be reviewed and updated periodically as necessary to reflect actual experience and increasing knowledge and understanding (e.g., knowledge gained through continuing scientific research), with account taken of any relevant operational feedback or other aspects that are relevant for safety (GSG-3) [27].

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

5.13 Although the focus of this Safety Guide is on radiological safety, non-radiological hazards (e.g. chemo-toxic, industrial) 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:

- Assessment of potential waste arisings and evaluation of options for disposition
- Waste generation and control
- Processing
  - Pretreatment
  - Treatment
  - Conditioning
- Storage
- Transport

6.2 Management options such as clearance (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 clearance for recycling and reuse. The limitations and controls for clearance and the control of discharge activities should be set by the regulatory body [15, 16, 17].

6.3 At various steps, when necessary, it should be verified that the waste complies with acceptance requirements. Therefore the radioactive waste should be characterized and classified at the various steps of its predisposal management, as necessary. Waste packages should have a system of identification that is unique, able to be linked to its associated records and that takes account of the need to be read in the long term future up to disposal.

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

6.5 Radioactive waste is handled and transported between and within the various steps in predisposal management of radioactive waste. Requirements and guidance on transport of radioactive waste can be found in SSR-6 [10] and TS-G-1.1 [32].

6.6 The on-site transport of radioactive waste may not need to meet all the requirements for off-site transport (SSR-6) [10], because transport is at all times under the control of the operator, who is responsible for the safety of on-site operations.

WASTE GENERATION AND CONTROL

Requirement 8 (GSR Part 5, Ref. [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 should include the following aspects:

(a) The careful selection of materials, processes and SSCs for the facility;

(b) The selection of design options, process and materials selection, construction methods, commissioning, and operational procedures that facilitate waste minimization throughout the facility's entire lifecycle, including its final decommissioning;

(c) The use of effective and reliable techniques and equipment;

(d) The containment and packaging of radioactive material to maintain its integrity;

(e) Adequate zoning to prevent the spread of contamination;

(f) Provisions for the decontamination of zones and equipment to prevent the spread of radioactive contamination.

6.8 The principle of waste generation and control should also be a factor for consideration in the selection of approaches to storage and processing, in order to minimize the generation of secondary radioactive waste resulting from predisposal management activities. Examples of processing steps for which this principle should be considered include the selection of conditioning processes and the testing programme invoked to verify treatment and conditioning processes. For the qualification of a conditioning process, the testing programme 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 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 enable regulatory control to be removed from the waste.

Radioactive waste from power reactors

Gaseous radioactive waste

6.10 Although the sources of gaseous radioactive waste differ according to the type of reactor, possible sources include:

- leakage from the coolant;
- the moderator systems or the reactor itself;
- degasification systems for the coolant;
- condenser vacuum air ejectors or pumps;
- the exhaust from turbine gland seal systems; and
- activated or contaminated ventilated air.

6.11 In all cases, spent fuel in storage or in handling operations is a potential source of gaseous radioactive waste.

Liquid radioactive waste

6.12 The primary coolant in water cooled reactors and water from the fuel storage pools are major sources of liquid radioactive waste since some of their radioactive content may be transported to the liquid radioactive waste stream via process streams or leakages. Although the composition of the liquid radioactive waste may vary appreciably according to reactor type, contributions to the stream may derive from:

(a) reactor coolant let-down;

(b) evaporator concentrates;

(c) equipment drains;

(d) floor drains;

(e) laundry waste;

(f) contaminated oil; and

(g) waste arising from the decontamination and maintenance of facilities and equipment.

Solid radioactive waste

6.13 Solid radioactive waste results from the operation, maintenance, and decommissioning of the nuclear power plant and its associated processing systems for gaseous and liquid radioactive waste. The nature of such waste varies considerably from plant to plant, as do the associated levels of activity. Solid radioactive waste may consist of:

(a) spent ion exchange resins (both bead and powder);

(b) cartridge filters and pre-coat filter cake;

(c) particulate filters from ventilation systems;

(d) charcoal beds;

(e) tools;

(f) contaminated metal scrap;

(g) core components;

(h) debris from fuel assemblies or in-reactor components; and

(i) contaminated rags, clothing, paper and plastic.

Radioactive waste from research reactors

Gaseous radioactive waste

6.14 The typical sources of gaseous radioactive waste generated during the operation of research reactors include:

(a) Gaseous radioactive elements or compounds from the pools, coolant systems, irradiation facilities and experimental facilities;

(b) Airborne radioactive material produced in ancillary facilities, including fume cupboards and decontamination areas.

Liquid radioactive waste

6.15 The typical sources of liquid radioactive waste generated during the operation of research reactors include:

(a) Cooling water draw-off;

(b) Primary system drains (in the case of light water reactors);

(c) Spent ion exchange resins[7];

(d) Liquid waste from the demineralized water plant;

(e) The drain of the ventilation water system;

(f) Demineralized waste water recovered from the drainage of large equipment in maintenance operations;

(g) Washbasin and shower liquids;

(h) Floor drain liquids;

(i) Liquids from laboratories (these can be radioactive or non-radioactive).

Solid radioactive waste

6.16 The typical sources of solid radioactive waste generated during the operation of research reactors include:

(a) Irradiated target cans;

(b) Used irradiation rigs and reactor components (e.g. thermocouples);

(c) Neutron beam guide tubes;

(d) Used control rods;

(e) Waste arising from the pool service area;

(f) Ventilation system waste (charcoal filters, HEPA filters);

(g) Cleaning materials and used personal protective items;

(h) Laboratory waste (gloves, tissue paper, disposable glassware, etc.);

[7] Although ion exchange resins are in fact solids, they are managed along with the carrier liquid as liquid waste in most applications. Resins are eventually separated from the carrier liquid during treatment and conditioning.

(i) Contaminated items arising from maintenance and other works.

CHARACTERIZATION AND CLASSIFICATION OF WASTE

Requirement 9 (GSR Part 5, Ref. [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.

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

6.18 For the purposes of determining arrangements for the handling, processing and storage of radioactive waste, consideration should be given to:

(a) Origin, the waste type and the physical state of the raw waste (liquid, solid, gaseous);

(b) Criticality risk (SSG-27) [21];

(c) Radiological properties (e.g. half-life, activity and concentration of nuclides, dose rates, heat generation);

(d) Other physical properties (e.g. size / mass, compactibility);

(e) Chemical properties (e.g. composition of raw waste, water content, solubility, corrosiveness, combustibility, gas generation properties, chemical toxicity);

(f) Biological properties (e.g. biological hazards);

(g) Intended methods of processing, storage and disposal.

6.19 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 monitoring the history of 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 facility decommissioning. Note that priority should be given to characterization of raw waste at the point of its generation.

6.20 The data requirements for characterization and 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 analysing the chemical, physical and radiological properties of the waste. The quality of waste packages may be investigated by non-destructive and, infrequently, also by destructive methods. However, it may be possible to apply indirect methods of characterization based on process control and process knowledge, including modelling, instead of or in addition to sampling and the inspection of waste packages in order to avoid undue occupational exposure. The methods of characterization in the processing of the waste should be acceptable to the regulatory body in the authorization process.

6.21 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 provide confidence in the quality of the characterization data that the envisaged that the properties of waste packages will be ensured.

6.22 The categorization and classification of radioactive waste assists in the development of management strategies and in 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 further processing, storage, transport and disposal. To make the appropriate segregation of waste, it will be necessary to know its properties and, hence, it will be 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.

6.23 Details of the purpose, methods and approaches to the classification of radioactive waste are provided in GSG-1 [7], Annex III of which also provides information on origin and types of radioactive waste, including waste from nuclear power production. It should be noted that the classification scheme is based on the long-term management (disposal) of the radioactive waste.

6.24 It should be borne in mind that certain types of radioactive waste contain alpha emitting radionuclides, which could arise from degraded or failed nuclear fuel[8]. Flammable, pyrophoric, corrosive or other hazardous materials should also be given special attention. Care should be taken to avoid mixing waste of these types.

6.25 Gaseous radioactive waste should be classified for treatment purposes into waste arising directly from the primary coolant systems of the reactor and waste arising from the ventilation of plant areas.

6.26 Liquid radioactive waste should be characterized for processing purposes according to its activity concentration and its content of chemical substances. For instance, radioactive waste containing boric acid or organic matter may need special treatment. Non-aqueous radioactive waste such as oil should be segregated for separate treatment.

6.27 Solid radioactive waste should be classified according to its radionuclide content (type and half-life) and activity concentration, taking into account the existing or likely disposal options, and

[8] The terms ‘degraded fuel’ or ‘failed fuel’ can cover a broad range of conditions, ranging from minor pinholes to cracked cladding to broken fuel pins. The nature and extent of failure is an important consideration.

segregated according to treatment and conditioning process. For instance, sludge, cartridge filters, contaminated equipment and components, ventilation filters and miscellaneous items (such as paper, plastic, towels) may be segregated in accordance with the type of treatment and conditioning process, such as compaction, thermal treatment or immobilization.

6.28 The segregation of radioactive waste into appropriate categories should be carried out as near to the point of generation as practicable. The waste should be segregated in accordance with written procedures.

6.29 Mixing of waste (e.g., concentration averaging) at the generating source may be allowed by certain State regulatory authorities in order to achieve specific waste acceptance requirements. Mixing waste streams should be limited to those streams that are radiologically and chemically compatible. If the mixing of chemically different waste streams is considered, an evaluation should be made of the chemical reactions that could occur, especially any exothermic reactions in order to avoid uncontrolled or unexpected reactions that could cause the unplanned release of volatile radionuclides or radioactive aerosols.

PROCESSING OF RADIOACTIVE WASTE

Requirement 10 (GSR Part 5, Ref. [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 during both normal operation and in accident conditions that could occur in the handling, storage, transport and disposal of waste.

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

6.31 Appendix 4 provides an illustrative example of a generic radioactive waste management system at a nuclear reactor. Appendix 5 provides an illustrative example of a radioactive waste management system of a pressurized water nuclear power reactor (partial flow condensate polishing). Appendix 6 provides an illustrative example of a radioactive waste management system of a pressurized water nuclear power reactor (full flow condensate polishing).

6.32 Processing of radioactive waste can either facilitate the recycling and re-use 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 on the requirements for the acceptance of the waste for disposal in order to provide guidance for its processing, which may include provisions for long-term storage. In some cases, the large components (e.g., reactor pressure vessel, steam generators, or other large vessels) may be used as a package itself due to their robustness and design aspects. For example, during the decommissioning of a reactor, it may be reasonable to dispose of a large component without cutting it into smaller pieces and packing it into additional containers. This is one way to reduce doses to personnel and may also be the most economical option.

6.33 Radioactive waste should be processed as early as practicable taking into account different aspects, such as safety, security, doses and economy in order to convert it in an optimized way into a passively safe waste form (WS-G-6.1) [9] and to prevent its dispersal during storage and disposal. The balance between potential mobility of the waste, ALARA considerations and operational impact should be part of the consideration.

Pretreatment

6.34 Pretreatment operations such as waste collection, segregation, chemical adjustment and decontamination may result in a reduction in the amount of waste needing further treatment and conditioning, storage and disposal. Actions can be performed to adjust the characteristics of the waste, to make it more amenable to further processing, and to reduce or eliminate certain hazards posed by the waste owing to its radiological, physical and chemical properties.

6.35 The first operation in the pretreatment of radioactive waste can be to collect waste materials, segregating them as necessary on the basis of their radiological, physical and chemical properties. Radioactive waste containing predominantly short-lived radionuclides should not be mixed with waste containing long-lived radionuclides. In the segregation of waste, it should also be taken into account whether regulatory control can be removed from the waste or whether it can be recycled or released, either directly or after allowing for a decay period.

6.36 To facilitate further treatment and enhance safety, solid waste should be segregated according to the facility specific waste management programme and the available facilities. Segregation is based on consideration of the following waste properties:

(a) Combustible or non-combustible, if 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 or non-fixed surface contamination, if decontamination is a viable option.

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

6.38 To the extent possible, liquid waste should be characterized on the basis of its physical, radiological and chemical properties to facilitate processing. With proper characterization it may be possible to discharge within authorized limits, provided that the non-radiological characteristics of the waste are appropriate. To the extent possible, liquid waste should be treated and conditioned (e.g., adsorption, immobilization, etc.) to promote safe handling, storage and disposal.

6.39 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 the secondary waste are compatible with subsequent steps in the waste management process.

6.40 Mixing 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., processing, storage, or disposal). If the mixing of chemically different waste streams is considered, an evaluation should be made of the chemical reactions that could occur, especially any exothermic reactions in order to avoid uncontrolled or unexpected reactions that could cause 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 its collection and storage should incorporate provisions for fire protection and explosion prevention.

Treatment

6.41 The treatment of radioactive waste may include:

(a) The reduction in volume of the waste (e.g., incineration of combustible waste, compaction of solid waste, and segmentation or disassembly of bulky waste components or equipment);

(b) The removal of radionuclides (e.g., evaporation or ion exchange for liquid waste streams and filtration of gaseous waste streams);

(c) Change of form or composition (e.g., chemical processes such as precipitation, flocculation and acid digestion, as well as chemical or thermal oxidation); and

(d) Change of the properties of the waste (e.g., solidification, sorption, encapsulation; common immobilization matrices include cement, bitumen and glass).

Solid waste

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

6.43 A great number of processes are available for producing acceptable waste packages. Such processes should be selected on the basis of the characteristics of the waste concerned. If possible, processes with high volume reduction factors should be applied, for example the use of proven techniques such as compaction or thermal treatment.

6.44 Thermal treatment of combustible solid waste normally achieves the highest volume reduction 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 for thermal treatment and the nature of the radionuclides in the waste. Thermal treatment is also an advantageous technique for treating radioactive organic liquids because the products of complete combustion are ash, carbon dioxide and water. It should be noted that thermal treatment will result in the 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 acid gases and corrosive combustion products, and the effects of corrosion of the incinerator's components and of acid releases to the atmosphere should therefore be considered. Off-gas scrubbing to prevent the discharge of radioactive and non-radioactive hazardous materials may be necessary and should be considered. Attention should be paid to radionuclides accumulating in residues of the gas cleaning system and those remaining in the ash, and to their further conditioning.

6.45 Releases of radionuclides to the environment are largely determined by the operational conditions of the incinerator, in particular through control of the temperature and the types and amounts of waste treated and its radionuclide content. For incinerators processing significant amounts of radioactive waste, the operator should monitor the radionuclides in the stack discharge by appropriate measures 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. The products of incineration can include acids, polychlorinated biphenyls and various other materials presenting non-radiological hazards, which should be taken into account.

6.46 Compaction is a suitable method for reducing the volume of certain types of waste. This may include the compaction of ashes originating from thermal treatment. 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;

(b) The possible release of contaminated liquid during compaction;

(c) The chemical reactivity of the material during and after compaction;

(d) The potential fire and explosion hazards due to pyrophoric or explosive materials or pressurized components;

(e) Criticality safety considerations when waste that contains fissile material is compacted into a single waste package. .

6.47 Segmentation or disassembly and other size reduction techniques may be used before conditioning waste that is bulky or oversize in relation to the intended processing (e.g. worn out components or structures). Processes to achieve this typically use cutters with high temperature flames, various sawing methods, hydraulic shearing, abrasive cutting and plasma arc cutting. Means of preventing the spread of particulate contamination should be considered in the choice of method and in the operation of the equipment.

6.48 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 metal scrap, with resultant homogenization of the radioactive material and its accumulation in the slag, may be considered as a means of achieving authorized reuse or removal of regulatory control.

Liquid waste and discharges

6.49 Methods for the treatment of aqueous waste include evaporation, chemical precipitation, ion exchange, filtration, centrifugation, ultrafiltration, incineration and reverse osmosis. In each case, process limitations due to 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 operations 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 (SSG-27) [21]. Conditions of optimum moderation and reflection should be considered in the determination of safe configurations of radioactive waste and in the development of operating procedures.

6.50 Spent ion exchange resins are usually flushed out as slurry and subsequently managed as liquid waste until the resin can be separated from the carrier liquid, although some operators retain the resins as a dry solid. 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 necessitate special maintenance. Special care should also be taken with their prolonged storage while awaiting conditioning, because of the potential for radiolysis or chemical reactions generating combustible gases or causing physical degradation or exothermic reactions.

6.51 Liquids for discharge may be produced as a consequence of 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 waste within authorized limits, provided that the non-radiological characteristics of the waste are appropriate.

6.52 All discharged liquids should be 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 waste also contains toxic or other chemicals that could adversely affect the environment or the treatment of sewage, the waste should be treated prior to discharge in accordance with the regulations in respect of health and safety and protection of the environment.

6.53 For routine discharges of liquids to the environment, the main types of control options are to provide either storage facilities, so that short lived radionuclides can decay before release, or treatment facilities 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 limitations and controls for such releases should be set by the regulatory body [16].

6.54 Organic radioactive waste requires management steps that not only take account of its radioactivity, but also of the chemical organic content since this can also have detrimental effects on the environment. The “dilute and disperse” option applied for some aqueous and gaseous waste is inappropriate for organic liquid waste. The treatment steps of organic liquid waste that should be considered incineration, emulsification to facilitate encapsulation into cement, absorption into matrix, distillation and wet oxidation.

Gaseous waste and discharges

6.55 In the operation of treatment systems for gaseous radioactive waste, consideration should be given to: the amount of gas to be treated; the 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. Noble gases with short half-lives should be retained in hold-up tanks or other delay systems that allow the radionuclides to decay to an acceptable activity or activity concentration before release.

6.56 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 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 the reliability of the system is fundamental to the achievement of safety, redundant systems such as two filters in sequence should be used in case one fails.

Additional components of the off-gas system that should be considered for detecting problems include those 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.

6.57 For both liquid and gaseous discharges, the arrangements should be identified for dose assessment and any necessary workplace monitoring in relation to the exposures resulting from the accumulation of the waste, the discharge of the waste, and to any groups at particular risk as a result of the discharge.

Conditioning

6.58 Conditioning of radioactive waste consists of those 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).

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

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

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

(a) Compatibility (physical and chemical) of the waste, any matrix materials and 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.

6.62 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 above apply for many types of solid waste. Some of the characteristics (in particular homogeneity and low voidage) do not apply for certain types of solid waste. For example, core components are enclosed in thick-walled waste containers without immobilization.

6.63 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 like zirconium can be flammable when the particle size/ surface area and environment are favourable. Chelating agents, organic liquids or oil and salt content in liquid waste may also be of concern in the conditioning process.

6.64 The waste and its container should be compatible. Depending on the waste characteristics and the method of handling, transport and storage, the container may also need to provide shielding for direct radiation. In selecting materials for the container and its outer surface finish, consideration should be given to the 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 consider the compatibility of the waste package and the overpack with respect to the waste acceptance criteria and transport requirements.

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

(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 acceptance requirements of the disposal facility.

STORAGE OF RADIOACTIVE WASTE

Requirement 11 (GSR Part 5, Ref. [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 the degradation of the waste containment.

6.66 Storage is an option that should be considered in the waste management strategy of a reactor. Proper storage should be available at all stages in waste processing for isolation and environmental protection; it should also facilitate retrieval for subsequent steps. Guidance for the storage of radioactive waste and for the storage of spent fuel is dealt with extensively in WS-G-6.1 [9], SSG-15 [8] and NS-G-1.4 [33].

6.67 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 has to be made for the regular monitoring, inspection and maintenance of the waste and of the storage facility to ensure their continued integrity.

6.68 Where necessary, provision should be made for containment in areas where radioactive effluent or radioactive waste is stored prior to its treatment and discharge. Provisions for the storage of waste in transit and for the removal of waste should also be considered.

6.69 Storage facilities and waste packages should take account of the waste form (i.e. solid, liquid or gas), radionuclide content and half-lives, activity concentrations, 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 and public radiation exposure or environmental impact.

6.70 Sufficient storage capacity should be provided for radioactive waste generated in normal operations 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.

6.71 To the extent practicable, radioactive waste should be stored in a passive condition, (e.g., radioactive material is immobile, 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 are minimized, storage environment optimizes the lifetime of the waste container, etc.). The operator should ensure the integrity of the structures, equipment, waste forms and containers are maintained over the expected duration of storage. Consideration should be given to interactions between the waste, the containers and their environment (e.g. corrosion processes due to chemical 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.

6.72 Radioactive waste containing short-lived radionuclides may be collected and stored to allow its radioactivity to decay to levels that permit authorized discharge, authorized use or removal of regulatory control. Storage may also be necessary for operational reasons; for example, to permit off-site transfer at specified time intervals.

6.73 Radioactive waste should be stored in a segregated manner such that it can be retrieved for further treatment, transfer to another storage facility or disposal. Radioactive waste should be stored separately from nonradioactive waste to avoid cross-contamination and accidental removal from control. Special attention may need to be given to storage of fissile materials, to avoid storage configurations which could lead to criticality concerns.

6.74 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 waste stored. The sophistication of the waste tracking system required (e.g. including labelling and bar coding) will depend on the number of waste packages, the anticipated duration of storage of the waste and the hazard associated with it.

6.75 If the waste is expected to be stored at the reactor for extended periods of time prior to its disposal or after the reactor has been permanently shut down and decommissioned, the regulatory body should confirm that the operator is providing the necessary human, technical and financial resources for the lifetime of the storage facility.

RADIOACTIVE WASTE ACCEPTANCE CRITERIA

Requirement 12 (GSR Part 5, Ref. [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.

6.76 Criteria are to be developed for the acceptance of radioactive waste in the facilities for predisposal management of radioactive waste. Account should be taken of all relevant operational limits and conditions of the reactor and the waste management facility (consistent with the safety case) and also of the future disposal facility. In fact, 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 requirements for its disposal. In order to provide reasonable assurance that the conditioned waste can be accepted for disposal, although there may not yet be any specific requirements, options for the future management of radioactive waste and the associated waste acceptance requirements should be anticipated as far as possible. The waste acceptance requirements 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.

6.77 Appendix 3 provides a listing of the typical properties and characteristics that should be considered for waste packages and spent nuclear fuel declared as waste. 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 that is approved by the regulatory body. A programme for quality assurance and control of waste packages should be developed and included in the management system. Subsequent to approval by the regulatory body, this programme should be implemented as a measure to confirm compliance with the waste acceptance criteria of the disposal facility.

6.78 The operator should ensure that the radioactive waste accepted in his facility (and installations) complies with the set criteria. Procedures for acceptance should be included in the management system.

6.79 Adequate techniques should be 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.

LIFETIME SAFETY CONSIDERATIONS

Siting and design

Requirement 17 (GSR Part 5, Ref. [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.

6.80 Criteria for siting and methods that could be used in a graded approach in the siting of nuclear installations are dealt with in NS-R-3 [34], SSG-9 [35], SSG-18 [36], SSG-21 [37], and DS433 (in preparation) [38]. Criteria for designing nuclear power plants and research reactors are dealt with in SSR-2/1 [39] and NS-G-4.6 [40], respectively.

6.81 Waste processing and storage facilities should be located in the same area as the reactor, to the extent practicable, to reduce the need for the transport of unconditioned waste between locations for processing and for storage.

6.82 In general, the design of nuclear reactors should incorporate features that facilitate the safe handling, storage, transport and disposal of radioactive waste and the control of discharges. The design should be such as to ensure adequate flexibility of the facilities for handling damaged containers and radioactive waste of non-standard physical or chemical composition.

6.83 The design of the reactor should be such as to minimize the generation of radioactive waste in all operational stages in the lifetime of the facility, including decommissioning. Such considerations should be compatible with the safety case and with regulatory limitations on radiation doses. The extent to which the containment or the means of confinement is vented in operational states to prevent the buildup of radioactive gases should be addressed in the design.

6.84 The design of research reactors should include provisions for the safe management of solid, liquid and gaseous radioactive waste associated with experimental devices. The varying nature of the radioactive waste and the circumstances that could have an influence on the characteristics of the waste should be taken into account especially in the design of the shielding and containment. Measures used in the design of research reactors vary but should include the following:

(a) Selection of materials that do not activate easily (e.g. use of plastic for the pneumatic ‘rabbit’ system irradiation target carriers) or materials that decay quickly when activated (e.g. use of aluminumح components near the core);

(b) Making allowance for the thermal expansion and contraction of pool water in a manner that avoids or minimizes over flow to liquid retention tanks;

(c) Minimization of air spaces near neutron sources to reduce the production of 41Ar .

6.85 In the design of the reactor and its associated facilities for the predisposal management of radioactive waste, due consideration should be given to the need for:

(a) Criticality Safety;

(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 proper selection of process gases and decay devices (e.g. the use of delay tanks or retention tanks) to minimize releases of radioactive material;

(d) The retrieval of stored waste (including waste generated during operation);

(e) Waste characterization and inventory control;

(f) The inspection of the waste and its containment;

(g) Dealing with waste and waste packages that do not meet specifications;

(h) The control of liquid and gaseous effluents;

(i) Managing waste giving rise to non-radiological hazards;

(j) Maintenance work and eventual decommissioning;

6.86 Measures considered in the design for the management of gaseous radioactive waste and effluents should include the following:

(a) Provision for radioactive gases to be channelled through proper ducting as appropriate and brought to monitored release point(s);

(b) Provision of means, such as stacks for the authorized discharge of gaseous radioactive waste, and of methods for sampling and monitoring those discharges.

6.87 Measures considered in the design for the management of liquid radioactive waste and liquid effluents (i.e., including waste arising from ion exchange resins) should include the following:

(a) Collection of radioactive liquid effluents to a common point such as a holding tank either for reuse (e.g. treatment using resins, solidification) or because the activity levels are too high for their immediate release to the environment;

(b) The potential for re-concentration downstream in the environment of some released radionuclides in relation to the collection of liquid radioactive waste with low levels of activity and the methods of monitoring such releases;

(c) The management and control of liquid radioactive waste with higher levels of activity, such as waste that might arise from planned major shutdowns of research reactors of some types;

(d) Provisions for decay storage to minimize releases of radioactive material;

(e) Provisions for representative sampling from and monitoring retention tanks prior to the release of liquid content, preferably at the point of release;

(f) Provisions as necessary for storing spent ion exchange resins and dehydrating liquid waste;

(g) Provisions for filtration in liquid waste collection lines to prevent the release of solids;

(h) Provisions for mixing/homogenization of stored liquids and slurries to prevent stratification and to facilitate the collection of representative samples from tanks and storage structures; and

(i) Provisions for filtration in liquid waste collection lines to prevent the release of solids.

6.88 Measures considered in the design for the management of solid radioactive waste should, as far as applicable, include the following:

(a) Provisions for segregating waste by type (mass, physical form, volume, isotopic composition and activity concentration);

(b) The handling, packaging and storage of solid radioactive waste with low level and very low level activity (e.g., contaminated cleaning equipment, clothing, paper and tools);

(c) The handling, packaging and storage of solid radioactive waste with intermediate level activity (e.g., waste arising from ion exchange resins, ventilation filters and charcoal beds);

(d) The handling, packaging, and storage of solid radioactive waste with high level activity (e.g., activated hardware);

(e) Areas and tools for handling and loading waste;

(f) Equipment and tools for radiation protection;

(g) Provisions for ensuring that the removal of radioactive material within authorized practices from any further regulatory control and the control of discharges are within authorized limits.

6.89 The reactor and waste management facilities should be designed to prevent material interactions that may compromise the containment of the waste or safety at the facility.

6.90 The predisposal management of radioactive waste may also entail the management of nonradioactive hazardous material. Measures should be taken so as 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.

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

6.92 The design of the reactor and the associated waste management facility of heat generating waste should incorporate systems (e.g. a system for monitoring and controlling the temperature) that are capable of maintaining the temperature of the waste within acceptable limits in all stages of predisposal management of radioactive waste, both in operational states (i.e. normal operation and anticipated operational occurrences) and under accident conditions (i.e. design basis accidents). 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 maximum extent practicable, the cooling systems for storage facilities for conditioned high-level waste should be passive and should need minimal maintenance. If forced circulation of coolant is used, the system should be highly reliable and redundant (robust). Examples of features that enhance the reliability of cooling systems are the capability of dealing with the settling of solids and with build-up on surfaces that affects the efficiency of heat removal. The storage facility itself should be designed to be capable of experiencing temporary loss of cooling events without damage to the stored waste. In addition, means of mitigation or recovery should be put in place to deal with such contingencies.

Construction and commissioning

Requirement 18 (GSR Part 5, Ref. [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.

6.93 Guidance for the construction of nuclear installations is dealt with in DS441 [40]. Criteria for commissioning of nuclear power plants are dealt with in SSR-2/2 [41].

6.94 For modular storage systems, most of the commissioning will have been 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.

Facility operation

Requirement 19 (GSR Part 5, Ref. [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 [25].

6.95 Criteria for operation of nuclear power plants are dealt with in SSR-2/2 [41]. Instructions and procedures should be prepared for normal operations of the facility and under accident conditions. Instructions and procedures should be prepared to be readily available when needed for the designated responsible persons.

6.96 Measures for preventing and limiting potential exposure associated with radioactive waste during normal operations should include:

(a) Provisions for the isolation of radioactive waste from site personnel and the public, including access control, e.g., zoning the facility in accordance with the potential for radioactive contamination and radiation exposure;

(b) Provisions for detection, collection and treatment of liquid spills;

(c) Provisions for the decontamination of personnel and equipment;

(d) Provisions for handling radioactive waste arising from decontamination activities.

6.97 The operating organization should ensure that operating procedures relating to the maintaining of subcriticality are subjected to rigorous review and 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:

(a) The type and class of the waste to be stored;;

(b) Geometries necessary to ensure subcriticality;

(c) Dependence of subcriticality on neutron absorbers;

(d) Conditions of optimum moderation and reflection;

(e) Waste form and waste packages;

(f) Handling operations;

(g) The potential for abnormal operation; and

(h) Defense in depth analysis.

6.98 Protection and safety considerations that should be taken into account in the development of emergency arrangements are addressed in the Safety Guides GS-G-2.1 and GSG-2 [42, 44]. When developing emergency arrangements, the operating organization should consider, but not be limited to, events such as the following:

(a) Failure of handling systems, such as severe crane failure or dropping of loads;

(b) Loss of safety related facility process systems such as supplies of electricity, process water, compressed air and ventilation;

(c) Explosions, including those due to the build-up of gases generated by radiolysis;

(d) Fires leading to the damage of items important to safety;

(e) External natural hazards, such as extreme weather conditions and earthquakes;

(f) External human induced hazards (airplane crash, sabotage, and other malicious acts).

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

Operational limits and conditions

6.100 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 consequences of events following 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 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 maintenance;

(f) Specification of the equipment that should be available to enable a full and proper response to postulated initiating events or design basis accidents;

(g) The minimum staffing levels needed to operate the facility safely.

6.101 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 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.

Maintenance

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

(e) analysis of maintenance requirements on the basis of previous experience or other applicable data (such as manufacturers' recommendations);

(f) work planning in relation to the availability of skilled personnel, tools and materials (including spare items);

(g) the monitoring programme for radiation protection and industrial safety;

(h) the potential for a loss of containment;

(i) impact to operating facilities.

6.103 Suitably qualified and experienced operating personnel should be deployed in the approval and implementation of the maintenance, inspection and testing programme and in the approval of associated working procedures and acceptance criteria.

Radiation protection programme

6.104 An operational radiation protection programme should be put in place that ensures that areas of the facility are classified according to the radiation levels and the potential for contamination. The programme should include the monitoring and control of all relevant radiological hazards in the facility and should include provisions to ensure that radiation 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 radiation exposures are kept as low as reasonably achievable.

Emergency preparedness

6.105 Emergency plans and procedures should be developed and documented, and made available to the personnel concerned. These plans and procedures should be subject to periodic review and revision as necessary in light of past experience and 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 in the emergency arrangements as necessary. The quality management programme should be in place to ensure that equipment, supplies, communication systems and other resources necessary for an emergency response are available and in working order when needed. (GS-R-2, GSG-2.1) [25, 44]

Decommissioning

Requirement 20 (GSR Part 5, Ref. [4]): Shutdown and decommissioning of facilities

The operator shall develop, in the design stage, an initial plan for the shutdown and decommissioning of predisposal radioactive waste management facilities 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.

6.106 The key elements that should be considered for the decommissioning of facilities for the predisposal management of radioactive waste, as specified in GSR Part 6 [22], include:

(a) The development of a decommissioning plan;

(b) The selection of a decommissioning option in which technical factors, costs, schedules and institutional factors are taken into account, and in which the radionuclides in the secondary waste are limited to the amount practicable;

(c) The specification of the critical tasks involved in their decommissioning; in particular decontamination, dismantling, demolition, surveillance and conducting a final radiological survey;

(d) The management functions important for their decommissioning, such as training, organizational control, radiological monitoring, planning and the control of waste management, nuclear security, safeguards and quality assurance;

(e) Allocation of decommissioning funds or financial instrument to cover decommissioning costs.

6.107 An initial version of the decommissioning plan should be prepared during the design of the facility in accordance with requirements and recommendations on decommissioning (GSR Part 6, WS-G-2.1) [22, 23].

6.108 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:

(a) Technological developments in decommissioning;

(b) Possible natural and human induced hazards of external events;

(c) Modifications to systems and structures affecting the decommissioning plan;

(d) Amendments to regulations and changes in government policy;

(e) Possible long term storage of radioactive waste at the site once the reactor has been permanently shut down, or delivery of radioactive waste to an authorized facility for storage or disposal in compliance with transport requirements;

(f) Availability of disposal options; and

(g) Cost estimates, financial provisions, and update of decommissioning funds based on characterization data and safety case updates.

6.109 A comprehensive decommissioning strategy should be developed for sites also having other facilities to ensure that interdependences are taken into account in the planning for individual facilities (WS-G-2.1) [23].

APPENDIX 1. KEY PROPERTIES AND CHARACTERISTICS OF WASTE PACKAGES AND SPENT NUCLEAR FUEL DECLARED AS WASTE

Properties and characteristics	Radioactive waste [9]	Unconditioned fuel	Conditioned fuel
Radiological data: number and types of radionuclides, half-life and activity for each radionuclide, total radioactivity content, activity concentrations, heat output	√	√	√
Fuel data: type, power history, initial fissile content, burn-up and cooling time		√	√
Activity: β–γ and α activity by radionuclide for the major contributors to activity	√	√	√
Criticality safety: geometrical configuration, concentration and inventory of fissile material (e.g. U-233, U-235, Pu-239, Pu-241), presence of neutron poisons and demonstration of non-criticality (taking into account appropriate safety margins)	√	√	√
Dose rate: neutron and γ dose rate at the surface and at a distance of 1 m	√	√	√
Surface contamination: levels of β–γ and α contamination	√		√
Thermal properties: thermal power, thermal conductivity and predicted maximum temperatures (with and without cooling by engineered systems)		√	√
Physical properties: density; porosity; permeability to water and gases; thermal stability; homogeneity and compatibility with the matrix; percentage of water incorporated, exudation of water under compressive stress, shrinkage and curing; leachability and corrosion rate, tensile strength, compressive strength and dimensional stability	√	Density only	
Chemical properties: pH, main chemical species and compounds, toxic substances and corrosive compounds	√	√	
Mass of waste and/or waste package: total mass (mass of waste form and canister, if applicable)	√	√	√

[9] Not all elements may be required; the relevant acceptance requirements will define the specific elements required

Properties and characteristics	Radioactive waste [9]	Unconditioned fuel	Conditioned fuel
Quality of canister/container: material specification, tare weight, dimensions, corrosion resistance, characteristics of lidding and seal arrangements, quality of seal weld, material certifications from manufacture; quality assurance records from conditioning process; compatibility with the waste form	√		√
Quality of waste package: diffusion and leaching of radionuclides in an aqueous medium; release of gas under standard atmospheric conditions or the conditions for acceptance; diffusion of tritium under standard atmospheric conditions or conditions for acceptance; capability for the fixation and retention of radionuclides; water-tightness and gas-tightness of the package sealing device	√		
Stackability and handling: number of packages stackable without deformation, results of package drop tests and requirements for lifting packages (e.g. lifting features)	√		√
Package labelling: unique permanent identification	√		√
Quality of matrix material: certification and quality assurance records for matrix material	√		√
Mass fractions of waste form: fractions of waste, fixation materials and additives	√		√
Robustness of the waste package: behaviour under temperature cycling; sensitivity to elevated temperatures and behaviour in a fire; behaviour under conditions of prolonged radiation exposure; sensitivity of the matrix to water contact; resistance to the action of micro-organisms; corrosion resistance in a wet medium (for metal containers); porosity and degree of gas-tightness; potential for swelling due to the internal build-up of evolved gases.	√		
Stability of the package: corrosion and/or leaching behaviour in relevant atmospheres or aqueous solutions, data on long term corrosion and data extrapolation, influence of surface area and solubility of radionuclides in relevant aqueous solutions		√	√

APPENDIX 2. FACILITY SPECIFIC WASTE MANAGEMENT PROGRAMME

The content of a facility specific waste management programme could include:

(a) The description of the processes in which the radioactive waste is generated by the facility;

(b) A description of the radioactive waste streams and the efforts to avoid and minimize them;

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

(d) A comprehensive list of waste categories and anticipated arisings and inventories, including historic and legacy waste;

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

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

(g) Identification of funding to implement the waste management program 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 based on the above and international good practices;

(i) Demonstration that the facility specific waste management programme is compatible with national policy and strategy;

(j) Demonstration, if necessary, of how the safety case is affected by the waste management programme, e.g. modification of the programme to incorporate longer storage than originally designed for would be a safety case impact.

The programme should include provisions for:

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

(b) Possible reuse and recycling of materials;

(c) 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) Collection, characterization and safe storage of radioactive waste;

(e) Adequate storage capacity for the radioactive waste expected to be generated, and an additional reserve storage capacity;

(f) Ensuring that the radioactive waste can be retrieved at the end of the anticipated storage period, by means of suitable techniques and procedures;

(g) Processing radioactive waste compatible with waste acceptance criteria to ensure safe storage and disposal;

(h) Safe handling and transport of radioactive waste and waste packages;

(i) Adequate control of discharges of effluents to the environment;

(j) Monitoring of sources (of effluent discharges) and the environment, for the demonstration of regulatory compliance;

(k) Maintaining facilities and equipment for the processing and storage of waste to ensure safe and reliable operation;

(l) Monitoring the status of the containment for the radioactive waste in the storage location;

(m) Monitoring changes in the characteristics of radioactive waste by means of inspection and regular analysis, in particular, if storage is continued for extended periods;

(n) Initiating, as necessary, research and development activities to improve existing methods for processing radioactive waste or to develop new methods and techniques;

(o) Systematic evaluation of operating experience and events at the facility;

(p) Adoption and implementation of corrective actions on the basis of the results of monitoring and operating experience feedback;

(q) Emergency preparedness and response[10].

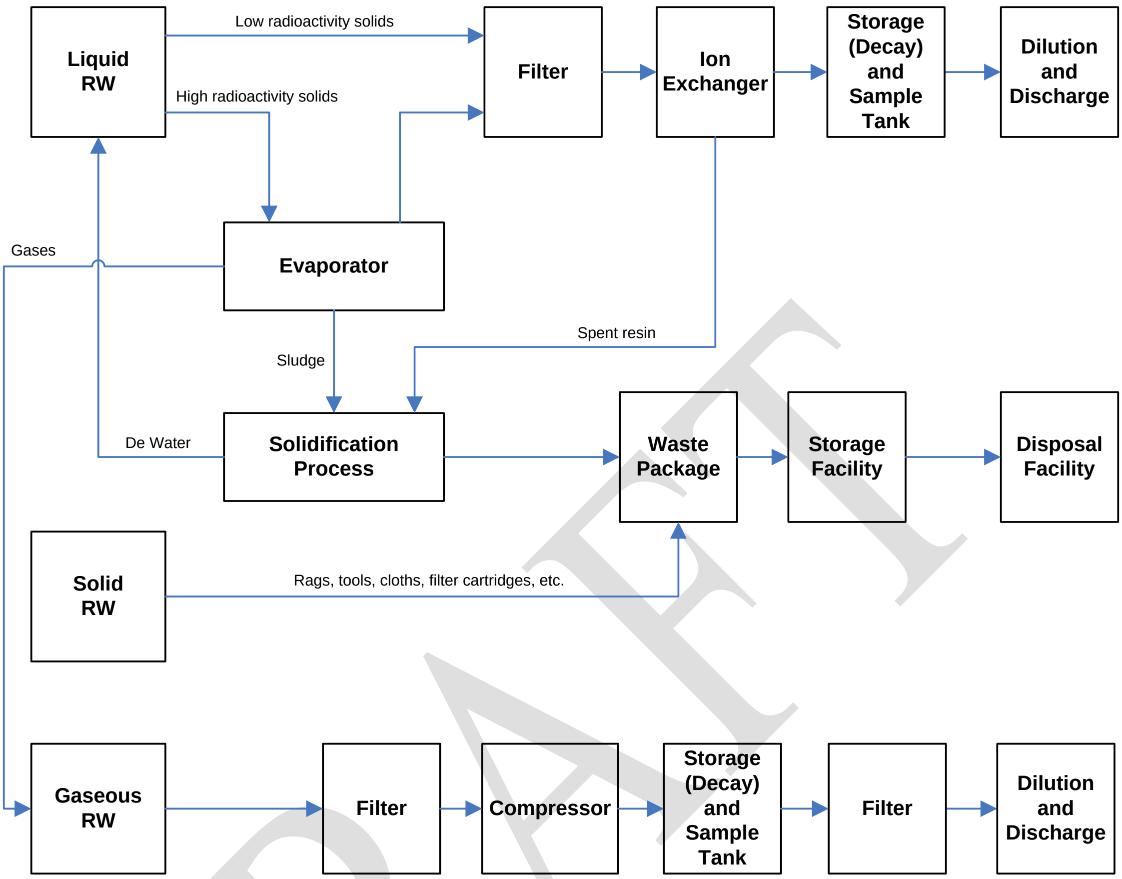
[10] Although emergency preparedness and response is mentioned under this programme, it may be part of the overall emergency arrangements for the entire facility. In this case, the programme should make reference to the overall emergency arrangements.

APPENDIX 3: EXAMPLES OF HAZARDS ASSOCIATED WITH WASTE MANAGEMENT ACTIVITIES AT NUCLEAR REACTORS

Waste management activities	Waste materials	Characteristics	Hazards (radiological)	Hazards (non-radiological)
Nuclear power plants				
Normal operation, maintenance, and decommissioning of the plant and its associated processing systems for gaseous and liquid radioactive waste	Solid waste: • Spent ion exchange resins; cartridge filters and pre-coat filter cake; particulate filters from ventilation systems; charcoal beds; tools; contaminated metal scrap; core components; debris from fuel assemblies or in-reactor components; contaminated rags, clothing, paper and plastic. Liquid waste: • Primary coolant in water cooled reactors and water from the fuel storage pools; • Reactor coolant let-down, evaporator concentrates, equipment drains, floor drains, laundry waste, contaminated oil and waste arising from decontamination and maintenance. Gaseous waste: • Leakage from the coolant, the moderator systems or the reactor itself (e.g., fuel assemblies); • Degasification systems for the coolant; • Condenser vacuum air ejectors or pumps; • Exhaust from turbine gland seal systems; • Activated or contaminated ventilated air; • Spent fuel in storage or in handling operations.	• Mostly activated solids from structural, moderator, and coolant materials • Corrosion products • Fission product contamination arising from the fuel	• Criticality • Alpha bearing materials • Elevated dose rates • Elevated radioactivity concentration levels • Radiation dose (internal/external)	• Radiolysis or chemical reactions generating combustible gases or causing physical degradation or exothermic reactions • Heat generating (amounts of plutonium with even mass numbers and those of americium) • Heavy metal toxicity • Environmental impact

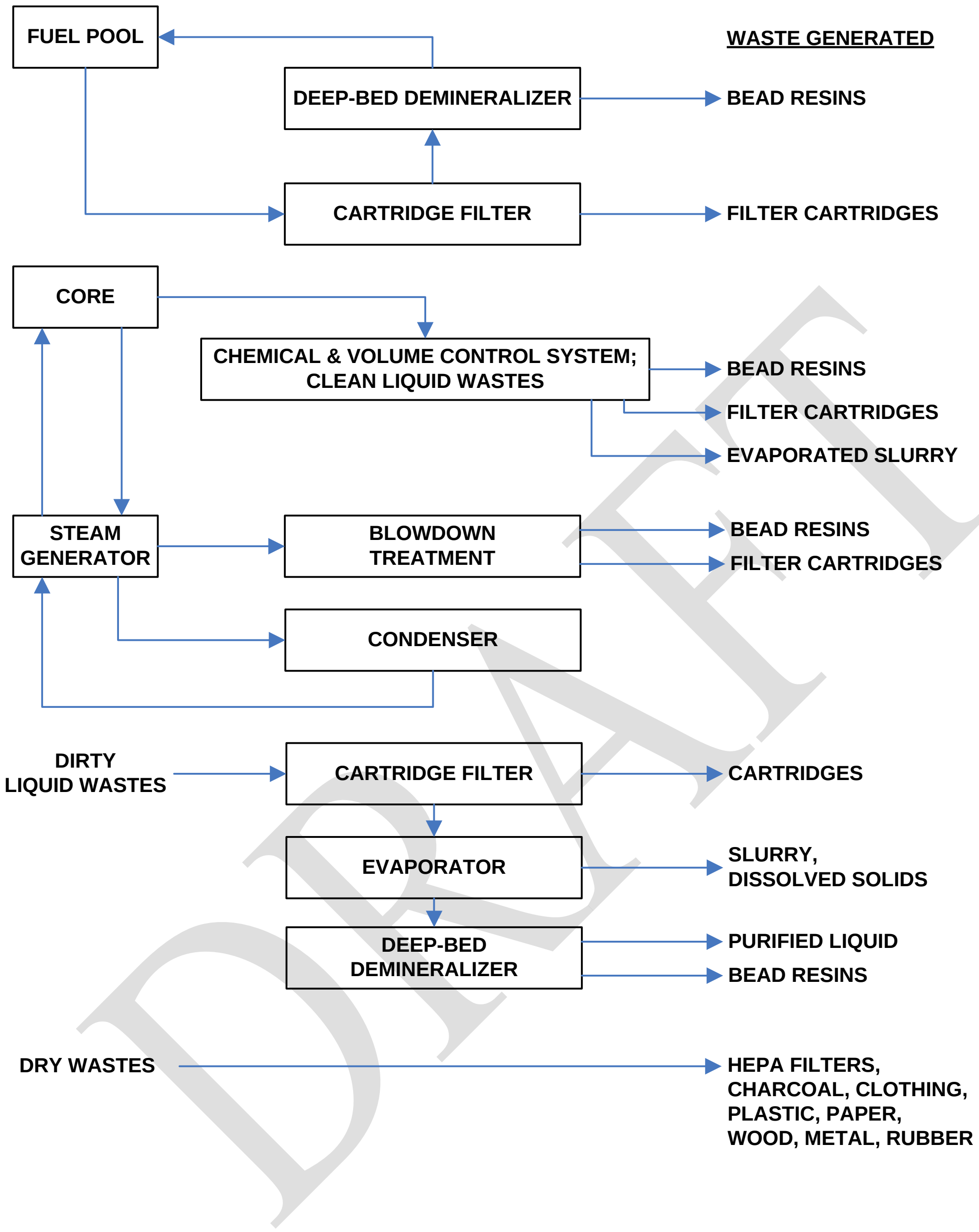
Waste management activities	Waste materials	Characteristics	Hazards (radiological)	Hazards (non-radiological)
Research reactors				
Normal operation, maintenance, and decommissioning of the plant and its associated processing systems for gaseous and liquid radioactive waste	Solid waste: • Irradiated target cans; • Used irradiation rigs and reactor components (e.g. thermocouples); • Neutron beam guide tubes; • Used control rods; • Waste arising from the pool service area; • Ventilation system waste (charcoal filters, HEPA filters); • Spent ion exchange resins; • Cleaning materials and used personal protective items; • Laboratory waste (gloves, tissue paper, disposable glassware, etc.); • Contaminated items arising from maintenance and other works. Liquid waste: • Cooling water draw-off; • Primary system drains (in the case of light water reactors); • Liquid waste from the demineralized water plant; • The drain of the ventilation water system; • Demineralized waste water recovered from the drainage of large equipment in maintenance operations; • Washbasin and shower liquids; • Floor drain liquids; • Liquids from laboratories (these can be radioactive or non-radioactive). Gaseous waste: • Gaseous radioactive elements or compounds from the pools, coolant systems, irradiation facilities and experimental facilities; • Airborne radioactive material produced in ancillary facilities, including fume cupboards and decontamination areas.	• Mostly activated solids from structural, moderator, and coolant materials • corrosion products • fission product contamination arising from the fuel	• Alpha bearing materials • Elevated dose rates • Elevated radioactivity concentration levels • Radiation dose (internal/external)	• Radiolysis or chemical reactions generating combustible gases or causing physical degradation or exothermic reactions • Heavy metal toxicity • Environmental impact

APPENDIX 4. EXAMPLE OF A GENERIC RADIOACTIVE WASTE MANAGEMENT SYSTEM IN A NUCLEAR REACTOR



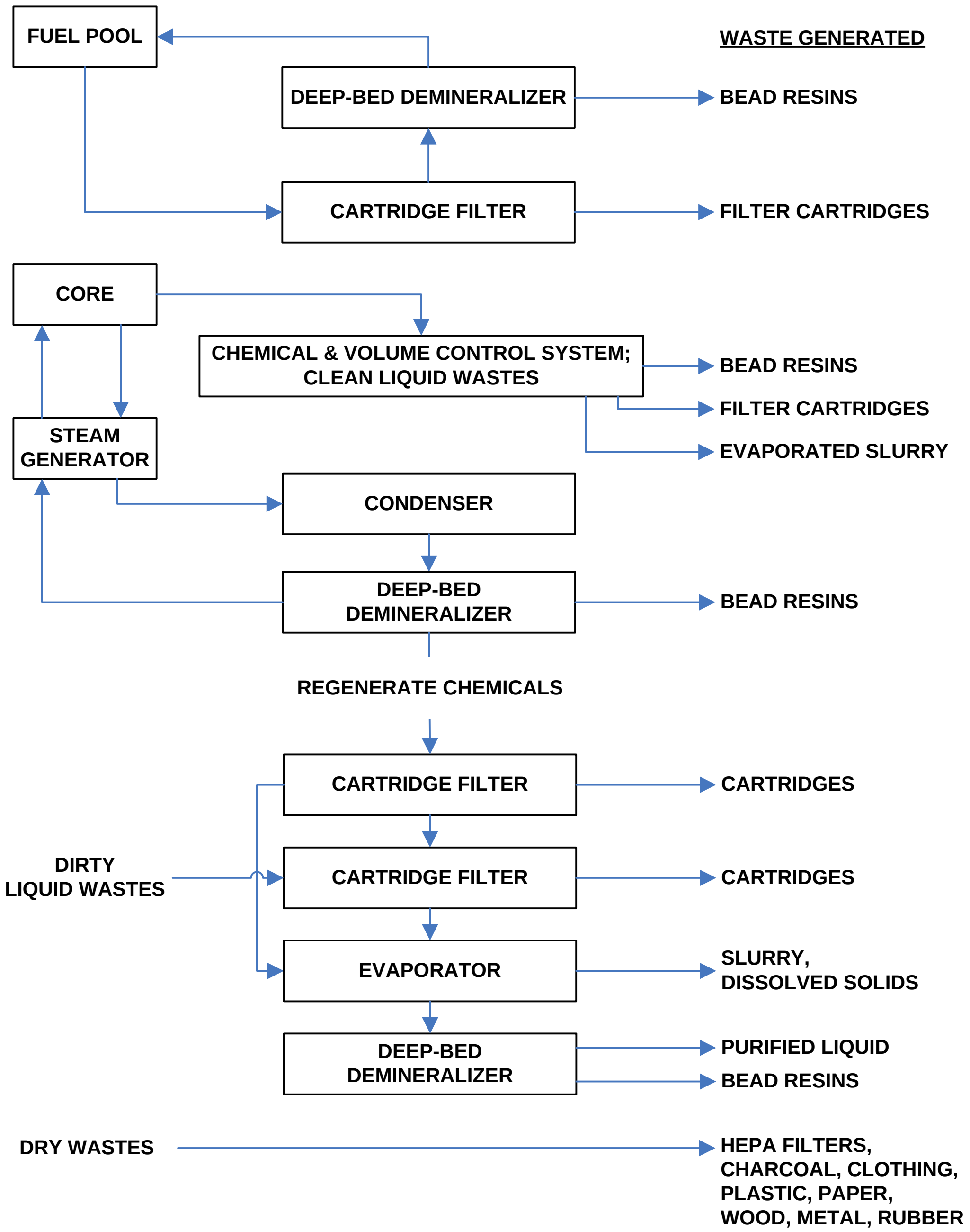
Source: Ref. [43]

APPENDIX 5. EXAMPLE OF RADIOACTIVE WASTE MANAGEMENT SYSTEM OF A PRESSURIZED WATER REACTOR (PARTIAL FLOW CONDENSATE POLISHING)



Source: Ref. [43]

APPENDIX 6. EXAMPLE OF RADIOACTIVE WASTE MANAGEMENT SYSTEM OF A PRESSURIZED WATER REACTOR (FULL FLOW CONDENSATE POLISHING)



Source: Ref. [43]

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