IAEA Safety Standards
for protecting people and the environment

Storage of Radioactive Waste

Safety Guide
No. WS-G-6.1

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International Atomic Energy Agency

IAEA SAFETY RELATED PUBLICATIONS

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STORAGE OF RADIOACTIVE WASTE

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

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FOREWORD

by Mohamed ElBaradei
Director General

The IAEA's Statute authorizes the Agency to establish safety standards to protect health and minimize danger to life and property — standards which the IAEA must use in its own operations, and which a State can apply by means of its regulatory provisions for nuclear and radiation safety. A comprehensive body of safety standards under regular review, together with the IAEA's assistance in their application, has become a key element in a global safety regime.

In the mid-1990s, a major overhaul of the IAEA's safety standards programme was initiated, with a revised oversight committee structure and a systematic approach to updating the entire corpus of standards. The new standards that have resulted are of a high calibre and reflect best practices in Member States. With the assistance of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its safety standards.

Safety standards are only effective, however, if they are properly applied in practice. The IAEA's safety services — which range in scope from engineering safety, operational safety, and radiation, transport and waste safety to regulatory matters and safety culture in organizations — assist Member States in applying the standards and appraise their effectiveness. These safety services enable valuable insights to be shared and I continue to urge all Member States to make use of them.

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

The IAEA takes seriously the enduring challenge for users and regulators everywhere: that of ensuring a high level of safety in the use of nuclear materials and radiation sources around the world. Their continuing utilization for the benefit of humankind must be managed in a safe manner, and the IAEA safety standards are designed to facilitate the achievement of that goal.

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. Radioactive waste is generated in a broad range of activities involving a wide variety of radioactive materials associated with, for example, the operation of nuclear facilities, the use of sealed radioactive sources in industry, the use of human made radionuclides in hospitals and laboratories, and the decommissioning of such facilities. The physical, chemical and radiological characteristics of the waste arising from these activities differ widely.

1.2. The principles and requirements for the safe management of radioactive waste for the protection of human health and the environment are established in the IAEA safety standards: The Fundamental Safety Principles [1], Legal and Governmental Infrastructure for Nuclear, Radiation, Radioactive Waste and Transport Safety [2], Predisposal Management of Radioactive Waste, Including Decommissioning [3] and the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (BSS) [4]. Recommendations on the application of these principles through the fulfilment of these requirements as they pertain to radioactive waste storage are provided in this Safety Guide and several associated Safety Guides [5–7].

1.3. Following its generation, untreated radioactive waste may be subject to a number of waste management processes prior to its disposal such as handling, treatment and conditioning. During these processing steps, radioactive waste may be subject to storage at a number of stages. Hence, radioactive waste will be stored in processed and unprocessed forms and for varying periods of time.

1.4. There are many reasons why it may be appropriate to store radioactive waste for varying periods of time. Examples include the following:

(a) To allow for the decay of short lived radionuclides to a level at which the radioactive waste can be released from regulatory control (clearance) or authorized for discharge, or recycling and reuse;
(b) To collect and accumulate a sufficient amount of radioactive waste prior to its transfer to another facility for treatment and conditioning;
(c) To collect and accumulate a sufficient amount of radioactive waste prior to its disposal;

(d) To reduce the heat generation rate of high level radioactive waste prior to its disposal and, in some cases, prior to steps in its predisposal management;
(e) To provide long term storage of radioactive waste in those States lacking a suitable disposal facility.

Examples (a), (b) and (c) are usually encountered at small storage facilities for radioactive waste, where storage is incidental to the primary purpose of the facility. Examples (d) and (e) are usually associated with larger facilities undertaking the treatment and storage of waste from nuclear fuel cycle facilities and from centralized facilities at which the waste from many small users of radioactive sources is collected and processed.

1.5. The period of storage may be highly variable and may be only a few days, weeks or months in the case of storage for decay or storage prior to the transfer of waste to another facility. Extended storage periods of many years may be necessary in the case of the storage of high level waste for cooling or for the long term storage of radioactive waste for which there is no disposal option yet available.

1.6. The storage facility may be located at the facility generating the waste, such as a nuclear power plant, a hospital or a laboratory, or it may comprise a separate entity such as a centralized facility or a national treatment and storage facility. Storage facilities can range from secure cabinets and closets at laboratories up to large facilities built for serving a nuclear power plant.

OBJECTIVE

1.7. The objective of this Safety Guide is to provide regulatory bodies and the operators that generate and manage radioactive waste with recommendations on how to meet the safety requirements established in Ref. [3] for the safe storage of radioactive waste. The guidance provided is applicable to all storage facilities, although there are separate sections for small and large storage facilities. The storage of radioactive waste means the holding of radioactive waste in a facility that provides for its containment, with the intention of retrieval.

SCOPE

1.8. This Safety Guide applies to the storage of solid, liquid and gaseous radioactive wastes in a wide range of facilities, including those at which waste is generated, treated and conditioned. The storage facility could range from a secure cupboard or closet in a laboratory, through to larger designated areas such as rooms or buildings, up to and including a large site dedicated to the storage of radioactive waste.

1.9. This Safety Guide does not address:

(a) The storage of waste arising from the mining and processing of uranium and thorium ores and minerals;
(b) The storage of other waste containing elevated concentrations of naturally occurring radionuclides and waste from mineral processing activities;
(c) The wet or dry storage of spent nuclear fuel, which is addressed in Refs [6, 8–10].

1.10. A wide variety of waste types and storage needs may be encountered in practice, for example, in terms of the storage duration, radioactive inventory, radionuclide half-lives and associated radiological hazards. The guidance given is therefore expected to be applied in accordance with the specific safety requirements appropriate to each storage situation. In a graded approach to the application of the safety requirements [11, 12], the implementation of safety measures should be commensurate with the nature and level of the hazard associated with the waste types and the radionuclide inventory. The regulatory body should provide guidance on the extent to which the various aspects of this Safety Guide are relevant and appropriate for a particular storage facility.

1.11. This Safety Guide is intended to apply to new facilities but it may also be applied to existing facilities. Dependent on the relative risk, a safety review of existing facilities should be conducted to determine whether steps to improve their safety may be required.

1.12. There may be significant non-radiological hazards associated with the storage of radioactive waste. Limited guidance is given in this Safety Guide on measures to be taken in this regard. If non-radiological properties such as corrosiveness, flammability, explosiveness, toxicity and pathogenicity may affect the safe management of the radiological hazard, then these should be taken into consideration during the safety assessment. Guidance in respect of non-radiological hazards should be sought from the relevant regulatory body in the areas of industrial health and safety and environmental protection.

STRUCTURE

1.13. This Safety Guide provides guidance that is specific to small and to large storage facilities and guidance that is common to both small and large facilities. Sections 2 and 3 address, respectively, the protection of human health and the environment, and roles and responsibilities. Section 4 outlines general safety considerations in the storage of radioactive waste that are common to both small and large storage facilities. Sections 5 and 6 provide guidance on safety in the design and operation of small and large storage facilities, respectively. Information on safety assessment as applied to the storage of radioactive waste is provided in the Appendix.

2. PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

2.1. Requirements for radiation protection are established in the BSS [4]. In particular, the radiation protection of any persons who are exposed as a consequence of the storage of radioactive waste is required to be optimized (see paras 2.24 and 2.25 of the BSS [4]), with due regard to dose constraints, and the exposures of individuals are required to be kept within the specified dose limits.

2.2. The storage of radioactive waste must ensure that both human health and the environment will be protected, both now and in the future, without imposing undue burdens on future generations [1]. The safety requirements established in Section 2 of Ref. [3] relating to the protection of human health and the environment are applicable to the storage of radioactive waste.

2.3. In the design and operation of storage facilities for radioactive waste, it is required to provide for the protection of workers, the public and the environment in accordance with the requirements and principles of Refs [1, 4], such that:

(a) Radiation doses to workers and the public as a consequence of waste storage activities do not exceed the relevant limits established in the BSS;
(b) Storage facilities are designed and operated in such a way that the radiation protection of workers and the public is optimized in accordance with the requirements of the BSS;
(c) The consequences of any foreseeable fault or accident condition would be such that protective actions are optimized as required by the BSS.

2.4. Discharges to the environment from storage facilities should be controlled in accordance with the guidance provided in Ref. [13] and any facility specific conditions imposed by the regulatory body.

2.5. The adequacy of control measures taken to limit the exposure of workers should be verified by means of individual monitoring and area monitoring.

2.6. In the generation and storage of waste, as well as subsequent management steps, a safety culture should be fostered and maintained to encourage a questioning and learning attitude to protection and safety and to discourage complacency [4, 14].

3. ROLES AND RESPONSIBILITIES

GENERAL

3.1. Storage of waste should be undertaken within an appropriate national legal framework that provides for a clear allocation of responsibilities [2] and ensures the effective regulatory control of facilities and activities [3]. The national legal framework should also ensure the fulfilment of other relevant national and international obligations. Requirements for establishing a national framework and the responsibilities of the regulatory body for ensuring safety, including the safety of the storage of radioactive waste, are established in Ref. [2]. International obligations, as applicable, are established in the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [15].

3.2. The management of radioactive waste may entail the transfer of waste from one operator to another. The legal framework should include provisions to ensure a clear allocation of responsibility for safety throughout the entire process of predisposal management, in particular with respect to storage, and including any transfer between operators. The continuity of responsibility for safety should be ensured by means of authorization by the regulatory body. For transfers between States, authorizations from each of the national regulatory bodies concerned should be obtained.

3.3. The regulatory and operational responsibilities for radioactive waste management should be clearly specified and functionally separated. A single organization should not be given both the operational and the regulatory responsibility for waste management.

RESPONSIBILITIES OF THE GOVERNMENT

3.4. The government is responsible for setting national policies and strategies for the management of radioactive waste and for providing the legal framework required to implement these policies and strategies. The policies and strategies for waste management should address the types of storage facility that are appropriate for the national waste inventory.

3.5. The government should consult interested parties (i.e. those involved in or affected by waste management activities) on matters relating to the development of policies and strategies that affect the safety of large storage facilities for radioactive waste.

RESPONSIBILITIES OF THE REGULATORY BODY

3.6. The regulatory body should provide guidance to operators on requirements relating to the storage of radioactive waste and the clearance of material (i.e. removal from any further regulatory control). Responsibilities may include contributing to the technical input for defining policies, safety principles and associated criteria and establishing regulations or conditions to serve as the basis of its regulatory actions (see Ref. [3], paras 3.1 and 3.2). In fulfilling its obligations, the regulatory body should fulfil the relevant functions that are established in Ref. [2].

3.7. Given the wide range of potential hazards, depending on the nature of the facility, a graded regulatory approach should be adopted that is commensurate with the level of hazard. Authorization in the form of registration may be sufficient for many small storage operations; the authorization of a small storage facility should be covered by the authorization for the facility in which radiation sources are used. For large storage facilities, licensing will probably be necessary to ensure the required level of control.

3.8. General recommendations on the review and assessment of the safety of nuclear facilities, including facilities for the storage of radioactive waste, by the regulatory body are provided in Ref. [16]. Recommendations on the documentation for the regulatory process for nuclear facilities are provided in Ref. [17]. Guidance concerning the elements of the national regulatory infrastructure that is necessary to achieve an appropriate level of protection and safety for radiation sources used in medicine, industry, agriculture, research and education is provided in Ref. [18].

3.9. Since waste may be stored for extended periods of time prior to its disposal, the regulatory body should confirm that the operator is providing the necessary human, technical and financial resources for the lifetime of the storage facility, to the extent that such confirmation is within its statutory obligations.

3.10. The regulatory body should periodically verify the acceptability of key aspects of the storage operation, such as the keeping of records, inventories and material transfer records; compliance with package acceptance criteria for storage; maintenance of the facility; and surveillance and monitoring. This may be carried out, for example, by routine inspections of the storage facility and formal audits of the operator's documentation. The regulatory body should confirm that the necessary records are prepared and that they are maintained for an appropriate period of time. A list of such records is included in Ref. [17].

RESPONSIBILITIES OF OPERATORS

3.11. The operator is responsible for the safety of all activities in the storage of radioactive waste and for the implementation of the programmes and procedures necessary to ensure safety. In accordance with the graded approach, the programmes and procedures necessary to ensure safety will generally be less extensive for the operator of a small facility.

3.12. The responsibilities of the operator of a large storage facility for radioactive waste would typically include:

(a) Making an application to the regulatory body to site, construct, operate, modify or decommission a waste storage facility;
(b) Conducting appropriate environmental assessments and safety assessments to support the application for a licence;
(c) Operating the facility in accordance with the licence conditions and the applicable regulations;
(d) Developing and applying acceptance criteria for the storage of radioactive waste;
(e) Providing periodic reports to the regulatory body in relation to the safety of the facility (e.g. on the current inventory and the estimated future inventory and waste transfers into and out of the facility).

Not all of the items listed here may apply to small operators. For example, a small operator may not be expected to go through a siting process.

3.13. Prior to the authorization of a facility for the storage of radioactive waste, the operator should provide the regulatory body with plans for the long term management of the radioactive waste being stored. The public, especially communities located near the storage facility, should be informed of these plans.

3.14. The operator should demonstrate the safety of the facility by means of a safety assessment that is commensurate with the hazards envisaged. For smaller and simpler facilities, the regulatory body may set generic inventory limits instead of requiring a full safety assessment. Guidance on preparing the safety assessment for facilities for the predisposal management of radioactive waste is provided in Refs [5–7]. Further information on safety assessment for the storage of radioactive waste is provided in the Appendix.

3.15. The operator of a storage facility for radioactive waste should use the safety assessment to propose facility specific operational limits and conditions. The operator may wish to set an administrative margin below the operational limits approved by the regulatory body as an operational target to remain within the approved operational limits and conditions.

3.16. The operator should determine the maximum quantities and concentrations of the radioactive materials or other hazardous materials that may be safely discharged to the environment and should document such discharges.

3.17. At an early stage in the lifetime of a waste storage facility, the operator of the facility should prepare plans for its eventual decommissioning. For new facilities, decommissioning should be taken into consideration at the design stage. Guidance on decommissioning is provided in Refs [19, 20].

3.18. The operator of a large storage facility for radioactive waste should carry out pre-operational tests and commissioning tests to demonstrate compliance with the safety requirements established by the regulatory body.

3.19. As appropriate to the hazards associated with the waste storage facility, the operator of the facility should prepare plans and implement programmes for personnel monitoring, area monitoring and environmental monitoring, and for emergency preparedness and response.

3.20. The operator of a waste storage facility should put in place appropriate mechanisms to ensure that sufficient financial resources are available to undertake all necessary tasks throughout the lifetime of the storage facility, including its decommissioning [2].

MANAGEMENT SYSTEM

3.21. A management system should be established, implemented, assessed and continually improved [11] by the operator and should be applied to all those stages of the storage of radioactive waste that have a bearing on safety. It should be aligned with the goals of the organization and should contribute to their achievement. The scope of the management system should include the siting, design, operation and maintenance of a storage facility for radioactive waste. The management system should be designed to ensure that the safety of the stored waste and that of the facility itself is maintained and that the quality of the records and of subsidiary information such as the marking and labelling of waste packages is preserved. A management system should also contain provision to ensure that the achievement of its goals can be demonstrated.

3.22. The management system should be applied to the processing of waste to ensure that all waste acceptance requirements are fulfilled for storage, and for disposal to the extent possible. General guidance on management systems for each stage in the lifetime of a storage facility for radioactive waste is provided in Ref. [11].

4. COMMON SAFETY CONSIDERATIONS FOR WASTE STORAGE FACILITIES

4.1. A storage facility for radioactive waste should be designed and operated to ensure that the radiation protection of workers and the public is optimized as required by the BSS and to ensure the containment and facilitate the retrieval of the waste.

4.2. To the extent practicable, radioactive waste should be stored according to recommendations for passive safety, including the following:

(a) The radioactive material should be immobile;
(b) The waste form and its container should be physically and chemically stable;
(c) Energy should be removed from the waste form;
(d) A multibarrier approach should be adopted in ensuring containment;
(e) The waste form and its container should be resistant to degradation;
(f) The waste storage environment should optimize the lifetime of the waste package;
(g) The need for active safety systems to ensure safety should be minimized;
(h) The need for monitoring and maintenance to ensure safety should be minimized;
(i) The need for human intervention to ensure safety should be minimized;
(j) The waste storage building should be resistant to foreseeable hazards;
(k) Access to the waste storage building should be provided for response to incidents;
(l) There should be no need for prompt corrective action in the event of an incident;
(m) The waste packages should be able to be inspected;
(n) The waste packages should be retrievable for inspection or reworking;
(o) The lifetime of the waste storage building should be appropriate for the storage period prior to disposal of the waste;
(p) The waste storage facility should enable the retrieval of waste;
(q) The waste package should be acceptable for final disposal of the waste.

4.3. For the storage of radioactive waste, a variety of records should be compiled, managed and maintained in accordance with a management system (see paras 3.21, 3.22). The scope and detail of the records will depend on the hazard associated with the facility and on the complexity of the operations and activities.

4.4. The scope and detail of the safety documentation should be appropriate to the hazards, the radioactive inventory and the characteristics of the waste. As applicable, para. 6.5 provides guidance on the content of safety documentation.

4.5. A safety assessment comprises an evaluation of the aspects of design and operation of a storage facility for radioactive waste to ensure the protection of workers and the public and the protection of the environment under normal conditions and in accident situations. The safety assessment should be periodically re-evaluated and, if necessary, revised to reflect changes in conditions, facilities or procedures.

4.6. Waste storage should be planned for on the basis of documented information (i.e. waste forecasts) on the quantities and types of waste that could be generated.

4.7. Storage facilities and waste packages should provide for the safe storage of waste by taking account of the waste form (i.e. solid, liquid or gas), its radionuclide content and half-lives, its activity concentrations, the total radioactive inventory, its 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.

4.8. Waste storage facilities should be designed and operated to minimize the probability and consequences of incidents and accidents.

4.9. Non-radiological hazards due to physical, chemical and pathogenic characteristics of waste should also be considered in the design and operation of storage facilities, as interactions of wastes may have consequences for human health and the environment. Such interactions could include generation of noxious gases by biological processes and generation of corrosive substances by chemical processes.

4.10. In the design of a waste storage facility, the focus should be on the containment of the waste; for example, on the integrity of the facility's structures and equipment, as well as the integrity of the waste forms and containers 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, bunding and impervious liners.

4.11. 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.

4.12. Security and access controls are required at storage facilities for radioactive waste to prevent the unauthorized access of individuals and the unauthorized removal of radioactive material. The level of security and access control required at a waste storage facility should be commensurate with the radiological hazards and the nature of the waste.

4.13. Training and qualification needs for staff will vary depending on the size of the facility, the radioactive inventory, the complexity and range of the activities conducted and the associated hazards. The operator should ensure that all staff understand the nature of the waste, its associated hazards and the relevant operating and safety procedures. Supervisory staff should be competent to perform their duties and should therefore be selected, trained, qualified and authorized for the purpose. Where appropriate, a radiation protection officer should be appointed to oversee the application of the requirements for safety and radiation protection.

4.14. Operating personnel should be trained to respond appropriately to deviations from normal operational conditions (i.e. emergency and accident conditions).

4.15. Sound operational practices and administrative controls appropriate to the level of hazard should be applied in the operation of a storage facility for radioactive waste. The operator of a large storage facility for radioactive waste should clearly establish and document the duties and responsibilities of all positions in the organizational structure.

4.16. 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. Segregation of the waste may also reduce the exposure of workers in normal operations and may limit the severity of any consequences under accident conditions. Radioactive waste should be stored separately from non-radioactive waste to avoid cross-contamination and accidental removal from control. Requirements are established and further guidance on the segregation of radioactive waste is provided in Refs [3, 5, 6].

4.17. The need for and the extent of commissioning activities and tests will vary depending on the size, complexity and contents of the storage facility. Commissioning involves a logical progression of tasks and tests to demonstrate the correct functioning of specific equipment and features incorporated into the design of the storage facility to provide for safe storage. The adequacy of the facility's design and of the operational procedures and the readiness of the staff to operate the facility should be demonstrated and confirmed.

4.18. Disused sealed sources should be segregated and stored separately because of their high hazard potential. Although they may not have been declared as waste, disused sealed sources awaiting reuse or recycle are commonly placed in storage facilities for radioactive waste. The safety and security of disused sources are discussed in Refs [21, 22].

4.19. Disused sealed sources may require conditioning or encapsulation before placement in a storage facility [23]. Conditioning methods should be subject to approval by the regulatory body. Disused sealed sources that are kept in storage for extended periods of time should be checked for leakage at regular intervals.

5. DESIGN AND OPERATION OF SMALL STORAGE FACILITIES FOR RADIOACTIVE WASTE

GENERAL

5.1. Small inventories of radioactive waste comprising radionuclides with relatively short half-lives are typically handled at small waste storage facilities. Simple waste treatment activities such as low force compaction may also be carried out at small waste storage facilities. In addition, sealed sources of various types may be handled at small waste storage facilities.

5.2. Some types of radioactive waste may be stored for periods specifically to allow the radioactivity of the waste to decay to levels that permit its authorized discharge or removal from regulatory control (i.e. clearance). Storage may also be necessary for operational reasons, for example, to accommodate the off-site transfer of waste to a waste treatment facility at specified time intervals.

5.3. The storage of waste in centralized facilities rather than in a multitude of on-site facilities should be considered, since there will be opportunities to adopt more stringent safety standards and at the same time to realize economies of scale.

5.4. For most small waste storage facilities, simple design features together with correspondingly simple operating procedures will be appropriate.

5.5. The stored radioactive waste should be characterized (e.g. by radionuclide type, inventory, activity concentration, half-life and the physical, chemical and pathogenic properties of the waste) and the results should be documented in an inventory log. If pathogenic radioactive waste is to be stored, it should be deactivated before its placement in storage [24].

5.6. All waste packages and their documentation should be identified with a unique code for the purposes of tracking. In most cases a simple indelible weather resistant tag and logbook will be sufficient.

5.7. Where biomedical radioactive waste is produced in large volumes, it should be considered whether a separate storage area for biomedical radioactive waste is necessary.

5.8. Waste that is to be shipped to a centralized waste management facility should be packaged in accordance with the waste acceptance criteria of the receiving facility.

5.9. Radioactive waste should be packaged in such a manner that it is not accessible to pests such as insects or rodents as they can present a serious threat to its containment. This is particularly relevant for the storage of biohazardous radioactive waste or where waste may be stored in plastic bags.

DECAY STORAGE

5.10. Storage for decay is particularly important for the clearance of radioactive waste containing short lived radioisotopes. Clearance is the removal of radioactive material from regulatory control provided that the radionuclide concentrations are below radionuclide specific clearance levels. Practical experience shows that storage for decay is suitable for waste contaminated by radionuclides with a half-life of less than about 100 d. For example, radioactive waste from nuclear medicine, such as excreta containing ^{99m}Tc (half-life about 6 h), may be stored for decay and subsequent discharge.

5.11. The decay storage period should be long enough to reduce the initial activity to levels lower than the clearance levels. Generic clearance levels and guidance for the derivation of clearance levels are provided in Refs [25, 26].

5.12. There should be rigorous control measures for the storage of radioactive waste for decay and its subsequent removal from regulatory control. The activity concentration of the waste should be carefully determined and such waste designated for decay should be segregated from other waste, from the point of generation up to the end of the decay storage period and its final disposal. Representative measurements should be carried out on samples taken and analysed prior to the removal of each batch from control. In taking samples, workers should be protected against both radiological and non-radiological hazards.

5.13. While storage for decay is also the preferred option for biohazardous radioactive waste and for other perishable waste such as animal carcasses, such wastes should be segregated and stored in a freezer or refrigerator cabinet for decay storage. Decayed biohazardous radioactive waste should not be disposed of in a landfill site unless specific approval has been obtained from the regulatory body. Incineration of such waste is usually the preferred option; further guidance should be sought from the relevant competent body concerning the conditions under which such waste can safely be incinerated.

EMERGENCY PREPAREDNESS

5.14. Emergency preparedness and response arrangements commensurate with the threat category of the facility, as required in Ref. [27], should be developed and implemented. The emergency plan should include: the training of staff to be competent to recognize and react to an accident or emergency, the assignment of responsibilities and the making of appropriate arrangements and provision of equipment to ensure the protection of emergency workers. For example, the planning for a small facility may include planning the appropriate preparedness and response to simple events such as a spill in a laboratory, the loss of a source or a fire. Requirements are established and further guidance is provided in relation to emergency preparedness and response in Ref. [27].

WASTE PACKAGING

5.15. Consideration should be given to the loads resulting from the stacking of waste packages. The wall thickness of the containers, their filled weight and the stacking orientation should be taken into account at the design stage. For a small facility, the use of suitable shelving should be considered.

5.16. Dispersible waste such as liquids, gases and powders should be monitored owing to their potential for leakage. The storage arrangements should facilitate monitoring and confinement so as to allow any failure of the confinement barrier to be detected. Containers of dispersible waste, in particular liquids, should be stored within an appropriately sized confinement barrier to provide secondary containment owing to the possibility of leaks or other accidental releases.

5.17. If the container shows signs of degradation during storage, then appropriate measures should be taken, which may include examination to confirm the integrity of the container and that of similar containers. In the event of a leak, provisions should be made for overpacking or repackaging.

5.18. Sharp objects such as syringes should be collected separately and stored in puncture resistant containers.

DESIGN OF SMALL STORAGE FACILITIES FOR RADIOACTIVE WASTE

Considerations of facility selection and design

5.19. A small waste 'storage facility' (e.g. at laboratories, hospitals and universities) may be simply a secure cabinet, a dedicated area, a room, a small building or an International Organization for Standardization shipping container.[1] The design will depend largely upon the properties, the total inventory and the hazard potential of the stored material. Design features should last for the expected lifetime of the facility.

5.20. Criteria that should be considered when selecting a storage facility include the following:

(a) The area outside the waste storage facility should have a low public occupancy factor and should be a low traffic area.
(b) The location should provide for an appropriate level of physical security (e.g. single point entry, no windows, robust construction).
(c) The location should be remote from other hazardous storage areas (e.g. stores for explosive and flammable materials) and should not be liable to flooding.
(d) The location should be suitable for the safe transfer of material into and out of the facility (e.g. there should be an adequate loading and unloading area outside the facility).

5.21. The storage facility, area or cabinet should be designed with account taken of its possible future uses after decommissioning (e.g. by the use of smooth, non-porous surfaces; plastic liners; equipment that is simple to dismantle).

5.22. The design of the storage facility should facilitate the retrievability of the waste and the inspection of the facility and the equipment and waste stored in the facility.

5.23. In the design of small waste storage facilities, both normal and abnormal operational conditions should be considered (e.g. spills, the consequences of dropping a package, the spread of contamination).

5.24. The waste package provides the primary containment for the stored radioactive waste. However, the storage facility should be designed to provide additional containment if this is required (e.g. for shielding, security, ventilation or filtration and drainage systems, or bunds).

[1] In this section, the term ‘design’ as applied to a small waste storage facility means either the development of a new facility or the selection of an existing facility for the storage of waste.

5.25. The storage facility should provide for an appropriate level of protection of the waste from the weather and from adverse environmental conditions to avoid degradation that could have implications for safety during storage or upon retrieval.

Shielding

5.26. The degree of shielding and the sophistication of its design, if shielding is required, will depend on the radiological hazards associated with the stored waste. Shielding devices can range from simple lead pots and source containers in secure cabinets and closets to specially constructed walls and pits that form part of the structure of the waste storage facility.

5.27. Where appropriate, maximum allowable radiation dose rates should be specified for the external surfaces of waste packages, shielding surfaces and the exterior surfaces of the waste storage facility. The shielding requirements should be set to ensure that the gamma radiation levels on the exterior surfaces of the facility are appropriate for public areas.

Ventilation

5.28. A small storage facility for radioactive waste may not require a ventilation system, although the need for a ventilation system should be assessed on a case by case basis. Factors to be considered include: the potential for the radioactive waste to give rise to airborne radioactive material that creates a radiological hazard (e.g. the buildup of ^{222}Rn from ^{226}Ra waste), the potential for the localized accumulation of flammable and explosive gases (such as hydrogen formed by radiolysis or in chemical reactions) and the need to control environmental conditions (e.g. humidity, temperature), both for the comfort of operators and for maintaining the integrity of packages. The design of ventilation systems may require provision for filtration to prevent the uncontrolled release of radionuclides in gaseous or particulate form to the environment.

Fire protection systems

5.29. It is unlikely that a small storage facility for radioactive waste would require fire protection beyond that which is required to satisfy local fire codes. In the absence of a local fire code, the need for a fire protection system (e.g. smoke detectors, fire extinguishers, sprinklers) of appropriate capacity and capability should be determined. The primary design goal should be the early detection and suppression of fires.

Commissioning

5.30. Owing to the limited inventory and low risks associated with most small storage facilities for radioactive waste, a formal commissioning process would not be required.

OPERATION OF SMALL STORAGE FACILITIES FOR RADIOACTIVE WASTE

General operational considerations

5.31. The operational activities of a small storage facility for radioactive waste should be described in and carried out in accordance with facility specific procedures. The operational activities may include: receipt, storage and retrieval of waste; labelling of waste packages; inventory control; package inspection; radiation protection; monitoring and surveillance; record keeping; and preparation of waste packages for dispatch to another facility. The scope and level of detail of the procedures should be commensurate with the radioactive inventory, the associated hazards and the extent of the storage activities. The procedures should be such as to ensure compliance with the operational limits and conditions approved by the regulatory body.

Radiation monitoring

5.32. Radiation monitoring should be conducted routinely to determine the external radiation levels and surface contamination levels inside the waste storage facility, along the boundaries of the storage facility and on the surface of waste packages. In facilities where loose waste is compacted and repackaged for storage or transport, monitoring for airborne contamination may be appropriate.

5.33. In storage facilities where there is a potential for surface contamination, fixed or portable instruments for detecting external contamination on workers should be provided at exit points from the area.

5.34. Monitoring instruments should be periodically tested and calibrated. The energy response and the measurement range of the instruments should be appropriate for the radionuclide composition of the waste and the expected ranges of radiation levels and contamination levels.

Radiation protection

5.35. A radiation protection programme should be developed as part of the application to the regulatory body for authorization. Information on the content of radiation protection programmes is provided in Refs [28, 29].

Maintenance, testing and inspection

5.36. The operation of most small storage facilities for radioactive waste will require only a very simple and limited programme of periodic maintenance, testing and inspection (this could be as simple as checking the effectiveness of the locks at the facility). The maintenance, testing and inspection records should be subject to periodic review.

Security

5.37. Owing to the limited waste inventory and low hazard levels encountered in most small storage facilities for radioactive waste, the measures for security and access control may consist simply of a locked door or cabinet (e.g. a locked storage area with authorized key holders and an access log). However, security for disused sealed sources of high activity may require additional consideration. Security and access controls specific for disused sources in storage are discussed in Ref. [22].

Decommissioning

5.38. Decommissioning involves the removal of all stored waste, followed by a survey to determine the residual surface contamination levels and external radiation levels. The facility may require decontamination and the removal of contaminated materials and equipment. Guidance on the decommissioning of small facilities is given in Ref. [20].

6. DESIGN AND OPERATION OF LARGE STORAGE FACILITIES FOR RADIOACTIVE WASTE

GENERAL

6.1. A large storage facility for radioactive waste may receive a wide variety of waste types from a number of different origins. The design and operation of a large waste storage facility should be commensurate with the potential hazards associated with it.

6.2. A tracking system for waste packages should be developed and maintained. For large waste storage facilities, the use of a computerized system for tracking packages should be considered. A storage plan that shows the configuration of the emplaced waste packages, including the zoning for the level of hazards, should be prepared and maintained.

6.3. Procedures should be developed for the safe operation of a large waste storage facility. The extent and the degree of detail of specific procedures should be commensurate with the safety significance of the particular subject of the procedures and should cover, where applicable:

(a) Operations, including all necessary limits and conditions;
(b) Commissioning;
(c) The management system;
(d) Maintenance, inspection and testing;
(e) Training;
(f) Modifications made during design, construction, commissioning and operation;
(g) Recording, reporting and investigation of events;
(h) Radiation protection and safety performance;
(i) Contingency and emergency arrangements;
(j) Safeguards;
(k) Security measures;
(l) Control of radioactive discharges to the environment;
(m) Acceptance criteria for waste packages.

EMERGENCY PREPAREDNESS

6.4. A threat assessment should be conducted of possible emergencies, as described in Ref. [27], and emergency preparedness arrangements should be put in place that are consistent with the international standards [27] for the threat category established in the threat assessment. Arrangements could include the development of scenarios of anticipated sequences of events and the establishment of procedures to deal with each of the scenarios, including checklists and lists of persons and organizations to be alerted. Emergency response procedures should be documented, should be available to the personnel concerned and should be kept up to date. The need for training exercises should be assessed. If there is such a need, exercises should be held periodically to test the emergency response plan and the degree of preparedness of personnel. Inspections should be performed regularly to ascertain whether the equipment and other resources needed in the event of an emergency are available and in working order.

DEVELOPMENT OF SAFETY DOCUMENTATION

6.5. The safety documentation to be developed in support of a licence application should, as a minimum, address the following:

(a) The expected volumes and characteristics of the waste to be stored and the relevant acceptance criteria;
(b) A description of handling and storage activities;
(c) A description of the facility and its components, equipment and systems;
(d) Site characterization;
(e) The organizational control of the operations;
(f) Procedures and operational manuals for activities with significant safety implications;
(g) Safety assessment;
(h) Monitoring programmes;
(i) The training programme for staff;
(j) The safeguards aspects, where applicable;
(k) The arrangements for physical protection of radioactive material;
(l) The emergency preparedness and response plan;
(m) The management system;
(n) Decommissioning;
(o) Acceptance criteria for waste packages.

Where the storage facility is part of a larger nuclear facility, the safety documentation may be subsumed within the documentation for the overall facility.

CHARACTERIZATION AND ACCEPTANCE CRITERIA FOR RADIOACTIVE WASTE

6.6. Waste acceptance criteria should be developed for the storage facility, with account taken of all relevant operational limits and future requirements for disposal, if the latter are known.

6.7. Waste characterization is generally performed by operators prior to shipment to the storage facility to verify that the waste meets the waste acceptance criteria. The characterization data should include all necessary information concerning the radionuclide inventory and the physical, chemical and pathogenic properties of the waste. Relevant documentation should accompany the waste each time it is shipped.

6.8. Waste from past activities may not have been characterized or may not have been characterized in accordance with present standards. In such cases, a means of characterizing the physical, chemical and radiological composition of the waste should be explored through inspection, measurement and the review of available information. If the radionuclide content and other required characteristics of the waste are not sufficiently well known, special precautions for its handling should be considered (e.g. the segregation of the waste within the facility).

6.9. Upon receipt, waste packages should be checked for leakage and surface contamination and to ensure that they are consistent with the documentation. Waste characterization, process control and process monitoring should be applied within a formal management system.

WASTE FORM AND WASTE PACKAGES

6.10. Containers should be designed and fabricated so that the waste is contained under all conditions of operation that might reasonably be expected to arise during their lifetime. Where the container itself is the primary barrier for containment of the waste, the strength and integrity of the container should be appropriate for the type of waste and the expected radionuclide concentrations.

6.11. In all cases, the waste should be in a form that is retrievable at the end of the storage period. For longer storage periods, this requires a more robust waste form and container. Paragraphs 6.86–6.90 provide additional guidance on long term storage.

6.12. Special properties of, and processes affecting, radioactive waste should be taken into account in the design of containers and storage facilities, such as the following:

(a) Corrosion due to chemical and galvanic reactions may result from interactions between the waste and its container.
(b) Metals may exhibit pyrophoric behaviour (Magnox, uranium or Zircaloy® fines) or may be chemically reactive (e.g. aluminium corrodes in alkaline conditions to generate hydrogen).
(c) Inorganic, non-metallic waste (such as concrete and some insulating materials) may be porous and may therefore be contaminated in bulk.
(d) Pore water in concrete is highly alkaline and can affect materials in contact with concrete during storage.
(e) Organic waste including cellulose, plastics (in electrical insulation, protective clothing, and laboratory and hospital disposables) and scintillation liquids may be combustible and may present a fire hazard.
(f) Powders and ashes are easily dispersible.
(g) Liquid waste may be in aqueous or organic form (such as oil) and can contain suspended solids (especially spent ion exchange resins, sludges and slurries). These can be chemically reactive and easily dispersible. Some suspended solids can settle or solidify after a period of storage.
(h) Compacted waste can, in some instances, expand again, causing difficulties in retrieving the waste. In addition, compaction of dissimilar materials in the same container could bring chemically reactive mixtures into close contact, which could result in enhanced corrosion, spontaneous combustion or other adverse effects.
(i) Gases such as hydrogen can be generated within some waste.
(j) Radiolysis of polyvinyl chloride may generate corrosive substances, such as hydrogen chloride or chlorine gas.
(k) There may be a potential for the generation of flammable gases by the chemical decomposition of waste (e.g. organic waste).

Some gaseous waste can be reacted chemically with inactive materials to produce a solid waste (such as barium carbonate for ^{14}C) that is more passively safe.

6.13. The hazard potential of waste should be reduced as far as reasonably achievable at each stage of waste processing, with account taken of known or likely requirements for subsequent steps in radioactive waste management, in particular disposal. Early processing of waste to convert it to a passively safe form or otherwise to stabilize it should be considered. This will facilitate its handling in normal operation and will also help to protect it in the event of incidents.

6.14. The requirements for the performance of the container, in the event of incidents and accidents, should be specified to ensure the protection of workers and the public.

6.15. The storage environment (e.g. the ranges in ambient temperature and humidity) should be taken into account in the design of storage containers. As appropriate, containers should be sufficiently resistant to corrosion over the duration of storage. The placement of storage containers on surfaces where condensation cycles can develop should be avoided.

6.16. For certain types of waste (particularly corrosive liquid waste), special precautions such as the use of double walled containers and/or the lining of storage rooms with stainless steel or other corrosion resistant material may be necessary. Also, liquid waste may require a collection and recovery system below the containers (i.e. a secondary containment) with provision for monitoring for any leakage. In keeping with the principles of passive safety, liquid wastes should be converted to solids as early as practicable.

6.17. Consideration should be given to the dynamic and static loads resulting from the handling and stacking of the waste packages. The wall thickness of the containers, their filled weight and the stacking orientation should be taken into account at the design stage.

6.18. Some waste may have the potential for generating airborne radionuclides within the container; many types of storage container vent naturally but some may require a purpose built vent. The need for package venting should be considered as part of the safety assessment.

6.19. The design of waste storage containers should facilitate monitoring to allow the early detection of any failure of the containment, as appropriate (e.g. for gases and liquids).

6.20. Liquid waste may contain suspended solids which could settle on the bottom of a container (e.g. tank waste) or may contain substances that could precipitate out of solution. For some wastes it may be necessary to prevent settling of solids; for example, to prevent criticality or to facilitate decommissioning. For such wastes, solids should be kept suspended by means of a mixing device such as a mechanical stirrer, a pneumatic mixer or a circulation pump. Sluicers may need to be part of the design to facilitate the removal of any waste that may have precipitated on the interior surfaces of a tank. Additional internal hardware should be minimized to limit obstructions.

DESIGN OF STORAGE FACILITIES FOR RADIOACTIVE WASTE

General design considerations

6.21. Waste storage facilities should be designed so that the waste can be received, handled, stored, inspected or monitored and so that it can be retrieved without undue occupational or public radiation exposure or environmental impact.

6.22. In designing a facility, a defence in depth approach should be adopted, as appropriate for the given situation. Credit can often be taken for the performance of the waste form in the design of the package and in the design of the storage facility. Credit can also often be taken for the container. Some safety assessments conservatively do not take any credit for the waste form or for the performance of the waste package.

6.23. The following should be provided for in the design of storage facilities for radioactive waste for normal operations:

(a) Containment of the stored materials;
(b) Prevention of criticality (when storing fissile materials);
(c) Radiation protection (shielding and contamination control);
(d) Removal of heat (if applicable);
(e) Ventilation, as necessary;
(f) Inspection and/or monitoring of the waste packages, as necessary;
(g) Maintenance and repair of waste packages;

(h) Retrieval of the waste, whether for processing, repackaging or disposal;
(i) Inspection of waste packages and of the storage facility;
(j) Future expansion of the storage capacity, as appropriate;
(k) Transport of waste inside the storage facility to improve the flexibility of operations;
(l) Decommissioning.

6.24. The effects that the stored waste may have on the functionality of systems and the operation of the waste storage facility should be considered in the design of the facility. It should be ensured that such factors are taken into account by means of design features, the selection of appropriate materials and maintenance programmes. Factors that should be considered include the following:

(a) Chemical stability against corrosion caused by processes within the waste and/or external conditions;
(b) Protection against radiation damage and/or thermal damage, especially stability against the degradation of organic materials and damage to electronic devices;
(c) Resistance to impacts from operational loads or due to incidents and accidents.

6.25. In addition to radiological hazards, external hazards (e.g. fire or explosion), which may contribute to radiologically significant consequences, should also be considered in the design of storage facilities for radioactive waste.

Site characteristics

6.26. A storage facility for radioactive waste may be established in connection with, or as part of, an existing nuclear installation. In this case, the site may be selected on the basis of factors that are important for the main facility and the waste storage facility may not require any additional considerations. The safety assessment performed for the siting of the main facility may demonstrate that the waste storage facility meets the radiological protection criteria in normal operation and in incident and accident conditions. If the siting requirements for the waste storage facility are more stringent than those for the main facility, then the safety case for storage should be addressed separately.

6.27. In cases where the waste storage facility is built separately from other licensed nuclear installations, the Safety Requirements publication on Site

Evaluation for Nuclear Installations [30] and the associated safety standards on the management system [11, 12] establish requirements and provide guidance that can be applied to waste storage facilities. The application of the requirements in respect of siting will, for waste storage facilities, depend on the potential radiological hazards posed by the waste stored.

Shielding

6.28. A waste storage facility should be designed to provide adequate shielding for workers and for the public. Maximum allowable radiation dose rates should be specified for waste packages and for shielding surfaces and other locations, in particular for structures and installations within the storage facility.

6.29. In making provisions for shielding in a waste storage facility, special care should be taken to prevent radiation streaming through the penetrations of shielding barriers, such as the penetrations for ventilation and cooling systems.

6.30. Where there is a possibility that a neutron generating source or neutron generating waste might be stored in the waste storage facility, the facility should also include neutron shielding.

Containment

6.31. The design of the facility should supplement the containment provided by the waste form and its container. The storage facility should incorporate features for:

(a) Limiting the spread of contamination by using materials that can be easily monitored and decontaminated;
(b) Controlling access to the radiation area, controlling movement between the radiation zone and/or contamination zones and, where applicable, maintaining an underpressure in rooms used for storage of contaminated material;
(c) Minimizing the release of airborne particulate radionuclides to the environment by the provision of filters in the exhaust ventilation;
(d) The removal of gaseous radionuclides, where applicable;
(e) The collection of leaks or spills of liquid waste by the provision of sumps or catchment areas below containers, together with measures for the detection of leaks.

Provisions for waste handling

6.32. Waste handling equipment should be designed to include provision for the following:

(a) Safe operation under all anticipated conditions;
(b) Avoiding damage to the waste package;
(c) Safe handling of defective or damaged waste packages;
(d) Minimizing contamination of the equipment itself;
(e) Avoiding the spread of contamination.

6.33. The design of the handling system should be considered in the safety assessment of the facility to ensure that handling failures could not result in unacceptable consequences. Where necessary, working practices and operational controls, such as the setting of limits on lift height and on the speed of moving equipment and the provision of dedicated transfer routes for loads, should be applied to minimize the consequences of impacts and collisions.

6.34. Where appropriate, equipment should be provided with suitable interlocks or physical limitations to prevent dangerous or incompatible operations, such as the incorrect placement of waste, the accidental release of loads or the application of incorrect forces in lifting and handling operations.

6.35. The need for remote handling should be considered in cases where the waste package is a source of radiation at high dose rates, where there is a risk that radioactive aerosols or gases could be released to the working environment, or where the waste might pose a significant non-radiological hazard (e.g. chemical toxicity).

6.36. Remote handling devices should be designed to provide the means for maintenance and repair (e.g. by the provision of a shielded service room) so as to keep occupational radiation exposures as low as reasonably achievable. Their design should incorporate a means to recover and to return to a stable and safe state in the event of a malfunction or breakdown.

Waste retrievability

6.37. The retrieval of waste for the purposes of inspection, remedial action and storage elsewhere should be made as straightforward as possible. Measures for achieving this include the appropriate design and construction of openings, passages and handling systems and the incorporation of appropriate stacking systems or spacing for waste packages. The packages should be able to be uniquely identified and linked to the corresponding documentation.

6.38. Tanks for the bulk storage of liquid waste should be designed with the minimum practicable ‘heel’, meaning the minimum practicable volume of stored material that cannot be removed using the installed emptying equipment.

Ventilation

6.39. The need for a ventilation system should be assessed on a case by case basis. Factors to be considered include: the potential for the waste to create an airborne radiological hazard; the potential for the localized accumulation of hazardous gases; and the need to control ambient conditions (e.g. humidity, temperature), both for the operator’s comfort and for maintaining the integrity of packages. The system design should include some spare capacity or equipment, as appropriate.

6.40. Waste may have the potential for generating airborne radionuclides. Ventilation systems to control airborne radioactive material should provide for the flow of air from areas with a low potential for contamination to those with a higher potential for contamination. As an extra precaution, a localized ventilation system could be installed for those areas with the highest potential for contamination.

6.41. The design of ventilation systems should be compatible with the measures taken for explosion safety and fire protection. Ventilation systems can be designed to control the accumulation of hazardous substances, e.g. flammable or explosive gases (such as hydrogen formed by radiolysis or chemical reactions).

6.42. The potential for drawing in hazardous gases, airborne radionuclides or humid air from external sources should be considered and, if necessary, design measures should be taken to prevent this.

6.43. The provision of off-gas cleaning systems or other measures to prevent the uncontrolled release of radionuclides in gaseous or aerosol form in normal operation and incidents and under postulated accident conditions should be considered. The ventilation discharge should be monitored for radioactivity.

Temperature control

6.44. Heat removal systems capable of cooling the waste may be necessary, especially for high level waste. The capability for heat removal should be such that the temperature of the stored waste does not exceed the maximum design temperature. The design of the heat removal system should take account of: the heat load of the waste; the heat transfer characteristics of the waste, the container and the facility; the maximum heat capacity of the facility and the need to mitigate the consequences of incidents and accidents.

6.45. If active heat removal systems are installed, consideration should be given to: the reliability of the systems, any need for redundancy and diversity, and the behaviour of the system in the event of incidents or accidents (e.g. the consequences of the failure of a common service). Passive heat removal systems (e.g. cooling by natural convection) are generally more reliable than active systems.

6.46. In some cases, such as for liquid aqueous wastes, the heating of a storage tank or of the facility may be necessary to prevent freezing and/or the precipitation of substances in cold weather.

Maintaining subcriticality

6.47. This Safety Guide does not specifically address the storage of spent fuel, for which guidance is given in Refs [8–10]. However, in some cases waste other than spent fuel may contain significant amounts of fissile material. In such cases, it should be ensured that in all anticipated conditions the waste will be kept at a concentration, in a configuration and in conditions that would prevent criticality during waste emplacement, storage and retrieval.

6.48. For the storage of waste containing fissile material, consideration should be given to the possible consequences of a change in the configuration of the waste, the introduction of a moderator or the removal of material (such as neutron absorbers), as a consequence of an internal or external event (e.g. movement of the waste, precipitation of solid phases from liquid waste, loss of containment of the waste or a seismic event).

Monitoring

6.49. Arrangements for monitoring the radiological conditions in the waste storage facility should be provided. The arrangements for monitoring should include, as necessary, measurements of: radiation dose rates, concentrations of airborne radioactive material (e.g. dispersibles), levels of both fixed and/or loose surface contamination and neutron flux rates. In controlled areas, the provision of fixed, continuously operating instruments with local alarms to give information on radiation dose rates and airborne activity concentrations may be appropriate.

6.50. Portable or mobile dose rate meters should be provided for monitoring individual locations in any contamination controlled areas. Fixed or portable instruments to detect external contamination on workers should be provided at the exits from any controlled areas or when moving from a zone of higher contamination to a zone of lower contamination.

6.51. Where warranted, chemical conditions (e.g. concentrations of chloride or of flammable gases, chemical properties of liquids) and non-radiological parameters (e.g. temperature, pressure, humidity, flow rates of water coolant) should also be monitored.

6.52. All monitoring instruments should have measurement ranges that are adequate to cover the expected range of observations and should be periodically tested and calibrated.

6.53. Storage tanks for liquid waste should be provided with catchment sumps, with monitoring equipment used for the detection of leaks.

Control and instrumentation

6.54. Whenever practicable, process system controls (e.g. waste handling equipment and ventilation systems) should be independent of protection systems. If this is not feasible, detailed justification should be provided for the use of shared and interrelated systems. Alarms and indications to the operator should be clear and should not cause confusion.

6.55. Information on the status of systems important to safety but which are not readily accessible (e.g. the level of the liquid waste in a tank) should be made available to the operator by means of appropriately located indicator systems or other appropriate means.

Inspection of facility components and stored waste

6.56. The storage facility should be designed to facilitate the inspection of the structures, systems and components of the facility and of the waste and waste packages stored in the facility to the extent that they are important for ensuring safety. For example, there should be adequate clearance around storage racks and to allow for access with equipment; inspection ports should be provided on storage tanks.

6.57. Consideration should be given to including inactive simulant packages or corrosion coupons with stored waste for the purpose of monitoring conditions and performance.

Reserve waste storage capacity

6.58. There should be reserve storage capacity available to accommodate waste arising in various situations. Such situations may include abnormal conditions (e.g. the need to empty a leaking tank) or periods when modifications or refurbishments are being undertaken.

Utilities and auxiliary systems

6.59. A number of auxiliary systems may be necessary to ensure the safe operation of waste storage facilities. The need for auxiliary systems and their backups should be assessed on a case by case basis, such as for the storage of high level waste, for example.

6.60. Provision should be made for adequate and reliable illumination in support of the operation, inspection and physical protection of waste storage areas. Requirements for emergency preparedness [27] may necessitate the provision of power for emergency lighting from a power supply independent of the normal electricity supply.

6.61. Provision should be made for adequate internal and external communications to satisfy the operational and emergency requirements of the facility. Requirements include direct telephone lines to a fire brigade, to the regulatory body or to a national emergency management body, and intercom systems for prompt and full alerting of personnel. The specific requirements should be defined for each facility on a case by case basis.

Fire protection systems

6.62. A fire protection system of appropriate capacity and capability should be provided where there is a credible risk of fire. The design goals should be to limit the risk of release of radionuclides or toxic substances to the environment and into areas of the facility outside the storage area, as well as to limit the risk of fire damage to waste storage areas and auxiliary systems. Particular attention should be paid to requirements applicable to combustible untreated waste and waste products. It should be noted that certain waste products may contain substances capable of sustaining a fire in the absence of oxygen. For the fire protection system, account should also be taken of the need for the adequate containment and recovery of fire suppression media, which may become contaminated in extinguishing a fire (e.g. by the provision of a drainage and collection system for contaminated water).

COMMISSIONING OF STORAGE FACILITIES FOR RADIOACTIVE WASTE

6.63. Commissioning of storage facilities will usually be carried out in several stages. For more complex facilities the following steps will normally be performed: construction, completion and inspection; equipment testing; demonstration of performance; non-active commissioning and active commissioning.

6.64. On completion of commissioning, a final commissioning report is usually produced. This report should document the ‘as built’ status of the facility and, in addition to providing information to facilitate operation, it should be consulted when considering possible future modifications and the decommissioning of the storage facility. The report should also document all testing, provide evidence of the successful completion of testing and document any modifications made to the facility or to procedures during commissioning. This report should be such as to provide assurance to the operator and the regulatory body that the conditions of authorization have been satisfied.

OPERATION OF STORAGE FACILITIES FOR RADIOACTIVE WASTE

General operational considerations

6.65. Typical operational activities associated with waste storage are the routine operations of receipt, processing, emplacement, storage and retrieval of waste packages and their preparation for disposal. Supporting activities include: radiation protection; monitoring and surveillance; testing and examination of waste packages; inspection of the components of the storage facility; maintenance and repair; labelling of waste packages and record keeping.

6.66. Storage facilities should be operated in accordance with written procedures. These procedures should be such as to ensure compliance with the operational limits and conditions approved for the storage facility by the regulatory body.

6.67. Modification of the storage conditions should be subject to specific plans and procedures and accompanied by appropriate authorizations from the regulatory body. The impact of any modifications on the safety of the stored waste should be considered in each case.

6.68. Operational practices and administrative controls appropriate to the level of hazard should be applied. Examples of these include:

(a) The use of pre-work assessments and training mock-ups to minimize exposure during operation and maintenance activities;
(b) The application of remote handling technologies for operation and maintenance;
(c) Establishment of contamination controls when items are transferred or removed from areas of higher contamination to areas of lower contamination;
(d) Appropriate planning for, and careful conduct of, storage activities so as to minimize exposure during operation and maintenance activities.

6.69. A system for tracking waste packages should be developed and maintained. For large storage facilities, a computerized system for tracking waste packages should be considered. Where practicable, a detailed storage plan showing the configuration of the emplaced waste packages, including the zoning for the level of hazards, should be prepared and maintained.

Operational limits and conditions

6.70. Storage facilities should be operated in accordance with a set of operational limits and conditions that are derived from the safety assessment of the facility to identify the safe boundaries of operation. Operational limits and conditions set out specifications relating to waste packages, safety systems and procedures, radiological criteria and requirements for personnel. Operational limits and conditions for storage facilities should be developed by the operator and should be subject to approval by the regulatory body. Operational limits and conditions should be revised as necessary in the light of experience from commissioning and operation, modifications made to the facility and changes in safety standards. Reference [31] provides guidance for the development and implementation of operational limits and conditions for nuclear power plants; much of this guidance is applicable to storage facilities for radioactive waste.

6.71. The risks posed by the waste and the conditions of its storage should be taken into consideration in determining the operational limits and conditions. The operational limits and conditions will be specific to each storage facility. The operator may wish to set administrative margins below the specified limits as an operational target to remain within the operational limits and conditions.

6.72. Operational limits and conditions for the storage of waste should include, as appropriate:

(a) Specifications for waste packages (waste form, radionuclide content and container characteristics) consistent with the waste acceptance criteria for the storage facility;
(b) Concentration limits for liquid waste, e.g. to prevent the precipitation of solids;
(c) Requirements for safety systems, e.g. requirements for ventilation, heat removal, tank agitation and radiation monitoring, including requirements for the availability of these features in normal and abnormal conditions;
(d) Periodic testing of equipment, especially backup systems that need to be available in emergency conditions;
(e) Maximum radiation dose rates, especially on container surfaces;
(f) Maximum levels of surface contamination for containers;
(g) Requirements for training and qualification of personnel and minimum staffing levels;
(h) Limits on the cumulative radionuclide inventory.

6.73. The initial operational limits and conditions should normally be developed in cooperation with the facility designers well before the commencement of operation to ensure that adequate time is available for their assessment by the regulatory body.

Operational procedures

6.74. Procedures should be developed for managing and operating the storage facility under normal conditions, in incidents and under postulated accident conditions. Procedures should address such issues as those listed in para. 6.5 and should be prepared so that the designated responsible person can understand and perform each action in the proper sequence. Responsibilities for the approval of any necessary deviations from procedures for operational reasons should be clearly defined. Any deviation from the approved operational procedures should be justified and its implications for safety should be determined.

6.75. In accordance with the management system, arrangements should be in place for the review and approval of operating procedures and for the communication to operating personnel of any revisions. Periodic reviews should be undertaken to take account of operational experience. Any revisions should be adopted only after they have been reviewed to ensure compliance with operational limits and conditions, approved by authorized persons and documented.

Radiation protection

6.76. The objectives of the radiation protection programme are to ensure that the radiation doses to workers and to members of the public arising from the normal operation and the possible abnormal operation of the storage facility do not exceed regulatory limits and that radiation protection is optimized. Releases of radioactive material to the environment should also be controlled in accordance with the requirements of the regulatory body. More detailed guidance on radiation protection is given in other IAEA publications [28, 29].

6.77. Additional procedures for radiation protection may be necessary for application to non-routine activities for waste storage, such as the movement of waste through passages and areas commonly used by personnel, the handling of packages with undocumented characteristics and the purging of areas where ventilation is intermittent.

6.78. Radiation dose rates should be specified for waste packages, shielding surfaces and other locations and radiation levels should be monitored at intervals sufficient to alert the operator to any changes due, for example, to the unexpected and undetected buildup of radioactive material or the degradation of shielding.

Maintenance, testing and inspection

6.79. Before the start of operations, the operator should prepare a programme of periodic maintenance, testing and inspection of systems that are essential to safe operation. The need for maintenance, testing and inspection should be addressed from the design stage. Non-intrusive testing and inspection that incorporates the diagnostic assessment of performance as part of normal in-service activities is to be preferred. Testing and inspection should establish and verify correct function, performance and conditions against acceptance criteria. The programme should be periodically reviewed with account taken of operational experience. Systems and components that should be considered for periodic maintenance, testing and inspection may include:

(a) Waste containment systems, including tanks and other containers;
(b) Waste handling systems, including pumps and valves;
(c) Heating and/or cooling systems;
(d) Radiation monitoring systems;
(e) Calibration of instruments;
(f) Ventilation systems;
(g) Normal and standby systems for electrical power supply;
(h) Utilities and auxiliary systems such as systems for water, gas and compressed air;
(i) The system for physical protection;
(j) Building structures and radiation shielding;
(k) Fire protection systems.

6.80. The frequency of maintenance, testing and inspection should be such as to ensure that the reliability of equipment remains high and that the effectiveness of systems remains in accordance with the design intent for the facility. The reliability of systems should not be significantly affected by the frequency of testing.

6.81. Suitably qualified, trained and experienced personnel should be deployed in the approval and implementation of the maintenance, testing and inspection programme and in the approval of associated procedures. Test procedures should normally include test acceptance criteria.

6.82. Records should be kept of activities for maintenance, testing and inspection. These records should be subject to periodic review to establish trends in system performance, the reliability of components in the system and the effectiveness of the maintenance programme. The reviews should include the identification of appropriate corrective measures.

Security and access control

6.83. Access to areas in which waste is stored should be controlled to ensure safety and the physical protection of materials. In meeting operational requirements to control access, a zoned approach, working inwards towards areas having more stringent controls, may be applied. There should be provisions for detecting any unauthorized intrusion and for taking countermeasures promptly.

DECOMMISSIONING OF STORAGE FACILITIES FOR RADIOACTIVE WASTE

6.84. Prior to decommissioning, a decommissioning plan should be prepared in which account is taken of any radioactive contamination that remains, technical factors, costs, schedules, institutional factors and the management of the waste arising from the decommissioning activities [19].

6.85. Where waste is stored in an independent facility, a specific decommissioning plan should be prepared for that facility [19]. Where the storage facility is part of a larger nuclear facility, the decommissioning plan for the storage facility will generally be a part of that for the larger nuclear facility.

LONG TERM STORAGE OF RADIOACTIVE WASTE

6.86. Long term storage of radioactive waste refers to situations in which waste is stored for periods that exceed the original design life of the containers and storage facilities, for example, owing to the disposal of the waste being delayed or postponed. Long term storage can also refer to situations in which the waste packages and storage facility are designed for relatively long periods of storage (e.g. 100 years).

6.87. Additional technical considerations for long term storage of waste are:

(a) Engineered systems, facilities and institutional controls should be more robust or should be more actively maintained. If possible, passive safety features should be used.
(b) Information should be retained in a readable and understandable form for future generations. For long periods of time, the deterioration of records (whether material or electronic) will be more significant.
(c) Inadvertent or deliberate intrusion into waste storage facilities may be more likely over longer time periods and intrusion should be considered in the safety assessment.

6.88. For storage beyond the original intended period of storage, the design life of the storage facility and that of the waste packages may be exceeded. This should prompt a re-evaluation of the storage strategy, which may include a re-evaluation of the initial design, operations, the safety assessment and other aspects of the waste storage facility.

6.89. For storage beyond the original intended period, testing, examination or evaluation may be necessary to assess the integrity of waste packages. Potential problems with waste packages should be considered in advance of the need for physical action (such as overpacking or placing the waste into new waste packages). In some cases it may be justified to move waste packages into a more robust storage facility rather than to overpack or replace them.

6.90. For unanticipated long term storage, consideration should be given to mitigation of the consequences of potential changes in the stored radioactive waste. Changes in the stored waste may include:

(a) The generation of hazardous gases caused by chemical and radiolytic effects (e.g. the generation of hydrogen gas by radiolysis) and the buildup of overpressure;
(b) The generation of combustible or corrosive substances;
(c) The corrosion of metals (e.g. carbon steel);
(d) Degradation of the waste form.

These considerations are especially important for long term storage for which small effects may accumulate over long periods of time. Uncertainties in parameters and models should be considered in analytical approaches used to evaluate processes over long periods of time.

Appendix

SAFETY ASSESSMENT OF FACILITIES FOR THE STORAGE OF RADIOACTIVE WASTE

A.1. With few exceptions, storage facilities for radioactive waste accommodate relatively small energy sources and as such there are relatively few credible mechanisms for the sudden release of radioactive material. Furthermore, storage facilities for radioactive waste are usually designed around passive rather than active safety systems and hence do not rely on the provision of complex systems to ensure safety.

A.2. A safety assessment comprises an evaluation of those aspects of the design and operation of a storage facility for radioactive waste that ensure the protection of workers, the public and the environment under normal conditions and in accident situations.

A.3. Safety assessment is typically an iterative process used to ensure that a storage facility for radioactive waste can be operated safely. Safety assessment should be used early in the design process to identify hazards and scenarios that may require modifications to the proposed design or to operational procedures to achieve safety as specified by the regulatory body. Generally, reliance should be placed principally on design features rather than on operational procedures in the control of radiation hazards.

A.4. The graded approach to safety assessment implies that the scope and the detail of the safety assessment and its supporting documentation are commensurate with the nature and extent of the potential hazards. For the purpose of grading, a generic system for categorization by level of radiological hazard may provide an indicator for the level of analysis required to support the safety assessment. The description of radiological threat categories in Appendix 4 of Ref. [32] suggests such a categorization system. Similar hazard categories are often specified in national laws and regulations.

A.5. The conditions, processes and events that may influence the integrity and safety of a storage facility for radioactive waste may be considered to originate either outside or within the facility. These conditions, processes and events will be primarily of three types: external natural phenomena, internal phenomena and external human induced phenomena. Annexes III–V of Ref. [5] provide good starting points for consideration in developing a safety assessment for a storage facility for radioactive waste. Generic lists should not be solely relied on, since site specific environmental conditions and phenomena and the design and operations of the facility will dictate the conditions, processes and events that should be evaluated in the safety assessment.

A.6. The types, quantities and physical and chemical characteristics of the waste should be considered in the safety assessment of storage facilities for radioactive waste. For example, radioactive waste that has been conditioned (e.g. solidified in a grouted form) will be likely to have a lower damage ratio under many accident conditions than similar waste in unconditioned form. The damage ratio is a parameter used to take account of the availability of material under accident conditions.

A.7. The safety assessment of a storage facility for radioactive waste should encompass the expected duration of operation of the facility. The storage of waste for longer periods of time would require events of lower likelihood to be evaluated in the safety assessment than for a shorter duration of storage. In addition, processes that may have been neglected for a shorter duration of storage may become significant for a longer duration of storage (e.g. radiolytic generation of gas, general corrosion of waste canisters or radiation induced embrittlement of polyethylene containers).

A.8. The different stages of the facility's lifetime should be taken into account in the safety assessment of a storage facility for radioactive waste. The safety assessment should be periodically evaluated and, if necessary, revised to reflect changes in the conditions, facilities or procedures.

SAFETY ASSESSMENT OF SMALL STORAGE FACILITIES FOR RADIOACTIVE WASTE

A.9. The approach to safety assessment for small storage facilities will usually rely on generic checklists for the identification of hazards and generic procedures; extensive quantitative safety analysis is usually not necessary. Many procedures and checklist items for safety assessment of small facilities such as laboratories are also applicable to small storage facilities for radioactive waste.

A.10. For small storage facilities for radioactive waste (e.g. a secure storage room in a medical facility), safety can be achieved by the application of documented procedures and limits. The topics to be covered in such procedures and limits are largely described in Sections 4 and 5 and could, for example, include:

(a) A description of the storage facility and how it is to be operated;
(b) Activity limits for the accumulated inventory of radionuclides;
(c) Discharge limits for radionuclides;
(d) Names of the individuals responsible for the facility;
(e) Access control;
(f) Surface dose rates;
(g) Materials that are permitted for storage;
(h) Rules for the segregation, packaging and labelling of waste;
(i) Record keeping;
(j) Emergency plans;
(k) A statement of the applicable regulations and guidance.

A.11. Having facility limits for the radionuclide inventory is one way of ensuring the safety of small storage facilities, in particular under abnormal operating conditions. The regulatory body may choose to set generic inventory limits for small storage facilities. Methods for preparing radiological assessments of facilities such as small storage facilities for radioactive waste (e.g. those at hospitals and universities) have been published by national agencies [33].

SAFETY ASSESSMENT OF LARGE STORAGE FACILITIES FOR RADIOACTIVE WASTE

A.12. Large storage facilities for radioactive waste, owing to their complexity and their large accumulations of radioactive material, will require site specific and facility specific safety analyses that employ both qualitative and quantitative methods of safety assessment.

A.13. The IAEA has yet to develop safety standards for the design and safety analysis of fuel cycle facilities such as storage facilities for radioactive waste, although safety requirements for fuel cycle facilities are at present being developed [34]. Some of the information on safety assessment that is available in IAEA technical documents is applicable to storage facilities [35–39]. A facility specific safety analysis would include steps such as:

(a) Description of the system (including an estimate of the maximum inventory of radioactive material) and a specification of the applicable regulations and guidance. The latter, for example, would indicate whether the facility should be seismically qualified.

(b) Systematic identification of conditions, processes and events associated with normal and abnormal conditions and external events (e.g. fires or handling accidents that involve the breach of waste containers).

(c) Hazard evaluation. Screening of combinations of conditions, processes and events that may result in the release of radioactive material from the waste storage facility, so as to eliminate from further consideration those of diminished likelihood or consequence.

(d) Risk calculation. The probabilities and consequences of the release(s) of radioactive material identified in the hazard evaluation are assessed by quantitative analysis and compared with regulatory limits.

(e) Establishment of limits, conditions and controls on the basis of the safety analysis. If necessary, the design of the facility is modified and the safety analysis is modified.

(f) Documentation of the safety assessment to support licensing of the facility.

The safety assessment should identify the key drivers of risk so that the limiting safety systems are identified and so that a level of confidence in the parameters supporting the safety assessment can be established that is commensurate with their significance (e.g. by sensitivity analysis).

A.14. The safety assessment should include an assessment of the risk during normal operation and abnormal operation and under the conditions associated with external events, and should provide an assessment of doses at the site boundary and potential exposures in areas where there is unrestricted access. As appropriate, authorized limits on discharges should be established for the facility, following the guidance provided in Ref. [13].

A.15. Different methods may be used for quantitative safety assessment of a large storage facility for radioactive waste (e.g. integrated safety analyses and probabilistic risk assessments). Whereas for a small facility it may be possible to rely on generic data (e.g. meteorological data, values of environmental parameters, damage ratios or leak path factors) to support the safety assessment, site specific information should be used for a large facility.

A.16. The process of safety assessment for a large storage facility for radioactive waste should usually be iterative. An initial safety assessment that yields results that are close to or exceed the limiting performance objectives would suggest the need for additional safety systems and controls and/or a more rigorous evaluation of the suitability of any generic data sources that have been used.

A.17. Safety assessment may be carried out to satisfy a requirement for periodic safety review, which is a regulatory requirement in many States. Periodic safety review is a key regulatory instrument for maintaining the safety of facility operations in the long term and for addressing requests by licensees for authorization to continue operation of the facility beyond an established licensed term or a period established by safety evaluation. A periodic safety review provides reassurance that there continues to be a valid licensing basis, with ageing of the facility, modifications made to the facility and current international safety standards taken into consideration. Guidance for the conduct of a periodic safety review is provided in Ref. [40].

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