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Predisposal Management of High Level Radioactive Waste

SAFETY GUIDE

No. WS-G-2.6

INTERNATIONAL
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IAEA SAFETY STANDARDS

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PREDISPOSAL MANAGEMENT OF HIGH 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.

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. Radioactive waste is generated in the generation of electricity in nuclear power plants 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 high level radioactive waste, which includes high level waste (HLW) in liquid form and solidified form from the reprocessing of spent fuel and also spent fuel itself, if declared as waste. The predisposal management of radioactive waste includes all the steps in the management of waste prior to its disposal and also includes decommissioning. This Safety Guide provides recommendations to regulatory bodies and other national authorities and operating organizations (operators) on the safe processing of waste and guidance on the properties necessary for waste packages to meet the requirements for handling, transport, storage and disposal. Meeting these requirements will ensure proper planning for and the safe management of HLW in the established nuclear regulatory framework.

1.4. HLW originates primarily from spent fuel. There are two fundamental approaches to managing spent fuel:

(a) Reprocessing to extract potentially valuable fissile material for recycling and the management of the resulting reprocessing waste (generally known as the ‘closed fuel cycle’);

(b) The direct disposal of the spent fuel, if it is declared as waste (generally known as the 'once through fuel cycle').

1.5. HLW may include the following: (1) spent fuel (if declared as waste); (2) the radioactive liquid (hereinafter referred to as liquid HLW) from the reprocessing of spent fuel, containing most of the fission products and actinides originally present in the spent fuel, and the waste form (hereinafter referred to as solidified HLW) resulting from the solidification of this material; and (3) other waste with an activity comparable with that of (1) and (2) above. HLW is both heat generating and long lived.

1.6. Programmes for managing HLW may include other waste streams that are directed to an HLW programme. Examples include reactor core components, the structural parts of fuel assemblies or other waste streams that arise from reprocessing and that may be concentrated and added to the liquid HLW for technical or economic reasons.

1.7. Spent fuel may be kept in a storage facility for an extended period pending a decision being made on whether to reprocess it. In addition to the protection of human health and the environment, several considerations will influence the choice of approach, such as: the accumulated amount of spent fuel and the available storage capacity; safety considerations (such as the integrity of the fuel cladding) relating to the long term storage of the fuel; the financial resources available; the state of the waste management systems available; public consultation; and uncertainties about future social and political conditions. If no decision is made on the disposal or reprocessing of the spent fuel it should be ensured that the capability and capacity for storage are adequate.

Processing and storage

1.8. The predisposal management of HLW may include one or more processing steps (e.g. pretreatment, treatment and conditioning). The handling, storage and transport of the waste will be necessary within, between and after such steps. The approaches to be taken for managing the HLW will determine the necessary processing steps (see Annex I).

1.9. The objective of predisposal management is to produce packages of conditioned HLW suitable for safe handling, transport, storage and disposal. If no disposal facility is available for the HLW, assumptions should be made on the requirements for the acceptance of the waste in the future at a repository in order to provide guidance for its predisposal management. In the absence of a disposal facility it should be ensured that all relevant parties are involved in the discussions that lead to the formulation of the necessary guidance.

Decommissioning

1.10. The decommissioning of a management facility for HLW involves various administrative and technical actions to be taken at the end of its useful life to enable the removal of some or all of the regulatory controls from the facility. Planning should be carried out at an early stage to enable the incorporation of design features to facilitate decommissioning and the specification of appropriate operational measures which, when taken together, should contribute substantially to the safe decommissioning of the facility. Requirements and recommendations for the decommissioning of nuclear facilities of various kinds are provided in Refs [3–6], and these safety standards should be consulted for their applicability to decommissioning activities for HLW.

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 HLW.

SCOPE

1.12. This Safety Guide applies to the predisposal management of HLW as defined in para. 1.5.

1.13. For liquid HLW arising from the reprocessing of spent fuel the recommendations of this Safety Guide apply from when liquid waste from the first extraction process is collected for storage and subsequent processing.

1.14. Recommendations and guidance on the storage of spent fuel, whether or not declared as waste, subsequent to its removal from the storage facility of a reactor are provided in Refs [7–9].

1.15. For spent fuel declared as waste this Safety Guide applies to all activities subsequent to its removal from the storage facility of a reactor and prior to its disposal.

1.16. Requirements pertaining to the transport of spent fuel, whether or not declared as waste, and of all forms of HLW (see para. 1.5) are established in Ref. [10] and related recommendations are presented in Ref. [11].

1.17. For any other type of waste or waste stream this Safety Guide applies when the waste is directed into the HLW stream under the respective predisposal management scheme. If not directed into the HLW stream, low and intermediate level waste streams, including those generated in the predisposal management of HLW, should be managed in accordance with the recommendations given in Ref. [12].

1.18. This Safety Guide provides recommendations on the safety aspects of managing HLW, including the planning, design, construction, commissioning, operation and decommissioning of equipment or facilities for the predisposal management of HLW. It addresses the following elements:

(a) The characterization and processing (i.e. pretreatment, treatment and conditioning) of HLW;
(b) The storage of liquid and solidified HLW;
(c) The storage of conditioned spent fuel.

1.19. Recommendations on the decommissioning of facilities for the predisposal management of HLW are provided in Ref. [4]. Recommendations on safety assessments for HLW facilities are to be included in a Safety Guide on Safety Assessment for Nuclear Fuel Cycle Facilities, Excluding Reactors and Waste Repositories, and particular recommendations on storage will be provided in a Safety Guide on Safe Storage of Radioactive Waste. This Safety Guide provides additional recommendations in these areas only if they are specific to the predisposal management of HLW.

1.20. Unless specific reference is made to one or more categories, the recommendations in this Safety Guide apply generally to all categories of HLW. The possibility of criticality is more significant for spent fuel than it is for other categories of HLW, and should be given appropriate consideration in all activities in which spent fuel is involved. The possibility of criticality involving liquid HLW should, however, also always be considered (see para. 5.3).

STRUCTURE

1.21. 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 HLW and Section 5 presents recommendations on the predisposal management of liquid HLW and spent fuel, 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. An appendix outlines the key properties and characteristics of HLW. Annex I presents a summary of practical steps in the predisposal management of HLW. Annexes II and III list site conditions, processes and events for consideration in a safety assessment for external natural phenomena and for external human induced phenomena, respectively. Annex IV 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 HLW. Activities in the predisposal management of HLW contribute to ensuring that HLW 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]. The predisposal management of HLW should form an essential part of a national system for the management of HLW and it should be ensured that the applicable safety requirements are met.

2.2. In the design of a facility and the planning of practices for the predisposal management of HLW 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).

2.3. Owing to the high radionuclide concentrations and high radiation levels associated with HLW, its predisposal management has the potential to give rise to significant exposure to radiation of workers and members of the public. Particular emphasis should therefore be placed on the prevention, detection and mitigation of incidents and accidents in the design, operation and decommissioning of facilities for the management of HLW.

2.4. Careful attention should also be paid to the control of occupational exposure in the design of a facility and in operational practices for the predisposal management of HLW. Doses due to occupational exposure should be maintained ALARA 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 HLW, including facilitating the eventual decommissioning of management facilities for HLW;
(b) Pre-work assessments and training mockups to minimize exposures during operational and maintenance activities;
(c) The use of remote handling technologies for operational and maintenance activities;
(d) Establishing controls, such as activity limits, if items are transferred or removed from areas of higher contamination to areas of lower contamination.

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

2.6. 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.

2.7. The primary safety concern with HLW 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 HLW. Protection from non-radiological hazards should be provided in accordance with the relevant standards on health and safety and environmental protection.

2.8. The management of HLW is required to be carried out in such a manner that no undue burdens are imposed on future generations (Ref. [1]; Ref. [3], para. 2.1). Decision making on the reprocessing or direct disposal of spent fuel, for example, is often postponed if no disposal facility is available. In practice, therefore, spent fuel is stored in an engineered facility, the design, operation and safety assessment of which should proceed in accordance with the recommendations and guidance given in Refs [7–9], respectively.

2.9. Operators responsible for the predisposal management of HLW should maintain an awareness of the potential national strategies for the disposal of HLW, and should study processes for its eventual disposal that are consistent with national planning. Programmes should be undertaken such that the generation of liquid HLW and the need for its long term storage are minimized to the extent practicable. Consideration should be given to stabilizing the waste while decisions on its disposal are pending. This should be in a form that is likely to meet the waste acceptance criteria for a future repository and that will provide greater protection to present and future generations.

2.10. Whichever strategy is chosen, all facilities involved in the predisposal management of HLW should be designed and operated, and all activities concerned should be conducted, in a manner that is consistent with the hazards of the particular form of the HLW. If treatment or an initial conditioning of the liquid HLW is performed, for example, to provide a safer form and to reduce the probability of its dispersal, consideration should be given to its subsequent processing and its compatibility with the final form of the conditioned waste. Consideration should also be given to all hazards associated with the techniques employed to stabilize waste.

2.11. "The generation of radioactive waste shall be kept to the minimum practicable, in terms of both its activity and volume…" (Ref. [1], para. 324). Minimizing the generation of HLW, if possible, should be a goal of the process in which it is generated. It should be a general goal to reduce the volume and activity of the secondary waste streams that can arise from the management activities for HLW. Elements that should be considered for reducing the amounts of such waste generated include the use of a well designed process, efficient operations and a well conceived and executed decommissioning of the facility.

2.12. A safety culture is required to be fostered and maintained in all organizations involved in the predisposal management of HLW, 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 HLW 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 HLW. 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 HLW are established in Ref. [2].

3.2. The predisposal management of HLW may involve the transfer of radioactive waste from one operator to another or the processing of HLW 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 HLW, including any transfer between operators. Consideration should also be given to the decommissioning of any facility at which HLW 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 HLW).

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 HLW, 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 HLW. 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 HLW 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 HLW 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 HLW 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 Ref. [17].

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

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

3.9. The regulatory body should verify the key aspects of operations for the predisposal management of HLW to be performed by the operator, such as the compliance of the conditioned HLW 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 HLW 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 HLW, 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 HLW 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 HLW 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 on 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 HLW. 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 HLW 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 HLW [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 HLW.

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 HLW, from the generation of the waste to its disposal. In selecting strategies and activities for the predisposal management of HLW, 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. Options for the storage of HLW should be selected so as to ensure that they will be compatible with the activities for waste processing.

4.2. The interdependences among the steps in the predisposal management of HLW should be considered so as to facilitate 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. For most programmes for the management of HLW, decisions about predisposal management have to be made before the waste acceptance requirements for disposal are finalized. Decisions on the predisposal management of HLW 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 HLW, 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. The suitability of waste packages should be kept under periodic review as the technology for waste disposal is developed.

CONTROL OF WASTE GENERATION

4.4. The generation of HLW, whether in the form of liquid HLW resulting from the reprocessing of spent fuel or in the form of spent fuel itself, is an inevitable consequence of operating a nuclear power plant. In general, the activity content is correlated with the type of nuclear fuel, the level of burnup, the decay period and the requirements for the selected reprocessing techniques.

4.5. It should be duly taken into account that treatments such as the neutralization of acidic liquid HLW in the predisposal management of HLW may increase the volume and solids content of the waste generated.

4.6. In particular, the principle of keeping the volume of waste to the minimum practicable should be a factor for consideration in the selection of approaches to storage and processing, in order to minimize the generation of secondary forms of HLW. Examples of processing steps for which this principle should be considered include the selection of conditioning processes and the testing programme invoked to verify treatment and conditioning processes. For a conditioning process in which components become contaminated, such as a melter for the vitrification of HLW, equipment of proven longevity should be used. For the qualification of a conditioning process the programme should be designed in such a way that the number of test specimens using actual HLW is minimized.

4.7. Since reduction at source is the most efficient means of keeping the amounts of radioactive waste generated to the minimum practicable, facilities for the predisposal management of HLW should be designed and operated and activities should be planned and conducted so as to minimize the amounts of secondary waste generated. Useful methods for the minimization of the amounts of such waste that are relevant to the predisposal management of HLW are outlined in Ref. [12].

CHARACTERIZATION OF WASTE

4.8. HLW 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 HLW (Ref. [3], paras 5.4 and 5.14).

4.9. The data requirements for characterization and methods for collecting data will differ depending on the form of the HLW (whether it is liquid HLW, solidified HLW or spent fuel). The characterization of HLW should normally be performed at the following stages: (a) the identification of pretreatment steps to provide safe storage; (b) the development of a suitable waste form and waste package; (c) the development of a qualified conditioning process; and (d) the completion of major processing activities.

4.10. The characterization of HLW should provide, as a minimum, the information outlined in the Appendix on its properties and characteristics.

4.11. When liquid HLW streams are processed, the products may have to be characterized by sampling and analysing the chemical, physical and radiological properties of the waste. 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 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. The characterization of solidified HLW should be performed by means of sampling the liquid HLW and the control of a well instrumented, qualified process with a sound process control programme. The characterization should provide all the information on the waste form and the waste container that is necessary for the handling, transport, storage and, as far as possible, disposal of the waste. Any additional requirements for characterization data that may be identified upon finalizing the requirements for disposal should be anticipated as far as possible. Additionally, it may be necessary to take account of changes in the chemical and physical form of the waste over time due to irradiation and the thermal energy of the HLW, especially if its disposal is significantly delayed.

4.13. Data for use in the characterization of spent fuel should be available from records on the operation of the reactor and the decay of radionuclides after the unloading of the spent fuel. Provision should be made to verify key parameters by means of non-destructive techniques such as the measurement of neutron fluxes. Consideration should also be given to the integrity of the fuel cladding.

ACCEPTANCE CRITERIA

4.14. An important objective of the predisposal management of HLW should be to produce waste packages that can be handled, transported, stored and disposed of safely. In particular, HLW 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 HLW 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 HLW and the engineered components of the disposal facility. The Appendix provides a listing of the typical properties and characteristics that should be considered for the waste package in the predisposal management of HLW. There should also be a quality assurance programme (see Section 8) governing the properties of waste packages.

4.15. 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. The listing of the tests that have been performed and the requirements that have been met, as demonstrated by the operator, should provide the basis for an agreement with the operator of the disposal facility. If, for example, a matrix material is applied in the conditioning of HLW, tests should be performed in order to confirm the expected performance of the waste form in its disposal environment. These tests include leach tests, simulated radiation damage tests and thermal stability tests. Accelerated leach tests to predict the long term durability of the matrix should be considered. Simulated radiation damage tests should be carried out to obtain information on changes in the waste form. Thermal stability tests to assess eventual phase changes, for example the crystallization of glass, should be considered. Guidance on implementing a quality assurance programme specific to the predisposal management of HLW is provided in Section 8.

QUALIFICATION OF STAFF

4.16. Operating staff should be qualified in accordance with the requirements of the regulatory body for the performance of their tasks in the predisposal management of HLW. Staff who are responsible for the operation of facilities in which HLW 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.

4.17. Personnel designated to select process technologies for the predisposal management of HLW also should be trained and qualified to perform their functions. Additionally, operators for the predisposal management of HLW 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

4.18. Predisposal management facilities for HLW have a limited useful lifetime. At the end of this useful lifetime, actions should be taken to remove, treat or condition any HLW remaining in the facility in advance of its decommissioning. Consideration should be given to the safety of decommissioning activities in the design of a facility for the management of HLW. 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 [4–6].

4.19. 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, including facilities for the processing and storage of HLW, are presented in Ref. [4]. The key elements that should be considered for the decommissioning of facilities for the predisposal management of HLW, as specified in Ref. [4], include:

(a) The selection of a decommissioning option in which the radionuclides in the residual HLW, the type of management facility for the HLW, 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.

4.20. 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.

4.21. The decommissioning of facilities for the predisposal management of HLW may give rise to many heavily contaminated components that are unamenable to decontamination. Designated storage, processing or disposal arrangements for such items should be provided. Controls to ensure that decontamination work is conducted safely and that requirements for the removal of material from regulatory control are complied with should be considered.

PREPARATION OF DOCUMENTATION ON SAFETY

4.22. The regulatory body will 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 HLW. Matters such as the following should be covered in the safety documents for such an 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.

ACCESS CONTROL

4.23. The control of access to areas in which HLW is handled, stored or processed may be necessary owing to the radiological or other hazards presented by the waste, or because the nature of the waste necessitates the application of safeguards provisions [19–21] and physical protection [22], and should therefore be considered.

4.24. In meeting the operational requirement to control access effectively, a zoned approach, working inwards towards areas of more stringent safety procedures and controls in a structured manner, should be considered.

4.25. There should be provisions for detecting any unauthorized intrusion reliably and rapidly and for taking countermeasures without delay.

EMERGENCY PREPAREDNESS

4.26. The potential radiological impacts of incidents and accidents should be assessed. Depending on the result of this assessment, provision should be made to ensure that there is an effective capability for reaction to incidents and accidents. Provision could include the development of scenarios of anticipated sequences of events and the establishment of procedures to deal with each of the scenarios, including checklists and lists of persons and organizations inside and outside the facility to be alerted [23]. Care should be taken to ensure that the necessary emergency response procedures are documented, that the documents are available to the personnel concerned and that the procedures and documents are kept up to date. The need for exercises should be assessed. If there is such a need, exercises should be held periodically to test the emergency response plan and the degree of preparedness of the personnel. Inspections should be performed regularly to ascertain whether the equipment needed in the event of an emergency is available and in working order.

5. SAFETY FEATURES FOR THE PREDISPOSAL MANAGEMENT OF HLW

GENERAL CONSIDERATIONS

5.1. Processing activities for HLW and their corresponding safety features vary depending on the initial characteristics of the waste and, ultimately, the acceptance requirements for waste disposal. For example, limits may be specified for the radionuclide content and thermal power, neutron flux, corrosion resistance of the containers, leach rates for the waste form, mechanical and thermal properties and the content of non-nuclear constituents. HLW should be characterized for its relevant properties as a prerequisite for safety.

5.2. Activity levels for HLW are significantly higher than those for most other types of radioactive waste. In order to provide an acceptable level of protection, the concept of defence in depth [24] should be applied in the design and operation of a facility for the predisposal management of HLW. The use of multiple levels of containment (i.e. physical barriers) should be a primary strategy in the predisposal management of HLW. For implementing this strategy, the design of a predisposal management facility for HLW should include features (engineering controls) to maintain containment, remove decay heat, control gaseous and liquid effluents, and prevent criticality, especially when concentrating HLW to reduce its total volume. The use of administrative controls as part of the defence in depth approach should be considered, although engineered controls are preferable.

5.3. Criticality safety should be an important concern for spent fuel but is much less so for other categories of HLW. However, even for liquid HLW, from which the fissile material has presumably been removed, the possibility of the carryover of some fissile material should always be considered and the possibility of criticality should be carefully examined. This is especially important if solids may settle or precipitate from the liquid.

ELEMENTS OF THE PREDISPOSAL MANAGEMENT OF HLW

Liquid HLW

5.4. The HLW that arises from the reprocessing of spent fuel is in a liquid form. The predisposal management of this waste includes storage in a liquid form, conversion into a solidified waste form, packaging and the storage of the waste package.

Paragraphs 5.5–5.17 provide recommendations for the safe management of liquid HLW.

Storage of liquid HLW

5.5. Recommendations for the design and operation of storage facilities and the associated activities for the storage of radioactive waste are under preparation and will be published in a Safety Guide. Recommendations relating to the storage specifically of liquid HLW are provided in paras 5.6–5.9.

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

5.7. Care should be taken to ensure that liquid HLW is chemically compatible with the process chemistry used for its conditioning and with the structural materials of vessels, pipes and other structures and components. In addition to the requirements for containment specified in paras 5.33 and 5.34, storage facilities for liquid HLW should usually incorporate other design features, such as double walled pipes and vessels, containment bunds and sumps for waste holding tanks and active ventilation systems that ensure that air flows from areas of lower contamination to areas of higher contamination. Collection and recovery systems for leaks or spills, such as cell lining and sump systems and liquid recycling systems, should be provided. Measures should also be in place to maintain solids in suspension in order to promote adequate cooling and to prevent their buildup on cooling surfaces.

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

5.9. Storage facilities for liquid HLW should be provided with off-gas systems that employ appropriate filtration systems to control the release of airborne effluents.

Processing of liquid HLW

5.10. The processing of radioactive waste includes a number of pretreatment operations, for example waste collection, segregation, chemical adjustment and decontamination. Liquid HLW should be collected, segregated and chemically adjusted to facilitate its subsequent treatment and conditioning. Specifically, if blending different batches of liquid HLW is not a feasible processing step, the segregation of such waste on the basis of its chemical properties, radiological properties (e.g. nuclide specific (actinide) content) and thermal properties (heat generation rates) should be considered.

5.11. The treatment of liquid HLW includes operations that will substantially change its characteristics and can include, for example, evaporation, ion exchange, flocculation, chemical addition, precipitation and filtration, and calcination. The requirements for treatment will depend upon the characteristics of the liquid HLW, the capability of the storage facility (in terms of both capacity and chemical compatibility between the material of the containers and the material stored) and the type of follow-on conditioning process selected. The treatment should be used to enhance safety by producing a more stable waste form for storage or conditioning, by facilitating the conditioning process or by removing non-radioactive hazardous compounds.

5.12. Conditioning involves the conversion of liquid HLW into a solid waste form, the enclosure of the solidified waste in containers (typically called canisters) and, as required, the placement of the containers into an overpack for storage or disposal. The solidified waste form, together with any containers, is generally described as a waste package; this waste package should be in a form suitable for disposal. The requirements for materials and the structural requirements for containers should be based on the known or expected requirements for acceptance for disposal. The waste package should be designed to ensure safety in handling, transport and storage.

5.13. The facilities available should have the capability to handle waste packages (including waste forms and any containers) that do not conform with the given specifications. For example, this may require the availability of separate facilities for the storage of non-conforming HLW packages or those that require remedial action.

5.14. Processing facilities for liquid HLW should be designed to have adequate redundancy and sufficient operational flexibility. This might include, for example, using multiple mode transfer systems such as air lift and steam eductors, multiple systems of filters and blowers for extracting and cleaning the off-gas, and backup electrical power for the solidification cell for liquid HLW. Such systems should be designed to prevent accidents or to mitigate their consequences.

Storage of conditioned HLW from reprocessing

5.15. The condition of waste packages containing conditioned waste should be maintained within the acceptance requirements during storage and should not be adversely affected by handling operations, including retrieval. Examples of the properties to be maintained include containment integrity and temperature. Means for monitoring the condition of the waste packages and the storage conditions should be provided or technical analyses should be performed to evaluate the condition of the packages from relevant parameters. If an overpack is provided, the monitoring arrangements should be capable of determining the conditions of waste packages by monitoring the overpack's parameters.

5.16. Storage facilities for conditioned reprocessing waste should be so designed and operated as to avoid unnecessary handling, in order to prevent the undue exposure of workers and to maintain the integrity of the waste packages.

5.17. Measures should be taken to detect and deal with any packages of conditioned waste that fail during storage.

Spent fuel

5.18. Unconditioned spent fuel should be stored in accordance with the guidance given in Refs [7–9]. Paragraphs 5.19–5.27 provide recommendations for the safe management of spent fuel during processing and in storage after conditioning.

Processing of spent fuel

5.19. Processing activities for spent fuel include its characterization and preparing the fuel for and performing its conditioning. Depending on the method of disposal chosen, spent fuel elements may be placed directly into a container without any further conditioning. Conditioning generally involves mechanical processes such as disassembling the fuel elements to fuel rods and packaging the fuel rods, either as they are or cut into smaller sections, into a container for disposal.

5.20. Conditioning spent fuel may alternatively involve the dissolution of the spent fuel, immobilization of the resulting liquid in an appropriate matrix or enclosure of the waste form in canisters. The processing operations for spent fuel are similar to those for liquid HLW and hence the same recommendations apply as for liquid HLW, with the additional recommendation that particular attention should be paid to criticality safety.

5.21. Characterization should be performed to ensure that incoming fuel is suitable for the selected conditioning process. For example, measures should be in place to detect failed fuel and to verify estimates of fuel burnup and thermal power.

5.22. Provision should be made for measures to control the hazards associated with the volatile radionuclides that may be released from spent fuel in the consolidation of fuel rods, particularly if the fuel rods have been cut.

5.23. If the selected option for spent fuel relies on the fuel cladding for its containment (which is not recommended as a primary approach to containment), means should be provided to preserve the integrity of the fuel cladding during processing and storage and to deal with failed fuel. Special attention should be paid to developing handling procedures and selecting handling equipment (see Section 2 of Ref. [7]) to preserve the integrity of the fuel cladding. Furthermore, an alternative means, such as the use of sealed canisters, should be provided for the primary containment of radioactive material.

5.24. Subcriticality should be ensured in facilities for processing spent fuel; for this, consideration should be given to the geometrical configuration of the fissile material handled, its concentration, the total inventory and the presence of reflecting and moderating material. Careful consideration should be given to any credit given for fuel burnup to ensure conservatism in criticality safety. The sequences of events leading to abnormal fuel configurations should be evaluated for both operational states and accident conditions. References [7, 8] provide guidance on the design and operation of facilities for storing spent fuel.

5.25. Special attention should be paid in the design of a facility for processing spent fuel to the consequences of a redistribution or change in the geometrical configuration of moderating material, the introduction of moderating material or changes in the configuration of neutron absorbers resulting from internal or external initiating events such as the introduction of water. If subcriticality cannot be ensured under these conditions, provision should be made for preventive measures such as setting operational limits on the amounts of the material to be treated.

5.26. Provision should be made to assist in identifying failed packages containing spent fuel and in remediating such failed fuel packages. Non-destructive testing and evaluation should be used to identify failed packages and techniques should be available for their repair (e.g. rewelding a canister seal if the seal does not meet requirements).

Storage of conditioned spent fuel

5.27. Much of the guidance provided in Refs [7–9] applies to the storage of conditioned spent fuel. Furthermore, many of the recommendations discussed above for conditioning spent fuel also apply to the storage of conditioned spent fuel. These include measures to preserve the integrity of fuel cladding if the cladding is to be relied upon as the primary containment for radioactive material and for ensuring a safe, subcritical arrangement of the conditioned spent fuel by means of its geometrical configuration or the use of neutron absorbers. The use of an alternative primary containment should be considered if fuel cladding is found to be defective. The use of neutron monitors and special handling procedures to prevent potential critical configurations from arising should also be considered. Systems should be put in place to detect and deal with packages containing spent fuel that fail during storage.

DESIGN OF A FACILITY FOR THE PREDISPOSAL MANAGEMENT OF HLW

5.28. A facility for the predisposal management of HLW should be designed for a specified design lifetime. The design should facilitate the maintenance and replacement of components as necessary in order to limit the radiation exposure of workers and to prevent accidents. In the design of a facility for the predisposal management of HLW, consideration should also be given to the following features, which may potentially have an impact on safety:

(a) The retrieval of stored HLW or secondary waste generated in management operations;
(b) The characterization of HLW;
(c) The inspection of stored HLW;
(d) The management of HLW for non-radiological hazards and of any secondary waste generated;
(e) The control of liquid and gaseous effluents;
(f) Protection against fires;
(g) Access control and the control of movement between radiation and/or contamination zones.

5.29. It should be ensured that any provision applicable to the facility made for the purpose of complying with national and international requirements [19–21] concerning safeguards and the security of material [22] do not jeopardize safety.

Material

5.30. Structural materials, fabrication and construction techniques, and testing procedures should be based on codes and standards that are acceptable to the regulatory body. Consideration should be given to the potential effects that the waste, any associated material and the environmental conditions may have on the capabilities of any safety related features of the facility to perform their intended functions. Processes and properties that should be considered include, for example, the high temperature corrosion of material and the effects of irradiation in high radiation fields. (See also Section 7 on safety assessment.)

5.31. Facilities for the predisposal management HLW should be designed to prevent material interactions that may compromise the containment of the waste or safety at the facility. The consideration of such interactions should extend to solidified HLW and its associated containers.

5.32. The predisposal management of HLW may also entail the management of non-radioactive hazardous material. Material should be selected and other measures should be taken so as to ensure that its management is in compliance with the applicable regulations relating to hazardous material and to take account of potential interactions between radioactive and non-radioactive constituents.

Containment

5.33. Depending on the type of waste concerned (whether liquid waste, immobilized waste or spent fuel) protection may be provided solely by a container or by a container supplemented by the safety systems of the facility, such as those for heat removal (either passive or active).

5.34. The emphasis for conditioned HLW should be placed on the design of the waste package itself, which should provide adequate containment and a means for mitigating any unexpected rise in temperature.

Criticality

5.35. The design and operation of a facility for the predisposal management of HLW should be carried out in such a way as to ensure subcriticality in both operational states and under accident conditions by means of safe geometrical configurations, limitations on concentrations and inventories of fissile material or the use of neutron poisons. An appropriate limiting neutron multiplication factor, with suitable safety factors for mass, concentration and other characteristics taken into account, should be selected in the design for the purpose of ensuring criticality safety, depending upon the conditions mentioned above. Additional organizational and administrative arrangements that may be necessary in the operation of such a facility to ensure subcritical conditions should be considered.

Heat removal

5.36. The design of a facility for the predisposal management of HLW should incorporate systems (e.g. a system for monitoring and controlling the temperature) that are capable of maintaining the temperature of the HLW within acceptable limits in all stages of predisposal management, both in normal operations and under accident conditions. Such temperature limits should be based on the properties of the waste and waste packages, with account taken of the material properties of the container, the containment structures and the waste form in all steps of management, including storage.

5.37. To the maximum extent practicable, the cooling systems for storage facilities for conditioned HLW should be passive and should need minimal maintenance. If the forced circulation of coolant is used, the system should be highly reliable. Examples of features that enhance the reliability of the cooling system are the capability of dealing with the settling of solids and with buildup on surfaces that affects the efficiency of heat removal. The storage facility itself should be designed to be capable of experiencing temporary loss of cooling events without damage to the stored waste. In addition, means of mitigation should be put in place to deal with such contingencies.

Radiation protection

5.38. Owing to the high radiation fields and high activities involved in the predisposal management of HLW, radiation doses should be kept ALARA by the use of features such as remote handling techniques for operations and maintenance and by establishing limits on the activities and dose rates for the items to be removed from highly contaminated or radioactive areas to less contaminated or radioactive areas [13]. When manual maintenance operations are foreseen, adequate protection should be provided, for example, by the decontamination of equipment and the use of temporary or permanent shielding.

OPERATION OF A FACILITY FOR THE PREDISPOSAL MANAGEMENT OF HLW

5.39. The operation of a facility for the predisposal management of HLW should follow pre-established rules and procedures. These rules and procedures should be developed by the operator and should be reviewed and approved by the regulatory body.

5.40. The predisposal processing and storage of HLW should be conducted in such a way as to prevent the leakage of radionuclides or the loss of containment integrity. Contingency plans should be put in place in case a leakage of radionuclides or loss of containment integrity does occur.

5.41. The design features to ensure subcriticality should be accompanied by operational practices, administrative measures and the training of the personnel concerned. Means should be put in place to prevent the unintentional introduction of material that could cause criticality. If the operational scheme for the processing of HLW is changed, it should be verified in advance that no situation can occur that could cause criticality.

5.42. The regulatory body should have a means in place of verifying the properties of the waste that have been established by the operator.

5.43. The operator of a facility for the predisposal management of HLW should make provision for adequate measures for radiation protection, such as by means of:

(a) The advance planning of maintenance work, including measures for radiation protection;
(b) Providing equipment for the monitoring and control of contamination, radiation exposure of workers and the public, and releases to the environment.

TRANSPORT

5.44. The operator should establish requirements and authorizations for ensuring the safety of on-site transport. Scenarios in which accidents give rise to the potential exposure of persons should be duly taken into account by the operator of the facility in the site emergency procedures.

5.45. HLW 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 the Ref. [10] or in international agreements.

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. [25], 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 liquid HLW or spent fuel 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 liquid HLW and spent fuel 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. Safety assessments are required to be prepared for facilities and activities for the predisposal management of HLW, including decommissioning activities, to demonstrate that the basis for safety is adequate and, more specifically, that such facilities and activities will be in compliance with the safety requirements established by the regulatory body (Ref. [3], para. 5.3). The safety assessment should also demonstrate that the packages for HLW will sufficiently confine the waste in normal operations and in postulated incidents and accidents.

7.2. A safety assessment is required to be conducted prior to the construction and operation of a facility for the predisposal management of HLW to demonstrate that the facility will provide adequate margins of safety for workers and the public in normal operations and in postulated incidents and accidents (Ref. [3], para. 5.3). If required by national legislation, an environmental impact assessment should be conducted to demonstrate that the anticipated environmental impacts of the construction, operation and decommissioning of the facility comply 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.

7.3. Requirements on the regulatory body in respect of the review and approval of safety assessments prepared by the operator for facilities for the predisposal management of HLW are established in Ref. [2]. Information on safety assessments for storage facilities for unconditioned spent fuel is provided in Ref. [9]. Recommendations on the content of safety assessments for facilities for the predisposal management of HLW are being developed.

7.4. A safety assessment for a facility for the predisposal management of HLW should, as a minimum, address the following topics:

(a) The specification of relevant safety criteria;
(b) Methods for the identification, collection and evaluation of data and information;
(c) The specification of normal and abnormal operating conditions;
(d) The determination of potential consequences of normal operations and abnormal events;
(e) An assessment of the potential consequences of normal operations and abnormal events on the basis of safety criteria.

7.5. Owing to the specific hazards associated with HLW, the following data and information as a minimum should be obtained and analysed in order to conduct a safety assessment for a facility for the predisposal management of HLW:

(a) Detailed data about the design of the facility, including a description of the plant, the equipment and the activities involved in the handling of the HLW, and the passive and active safety systems (e.g. the means to avoid unexpected chemical reactions or criticality or to avoid conditions that could cause explosions or fires);
(b) Data on the physical and chemical properties of the HLW, such as volumes, radionuclide inventories and non-radioactive components, in all stages of processing;
(c) Possible variations in the composition of the HLW;
(d) Data on the selected site that are necessary to assess the possible impacts of environmental factors that should be addressed for the design and operation of the facility;
(e) Data on the operating ranges or limits necessary to establish safety limits and operating conditions.

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 II and III 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 IV provides an aid to memory to assist in their identification.

7.8. The process that should be used for identifying normal and abnormal operational conditions, including potential accidents, should be agreed upon with the regulatory body. Information should be obtained on the following matters, which have a bearing on the safety of facilities for the predisposal management of HLW: (a) the nature and severity of the exposures of workers and of the radiological consequences for the environment (e.g. due to discharges during waste processing, maintenance work and decommissioning activities); (b) organizational safety features (e.g. the operator's goals for safety, human health and the environment, and the operator's safety organization); and (c) the operator's quality assurance programme.

7.9. A safety assessment of abnormal operational conditions should cover anticipated operational occurrences and accident conditions. Potential abnormal operational occurrences that are important for processing facilities for HLW include the receipt of waste either containing, or with concentrations of, radionuclides other than those expected, plant configurations altered under maintenance or outage conditions and the high temperature conditions typical of the conditioning processes for the reprocessing of HLW.

8. QUALITY ASSURANCE

8.1. A quality assurance programme for the predisposal management of HLW 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. [25] 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 HLW 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 HLW, 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 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.

8.3. Safety related systems and components should be managed in accordance with their importance for the safe operation of facilities for the predisposal management of HLW. The extent of quality assurance applied to the design, fabrication, construction and operation of such components and systems should be related to their importance to safety.

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

8.5. For HLW from the reprocessing of spent fuel a characterization programme should be followed to assess the suitability of the pretreated and/or treated HLW for the conditioning process chosen as well as to optimize the composition of the solidified waste (i.e. the waste form). A reference composition of the waste form (with appropriate levels of tolerance), including the characteristics that should be verified, should be established. Proposals for deviations from this reference composition or from the characterization programme should be assessed to determine their possible effect on the quality of waste packages. Possible deviations should be assessed and, if they do not affect the safety of the waste package and its acceptance at the storage or disposal facility, it may be appropriate to accept the waste package.

8.6. The specifications for an HLW 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.

8.7. The specifications for HLW should include:

(a) For liquid HLW: the characteristics and properties of the treated waste before conditioning; and the characteristics, properties and limiting values of the parameters for the conditioned waste (i.e. the waste form and any canister and/or container).
(b) For spent fuel: the characteristics, properties and limiting values of the parameters for incoming spent fuel and for conditioned spent fuel (i.e. the spent fuel in an appropriate form and any associated canister and/or container).

8.8. Quality records should be established and maintained for each conditioned package of HLW. 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 HLW.

8.9. It may not be feasible or recommended to sample HLW from the reprocessing of spent fuel during its processing and storage. However, records generated at all stages of the predisposal management of HLW 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 HLW 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 canister or 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.

8.10. If no treatment or conditioning facility is available it may be necessary to store HLW for long periods. There may also need to be a long period of storage before disposal if no disposal facility for HLW is available or if time has to be allowed for the thermal power to decrease. In such cases the quality assurance programme should be designed to ensure that the quality and integrity of the 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.

8.11. 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 HLW 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.

8.12. 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.

8.13. 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.

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

Appendix

KEY PROPERTIES AND CHARACTERISTICS OF HLW

Key properties and characteristics of HLW are given in Table I for unconditioned fuel, conditioned fuel, and liquid HLW and conditioned HLW from the reprocessing of spent fuel.

TABLE I. KEY PROPERTIES AND CHARACTERISTICS OF HLW

Properties and characteristics	Unconditioned fuel	Conditioned fuel	Liquid HLW from reprocessing	Conditioned HLW from reprocessing
Fuel data: Type, power history, initial fissile content, burnup and cooling time	√	√	To interpolate from sampled data	To interpolate from sampled data
Activity: β–γ and α activity by radionuclide for the major contributors to activity	√	√	√	√
Criticality safety: Geometrical configuration, concentration and inventory of fissile material (e.g. ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu), presence of neutron poisons and demonstration of non-criticality	√	√	√	√
Dose rate: Neutron and γ dose rate at the surface and at a distance of 1 m	√	√	√	√
Surface contamination: Levels of β–γ and α contamination		√		√
Thermal properties: Thermal power, thermal conductivity and predicted maximum temperatures of the HLW (with and without cooling by engineered systems)	√	√	√	√
Chemical properties: pH, main chemical species and compounds, toxic substances and corrosive compounds	√		√	
Physical properties: Viscosity and density	Density only		√	Viscosity during the pouring of glass
Mass of waste and/or waste package: Total mass (mass of waste form and canister, if applicable)	√	√	√	√

TABLE I. (cont.)

Properties and characteristics	Unconditioned fuel	Conditioned fuel	Liquid HLW from reprocessing	Conditioned HLW from reprocessing
Quality of canister/container: Material specification, tare weight, dimensions, corrosion resistance, quality of seal weld, material certifications from manufacture; quality assurance records from conditioning process; compatibility with the waste form		√		√
Stackability and handling: Number of packages stackable without deformation, results of package drop tests and requirements for lifting packages (e.g. lifting features)		√		√
Package labelling: Unique permanent identification		√		√
Quality of matrix material: Certification and quality assurance records for matrix material		√	Possible for intermediate waste forms (e.g. calcine)	√
Mass fractions of waste form: Fractions of waste, fixation materials and additives (to be within specified limits)		√		√
Stability of the HLW package: Corrosion and/or leaching behaviour in relevant atmospheres or aqueous solutions, data on long term corrosion and data extrapolation, influence of surface area and solubility of radionuclides in relevant aqueous solutions	√	√		√
Homogeneity of the waste form: Reasonably achievable homogeneity and distribution of radionuclides				√

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Annex I

PRACTICAL STEPS IN THE PREDISPOSAL MANAGEMENT OF HLW

BACKGROUND

I–1. HLW is characterized by reference to its radionuclide concentrations, thermal power and content of long lived waste. HLW originates from spent fuel from nuclear reactors. There are two main alternatives in managing spent fuel: (a) reprocessing and (b) direct disposal. The deferral of a final decision on which alternative to take necessitates the storage of spent fuel while the alternatives are under consideration.

I–2. The decision on an option for the management of spent fuel will be a complex one in any State and there will be many constraints that will influence the final outcome. Storage is the first step in all alternatives for the management of spent fuel, and for each technical approach the final step is disposal.

I–3. In reprocessing, spent fuel is dissolved in an acid solution and plutonium and uranium are removed from the solution in a chemical separation plant. HLW from reprocessing is the remaining solution produced in the first cycle of solvent extraction, which contains most of the fission products, traces of plutonium and uranium, other actinides originally present in the fuel and various activation and corrosion products (depending on the fuel and the reprocessing operations carried out).

I–4. If spent fuel is declared as waste it will be solidified HLW, but it will also include some volatile fission products in the fuel rods. The specific activity of spent fuel is very high. The specific activity and the actinide content will depend on the properties of the fresh fuel, the burnup and the cooling time. Cladding and the structural material from spent fuel may also be managed with the spent fuel as HLW.

LIQUID HLW

I–5. The most common method used for the reprocessing of spent fuel is to dissolve the fuel in an acid solution and to separate the plutonium and uranium from this solution. The remaining waste, which will contain nearly all the fission products and actinides except for uranium and plutonium, is collected in tanks, in which volume reduction and concentration and sampling are performed. Safe operation is of great importance at this stage, owing to the high activity and thermal decay rate of the waste and the possibility of criticality. While still in the reprocessing plant, the liquid

HLW is pretreated before its transfer to larger storage tanks. Such pretreatments include the removal of organic solvents (typically tributyl phosphate), which is necessary to prevent explosive compounds being formed as these would give rise to a safety hazard. Chemical additives are also used at this stage to reduce the likelihood of an explosion. In addition, certain species (e.g. mercury and technetium) may be removed in order to improve the quality of the matrix for the conditioned waste.

I–6. The HLW may be further treated and blended in the main storage tanks. Such treatment includes the possible addition of acidic liquid waste streams from elsewhere in the reprocessing cycle and further volume reduction by evaporation. Such concentration is limited by the thermal output of the HLW, which in turn depends upon the burnup and cooling time of the fuel from which it was derived.

I–7. During storage, the liquid HLW is cooled and may be agitated (to keep solids in suspension), thus preventing the accumulation of fissile material and reducing variations in composition within the tanks. Agitation also promotes the release of entrained gases, thus preventing any buildup of mixtures of explosive gases if venting is also provided.

I–8. The waste is then conditioned; a number of waste forms have been developed (e.g. glasses, vitroceramics, crystalline ceramic (synroc), and supercalcine and tailored ceramics). These processes have been developed to differing levels; the production of borosilicate glass has been developed to an industrial scale in several States.

I–9. The vitrification of the liquid HLW forms may involve denitrating the solution and the drying, calcination and vitrification of the waste. Vitrification is a high temperature process (over 1000°C) that necessitates special procedures to avoid incidents. High pressures are necessary for ceramic matrices, which, for safety, require special considerations and arrangements.

I–10. Solidified waste is packaged either by pouring for glass or by packing for ceramics. The package is then allowed to cool naturally, typically for around 24 h, before the closure of the canister. In order to reduce cracking in the matrix it is important to avoid excessive thermal shock at this stage. Additionally, for glass, it is also important not to allow the matrix to cool too slowly, as this could promote crystal growth, which could reduce the durability of the matrix in repository environments in which groundwater may be present.

I–11. The canister is then sealed, typically by welding. As the welding process is carried out in a high radiation field, inspection for weld integrity by classical methods (such as radiography or a dye penetration method) is impossible. Therefore, in order to ensure a high quality seal, welding processes have been developed that have a high degree of automation. This provides confidence that radionuclides that may escape from the matrix surface (the recoil effect) will be contained within the canister.

I–12. After closure, the package is inspected for loose surface contamination (which is typically kept below the transport levels for casks), monitored for its dose rate (testing for gamma and neutron radiation may be necessary, depending upon the fissile actinide content of the waste) and visually inspected for surface defects. If necessary, the canister is decontaminated to the contamination levels that are acceptable for its transport. The packages are then transferred to an interim storage facility prior to their transport to a repository in shielded casks similar in design and integrity to those used to transport spent fuel.

I–13. Conditioned HLW from reprocessing is typically stored in either vault type or free standing cask stores. In either case the maintenance of stable temperature conditions is important for the storage facility and for the waste. In most cases high integrity natural cooling systems are applied. Forced cooling systems need a high level of redundancy incorporated into their design.

SPENT FUEL

I–14. The option of the direct disposal of spent fuel in a disposal facility is an alternative to reprocessing the spent fuel and disposing the residual HLW. Before this option can be properly evaluated it is necessary to have an understanding of the behaviour of such a waste form fuel in a disposal facility.

I–15. Processing spent fuel may involve the following three approaches: (a) the fuel rods are not altered (i.e. the fuel assemblies are unmodified or are disassembled into fuel rods); (b) the fuel rods are worked mechanically (e.g. by degassing or cutting); or (c) the fuel rods are altered mechanically and chemically (such as by the vitrification of the fuel after dissolution). If the fuel rods are not altered, the process of preparing spent fuel for conditioning, in a consolidated form, typically involves the following steps: removing the end fittings; withdrawing the fuel rods from the non-fuel-bearing components; loading the fuel rods into a transfer canister of the required shape; treating the non-fuel-bearing components; and loading the non-fuel-bearing components into a disposal container. The rod consolidation process can take place in both wet (storage pool) and dry (hot cell) conditions. The cutting of fuel rods is a standard procedure for mechanically worked fuel rods. The minimization of gaseous emissions is a main concern in the design of a facility.

I–16. The next step is to package the spent fuel, which may involve: (a) loading the spent fuel, in accordance with procedures that will depend on the history of the fuel and the proportion of intact fuel assemblies, loading consolidated fuel assemblies or loading cut or uncut rods; (b) the final closure and/or sealing of the waste packages; and (c) measures for protection against corrosion. Where the container alone is not designed to withstand the mechanical loads anticipated in a disposal facility, the internal void space of the container can be filled with a material that is suitable for providing internal support, such as copper obtained by means of hot isostatic pressing.

I–17. Depending on the process chosen for packaging, differing amounts of secondary waste, which will have to be treated and disposed of, will arise. Solid waste that is part of the disassembled fuel element may be conditioned together with the spent fuel.

I–18. The waste package consists of the consolidated and/or unconsolidated spent fuel, the non-fuel-bearing components (if present), the container and the internal structural elements for the positioning of the waste and for heat transfer to the surface of the container. In some cases a neutron absorber may be included to prevent criticality.

I–19. The use of multipurpose containers (i.e. containers that can be used for transport, storage and disposal) is being considered. A number of metals and their alloys have been considered, including corrosion allowance materials (e.g. iron and stainless steel) and corrosion resistant material (e.g. nickel and nickel based alloys, copper and copper based alloys, and titanium). The selection of the material and the concepts to be applied will be greatly influenced by the geological formation, the geochemical environments and the prevailing temperatures and pressures, which will govern the various corrosion mechanisms. Long term tests will have to be carried out to investigate certain phenomena, such as localized corrosion, stress corrosion and hydrogen embrittlement, that are only initiated after long periods of emplacement.

I–20. Storage facilities for conditioned spent fuel are similar to those for conditioned HLW from the reprocessing of spent fuel. One primary difference is the concern for criticality, which is more relevant for spent fuel than for solidified HLW.

Annex II

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 III

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 IV

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.

CONTRIBUTORS TO DRAFTING AND REVIEW

Ali, S.S.	Bhabha Atomic Research Centre, India
Baillif, L.	NUSYS, France
Bergé, F.	NUSYS, France
Carter, P.B.	Consultant, United Kingdom
Conlon, P.	International Atomic Energy Agency
De Pahissa, M.H.	Comisión Nacional de Energía Atómica, Argentina
Duthé, M.	Direction de la sûreté des installations nucléaires, France
Engström, S.	Swedish Nuclear Fuel and Waste Management Co., Sweden
FitzPatrick, B.	International Atomic Energy Agency
Lavrinovitch, A.	Federal Nuclear and Radiation Safety Authority of Russia, Russian Federation
Müller, W.	Institut für Sicherheitstechnologie GmbH, Germany
Picha, K.	Department of Energy, United States of America
Ruokola, E.	Radiation and Nuclear Safety Authority, Finland
Sasaki, N.	Power Reactor and Nuclear Fuel Development Corporation, Japan
Shoaib, K.A.	Permanent Mission of Pakistan, Austria
Street, J.	British Nuclear Fuels Ltd, United Kingdom
Timul'ák, J.	Decom Slovakia Ltd, Slovak Republic
Torata, S.	Japan Nuclear Cycle Development Institute, Japan
Vogt, J.	Swedish Nuclear Fuel and Waste Management Co., Sweden
Warnecke, E.	International Atomic Energy Agency
Wurtinger, W.	Institut für Sicherheitstechnologie GmbH, Germany

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Note: an asterisk (*) denotes a corresponding member. Corresponding members receive drafts for comment and other documentation but they do not generally participate in meetings.