IAEA SAFETY STANDARDS SERIES

Predisposal Management of Low and Intermediate Level Radioactive Waste

SAFETY GUIDE

No. WS-G-2.5

INTERNATIONAL
ATOMIC ENERGY AGENCY
VIENNA

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PREDISPOSAL MANAGEMENT OF LOW AND INTERMEDIATE LEVEL 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

One of the statutory functions of the IAEA is to establish or adopt standards of safety for the protection of health, life and property in the development and application of nuclear energy for peaceful purposes, and to provide for the application of these standards to its own operations as well as to assisted operations and, at the request of the parties, to operations under any bilateral or multilateral arrangement, or, at the request of a State, to any of that State's activities in the field of nuclear energy.

The following bodies oversee the development of safety standards: the Commission on Safety Standards (CSS); the Nuclear Safety Standards Committee (NUSSC); the Radiation Safety Standards Committee (RASSC); the Transport Safety Standards Committee (TRANSSC); and the Waste Safety Standards Committee (WASSC). Member States are widely represented on these committees.

In order to ensure the broadest international consensus, safety standards are also submitted to all Member States for comment before approval by the IAEA Board of Governors (for Safety Fundamentals and Safety Requirements) or, on behalf of the Director General, by the Publications Committee (for Safety Guides).

The IAEA's safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA in relation to its own operations and on States in relation to operations assisted by the IAEA. Any State wishing to enter into an agreement with the IAEA for its assistance in connection with the siting, design, construction, commissioning, operation or decommissioning of a nuclear facility or any other activities will be required to follow those parts of the safety standards that pertain to the activities to be covered by the agreement. However, it should be recalled that the final decisions and legal responsibilities in any licensing procedures rest with the States.

Although the safety standards establish an essential basis for safety, the incorporation of more detailed requirements, in accordance with national practice, may also be necessary. Moreover, there will generally be special aspects that need to be assessed on a case by case basis.

The physical protection of fissile and radioactive materials and of nuclear power plants as a whole is mentioned where appropriate but is not treated in detail; obligations of States in this respect should be addressed on the basis of the relevant instruments and publications developed under the auspices of the IAEA. Non-radiological aspects of industrial safety and environmental protection are also not explicitly considered; it is recognized that States should fulfil their international undertakings and obligations in relation to these.

The requirements and recommendations set forth in the IAEA safety standards might not be fully satisfied by some facilities built to earlier standards. Decisions on the way in which the safety standards are applied to such facilities will be taken by individual States.

The attention of States is drawn to the fact that the safety standards of the IAEA, while not legally binding, are developed with the aim of ensuring that the peaceful uses of nuclear energy and of radioactive materials are undertaken in a manner that enables States to meet their obligations under generally accepted principles of international law and rules such as those relating to environmental protection. According to one such general principle, the territory of a State must not be used in such a way as to cause damage in another State. States thus have an obligation of diligence and standard of care.

Civil nuclear activities conducted within the jurisdiction of States are, as any other activities, subject to obligations to which States may subscribe under international conventions, in addition to generally accepted principles of international law. States are expected to adopt within their national legal systems such legislation (including regulations) and other standards and measures as may be necessary to fulfil all of their international obligations effectively.

EDITORIAL NOTE

An appendix, when included, is considered to form an integral part of the standard and to have the same status as the main text. Annexes, footnotes and bibliographies, if included, are used to provide additional information or practical examples that might be helpful to the user.

The safety standards use the form 'shall' in making statements about requirements, responsibilities and obligations. Use of the form 'should' denotes recommendations of a desired option.

The English version of the text is the authoritative version.

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1. INTRODUCTION

BACKGROUND

1.1. Radioactive waste is generated in the generation of electricity in nuclear power reactors and in the use of radioactive material in industry, research and medicine. The importance of the safe management of radioactive waste for the protection of human health and the environment has long been recognized. The principles and requirements that govern the safety of the management of radioactive waste are presented in The Principles of Radioactive Waste Management [1], Legal and Governmental Infrastructure for Nuclear, Radiation, Radioactive Waste and Transport Safety [2] and Predisposal Management of Radioactive Waste, Including Decommissioning [3].

1.2. Reference [3] establishes requirements for the safe management of radioactive waste prior to its disposal. These requirements are derived from the principles for radioactive waste management established in the Safety Fundamentals publication The Principles of Radioactive Waste Management [1] and include requirements for the protection of human health and the environment and associated responsibilities. Recommendations on the fulfilment of these requirements are provided in this Safety Guide and several associated Safety Guides.

1.3. This Safety Guide provides recommendations on how to meet the safety requirements for the predisposal management of low and intermediate level radioactive waste from nuclear fuel cycle facilities (excluding facilities for the mining and milling of uranium and thorium bearing ores), large research and development installations and radioisotope production facilities. Low and intermediate level waste (LILW) is radioactive waste that has lower level radiological characteristics than those of high level waste but which remains under regulatory control (i.e. has not been found suitable for the removal of regulatory control).

1.4. All these facilities generate LILW in various forms. The amount of LILW can be minimized by means of good operating practices, but LILW cannot be fully eliminated and it may contain quantities of radionuclides sufficient to present hazards to human health and the environment if it is not adequately managed.

1.5. In a well established nuclear fuel cycle the waste arising from the various facilities can be characterized by a number of typical groups with respect to the nature and amount of waste, the radionuclides present, their corresponding activity and their proportions. The recommended approaches for waste classification on the basis of prevailing characteristics can be found in Ref. [4]. Annex I provides a summary of the nature and sources of LILW from nuclear facilities.

1.6. The waste from research installations, nuclear applications in medicine and industry, and radioisotope production facilities is usually more diverse and variable in nature and encompasses a broader range of radionuclides than the waste from the nuclear fuel cycle itself, although the radionuclides are in much smaller quantities. Because of the variability and diversity in the waste streams from these facilities, particular and constant attention has to be given to all stages of the management of the waste.

1.7. The predisposal management of LILW includes all steps or activities in the management of waste, from its initial generation to its final acceptance at a repository or other disposal site, or the removal of regulatory control. It may include pretreatment, treatment, conditioning, decommissioning, storage and activities in preparation for transport, and any associated activities such as characterizing the initial waste, waste form or waste package at appropriate stages in the processing of the waste, until the delivery of a waste package to a repository or the removal of regulatory control. The predisposal management of radioactive waste also includes the decommissioning of nuclear facilities.

1.8. Pretreatment may include waste collection, segregation, chemical adjustment and decontamination. Treatment includes those operations intended to enhance safety and/or economy by changing the characteristics of the radioactive waste. The basic treatment concepts are volume reduction, radionuclide removal and change of composition. Conditioning LILW involves those operations that transform radioactive waste into a form suitable for subsequent activities such as handling, transport, storage and disposal. The operations may include the immobilization of waste, placing of the waste into containers and provision of additional packaging. Storage is the placement of waste in a facility where isolation, environmental protection and monitoring are provided. It is an interim activity with the intent that the waste will be retrieved at a later date for release from regulatory control or processing and/or disposal.

1.9. The predisposal management of LILW may take place in a separate, dedicated waste management facility or at specific locations within a larger facility operated for other purposes. In this Safety Guide the term ‘facility’ is used to refer to either of these possibilities and the term ‘operator’ is used for the operating organization or operator of a designated waste management facility or a waste generator who also performs activities for the predisposal management of waste.

1.10. In addition to its radiological hazard, LILW may present additional hazards owing to its physical, chemical or pathogenic characteristics, and these should also be taken into account in the predisposal management of radioactive waste.

OBJECTIVE

1.11. 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 principles and requirements established in Refs [1–3] for the predisposal management of LILW.

SCOPE

1.12. This Safety Guide deals with the safety issues associated with the predisposal management of LILW from nuclear fuel cycle facilities, large research and development installations and radioisotope production facilities. This includes all steps and activities in the management of waste, from its initial generation to its final acceptance at a waste disposal facility or the removal of regulatory control.

1.13. The predisposal management of radioactive waste includes decommissioning. The term ‘decommissioning’ encompasses both the process of decommissioning a facility and the management of the waste that results (prior to its disposal). Recommendations on the process of decommissioning are provided in Refs [5–7]. Recommendations on the management of the waste resulting from decommissioning are included in this Safety Guide.

1.14. Although the mining and milling of uranium and thorium ores is part of the nuclear fuel cycle, the management of the operational waste (e.g. waste rock, tailings and effluent treatment waste) from these activities is not within the scope of this Safety Guide. The LILW that is considered in this publication begins with the refining and conversion of uranium concentrates. Recommendations on the management of radioactive waste from the mining and milling of uranium and thorium ores are provided in Ref. [8].

1.15. Some parts of the nuclear fuel cycle generate both high level waste and LILW. The management of high level waste itself generates LILW. The predisposal management of this LILW is included in the scope of this Safety Guide. Recommendations on the predisposal management of high level waste are provided in Ref. [9].

1.16. The recommendations in this Safety Guide primarily concern complex management activities for LILW. The regulatory body should decide which parts of this Safety Guide are relevant and appropriate for particular circumstances, and the extent to which the recommendations and guidance apply.

1.17. This Safety Guide provides only introductory material on the transport and storage of LILW. Requirements and recommendations are provided in Refs [10–12].

1.18. There may be non-radiological hazards associated with the predisposal management of LILW. Some guidance is given on the safety measures to be taken against non-radiological hazards if they have potential consequences for radiation safety. However, detailed recommendations are beyond the scope of this Safety Guide. The user should seek guidance from the regulatory body in the areas of health and safety and environmental protection.

STRUCTURE

1.19. Section 2 deals with the protection of human health and the environment and Section 3 with the roles and responsibilities of the regulatory body and the operator. Section 4 outlines safety considerations in the predisposal management of LILW and Section 5 presents recommendations on the predisposal management of LILW, on the design and operation of facilities and on acceptance requirements. Section 6 provides recommendations on record keeping and reporting and Section 7 deals with safety and environmental assessments. Section 8 is on quality assurance. Annex I is an overview of the nature and source of waste from nuclear fuel cycle facilities. Annex II describes the development of waste package specifications. Annexes III and IV list site conditions, processes and events for consideration in a safety assessment for external natural phenomena and for external human induced phenomena, respectively. Annex V lists postulated initiating events (internal phenomena) for consideration in a safety assessment.

2. PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

2.1. The requirements established in Section 2 of Ref. [3] for the protection of human health and the environment apply to the predisposal management of LILW. Activities in the predisposal management of LILW contribute to ensuring that LILW is dealt with in a manner that protects human health and the environment, both now and in the future, without imposing undue burdens on future generations [1].

2.2. In the design of a facility and the planning of practices for the predisposal management of LILW it is required to take into account the need to protect both workers and the public against exposure to radiation, in accordance with the Basic Safety Standards [13], which require that occupational doses be kept below established dose limits and as low as is reasonably achievable (ALARA), economic and social factors being taken into account (Ref. [13], Section 2). This can be accomplished by means of sound operational and engineering practices and administrative controls. Examples of such measures include:

(a) Thorough planning for and careful execution of activities for the management of LILW, including facilitating the eventual decommissioning of management facilities for LILW;
(b) Pre-work assessments and training mockups to minimize exposures during operational and maintenance activities, if warranted by the hazards;
(c) The use of remote handling technologies for operational and maintenance activities, if warranted by the hazards;
(d) Establishing controls, such as activity limits, if items are transferred or removed from areas of higher contamination to areas of lower contamination.

2.3. The adequacy of controls provided to limit the exposure of workers and the public should, where appropriate, be verified by means of personal, area and discharge monitoring.

2.4. Releases of radioactive material to the environment from predisposal management facilities for LILW should be controlled in accordance with the recommendations provided in Ref. [14], and the limits and conditions set by the regulatory body.

2.5. The predisposal management of LILW is sometimes carried out under contractual arrangement in another State or, in some cases, waste management activities in one State could result in exposures in adjacent States. Exposures both within and beyond national borders should therefore be taken into account in taking measures for the reduction of exposures in the predisposal management of LILW.

2.6. A facility for the predisposal management of LILW should be designed so that as far as possible incidents will be avoided and accidents will be prevented, and if they do occur the consequences will be mitigated.

2.7. The primary safety concern with LILW is the radiological hazard. However, hazards to human health and the environment due to its other physical and chemical characteristics should also be taken into account in designing and operating facilities for the predisposal management of LILW. Protection from non-radiological hazards should be provided in accordance with the relevant standards on health and safety and environmental protection.

2.8. A safety culture is required to be fostered and maintained in all organizations involved in the predisposal management of LILW, from its generation to its eventual disposal, so as to encourage an enquiring, learning and self-disciplined attitude to protection and safety and to discourage complacency (Ref. [13], para. 2.28; Ref. [15]).

3. ROLES AND RESPONSIBILITIES

GENERAL CONSIDERATIONS

3.1. The predisposal management of LILW is required to take place within an appropriate national legal framework that provides a clear allocation of responsibilities [1] and effective regulatory control of the facilities and activities concerned (Ref. [2]; Ref. [3], paras 3.5–3.9). The national legal framework will also permit compliance with other national and international laws. Although laws are normally of a general nature, the national legal system may permit the issuing of site specific regulations for the predisposal management of LILW. Requirements in respect of the responsibilities for establishing such a framework and the responsibilities of the regulatory body for ensuring the safety of the predisposal management of LILW are established in Ref. [2].

3.2. The predisposal management of LILW may involve the transfer of radioactive waste from one operator to another or the processing of LILW in another State. The established legal framework should include provisions to ensure that there is a clear allocation of responsibility for safety during the entire predisposal management process for LILW, including any transfer between operators. Consideration should also be given to the decommissioning of any facility at which LILW is managed. This continuity of responsibility for safety should be ensured by means of appropriate authorizations by the regulatory body (e.g. by means of a licence or a sequence of licences, in accordance with the national legal framework and agreements among the States involved in the transboundary movement of LILW).

3.3. An individual governmental organization should not be given both operational and regulatory responsibility for radioactive waste management. However, if this cannot be avoided, the regulatory and the operational responsibilities should be clearly specified and functionally separated.

RESPONSIBILITIES OF THE REGULATORY BODY

3.4. For the predisposal management of LILW, as in all areas of its statutory obligations, the regulatory body is required to act within the national legal framework, to define policies, safety principles and associated criteria and to establish requirements to serve as the basis for its regulatory actions (Ref. [2], paras 3.1 and 3.2). The regulatory body is required to provide guidance to operators on meeting the requirements for the predisposal management of LILW. In fulfilling its obligations the regulatory body is required to carry out a number of the functions that are established in Ref. [2], the primary ones being:

(a) To review and assess submissions on safety from the operators;
(b) To issue, amend, suspend or revoke authorizations;
(c) To carry out regulatory inspections;
(d) To ensure that corrective actions are taken if unsafe or potentially unsafe conditions are detected;
(e) To take the necessary enforcement action in the event of a violation of the regulatory requirements.

3.5. Recommendations on the review and assessment of facilities and activities involved in the management of LILW by the regulatory body are provided in Ref. [16]. Recommendations on the documentation that the regulatory body should require the operator of a nuclear facility to produce for the regulatory process are given in Ref. [17].

3.6. The regulatory body should prepare guidelines for the decommissioning of management facilities for LILW as early as possible. The operator should follow such guidelines in choosing design options and operating practices to facilitate decommissioning.

3.7. Owing to the potentially long time periods between the conditioning of LILW and its disposal, particular attention should be paid to ensuring that the necessary human, technical and financial resources will be available when required and that the appropriate information is available. The regulatory body should ensure that a means for obtaining the resources is in place, as appropriate, and that the necessary records are prepared and maintained for an appropriate period of time. A listing of the necessary records is included in Refs [2, 17].

3.8. The regulatory body should typically provide guidance to the operators carrying out the predisposal management of LILW on:

(a) Criteria for the protection of human health and the environment;
(b) Requirements for nuclear safety;
(c) Criteria for authorized discharges and authorized recycling;
(d) Requirements for removing regulatory control from material;
(e) Criteria for the characterization and classification of radioactive waste;
(f) Strategies for the management of radioactive waste;
(g) Acceptance criteria for the long term storage and/or disposal of radioactive waste;
(h) Processes and procedures for the granting of a licence or another type of authorization;
(i) Procedures for the modification of plant or procedures;
(j) Policies and procedures used by the regulatory body for verifying compliance and enforcement;
(k) The timing and content of periodic reports to be submitted by the operator to the regulatory body;
(l) Safety culture;
(m) Quality assurance.

3.9. The regulatory body should verify the key aspects of operations for the predisposal management of LILW to be performed by the operator, such as the compliance of the conditioned LILW package with the acceptance requirements of the disposal facility or long term storage facility.

3.10. It is expected that the government will consult the regulatory body on all matters relating to policy and strategy on the safety of LILW management and the regulatory body should provide such advice on matters relating to the safety of facilities and activities, and on protection and safety in emergencies (Ref. [2], paras 3.3 and 6.6).

RESPONSIBILITIES OF OPERATORS

3.11. Prior to commencing the construction or significant modification of any facility for the predisposal management of LILW, the operator is required to submit to the regulatory body an application detailing the proposed design and operational practices together with a safety assessment, in accordance with regulatory requirements (Ref. [2], Section 5). This submission should justify the proposed practices and should demonstrate their safety by means of an assessment as described in Section 7. Prior to the regulatory body's granting of an authorization to commence operations using radioactive material, the operator should carry out pre-operational and commissioning tests, as required by the regulatory body, in order to demonstrate compliance with the requirements for design and other safety requirements.

3.12. The operator may process, store and/or dispose of LILW in an approved manner using its own facilities or may transfer waste at some point to another operator. In so doing, the operator should identify suitable destinations and should ensure that any transfer of LILW is made only to authorized organizations. It should be the responsibility of the operator to ensure that radioactive waste is transported safely and in accordance with national and international regulations for the safe transport of radioactive material [10]. The operator is responsible for the safety of all activities in the predisposal management of waste, even if the work is contracted to a third party. Any transport of waste to other States must comply with international obligations such as Article 27 of the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management [18]. The operator should also have full responsibility for ensuring that the waste packages comply with the acceptance requirements for the disposal of LILW. If no such requirements apply, the operator should give thorough consideration to the compatibility of the waste package with the anticipated acceptance requirements for disposal, so as to provide reasonable assurance that the conditioned LILW will be accepted for disposal.

3.13. The operator should prepare plans for decommissioning activities and emergency management and should put in place mechanisms to ensure that financial resources are sufficient to undertake all tasks throughout the lifetime of a facility for the management of LILW [3]. Activities that are the responsibility of the operator are detailed in Ref. [2], the requirements of which should be adapted as appropriate to the predisposal management of LILW.

3.14. In some States specialized agencies have been established for the purpose of providing waste management services. There should be adequate communication among all parties in order to ensure the effectiveness and efficiency of the overall system. Although potentially of general benefit, the sharing of information referred to above should have as its primary objective the enhancement of safety through lessons learned from operation.

4. GENERAL SAFETY CONSIDERATIONS

INTERDEPENDENCE

4.1. Interdependences exist among all steps in the management of LILW, from the generation of the waste to its disposal. In selecting strategies and activities for the predisposal management of LILW, planning should be carried out for all the various steps so that a balanced approach to safety is taken in the overall management programme and conflicts between the safety requirements and operational requirements are avoided. There are various alternatives for each step in the management of LILW. To ensure safety, all the different steps should be evaluated, both as isolated steps in the process and also as part of an integrated system in which the steps are complementary and mutually dependent. For example, treatment and conditioning options for LILW are influenced by the established or anticipated acceptance requirements for a repository.

4.2. The interdependences among the steps in the predisposal management of LILW should be considered for achieving continuity in operations. The following aspects in particular should be considered:

(a) The identification of interfaces and the definition of the responsibilities of the various organizations involved at these interfaces;
(b) The establishment of acceptance criteria, where necessary, and the confirmation of conformance with the acceptance criteria by means of verification tests or the examination of records.

4.3. The individual stages in the LILW management programme should be assessed systematically to identify hazards. Hazards should be eliminated if this is practicable; if not, they should be minimized by means of changes to the design or to operational procedures.

4.4. For most programmes for the management of LILW, decisions about predisposal management have to be made before the waste acceptance requirements for disposal are finalized. Decisions on the predisposal management of LILW should be made and implemented so as ultimately to ensure compliance with the waste acceptance requirements for disposal. In particular, in the design and preparation of waste packages for the disposal of LILW, consideration should be given to the suitability of the packages for transport and storage, including retrieval, and to their suitability for emplacement in a disposal facility on the basis of the anticipated waste acceptance requirements.

4.5. As established in Section 4 of Ref. [3], the operator and the regulatory body are required to have specific responsibilities in defining appropriate options for the predisposal management of LILW and in avoiding the setting of conflicting requirements that could compromise the safety of the predisposal management of LILW.

CHOICE OF PREFERRED OPTION

4.6. The operator should specify and evaluate a range of options for managing LILW and should justify the preferred selection. Factors that should be taken into account include:

(a) The types, physical properties, chemical composition, volumes and radionuclide content of existing radioactive waste inventories and forecasts for the future generation of radioactive waste;
(b) The authorized acceptance criteria for radioactive waste for all management steps, including storage and disposal;
(c) The availability of appropriate facilities and disposal options;
(d) The availability of appropriate processing technologies;
(e) The regulatory requirements for authorized use, authorized discharges and removal of regulatory control.

CONTROL OF WASTE GENERATION

4.7. The generation of radioactive waste cannot be prevented entirely but it should be kept to the minimum practicable ('waste minimization') as an essential objective of radioactive waste management [1]. Waste minimization relates to both volume and activity and to both the waste generated by an initial undertaking and the secondary waste resulting from the predisposal management of radioactive waste. The chemical characteristics of the waste should also be controlled at the source to facilitate the subsequent processing of the waste.

4.8. Useful strategies for waste minimization include:

(a) Reducing the volume of radioactive waste to be managed, by adequate segregation and by keeping non-radioactive material out of controlled areas to prevent contamination;
(b) The proper planning of activities and the use of adequate equipment for handling waste so as to control the generation of secondary waste;

(c) The decontamination of material, together with the control of secondary waste arising from decontamination;
(d) The recycle and reuse of materials and structures, systems and components.

4.9. Radioactive waste should be reduced at source as the most efficient method for waste minimization. Consideration should be given to the design of the facility and to operational features for waste minimization, including the following aspects:

(a) The careful selection of materials, processes and structures, systems and components for the facility;
(b) The selection of design options that favour waste minimization when the facility is eventually decommissioned;
(c) The use of effective and reliable techniques and equipment;
(d) The containment and packaging of radioactive material to maintain its integrity;
(e) The decontamination of zones and equipment and the prevention of the spread of contamination.

CHARACTERIZATION OF WASTE AND ACCEPTANCE CRITERIA

4.10. LILW is required to be characterized at the various stages in its predisposal management to obtain information on its properties for use in controlling the quality of the products, verifying the process and thus facilitating the subsequent steps for safely processing and finally disposing of the LILW (Ref. [3], paras 5.4 and 5.14).

4.11. The data requirements for characterization and methods for collecting data will differ depending on the type and form of the LILW (whether it is liquid LILW or solidified LILW). When waste streams are processed, characterization may be performed by sampling and analysing the chemical, physical and radiological properties of the waste. The quality of waste packages may be investigated by non-destructive and, infrequently, also by destructive methods. However, it may be possible to apply indirect methods of characterization based on process control and process knowledge instead of or in addition to sampling and the inspection of waste packages in order to avoid undue occupational exposure. The methods of characterization in the processing of the waste should be approved by the regulatory body in the authorization process.

4.12. An important objective of the predisposal management of LILW should be to produce waste packages that can be handled, transported, stored and disposed of safely. In particular, LILW should be conditioned to meet the acceptance requirements for its disposal. In order to provide reasonable assurance that the conditioned waste can be accepted for disposal, although there may not yet be any specific requirements, options for the future management of LILW and the associated waste acceptance requirements should be anticipated as far as possible. The waste acceptance requirements may be met by providing an overpack that is tailored to the specific conditions at the repository site and to the characteristics of the LILW and the engineered components of the disposal facility. Annex II provides a listing of the typical properties and characteristics that should be considered for waste packages in the predisposal management of LILW.

4.13. To ensure the acceptance of waste packages for disposal, a programme should be established to develop a process for conditioning that is approved by the regulatory body. The features adopted for waste characterization and process control should provide confidence that the properties of waste packages will be ensured. Guidance on implementing a quality assurance programme specific to the predisposal management of LILW is provided in Section 8.

QUALIFICATION OF STAFF

4.14. In a typical waste management process each step in the process is dependent upon the requirements for the activities in the previous step being satisfactorily met. Staff who are responsible for the operation of facilities in which LILW is generated and/or managed should undertake a specified training programme that will ensure that they understand the processes involved and the interrelationships of all stages in the process of waste management and the consequences of operator error for safety and the generation of waste. Without such knowledge, for example, a waste package could be produced that would not meet the acceptance criteria for subsequent processing, storage or disposal or that could present a hazard.

4.15. Personnel designated to select process technologies for the predisposal management of LILW also should be trained and qualified to perform their functions. Additionally, operators for the predisposal management of LILW should provide adequate numbers of suitably qualified and experienced personnel to operate and maintain the equipment, processes and systems for the predisposal management of radioactive waste and for service systems. For all stages in the predisposal management of radioactive waste the operator should ensure that the operating, maintenance and technical staff understand the nature of the waste and its associated hazards, the relevant operating procedures and the associated safety procedures and procedures to be followed in the event of an incident or accident.

FACILITATION OF DECOMMISSIONING

4.16. Consideration should be given to the eventual decommissioning of the facility, as regards both facilitating the decommissioning activities and keeping the generation of radioactive waste to the minimum practicable, in the design of a facility for the predisposal management of radioactive waste. A final goal of decommissioning is to enable the partial or complete removal of regulatory control from the facility. Further recommendations on decommissioning are given in Refs [5–7].

4.17. The requirements for decommissioning facilities for the predisposal management of radioactive waste are established in Ref. [3]. Recommendations on how to fulfil those requirements for facilities for the predisposal management of radioactive waste are presented in Ref. [5]. The key elements that should be considered for the decommissioning of facilities for the predisposal management of LILW, as specified in Ref. [5], include:

(a) The selection of a decommissioning option in which the radionuclides in the residual waste, technical factors, costs, schedules and institutional factors are taken into account.
(b) The development of a decommissioning plan, including an initial plan and a final plan in which any major modifications to the facility and information derived from its operational history after the preparation of the initial decommissioning plan are taken into account.
(c) The specification of the critical tasks involved in their decommissioning; in particular decontamination, dismantling, demolition, surveillance and conducting a final radiological survey.
(d) The management functions important for their decommissioning, such as training, organizational control, radiological monitoring, planning and the control of waste management, physical protection, safeguards and quality assurance.

4.18. Both the design and operational aspects that will have an influence on decommissioning safety (e.g. the chemical processes or mechanical processes involved) should be duly considered so as to facilitate the eventual decommissioning of a facility. The design considerations for decommissioning and the decommissioning measures should be consistent with the hazards expected to be associated with the facility.

PREPARATION OF DOCUMENTATION ON SAFETY

4.19. Within a national system for the management of radioactive waste, and in accordance with the responsibilities of operators [2], the regulatory body may request the operator to submit safety documentation in support of an application for a licence or another type of authorization for a facility for the predisposal management of waste. Matters such as the following should be covered in the safety documents for a complex undertaking:

(a) A description of the facility and its components, equipment and systems;
(b) The characteristics of the site;
(c) The characteristics of the waste to be managed and the relevant acceptance criteria;
(d) A description of the handling and processing methods and the resulting form of the waste;
(e) The temporary storage of the waste at the various stages of its processing;
(f) The generation and management of secondary radioactive waste;
(g) The control of effluent discharges;
(h) The organizational control of operations;
(i) Safety assessments and environmental impact assessments;
(j) Monitoring programmes;
(k) The training programme for staff;
(l) The safeguards aspects, where applicable, and the security of radioactive material;
(m) The emergency preparedness plan;
(n) The quality assurance programme;
(o) The decommissioning plan.

5. SAFETY FEATURES FOR THE PREDISPOSAL MANAGEMENT OF LILW

GENERAL CONSIDERATIONS

5.1. The main purpose of the predisposal management of LILW is to produce a waste product that meets the acceptance criteria for disposal and the requirements for any associated activities for handling, transport and storage. The predisposal management of LILW may also lead to the generation of waste or material that is suitable for authorized discharge, authorized use, the removal of regulatory control or disposal.

5.2. LILW should be processed and stored in accordance with documented procedures, on the basis of safety documents approved by the regulatory body and of operational experience. Activities for the predisposal management of LILW should be carried out in a rigorous manner so as to ensure that the proper standard of operation is achieved and maintained. Details of any changes in operation that are important to safety should be communicated to the regulatory body. If such a change is a deviation from the basis for the licence or authorization, approval from the regulatory body may be required.

5.3. General concerns relating to radioactive materials and the safety of the facility in the predisposal management of LILW include:

(a) Limitation of the external and internal exposure of the workers due, for example, to external irradiation and airborne radionuclides;
(b) The avoidance of fires and explosions;
(c) The minimization of the leakage of liquid waste;
(d) The minimization of releases of volatile or airborne radionuclides;
(e) The prevention of criticality, particularly in circumstances in which waste containing fissile isotopes might be concentrated owing to processing, such as precipitation or the incineration of waste.

DESIGN OF A FACILITY AND EQUIPMENT FOR THE PREDISPOSAL MANAGEMENT OF LILW

5.4. The requirements for facilities for the predisposal management of LILW will vary according to the volume and characteristics of the waste, such as the nature of the radionuclides, the activity, the chemical composition and physical form of the waste, and any non-radiological hazards.

5.5. Facilities for the predisposal management of LILW should have sufficient capacity to process all such waste generated and the storage capacity should be sufficient to account for uncertainties in the availability of facilities for treatment, conditioning and disposal. The possible need to process waste that may arise non-routinely from incidents and accidents, and for major maintenance necessitating the dismantling of structures, systems or components at nuclear facilities, should be taken into account in the design of a facility.

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

5.7. In the design of a facility for the predisposal management of LILW, due consideration should be given to the need for:

(a) Protection against radiation exposure (by shielding and containment);
(b) The control of access to areas for waste processing and storage and the control of movement between radiation zones and contamination zones;
(c) The retrieval of stored waste;
(d) Waste characterization and inventory control;
(e) The inspection of the waste and its containment;
(f) Dealing with waste and waste packages that do not meet specifications;
(g) The control of liquid and gaseous effluents;
(h) Ventilation and the filtration of airborne releases of radioactive material;
(i) Managing waste giving rise to non-radiological hazards;
(j) Maintenance work and eventual decommissioning;
(k) Fire protection and the prevention of explosions;
(l) The prevention of criticality;
(m) Safeguards controls and controls for the physical security of nuclear materials with due regard for safety.

PROCESSING OF LILW

Pretreatment

5.8. The processing of LILW will include pretreatment operations such as waste collection, segregation, chemical adjustment and decontamination.

5.9. Pretreatment may result in a reduction in the amount of LILW needing further processing and disposal. Actions can be performed to adjust the characteristics of the waste, to make it more amenable to further processing, and to reduce or eliminate certain hazards posed by the waste owing to its radiological, physical, chemical or pathogenic properties.

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

5.11. To facilitate further treatment and enhance safety, solid LILW should be segregated according to the overall waste management strategy and the available facilities. Considerations for segregation include:

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

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

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

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

5.14. Mixing LILW streams should be limited to those streams that are radiologically and chemically compatible. If the mixing of chemically different waste streams is considered, an evaluation should be made of the chemical reactions that could occur in order to avoid uncontrolled or unexpected reactions, especially the unplanned release of volatile radionuclides or radioactive aerosols. Organic liquid waste needs different treatment owing to its chemical nature and should be segregated and kept separate from aqueous LILW streams. Organic liquid waste may also be flammable and its collection and storage should incorporate provisions for adequate ventilation and fire protection.

Removal of regulatory control from waste material and discharges to the environment

5.15. The management of LILW, in particular segregation and pretreatment activities, should be carried out so as to minimize the amount of radioactive waste to be further treated, stored and disposed of [1]. Management options such as authorized discharge, authorized disposal, recycle, reuse and the removal of regulatory control from materials, in compliance with the conditions and criteria established by the regulatory body, should be used as far as practicable [3]. Decontamination and/or a sufficiently long period of storage to allow for radioactive decay should be used where appropriate to enable regulatory control to be removed from the waste material.

Removal of regulatory control from materials

5.16. The Basic Safety Standards provide that "Sources, including substances, materials and objects [including waste], within notified or authorized practices may be released from further requirements of the Standards subject to complying with clearance levels approved by the [regulatory body]. Such clearance levels shall take account of the exemption criteria specified in Schedule I [an effective dose of the order of 10 μSv or less in a year; and either 1 man Sv collective effective dose committed from one year, or an assessment for the optimization of protection showing that exemption is the optimum option] and shall not be higher than the exemption levels specified in Schedule I or defined by the [regulatory body] on the basis of the criteria specified in Schedule I, unless otherwise approved by the [regulatory body]" (Ref. [13], para. 2.19).

5.17. The waste generator or operator should have a formal mechanism in place to demonstrate compliance with regulatory requirements in respect of clearing materials from regulatory control. Additionally, there should be compliance with other requirements on release regarding any other hazardous aspects of the waste.

Discharges of airborne and liquid radioactive material to the environment

5.18. The principles for safe radioactive waste management include keeping the releases from the various processes in waste management to the minimum practicable [1]. However, as part of an optimized programme for radioactive waste management, the discharge of radioactive effluents to the environment, under control and authorized by the regulatory body, may be the most reasonable option. The limitations and controls for such discharges should be set by the regulatory body [14].

Removal of regulatory control from buildings and sites

5.19. When buildings and sites are decommissioned and before the removal of regulatory control, any residual waste should be properly managed, removed and transferred to an authorized storage or disposal facility. The facilities and sites should be decontaminated to the levels required by the regulatory body. Recommendations and guidance are provided in Refs [5–7].

Treatment

5.20. The treatment of LILW may include:

(a) The reduction in volume of the waste (by incineration of combustible waste, compaction of solid waste and segmentation or disassembly of bulky waste components or equipment);
(b) The removal of radionuclides (by evaporation or ion exchange for liquid waste streams and filtration of gaseous waste streams);
(c) Change of form or composition (by chemical processes such as precipitation, flocculation and acid digestion as well as chemical and thermal oxidation);
(d) Change of the properties of the waste.

5.21. Incineration of combustible solid LILW normally achieves the highest volume reduction as well as yielding a stable waste form. After combustion, radionuclides from the waste will be distributed between the ash, the products from cleaning the exhaust gases and the stack discharges. The distribution will depend on the design and operating parameters of the incinerator and the nature of the radionuclides in the waste. Incineration is also an advantageous technique for treating radioactive organic liquids because the products of complete combustion are ash, carbon dioxide and water. Other constituents in the waste may yield acid gases and corrosive combustion products, and the effects of corrosion of the incinerator’s components and of acid releases to the atmosphere should therefore be considered. Off-gas scrubbing to prevent the discharge of radioactive and non-radioactive hazardous materials may be necessary and should be considered. Attention should be paid to radionuclides accumulating in residues of the gas cleaning system and those remaining in the ash, and to their further conditioning.

5.22. Releases of radionuclides to the environment are largely determined by the operational conditions of the incinerator, in particular through control of the temperature and the types and amounts of waste incinerated and its radionuclide content. For incinerators processing significant amounts of radioactive waste, the operator should monitor the radionuclides in the stack discharge by appropriate measures to ensure that the concentrations and amounts discharged are within the limits specified by the regulatory body and are consistent with the parameters modelled in the safety assessment. The products of incineration can include acids, polychlorinated biphenyls and various other materials presenting non-radiological hazards, which should be taken into account.

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

(a) The possible release of volatile radionuclides and other airborne radioactive contaminants;
(b) The possible release of contaminated liquid during compaction;
(c) The chemical reactivity of the material during and after compaction;
(d) The potential fire and explosion hazards due to pyrophoric or explosive materials or pressurized components.

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

5.25. For non-combustible and non-compressible solid waste, for which delay and decay or decontamination is not a viable option, direct conditioning without prior treatment should be considered. Melting LILW metal scrap, with resultant homogenization of the radioactive material and its accumulation in the slag, may be considered as a means of achieving authorized reuse or removal of regulatory control.

5.26. Methods for the treatment of aqueous waste include evaporation, chemical precipitation, ion exchange, filtration, centrifugation, ultrafiltration, electrodialysis, incineration and reverse osmosis. In each case, process limitations due to corrosion, scaling, foaming and the risk of fire or explosion in the presence of organic material should be carefully considered, especially with regard to the safety implications of operations and maintenance. If the waste contains fissile material, the potential for criticality should be evaluated and eliminated to the extent practicable by means of design features and administrative features.

5.27. Spent ion exchange resins are usually flushed out as a slurry and subsequently managed as liquid waste, although some operators retain the resins as a dry solid. When resins are slurried, care should be taken to prevent blockages of the flow as these may cause radiation hot spots and necessitate special maintenance. Special care should also be taken with their prolonged storage while awaiting conditioning, because of the potential for radiolytic or chemical reactions generating combustible gases or causing physical degradation or exothermic reactions.

5.28. Liquids for discharge may be produced as a consequence of the treatment of LILW. All discharged liquids should be readily dispersible in water. If the liquid contains suspended materials, it may need to be filtered prior to discharge. Waste that is immiscible with water should be completely excluded from discharge. Acidic or alkaline liquids should be neutralized prior to discharge. If the waste also contains toxic or other chemicals that could adversely affect the environment or the treatment of sewage, the waste should be treated prior to discharge in accordance with the regulations in respect of health and safety and environmental protection.

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

5.30. Used filters and sorption beds are considered to be solid waste. The physical and chemical properties of the selected filter masses should therefore be compatible with the treatment and conditioning processes for the solid LILW streams in which they will be treated. Care should be taken to ensure that the trapped radioactive substances are not dispersed in an uncontrolled manner during the replacement of the filters or the subsequent treatment of radioactive substances.

Conditioning

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

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

5.33. Liquid LILW is often converted into a solid form by solidifying it in a suitable matrix such as cement, bitumen or polymer. Solidification may also be achieved without a matrix material, for example by drying. The product is then enclosed in a container.

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

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

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

5.35. It should be taken into account that certain metals, such as aluminium, magnesium and zirconium, could react with, for example, the alkaline water of a cement slurry or water diffused from a concrete matrix, to produce hydrogen. Chelating agents, organic liquids or oil and salt content in liquid waste may also be of concern in the conditioning process.

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

5.37. If there may be a significant delay before an acceptable disposal route becomes available, the container should provide integrity during the predisposal storage period and should be capable of allowing for:

(a) Retrieval at the end of the storage period;
(b) Enclosure in an overpack, if necessary;
(c) Transport to and handling at a disposal facility;
(d) Performance as required in the disposal environment.

STORAGE

5.38. Storage is an option that should be considered in any waste management strategy. Proper storage should be available at all stages in waste processing for isolation and environmental protection; it should also facilitate retrieval for subsequent steps. Recommendations on the safe storage of radioactive waste are provided in Ref. [12].

5.39. LILW may be stored to allow its radioactivity to decay to levels that permit authorized discharge, authorized use or removal of regulatory control. Storage may also be necessary for operational reasons; for example, to permit off-site transfer at specified time intervals.

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

5.41. Waste contaminated with radionuclides of very short half-life (up to about 100 days) could be collected and stored until it meets criteria established by the regulatory body for the removal of regulatory control from material or for authorized discharge or use.

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

5.43. Collection and storage tanks should have appropriate equipment for stirring, venting and waste transfer to prevent the sedimentation of sludges and the accumulation of hazardous gases in the tank. Provision should be made for sampling and for the reserve capacity necessary for unplanned events. The floor of the room or area where liquid waste is stored or processed should be sealed against the penetration of liquids for ease of decontamination.

5.44. The integrity of waste packages in storage should be ensured and the storage facility should be capable of maintaining the 'as received' integrity of the waste package until it is retrieved for further treatment, conditioning or disposal. The design of the facility should permit radiation monitoring and inspection, including visual or other examination of the waste packages to obtain an early indication of any physical deterioration or signs of leakage or the buildup of gas in the containers.

5.45. Radiation monitoring and visual inspection should be performed whenever the waste is handled or moved (placed into storage, retrieved or transported off the site). This serves to protect workers handling the waste, helps to prevent the accidental spread of contamination and provides an additional check of the record keeping system.

5.46. The storage facility should be adequately ventilated to exhaust any gas generated in normal operation or under anticipated accident conditions. Measures to prevent, detect and control fires should be incorporated into the design of facilities for the storage of combustible waste.

TRANSPORT

5.47. LILW should be adequately packaged and contained for transport by road, rail, air or sea in accordance with the national legal requirements. These national legal requirements should be based on the requirements established in Ref. [10] or in international agreements.

5.48. The on-site transport of LILW may not need to meet all the requirements for off-site transport, because the shipment is at all times under the control of the operator, who is responsible for on-site operations. The operator should establish requirements and authorizations to ensure the safety of on-site transport. The facility operator should take into account in the site emergency procedures the possible exposure of a member of the public as a consequence of the on-site transport of LILW, although such an exposure is unlikely.

6. RECORD KEEPING AND REPORTING

RECORD KEEPING

6.1. The operator of a facility should establish a procedure for maintaining adequate documentation and records in accordance with the quality assurance programme. Recommendations on document control and record keeping are given in Ref. [19], Safety Guide Q3. The scope and detail of the records will depend on the hazard and/or the complexity of the proposed operation and should be subject to approval by the regulatory body.

6.2. Records will have varying periods of usefulness. The requirements are for the records that relate to the waste management facility, the waste itself and compliance with the acceptance criteria for waste disposal to be retained for a period as required by the regulatory body (Ref. [3], paras 3.9 and 3.12). These records should include:

(a) The data needed for a national inventory of waste;
(b) The data needed for waste characterization;
(c) The records from the control processes for treatment, packaging and conditioning;
(d) The documents on the procurement of containers required to provide confinement for a certain period (e.g. in a repository);
(e) The specifications for waste packages and audit records for individual containers and packages;
(f) Trends in operating performance;
(g) Non-compliances with the specifications for waste packages and the actions taken to rectify them;
(h) The monitoring records;

(i) The results of safety assessments;
(j) The written operating procedures;
(k) Any additional data as required by the regulatory body.

6.3. A waste characterization record should contain the following information pertaining to the waste:

(a) The source or origin;
(b) The physical and chemical form;
(c) The amount (volume and/or mass);
(d) The radiological characteristics (the activity concentration, the total activity, the radionuclides present and their relative proportions);
(e) The classification in accordance with the national waste classification system;
(f) Any chemical, pathogenic or other hazards associated with the waste and the concentrations of hazardous material;
(g) Any special handling necessary owing to criticality concerns, the need for the removal of decay heat or significantly elevated radiation fields.

REPORTING

6.4. The operator of the facility should periodically submit reports on compliance with the conditions of authorization to the regulatory body, in accordance with the required schedule. Routine reports should provide information on the waste management operations conducted during the reporting period and the situation at the time of reporting. In general, the report should include a summary description of:

(a) The waste received, either of external origin or generated within the facility itself, including secondary waste from the processing of primary waste and waste from the maintenance or decommissioning of any structures, systems or components at the facility;
(b) The processing of the waste, as well as details of the processes used;
(c) Any waste released by transfer;
(d) Effluent discharges;
(e) Material from which regulatory control is removed;
(f) An inventory and the net changes over several years in the inventory of the waste received, processed, stored and transferred at the facility, as well as trends in safety performance;
(g) Estimates of the impacts of the facility in terms of the radiation exposure of workers and the public;
(h) Non-compliances with the waste acceptance criteria or other requirements.

6.5. The operator of a facility should report promptly to the regulatory body any incident or accident or the discovery of any information that calls into question any aspect of the safety of the facility or the basis for its authorization. Non-compliances with the acceptance criteria for waste and the actions taken or proposed to rectify the situation should also be reported to the regulatory body.

7. SAFETY ASSESSMENT

7.1. Operators are required to include a specific safety assessment report as part of the application for a licence or other type of authorization (Ref. [3], para. 5.3). The detail, scope and rigour of such an assessment will depend on the nature of the waste management operations and on the radiological hazard. If required by national legislation, an environmental impact assessment should be conducted to demonstrate that the anticipated environmental impact of the construction, operation and decommissioning of the facility complies with the regulations issued by the appropriate national authority. It may be required to reassess the anticipated impacts of decommissioning after operational experience has been gained and to conduct a safety assessment.

7.2. A safety assessment is required to be conducted to demonstrate that the performance objectives can be satisfied and that the overall process is acceptable for licensing or authorization (Ref. [3], para. 5.3). The results should include predicted impacts on the workers, the public and the environment. The quantities and concentrations of radioactive or other hazardous materials that may be safely discharged from the facility should be determined and documented. Recommendations on preparing a safety assessment for the predisposal management of LILW are provided in Ref. [20].

7.3. A safety assessment should be conducted with due regard to all relevant regulations and safety guidelines pertinent to the potential hazards at each stage of the waste management operation. The safety assessment should cover all of the operations and inherent hazards associated with every aspect of the management of radioactive waste at the facility. Safety assessments may also be required for practices for waste management off the site, including the transport of the waste.

7.4. The full range of characteristics of the waste that are anticipated should be considered and the impacts and environmental effects of normal operations of the facility and potential accident conditions should be evaluated in the safety assessments. This will entail identifying the environmental pathways for radionuclides to humans and the potential exposures. Values for acceptable levels for all liquid and gaseous effluents that may be routinely discharged to the environment from the facility should be derived on the basis of the potential exposures. The adequacy of equipment used to monitor and control the levels of such discharges should also be assessed. Recommendations and guidance on limiting the releases of radioactive effluents during the normal operations of facilities are provided in Ref. [14]. The safety assessments should be reviewed from time to time and updated as necessary on the basis of the information gathered by monitoring the workplace and the environment.

7.5. Where a hazard is identified by means of a safety assessment, design changes may be made or operational procedures established to control the hazard, or additional steps such as effective personnel training may be considered.

7.6. The conditions, processes and events that influence the integrity and safety of a facility can be considered to originate either outside or inside the facility. Those originating outside the facility will be very site dependent and should be identified on a site specific basis. Annexes III and IV provide aids to memory to assist in their identification.

7.7. The challenges to safety that originate within the facility will be highly dependent on the nature of the facility and on the processes and activities that take place in it and should be identified for the facility in question. Annex V provides an aid to memory to assist in their identification.

7.8. If changes are made to the operational procedures, a process should be put in place to review the safety assessment to ensure that the potential risks have not increased as a result of these changes. Records should be kept of all accidents and incidents (and also of accidents and incidents that were narrowly averted) and should be periodically reviewed in conjunction with the safety assessment and control procedures. Such a review can be used to verify the accuracy of the safety assessment and the effectiveness of the procedures.

8. QUALITY ASSURANCE

8.1. A quality assurance programme for the predisposal management of LILW is required to be established and implemented by the operator of the facility concerned in accordance with the requirements and recommendations for quality assurance provided in Ref. [19] and as required by the regulatory body (Ref. [3], para. 3.12). The purpose of such a programme is to provide assurance that:

(a) Facilities and equipment for the predisposal management of waste are designed, constructed, commissioned, operated and decommissioned in accordance with the appropriate specifications and requirements for safe operation;
(b) Steps in the predisposal management of waste, from its generation through to its conditioning, are such as to facilitate compliance with known or anticipated acceptance requirements for the storage and disposal of the waste;
(c) The regulations and conditions of authorization are complied with.

8.2. The scope and detail of the quality assurance programme for the predisposal management of LILW should be commensurate with the extent and complexity of the activities in relation to the waste and the quantities and potential hazards associated with the waste. The quality assurance programme should focus on items identified as important to radiological safety and to waste containment and isolation.

8.3. The quality assurance programme should address the managerial elements, including planning and scheduling activities and the use of resources. These elements should be documented in the quality assurance programme plan (or description) and the results of the activities should be recorded. The responsibilities and authorities of the personnel and organizations involved should be clearly specified in the plan. This plan should be submitted for approval by the regulatory body.

8.4. It should be ensured that waste packages are prepared in compliance with the requirements for the acceptance of the waste at a storage facility or for disposal. Non-conformances in waste packages should be prevented, particularly for those activities that could lead to an irreversible non-conformance if not properly performed. This may be achieved by means of a quality assurance programme, including implementing procedures, for the following activities:

(a) The characterization of the waste;
(b) The development of the specifications for packages for LILW;
(c) The approval of the conditioning process for the waste;
(d) The confirmation of the characteristics for waste packages;
(e) The review of quality control records.

8.5. The specifications for a waste package should specify the waste acceptance requirements for handling, transport, storage and, as far as possible, disposal.

The operator should develop a conditioning process that results in the production of waste packages within the specifications. Part of this process should be to identify those parameters that should be controlled and the values that are essential for ensuring the production of waste packages in compliance with the specifications.

8.6. Quality records should be established and maintained for each conditioned package of LILW. These records should be reviewed against the specifications to determine the acceptability of the waste package. A record of the results of the review should be made and retained for a specified period of time as approved by the regulatory body. Should a waste package not meet the specifications or the waste acceptance requirements, the nature of the non-conformance should be recorded as well as any decision taken to carry out appropriate corrective actions. The operator should develop a plan for resolving non-conformances prior to the start of conditioning operations for LILW.

8.7. Records generated at all stages of the predisposal management of waste may be important for demonstrating the compliance of the waste package with the specifications. Such records should ensure the traceability of the characteristics of the waste from its collection through to its processing and storage. A system for documentation that includes the development of such records should be established. Examples of the contents of such records for the quality control of waste packages include:

(a) The characterization data for the waste as generated;
(b) The values of the key process parameters for the LILW during its pretreatment, treatment and conditioning;
(c) The calibration records for equipment and systems for process control;
(d) The characterization of the waste form and the associated container (e.g. material certificates for the container and its lid and welds or seals, including quality control tests and their records);
(e) The values of significant monitoring parameters;
(f) The identification of waste packages and storage locations.

These data may be provided for individual waste packages or for all the waste packages together from a uniform process batch.

8.8. If no treatment or conditioning facility is available it may be necessary to store LILW for long periods. There may also need to be a long period of storage before disposal. In such cases the quality assurance programme should be designed to ensure that the quality and integrity of the waste products are sustained and that the records, as well as the marking and labelling of waste packages, are of sufficient quality to identify, maintain and preserve such information.

8.9. An audit programme should be developed that includes provisions for self-assessments and independent assessments (audits). Such assessments should be made to determine whether the programme and plans for the predisposal management of LILW meet the applicable requirements and to confirm that certain activities are covered by the procedures and that the programme is being implemented adequately. Process audits should be conducted for verifying that waste management processes are being conducted within specified parameters, in compliance with the procedures for safe operation and with the requirements established by the regulatory body in a licence or an authorization of another type.

8.10. Process audits should focus on:

(a) Ensuring that important process variables have not changed unfavourably from those values established at the time that the original safety assessment was carried out;
(b) Ensuring that required inspections and measurements are performed and that records are retained;
(c) Verifying that traceability is maintained during the transfer and storage of waste;
(d) Ensuring that the instrumentation used to monitor or control waste processing has not degraded in service or has not been modified without approval, and that a recalibration of instruments is carried out at appropriate intervals in accordance with the applicable specifications or other requirements;
(e) Ensuring that the values of all important parameters of the waste packages are kept within established limits;
(f) Ensuring that the facility is being operated within the assumptions of the safety assessment;
(g) Ensuring that only suitable containers that have been tested as fit for the purpose are used, and within the original specifications for test parameters, as required by any applicable regulations or as recommended in any relevant guidance;
(h) Ensuring that there is a satisfactory training programme for staff to keep them informed about safety requirements and process control.

8.11. Product audits include the examination of the waste form, the waste container or the waste package, usually by non-destructive methods. They should be performed when the auditing organization considers it necessary. Additional audits may be performed by the operator of the disposal facility to assess compliance with the disposal requirements.

8.12. Activities in research and development for the predisposal management of LILW should be performed as appropriate to provide any necessary confirmation of properties and characteristics important to safety.

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Annex I

NATURE AND SOURCES OF LILW FROM NUCLEAR FACILITIES

EXAMPLES OF WASTE FROM NUCLEAR FACILITIES

I–1. Nuclear facilities generate many different types of LILW in a wide range of radionuclide concentrations and in various physical forms and of various chemical compositions. LILW includes contaminated and activated materials with both short and long lived radionuclides. In addition to operational waste streams, waste also arises during the decommissioning of nuclear facilities and restoration activities. Incidents or accidents may also generate waste in variable amounts and of variable composition.

I–2. The sources of LILW considered in this annex are:

(a) The nuclear fuel cycle, including the refining and conversion of uranium concentrates (yellow cake), enrichment and fuel fabrication;
(b) Operations of nuclear power reactors;
(c) The management of spent fuel, including reprocessing;
(d) Support facilities, such as laboratories, research and development facilities, hot cells and other specialized facilities and maintenance and repair facilities;
(e) Decommissioning activities.

Gaseous waste

I–3. The main kinds of gaseous radioactive waste generated in the operation of nuclear facilities are:

(a) Effluents from ventilation systems in buildings;
(b) Off-gas from systems for primary coolant degasification in nuclear reactors;
(c) Off-gas from various processing systems, including spent fuel reprocessing;
(d) Off-gas from the venting of storage tanks.

I–4. The most significant feature to be considered is whether the radioactive material is present in particulate, aerosol or gaseous form.

I–5. The activity of gaseous waste is dependent on its origin. Building ventilation air usually has lower contamination levels than process or coolant off-gas or off-gas from the venting of liquid waste storage tanks.

Liquid waste and slurries

I–6. The main kinds of liquid radioactive waste generated in nuclear facilities are:

(a) Water from laundries, showers, etc.;
(b) Drainage water from floors and equipment;
(c) Organic liquids;
(d) Liquids from decontamination, which may also contain complexing agents;
(e) Liquids resulting from chemical processes.

I–7. Slurries include mainly:

(a) Spent ion exchange resins;
(b) Filter aids;
(c) Sludges;
(d) Precipitation flocculants;
(e) Evaporator concentrates.

Solid waste

I–8. The main kinds of solid radioactive LILW generated in nuclear facilities are:

(a) Trash;
(b) Metallic components and tools;
(c) Fuel cladding and other parts of the fuel assembly;
(d) Incineration residues (ashes, slag and bag house dust);
(e) Protective covers, clothing, masks, gloves and filter boxes;
(f) Concrete, wood, debris and soil;
(g) Activated reactor core components and radiation sources.

SOURCES OF WASTE

Nuclear fuel supply

I–9. LILW from the nuclear fuel supply includes, for example, waste generated in the refining and conversion of uranium and thorium, the enrichment of uranium and the fabrication of fuel elements. This waste consists of contaminated solid items, including both combustible and non-combustible materials, process sludges and residues, and aqueous and organic liquids. LILW from the fuel supply includes primarily long lived alpha emitters.

Nuclear power plant operations

I–10. Waste from nuclear power plants includes contaminated and activated materials originating from various operations in the controlled areas of the plant. Most of this waste is short lived.

I–11. Liquid waste arises from contaminated coolant water, water cleanup systems, fuel storage pool water, equipment drains, floor drains and laundry waste. Wet solid waste with a high water content arises from treatment processes such as filtration, evaporation, chemical precipitation and ion exchange. These processes result in the production of sludges, spent ion exchange resins and evaporator concentrates. Contaminated oil and liquids containing organic material may arise from the decontamination, repair and maintenance of facilities and equipment.

I–12. Solid waste generated in routine reactor operations may include contaminated clothing, floor sweepings, plastic, paper, gas trapping devices, filters and discarded components. Both combustible and non-combustible solid waste is generated.

I–13. Gaseous waste sources vary according to reactor type. They may include gases removed from the coolant through degasification and venting systems or air ejectors, and coolant discharges and leakages. In addition, all types of reactor produce activated and contaminated ventilation air and noble gases.

I–14. LILW from nuclear power plants includes short lived and long lived fission and activation products generated as a consequence of the neutron flux in the reactor.

Spent fuel management

I–15. Spent fuel management facilities include spent fuel storage facilities, reprocessing facilities and conditioning facilities. Spent fuel storage facilities generate LILW, for example from the treatment of cooling pond water in wet storage facilities. Such waste includes solid, liquid and gaseous LILW.

I–16. Reprocessing operations generate solid, liquid and gaseous LILW. Solid waste includes fuel element cladding, fuel assembly components, insoluble residues and waste that is characteristic of the technology used. This solid waste may contain both activation and fission products. Liquid waste includes sludges and concentrates from the treatment of liquid effluents, and concentrates from solvent washing and acid recovery, including aqueous and organic liquids. Gaseous fission product waste may be generated in the fuel dissolution process. Reprocessing waste includes long lived and short lived radionuclides.

Support research facilities and pilot plants

I–17. Support facilities generating LILW include research reactors, hot cells, pilot fuel reprocessing, maintenance and repair facilities, post-irradiation examination facilities, research and development facilities and laboratory facilities. There is no ‘typical’ waste from these facilities; the waste is diverse and variable.

Decommissioning and restoration

I–18. LILW is generated during the decommissioning of nuclear facilities and in the restoration of sites. Such waste varies greatly in type, activity, size and volume, and includes both activated materials and contaminated items. Solid waste includes mainly process equipment, plant components, building materials and soil. Liquid waste results from cleaning and decontamination operations. The radionuclides present in decommissioning waste correspond to those used or generated in the nuclear facility in operation.

Annex II

DEVELOPMENT OF SPECIFICATIONS FOR WASTE PACKAGES

II–1. Specifications for conditioned LILW are established to ensure that the waste package satisfies the relevant acceptance criteria for transport, storage or disposal. The waste package specifications are determined in such a way as to ensure that the final product (the waste package) will meet applicable waste acceptance criteria, in particular for disposal. The radiological characteristics (radionuclide concentrations, activity and dose rate) of the waste are the most important ones and are identified at an early stage. Other waste package specifications may be divided into four main topics: chemical and physical properties, mechanical properties, containment capacity and stability. This last topic, 'stability', concerns the capacity of the waste package to retain radionuclides over extended periods of time.

CHEMICAL AND PHYSICAL PROPERTIES

II–2. The chemical and physical properties of the waste form include:

(a) Its chemical composition;
(b) Its density, porosity, permeability to water and permeability to gases;
(c) Its homogeneity and the compatibility of the waste with the matrix;
(d) Its thermal stability;
(e) The percentage of water incorporated, exudation of water under compressive stress, shrinkage and curing;
(f) Its leachability and corrosion rate.

II–3. The chemical and physical properties of the container include:

(a) Its materials;
(b) Its porosity, permeability to water and permeability to gases;
(c) Its thermal conductivity;
(d) Its solubility and corrosion in corrosive atmospheres or liquids such as water or brines.

II–4. The physical properties of the waste package include:

(a) The number of voids in the container (which are to be minimized);
(b) The characteristics of the lidding and sealing arrangements;
(c) Its sensitivity to changes in temperature.

MECHANICAL PROPERTIES

II–5. The mechanical properties of the waste form include its tensile strength, compressive strength and dimensional stability.

II–6. The mechanical properties of the waste package include its behaviour under mechanical (static and impact) or thermal loads.

CONTAINMENT CAPABILITY

II–7. The containment capability of the waste package concerns:

(a) The diffusion and leaching of radionuclides in an aqueous medium;
(b) The release of gas under standard atmospheric conditions or the conditions in a repository;
(c) The diffusion of tritium under standard atmospheric conditions or conditions in a repository;
(d) The capability for the fixation and retention of radionuclides;
(e) The watertightness and gastightness of the package sealing device.

STABILITY

II–8. Stability of the waste package concerns:

(a) Its behaviour under temperature cycling;
(b) Its sensitivity to elevated temperatures and behaviour in a fire;
(c) Its behaviour under conditions of prolonged radiation exposure;
(d) The sensitivity of the matrix to water contact;
(e) Its resistance to the action of micro-organisms;
(f) The corrosion resistance in a wet medium (for metal containers);
(g) Its porosity and degree of gastightness;
(h) Its potential for swelling due to the internal buildup of evolved gases.

Annex III

SITE CONDITIONS, PROCESSES AND EVENTS FOR CONSIDERATION IN A SAFETY ASSESSMENT (EXTERNAL NATURAL PHENOMENA)

In making use of this list it should be recognized that the initiating events given would not necessarily be applicable to all facilities and all sites. The list is provided for use as an aid to memory.

(1) The meteorology and climatology of the site and region:
  - (i) Precipitation (averages and extremes, including frequency, duration and intensity):
    - — rain, hail, snow and ice;
    - — snow cover and ice cover (including potential for blocking inlets or outlets);
    - — drought.
  - (ii) Wind (averages and extremes, including frequency, duration and intensity):
    - — tornadoes, hurricanes and cyclones.
  - (iii) Rate and duration of the input of direct solar radiation (insolation, averages and extremes).
  - (iv) Temperature (averages and extremes, including frequency and duration):
    - — permafrost and the cyclic freezing and thawing of soil.
  - (v) Barometric pressure (averages and extremes, including frequency and duration).
  - (vi) Humidity (averages and extremes, including frequency and duration):
    - — fog and frost.
  - (vii) Lightning (frequency and intensity).

(2) The hydrology and hydrogeology of the site and region:
  - (i) Surface runoff (averages and extremes, including frequency, duration and intensity):
    - — flooding (frequency, duration and intensity);
    - — erosion (rate).
  - (ii) Groundwater conditions (averages and extremes, including frequency and duration).
  - (iii) Wave action (averages and extremes, including frequency, duration and intensity):
    - — high tides, storm surges and tsunami;
    - — flooding (frequency, duration and intensity);
    - — shore erosion (rate).

(3) The geology of the site and region:
  (i) Lithology and stratigraphy:
    — the geotechnical characteristics of site materials.
  (ii) Seismicity:
    — faults and zones of weakness;
    — earthquakes (frequency and intensity).
  (iii) Vulcanology:
    — volcanic debris and ash.
  (iv) Historical mining and quarrying:
    — ground subsidence.

(4) The geomorphology and topography of the site:
  (i) Stability of natural material:
    — slope failures, landslides and subsidence;
    — avalanches.
  (ii) Surface erosion.
  (iii) The effects of the terrain (topography) on weather conditions or on the consequences of extreme weather.

(5) The terrestrial and aquatic flora and fauna of the site (in terms of their effects on the facility):
  (i) Vegetation (terrestrial and aquatic):
    — the blocking of inlets and outlets;
    — damage to structures.
  (ii) Rodents, birds and other wildlife:
    — direct damage due to burrowing, chewing, etc.;
    — accumulation of nesting debris, guano, etc.

(6) The potential for:
  (i) Naturally occurring fires and explosions at the site.
  (ii) Methane gas or natural toxic gas (from marshland or landfill sites).
  (iii) Dust storms or sand storms (including the possible blocking of inlets and outlets).

Annex IV

SITE CONDITIONS, PROCESSES AND EVENTS FOR CONSIDERATION IN A SAFETY ASSESSMENT (EXTERNAL HUMAN INDUCED PHENOMENA)

In making use of this list it should be recognized that the initiating events given would not necessarily be applicable to all facilities and all sites. The list is provided for use as an aid to memory.

(1) Explosion:
  (i) Solid substance;
  (ii) Gas, dust or aerosol cloud.
(2) Fire:
  (i) Solid substance;
  (ii) Liquid substance;
  (iii) Gas, dust or aerosol cloud.
(3) Aircraft crash.
(4) Missiles due to structural or mechanical failure in nearby installations.
(5) Flooding:
  (i) The structural failure of a dam;
  (ii) The blockage of a river.
(6) Ground subsidence or collapse due to tunnelling or mining.
(7) Ground vibration.
(8) The release of any corrosive, toxic and/or radioactive substance:
  (i) Liquid;
  (ii) Gas, dust or aerosol cloud.
(9) Geographic and demographic data:
  (i) Population density and expected changes over the lifetime of the facility;
  (ii) Industrial and military installations and related activities and the effects on the facility of accidents at such installations;
  (iii) Traffic;
  (iv) Transport infrastructure (highways, airports and/or flight paths, railway lines, rivers and canals, pipelines and the potential for impacts or accidents involving hazardous material).
(10) Power supply and the potential loss of power.
(11) Civil strife:
  (i) Terrorism, sabotage and perimeter incursions;
  (ii) The failure of infrastructure;

(iii) Civil disorder;
(iv) Strikes and blockades;
(v) Health issues (e.g. endemic diseases or epidemics).

Annex V

POSTULATED INITIATING EVENTS FOR CONSIDERATION IN A SAFETY ASSESSMENT (INTERNAL PHENOMENA)

In making use of this list it should be recognized that the initiating events given would not necessarily be applicable to all facilities and all sites. The list is provided for use as an aid to memory.

(1) The acceptance (inadvertent or otherwise) of incoming waste, waste containers, process chemicals, conditioning agents, etc., that do not meet the specifications (acceptance criteria) included in the design basis.

(2) The processing of waste that meets acceptance criteria but that is subsequently processed in an inappropriate way for the particular type of waste (either inadvertently or otherwise).

(3) A criticality event due to the inappropriate accumulation of fissile material, change of geometrical configuration, introduction of moderating material, removal of neutron absorbing material or various combinations of these.

(4) Explosion due to the evolution of explosive gas mixtures as a result of:
  - (i) Radiolysis.
  - (ii) Off-gassing or volatilization.
  - (iii) Chemical reactions from inappropriate mixing or contact with:
    - — different waste streams;
    - — waste and conditioning agents;
    - — waste container material and conditioning agents;
    - — process chemicals;
    - — waste, waste containers, conditioning agents, process chemicals and the prevailing conditions of the work environment or storage environment.
  - (iv) The inclusion of items such as bottles of compressed gas in the input to incinerators or compactors.

(5) Fire due to:
  - (i) Spontaneous combustion;
  - (ii) Local hot spots generated by malfunctions of structures, systems or components.
  - (iii) Sparks from machinery, equipment or electrical circuits.
  - (iv) Sparks from human activities such as welding or smoking.
  - (v) Explosions.

(6) Gross incompatibilities between the components of a process system and the materials introduced into the system.

(7) The degradation of process materials (chemicals, additives or binders) due to improper handling or storage.
(8) The failure to take account of the non-radiological hazards presented by the waste (physical, chemical or pathogenic).
(9) The generation of a toxic atmosphere by chemical reactions due to the inappropriate mixing or contact of various reagents and materials.
(10) Dropping waste packages or other loads due to mishandling or equipment failure, with consequences to the dropped waste package and possibly to other waste packages or to the structures, systems and components of the facility.
(11) Collisions of vehicles or suspended loads with structures, systems and components of the facility or with waste packages, waste containment vessels and pipes.
(12) Failures of structures, systems and components due to:
  (i) The loss of structural competence or mechanical integrity.
  (ii) Vibrations originating within the facility.
  (iii) Pressure imbalances (pressure surges or pressure collapses).
  (iv) Internal corrosion or erosion or the chemical effects of the work or storage environment.
(13) The generation of missiles and flying debris due to the explosion of pressurized components or the gross failure of rotating equipment.
(14) The malfunctioning of heating or cooling equipment, leading to unintended temperature excursions in process systems or storage systems.
(15) The malfunctioning of process control equipment.
(16) The malfunctioning of equipment that maintains the ambient conditions in the facility, such as the ventilation system or dewatering system.
(17) The malfunctioning of monitoring or alarm systems so that an adverse condition goes unnoticed.
(18) Incorrect settings (errors or unauthorized changes) on monitors, alarms or control equipment.
(19) The failure to function when called upon of emergency equipment such as the fire suppression system, pressure relief valves and ducts.
(20) The failure of the power supply, either the main system or various subsystems.
(21) The malfunctioning of key equipment for handling waste, such as transfer cranes or conveyors.
(22) The malfunctioning of structures, systems and components that control releases to the environment, such as filters or valves.
(23) The failure properly to inspect, test and maintain structures, systems and components.
(24) Incorrect operator action due to inaccurate or incomplete information.
(25) Incorrect operator action in spite of having accurate and complete information.

(26) Sabotage by employees.
(27) The failure of systems and components such as incinerator linings, compactor hydraulics or cutting machinery that poses the risk of significant additional radiation exposure of personnel called on to assist in effecting repairs or replacements.
(28) Encountering an unanticipated radiation source in decommissioning (e.g. different in nature or amount) and not recognizing immediately the changed circumstances.
(29) Removing or weakening a structure or component in decommissioning without realizing the possible effects on the structural competence of other structures and components.

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