

IAEA Safety Standards

for protecting people and the environment

Geological Disposal Facilities for Radioactive Waste

Specific Safety Guide

No. SSG-14



IAEA

International Atomic Energy Agency



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GEOLOGICAL DISPOSAL FACILITIES FOR 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".

IAEA SAFETY STANDARDS SERIES No. SSG-14

GEOLOGICAL DISPOSAL FACILITIES FOR RADIOACTIVE WASTE

SPECIFIC SAFETY GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2011

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FOREWORD

by Yukiya Amano
Director General

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

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

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

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

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

THE IAEA SAFETY STANDARDS

BACKGROUND

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

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

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

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

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

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

THE IAEA SAFETY STANDARDS

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

With a view to ensuring the protection of people and the environment from harmful effects of ionizing radiation, the IAEA safety standards establish

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

Safety measures and security measures¹ have in common the aim of protecting human life and health and the environment. Safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

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

Safety Fundamentals

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

Safety Requirements

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

Safety Guides

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures). The Safety

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

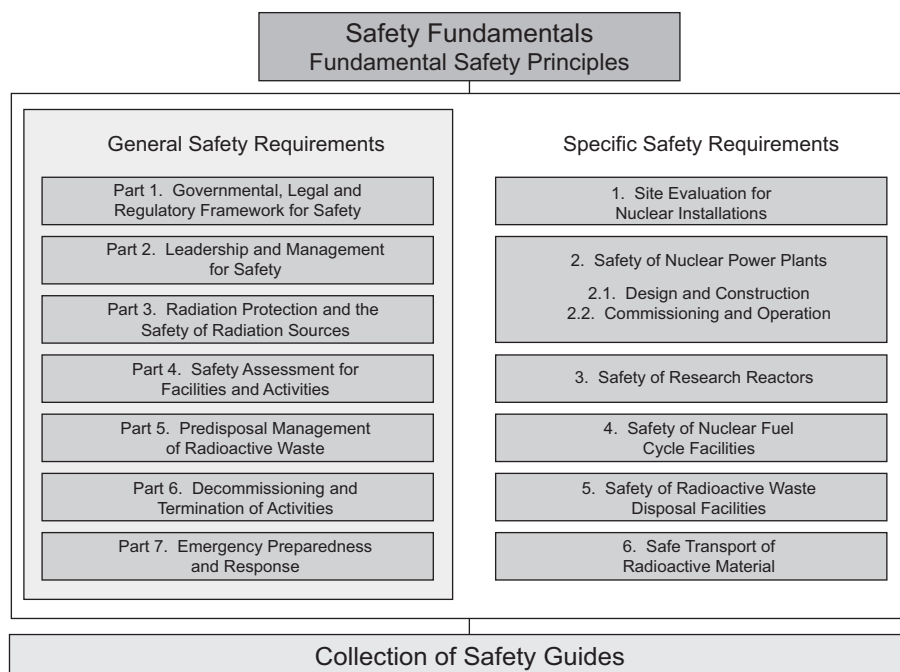


FIG. 1. The long term structure of the IAEA Safety Standards Series.

Guides present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as ‘should’ statements.

APPLICATION OF THE IAEA SAFETY STANDARDS

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

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

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

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

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

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

DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

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

All IAEA Member States may nominate experts for the safety standards committees and may provide comments on draft standards. The membership of the Commission on Safety Standards is appointed by the Director General and includes senior governmental officials having responsibility for establishing national standards.

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

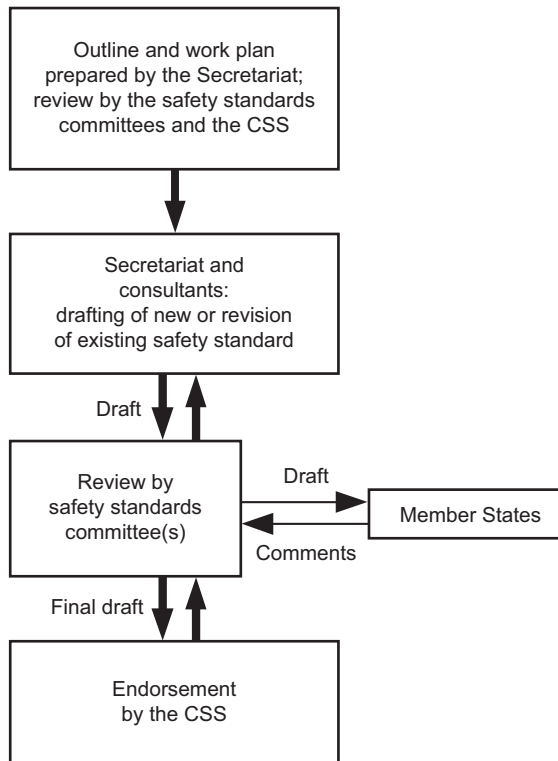


FIG. 2. The process for developing a new safety standard or revising an existing standard.

safety standards, policies and strategies, and corresponding functions and responsibilities.

INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

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

INTERPRETATION OF THE TEXT

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

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

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

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

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1. INTRODUCTION

BACKGROUND

1.1. Radioactive waste is material in gaseous, liquid or solid form for which no further use is foreseen. It contains, or is contaminated with, radionuclides at concentrations or activities greater than the clearance levels as established by the regulatory body. Radioactive waste arises from the operation of nuclear power plants and research reactors, from nuclear fuel cycle operations and from other activities in which radioactive material is used. Radioactive waste presents a potential hazard to human health and the environment and it must be managed so as to ensure any associated risks do not exceed acceptable levels.

1.2. The term ‘geological disposal’ refers to the disposal of solid radioactive waste in a disposal facility located underground in a stable geological formation so as to provide long term containment of the waste and isolation of the waste from the accessible biosphere. Disposal means that there is no intention to retrieve the waste, although such a possibility is not ruled out. Geological disposal is a method for disposing of, in particular, the more hazardous types of radioactive waste, which pose a significant radiological hazard over long time periods.

1.3. This Safety Guide provides guidance for policy makers, regulatory bodies and operators concerned with the development and regulatory control of facilities for the geological disposal of radioactive waste. It provides recommendations on how to meet the safety requirements for the disposal of radioactive waste established in SSR-5 [1]. Both this Safety Guide and Ref. [1] are consistent with the safety principles to be applied in all radioactive waste management activities as set out in the Fundamental Safety Principles [2]. The same principles form the technical basis for the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [3]. The relevant principles and requirements for radiation protection are also established in the Fundamental Safety Principles [2] and the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (BSS) [4], respectively.

1.4. Research into the geological disposal of radioactive waste has been under way for several decades [5]. At present, practical experience gained in the disposal of radioactive waste in geological formations is limited. For high level waste, characterization of sites for proposed geological disposal facilities has

been carried out in a number of States, and a few States have constructed underground laboratories or facilities for characterization of the host rocks. There are only a few operating geological disposal facilities for intermediate level waste. Experience in closing of geological disposal facilities is very limited.

1.5. Disposal in geological formations has, in particular, been advocated as a long term management solution for high level and intermediate level waste. Feasibility studies, site specific safety cases and operational experience have generally strengthened confidence in the safety of geological disposal. The decision to adopt this option in a particular State is a matter for national decision makers, taking account of economic and social factors and national radioactive waste management policies, needs and requirements.

1.6. As noted, experience in the construction and operation of geological disposal facilities is limited, and there is limited practical experience with facility closure. Therefore, the recommendations provided in this Safety Guide are based on the safety principles established by the IAEA [2] and other international organizations for the geological disposal of radioactive waste and on practical experience gained in different States. This Safety Guide will be revised and expanded in the future as further experience is gained and as geological disposal programmes mature.

1.7. There is a notable difference in the approach to safety taken for a geological disposal facility compared with that for a nuclear installation. This is primarily because the core mission of a nuclear installation, such as a fuel fabrication plant, a nuclear power plant or a reprocessing facility, is carried out during its operating life and involves a production activity such as the generation of electrical power. Nuclear installations rely on operational limits and conditions for the active safety systems they employ. In contrast to a nuclear installation, the core mission of a geological disposal facility for long lived waste is to provide passive safety over very long time periods (of the order of thousands of years and longer). Operational limits and conditions have a different importance for geological disposal facilities because overall safety is evaluated on the assumption that such measures will not be effective or relied on for ensuring safety.

OBJECTIVE

1.8. The objective of this Safety Guide is to provide guidance and recommendations relating to the development and regulatory control of facilities for the geological disposal of radioactive waste to meet the safety requirements

established in Ref. [1]. It is primarily intended for use by those involved with the regulatory control and implementation of geological disposal. The decision to adopt geological disposal as a waste management option is not addressed in this Safety Guide.

SCOPE

1.9. The scope of this Safety Guide is the safe development of an excavated underground disposal facility. It does not apply to borehole disposal facilities, for which recommendations are provided in Ref. [6]. Disposal of radioactive waste in pre-existing excavations may be contemplated, but would need to meet the same safety requirements established in Ref. [1].

1.10. This Safety Guide is primarily concerned with activities associated with the development of geological disposal facilities after a site has been selected. It should be noted that siting encompasses a range of activities from initial conceptual design and site selection through to confirmation of the site for construction of a disposal facility. Whilst site characterization and site confirmation are addressed in this Safety Guide, site selection is not because it includes many aspects that are non-technical and specific to the societal context. General recommendations regarding the technical and scientific aspects of siting are provided in Appendix I.

1.11. This Safety Guide applies to solid waste that, owing to its radioactive content, is unsuitable for disposal in landfill facilities or in near surface facilities. However, it may be decided to dispose of waste that is suitable for near surface facilities in a geological disposal facility (e.g. co-disposal of low level waste with intermediate level waste). When such a course of action is adopted, although the safety requirements in Ref. [1] apply, some aspects of this Safety Guide may not be applicable. In accordance with the graded approach set out in the BSS [4], the ability of the chosen disposal system to provide containment of the waste and isolation of the waste from people and the environment is required to be commensurate with the hazard potential of the waste.

1.12. The safety of waste transport to such facilities is addressed in the Regulations for the Safe Transport of Radioactive Material [7]. Guidance for the safety of the encapsulation plants and other plants that may be co-located with disposal facilities is not provided in this Safety Guide; IAEA safety standards for non-reactor facilities apply for these types of facility [8].

1.13. The development of disposal facilities that incorporate design or operational provisions to facilitate reversibility (see para. 2.6), including retrievability of waste, is being considered in several national programmes. In some States, post-closure retrievability is a legal requirement and constitutes a boundary condition for the options available, which must always satisfy the safety requirements for disposal. Reference [1] states that “No relaxation of safety standards or requirements could be allowed on the grounds that waste retrieval may be possible or may be facilitated by a particular provision. It would have to be ensured that any such provision would not have an unacceptable adverse effect on safety or on the performance of the disposal system”. This Safety Guide applies to all geological disposal facilities, irrespective of whether or not retrievability is incorporated into the design or operational plans.

STRUCTURE

1.14. Section 2 provides an overview of geological disposal and its implementation and the step by step approach to developing a geological disposal facility. Section 3 provides guidance on organizational responsibilities. Section 4 discusses the safety approach and Section 5 provides guidance on the preparation of the safety case and safety assessment. Section 6 presents guidance for specific steps in the development of a geological disposal facility. Appendix I provides additional information and guidance on the siting of geological disposal facilities, specifically concerning data needs, and Appendix II provides additional information on post-closure safety assessment.

1.15. Reference [1] establishes 26 specific safety requirements that are applicable to the geological disposal of radioactive waste, and in support of which the recommendations in this Safety Guide have been developed. For convenience, the text of each safety requirement of Ref. [1] is reproduced in this Safety Guide, followed by the related recommendations.

2. OVERVIEW OF GEOLOGICAL DISPOSAL AND ITS IMPLEMENTATION

2.1. Geological disposal is the emplacement of solid radioactive waste in a facility located underground in a stable geological formation. A distinctive feature of geological disposal is that post-closure safety of the facility is

provided, in part, by passive means inherent in the characteristics of the geological formation. The depth chosen for disposal in a particular facility will depend on a number of factors including, but not limited to, climatic and groundwater conditions, rock stability, host rock composition and the nature and hazard of the waste.

2.2. Containment of the waste and isolation of the waste from the biosphere, is an accepted management strategy for radioactive waste [1]. Containment and isolation can be provided through a series of complementary barriers, e.g. the waste form itself, waste containers, backfill materials and the host geology, each of which will be effective over different timescales. The depth of disposal and the characteristics of the host geological environment provide isolation from the biosphere and reduce the likelihood of inadvertent or unauthorized human intrusion. Moreover, emplacement at depth in a stable geological formation may significantly reduce the influence of climatic and other surface processes.

2.3. In the context of radiation safety, it is convenient to identify three broad periods associated with the development of a geological disposal facility:

- (1) The *pre-operational period* includes the definition of concepts, site investigation and confirmation, safety assessment, site selection, design studies and development of the aspects of the safety case for safety during operation and safety after closure that are required in order to set the conditions of authorization, to obtain the authorization and to proceed with the construction of the disposal facility and the initial operational activities. The monitoring and testing programmes necessary to inform operational management decisions are put in place in this period. Section 6 and Appendix I provide further recommendations on siting.
- (2) The *operational period* begins when waste is first received at the facility. From this time, radiation exposures may occur as a result of waste management activities and these are subject to control in accordance with the requirements for radiation protection and safety. Monitoring, surveillance and testing programmes continue to inform operational management decisions and to provide the basis for decisions concerning the closure of the facility or parts of it. The safety case and safety assessments for the period of operation and for the period after closure are updated as necessary to reflect actual experience and increasing knowledge. During the operational period, construction activities may take place at the same time as waste emplacement in some parts of the facility and closure of other parts of the facility. This period may include activities for waste retrieval prior to

closure (if retrieval is considered necessary), activities following the completion of waste emplacement, and closure.

- (3) The *post-closure period* begins at the time when all the engineered containment and isolation features have been put in place, operational buildings and supporting services have been decommissioned and the facility is in its final configuration. After closure, the safety of the disposal facility is provided for by passive means inherent in the characteristics of the site and the facility and in the waste package characteristics, although institutional controls, including some post-closure monitoring, may continue, for example, for the purposes of providing public assurance. The licence will be terminated when all the necessary technical, legal and financial requirements have been fulfilled.

2.4. The development of a geological disposal facility is likely to take place over several decades. These long timescales, the large volume of information (to be acquired from site characterization and other activities that will support the safety case) and its diversity make it essential to subdivide the programme into a series of steps so that the work can be performed, reviewed and assessed in manageable ‘packages’ with the overall objective of exercising proper control throughout the programme. This comprises the step by step process. Operators of geological disposal facilities may define a number of steps in their own programme. However, in this Safety Guide the step by step process refers to the steps imposed by the regulatory and political decision making processes.

2.5. After site selection, for any disposal programme, a number of activities, grouped in broad areas, should be undertaken, namely, detailed site characterization and confirmation, design of the geological disposal facility, construction of the disposal facility, operation of the disposal facility (i.e. receipt and emplacement of waste) and closure of the disposal facility. These activities may not occur sequentially and there may be overlap. The last three of these correspond to three important steps in the regulatory approval of a geological disposal facility (see Fig. 1). The inclusion of additional steps will largely be a matter of national preference. Site characterization and design activities may be expected to continue, at some level, up to facility closure.

2.6. The step by step process provides flexibility so that the programme can be adapted in response to new technical information. The step by step process facilitates the consideration of reversibility in the development of a disposal facility and, at each step, enables a decision to be made on proceeding to the next step, to wait for additional information before making a decision, or to reverse a decision.

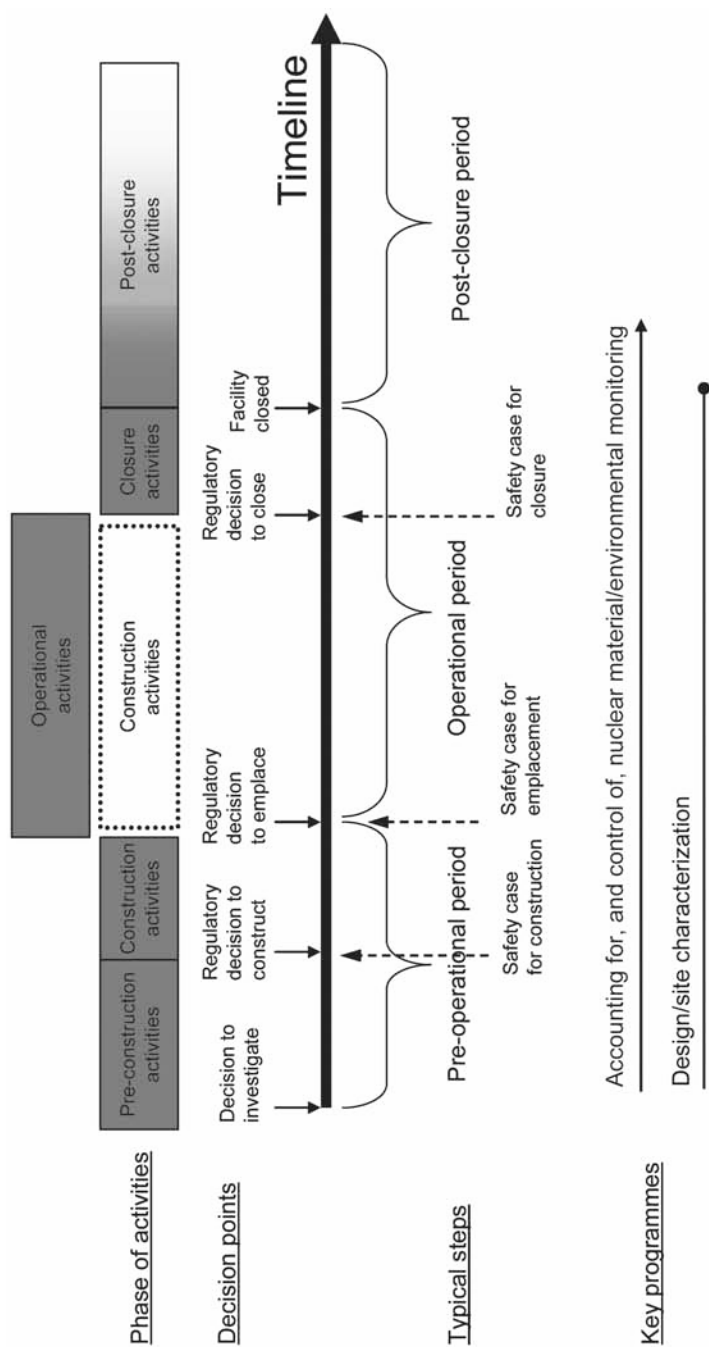


FIG. 1. Timeline to illustrate the development of a geological disposal facility.

3. LEGAL AND ORGANIZATIONAL INFRASTRUCTURE

3.1. The development of a geological disposal facility requires the assignment of responsibilities among three types of organization: the national government, the appointed regulatory body (or bodies) and the operator of the facility. Recommendations on the responsibilities of each of these are provided in this section.

GOVERNMENT RESPONSIBILITIES

3.2. Geological disposal requires special consideration within the national legal and organizational framework [9] because of the relatively long time period necessary for the development of such projects.

Requirement 1 of SSR-5 (Ref. [1]): Government responsibilities

The government is required to establish and maintain an appropriate governmental, legal and regulatory framework for safety within which responsibilities shall be clearly allocated for disposal facilities for radioactive waste to be sited, designed, constructed, operated and closed. This shall include: confirmation at a national level of the need for disposal facilities of different types; specification of the steps in development and licensing of facilities of different types; and clear allocation of responsibilities, securing of financial and other resources, and provision of independent regulatory functions relating to a planned disposal facility.

3.3. The national, legal and organizational framework for geological disposal has to include the following [1]:

- (a) Defining the national policy for the long term management of radioactive waste of different types;
- (b) Setting clearly defined legal, technical and financial responsibilities for organizations that are to be involved in the development of geological disposal facilities;
- (c) Ensuring the adequacy and security of financial provisions, for example, by requiring the owners of the waste to establish segregated funds;

- (d) Defining the overall process for the development, operation and closure of geological disposal facilities, including the legal and regulatory requirements at each step, and the processes for decision making and the involvement of interested parties;
- (e) Ensuring that the necessary scientific and technical expertise is available to support site and facility development, regulatory review and other national review functions;
- (f) Defining legal, technical and financial responsibilities and, if necessary, providing for any institutional arrangements that are envisaged after closure, including any monitoring and any other arrangements that may be required for ensuring the security of the disposed waste.

It should also be ensured that specific laws and regulations regarding geological disposal are harmonized with the national legal infrastructure. The types of involvement of interested parties in decision making processes concerning geological disposal of radioactive waste will vary depending on national laws, regulations and preferences. Information in regard to interested party (stakeholder) involvement can be found in Ref. [10].

REGULATORY BODY RESPONSIBILITIES

3.4. These recommendations refer to a single regulatory body, but it is recognized that in practice the safe regulation of geological disposal facilities could involve the participation of multiple regulatory bodies to address the concurrent activities of nuclear, industrial and mining safety, and environmental and radiation protection.

Requirement 2 of SSR-5 (Ref. [1]): Responsibilities of the regulatory body

The regulatory body shall establish regulatory requirements for the development of different types of disposal facility for radioactive waste and shall set out the procedures for meeting the requirements for the various stages of the licensing process. It shall also set conditions for the development, operation and closure of each individual disposal facility and shall carry out such activities as are necessary to ensure that the conditions are met.

3.5. In developing regulations, guidance and other regulatory criteria specific to geological disposal facilities, the regulatory body should ensure consistency with the national policy and give due regard to the objectives and criteria set out in Ref. [1]. The regulations and guidance may include:

- (a) Radiation protection criteria and environmental protection criteria for operational and post-closure safety;
- (b) Requirements for the content of the safety case of a disposal facility, including the safety assessment and the management system;
- (c) Criteria and requirements for the siting, design, construction, operation and closure of disposal facilities;
- (d) Criteria and requirements for the waste, waste form, disposal container, any backfill and sealing material and other components of the waste package to be disposed of;
- (e) Requirements for involvement of interested parties.

3.6. The regulatory body has to establish and document the procedures for its use in evaluating the safety of a geological disposal facility and the procedures that operators are expected to follow in the licensing process and in demonstrating compliance with the safety requirements [1]. The procedures established by the regulatory body and the responsibilities of the regulatory body may include:

- (a) Specification of the information to be supplied by the operator;
- (b) Review of the required submissions and assessment of the compliance with regulatory requirements;
- (c) Issue of approvals and licences and setting of conditions in conformity with legislation and regulations;
- (d) Inspection and audit of the operator's data gathering, safety assessment and activities in construction and operation to ensure quality and compliance with terms of approvals and licences;
- (e) Periodic reviews of the procedures for approvals, licences and inspections, to determine their continued suitability or the need for amendments;
- (f) Involvement of interested parties;
- (g) Requirements for termination of regulatory control.

3.7. The regulatory body has to arrange for independent research and assessments, and has to participate in international cooperation as necessary in order to carry out its regulatory functions. It should also periodically review the adequacy of its regulations and guidance. It may not be necessary to undertake independent research if the regulatory body is satisfied that the operator is

undertaking appropriate research that is of sufficient quality and that is subject to independent expert review.

RESPONSIBILITIES OF THE OPERATOR

Requirement 3 of SSR-5 (Ref. [1]): Responsibilities of the operator

The operator of a disposal facility for radioactive waste shall be responsible for its safety. The operator shall carry out safety assessment and develop and maintain a safety case, and shall carry out all the necessary activities for site selection and evaluation, design, construction, operation, closure and, if necessary, surveillance after closure, in accordance with national strategy, in compliance with the regulatory requirements and within the legal and regulatory infrastructure.

3.8. The operator is responsible for developing a safe geological disposal facility. In developing the design of the disposal facility and the safety case, the operator has to take account of the characteristics and quantities of the radioactive waste to be disposed of, the prevailing geological environment, the engineering and mining techniques available and the national legal infrastructure and regulatory requirements.

3.9. The operator has to conduct or commission the research and development necessary to ensure and to demonstrate that the planned technical operations can be safely accomplished, and the research necessary to investigate, understand and support the basis on which the safety of the geological disposal facility depends [1]. This includes all the investigations of the site, the disposal facility design and the waste characteristics necessary for the development of an appropriate safety case.

3.10. The operator has to develop technical specifications to ensure that the geological disposal facility is constructed, operated and closed in accordance with the regulatory requirements and the assumptions included within the safety case. This includes waste acceptance criteria and other controls and limits to be applied during construction, operation and closure.

3.11. The operator should undertake safety assessments for the operational period and for the post-closure period and has to demonstrate the suitability of the disposal facility by the development of a safety case.

3.12. In meeting the requirements, it is necessary that the operator retain all information relevant to the safety case and the supporting safety assessments of the geological disposal facility, and the records that demonstrate compliance with regulatory requirements. Such information and records have to be retained by the operator unless or until such time as another organization assumes responsibility for the facility, at which time the records should be transferred to the organization that assumes that responsibility.

3.13. The operator should avoid potential conflicts of interest between the efforts to address long term safety objectives and operational objectives, that is, operational expediency should not jeopardize long term safety.

4. SAFETY APPROACH

4.1. The safety approach includes all the ways in which the safety of people and the environment is ensured throughout the lifetime of a geological disposal facility. It may be useful for the government and the regulatory body to set out the national approach in a formal safety strategy document that is produced at the start of the geological disposal programme and updated periodically. A safety strategy is defined by the OECD Nuclear Energy Agency [11] as “the high-level integrated approach adopted for achieving safe disposal”. It includes strategies to select a site and to design, construct and operate a disposal facility. In addition, the strategy may include recommendations for the preparation and maintenance of the safety case, which can be used in decision making and procedures for regulatory approval (see Section 5).

4.2. As yet, there are no specific international standards for protection of the environment from harmful effects of ionizing radiation. In the requirements of the BSS [4] and the recommendations of the International Commission on Radiological Protection [12], it is assumed that, subject to the appropriate definition of groups of exposed people, the protection of people against radiation hazards associated with a geological disposal facility will also satisfy the principle of protection of the environment. The main issues of radiation protection of the environment and the possible development of standards for this purpose are discussed in Refs [13] and [14].

IMPORTANCE OF SAFETY IN THE DEVELOPMENT PROCESS

Requirement 4 of SSR-5 (Ref. [1]): Importance of safety in the process of development and operation of a disposal facility

Throughout the process of development and operation of a disposal facility for radioactive waste, an understanding of the relevance and the implications for safety of the available options for the facility shall be developed by the operator. This is for the purpose of providing an optimized level of safety in the operational stage and after closure.

4.3. The development of a geological disposal facility involves an iterative process of site characterization and the design and evolution of the safety case and the supporting safety assessment to provide an optimized level of operational and post-closure safety (see the appendix of Ref. [1]). Geological disposal facilities for radioactive waste may be developed and operated over a period of several years or several decades. Key decisions, such as decisions on the choice of concept, site selection and evaluation, design, construction, operation and closure of the disposal facility, are expected to be made as the project develops. In this process, decisions are made on the basis of information available at the time, which may be qualitative and/or quantitative, and on the confidence that can be placed in that information. Facility development, operation and closure decisions are influenced by external factors, such as national policy and preferences. “An adequate level of confidence in the safety of each disposal facility has to be developed before decisions are taken” [1].

4.4. “At each major decision point, the implications for the safety of the available design options and operational options for the disposal facility have to be considered and taken into account. Ensuring safety, both in the operational stage and after closure, is the overriding concern at each decision point. If more than one option is capable of providing the required level of safety, then other factors also have to be considered. These factors could include public acceptability, cost, site ownership, existing infrastructure and transport routes” [1].

4.5. Critical components of the disposal system (i.e. the disposal facility and the environment in which it is sited) should be qualified, as appropriate and practical, using standardized and accepted testing methods to gain confidence in their ability to perform the required function(s). If new techniques are employed, they should be developed and qualified within a time frame that is compatible with the project schedule.

4.6. Operational safety is provided by means of active and passive systems. Active systems could include monitoring for releases of radioactive material and operational controls, whereas passive systems could include engineered features such as shielding. Where appropriate, operational experience and technologies adopted from operating nuclear facilities (e.g. techniques for fuel handling) should be used in the development of safety systems for operational safety. Safety mechanisms for the post-closure period are distinct from those employed in the operational period, and therefore, the remainder of Section 4 provides recommendations on the approach to safety after closure of the geological disposal facility.

4.7. The objective of geological disposal of radioactive waste is to provide containment and isolation of the radionuclides in the waste from the biosphere. There is no universally accepted method of distinguishing between the safety characteristics of a geological disposal system that contribute to containment and those that contribute to isolation. Although it is not critical to separate safety characteristics into either containment or isolation, and they are not necessarily mutually exclusive, for the purposes of clarity, in this Safety Guide the following descriptions for containment and isolation will be assumed:

- (a) The containment characteristics of a geological disposal system include those processes and features of the disposal facility and host geological formation that are aimed at ensuring that radionuclides remain within the disposal area of the facility.
- (b) The isolation characteristics of a geological disposal system include those processes and features of the host rock that ensure radionuclides remain within the geosphere, physically separated from the wider biosphere, (i.e. characteristics that isolate waste from humans) or which migrate to the biosphere only in quantities that are not radiologically significant.

CONTAINMENT

Requirement 8 of SSR-5 (Ref. [1]): Containment of radioactive waste

The engineered barriers, including the waste form and packaging, shall be designed, and the host environment shall be selected, so as to provide containment of the radionuclides associated with the waste. Containment shall be provided until radioactive decay has significantly reduced the hazard posed by the waste. In addition, in the case of heat generating waste, containment shall be provided while the waste is still

producing heat energy in amounts that could adversely affect the performance of the disposal system.

4.8. Containment of waste implies designing the disposal facility to postpone or minimize the release of radionuclides. Containment may be provided both by means of a durable waste form and packaging, compatible with the other engineered barriers and the host geological formation. The safety case and supporting safety assessment for the particular waste type and site will provide the required demonstration of the containment capability of the disposal system. A long containment period provided by durable waste packages may not be practicable or necessary for lower activity long lived waste.

4.9. For the most highly concentrated radioactive waste, such as spent nuclear fuel (if designated as radioactive waste) and vitrified waste from fuel reprocessing, it is necessary that the engineered barriers provide practically complete containment over a period of several hundreds of years to several thousand years. This will ensure that the majority of shorter lived radionuclides decay in situ and uncertainty associated with the degradation of the waste form and migration of radionuclides when pronounced thermal gradients are present is reduced (i.e. any release of radionuclides would occur only after the heat generated by radioactive decay has substantially decreased).

ISOLATION

Requirement 9 of SSR-5 (Ref. [1]): Isolation of radioactive waste

The disposal facility shall be sited, designed and operated to provide features that are aimed at isolation of the radioactive waste from people and from the accessible biosphere. The features shall aim to provide isolation for several hundreds of years for short lived waste and at least several thousand years for intermediate and high level waste. In so doing, consideration shall be given to both the natural evolution of the disposal system and events causing disturbance of the facility.

4.10. Isolation means retaining the waste and keeping its associated hazard away from the biosphere in a disposal environment that provides substantial physical separation from the biosphere, making human access to the waste difficult without special technical capabilities, and that restricts the mobility of most of the long lived radionuclides. For geological disposal of radioactive waste, isolation is

provided primarily by the host geological formation as a consequence of the depth of disposal.

4.11. Location of a geological disposal facility at an appropriate depth in a stable geological formation provides protection of the facility from the disruptive effects of geomorphological processes such as erosion and glaciation. Location away from known areas of underground mineral resources and other valuable resources will reduce the likelihood of inadvertent disturbance of the geological disposal facility.

4.12. An appropriate depth for the geological disposal facility should be determined, with account taken of the nature and the hazard of the waste, local geological and hydrogeological conditions, including the hydraulic head gradients, and geochemical and geomechanical characteristics.

MULTIPLE SAFETY FUNCTIONS

Requirement 7 of SSR-5 (Ref. [1]): Multiple safety functions

The host environment shall be selected, the engineered barriers of the disposal facility shall be designed and the facility shall be operated to ensure that safety is provided by means of multiple safety functions. Containment and isolation of the waste shall be provided by means of a number of physical barriers of the disposal system. The performance of these physical barriers is achieved by means of diverse physical and chemical processes together with various operational controls. The capability of the individual barriers and controls together with that of the overall disposal system to perform as assumed in the safety case shall be demonstrated. The overall performance of the disposal system shall not be unduly dependent on a single safety function.

4.13. Multiple safety functions enhance both safety and confidence in safety by ensuring that the overall performance of the geological disposal system is not unduly dependent on a single safety function. The presence of multiple safety functions provides assurance that even if one safety function does not perform fully as expected (e.g. owing to an unforeseen process or an unlikely event), other safety functions will ensure that the overall performance of the disposal system as a whole is not jeopardized.

4.14. In the long term, progressive degradation of the engineered barrier system cannot be ruled out and, consequently, radionuclides may be released into the geological environment where they may eventually migrate to the biosphere. The disposal system should provide a combination of natural and engineered characteristics to support efficient containment and isolation of the waste by maintaining package integrity, limiting the solubility of radionuclides and the waste form, minimizing where possible groundwater inflow and/or providing a long travel time for radionuclide transport from the disposal facility to the biosphere. Factors limiting inflows and contributing to long travel times include low permeability formations, low hydraulic gradients and dispersion characteristics of the geosphere. Any potential concentrations of radionuclides in the biosphere would be further reduced by the retardation and precipitation capability of the engineered barriers and the host rock. In addition, radioactive decay progressively reduces the activities of radionuclides present in the disposal system. Materials used for backfilling or sealing should have properties that do not degrade unduly the safety functions of the geological barriers.

4.15. A safety function may be provided by means of a physical entity, such as the waste form, waste package, the backfill or the host geological formation, the characteristics of which inherently prevent or restrict the migration of radionuclides. A safety function may also be provided by means of a chemical property or process, such as solubility, corrosion rate, dissolution rate or leach rate. A particular barrier may perform a number of safety functions. For example, the backfill may provide chemical conditioning of the groundwater in addition to retention of radionuclides. Therefore, the requirement to ensure that safety is provided by means of multiple safety functions may be achieved through consideration of the safety functions offered by a single barrier, particularly for waste that poses a lower hazard.

4.16. The performance of a geological disposal system is dependent on different physical components and other features having different safety functions, the importance of which may vary over different time periods. To meet the requirement for multiple safety functions, it is necessary for the safety case to explain and justify the functions provided by each physical component and other features and indicate the time periods over which they are expected to perform. It is also necessary for the safety case to identify the complementary safety functions that will be effective if a physical component or other safety function does not fully perform.

PASSIVE SAFETY

Requirement 5 of SSR-5 (Ref. [1]): Passive means for the safety of the disposal facility

The operator shall evaluate the site and shall design, construct, operate and close the disposal facility in such a way that safety is ensured by passive means to the fullest extent possible and the need for actions to be taken after closure of the facility is minimized.

4.17. During the operational period, passive features such as shielding and containment provided by the packaging material can provide safety. However, “certain active control measures have to be applied” in the operational period [1].

4.18. Safety after closure is provided by passive systems such as geological and engineered barriers. Geological disposal, at appropriate depths, provides isolation as an inherent safety feature. Monitoring or institutional controls is not to be relied on for the safety of the facility after closure. This does not mean that post-closure monitoring need not be carried out, if present or future generations choose to do so. It is likely that passive institutional controls, such as the use of markers and control on land use, will be implemented and maintained, at least for a certain period immediately after closure. Active institutional controls such as monitoring may also be applied for a period after closure of a geological disposal facility, for example, to address public concerns and licensing requirements or as protection against human intrusion.

5. THE SAFETY CASE AND SAFETY ASSESSMENT

5.1. A safety case is a collection of arguments and evidence that demonstrates that a particular facility, part of a facility or an activity on a site is safe. The safety case should be prepared for at least each major step in the development, operation and closure of a geological disposal facility and may include some or all of the submissions to the regulatory body seeking approval to proceed from one step to the next. The safety case is progressively enhanced as development, operation and closure are carried out, so that all safety related occurrences and the remedial actions taken are recorded, and that there is at all times an up to date set of documents that demonstrate that the facility is safe and is expected to remain safe

over the long term. In this section, the terms ‘operational safety case’ and ‘post-closure safety case’ are used. In practice, these may be separate entities or parts of one overall safety case for the facility.

5.2. “The safety case has to include the output of the safety assessment ([see the following]), together with additional information, including supporting evidence and reasoning on the robustness and reliability of the facility, its design, the logic of the design, and the quality of safety assessment and underlying assumptions. The safety case may also include more general arguments relating to the disposal of radioactive waste and information to put the results of safety assessment into perspective” [1]. Such arguments include comparisons of predicted radionuclide releases with exposures to natural background concentrations and radiation levels, as well as comparisons with natural analogues. Remaining uncertainties and “Any unresolved issues at any step in the development or in the operation or closure of the facility have to be acknowledged in the safety case” [1]. Further work to address unresolved issues is likely to be necessary if they impact on the evaluation of safety.

5.3. Safety assessment is the process of using appropriate methods to analyse systematically the risk associated with the facility, and the ability of the site and the design of the facility to meet safety requirements. A safety assessment for a geological disposal facility “has to include quantification of the overall level of performance, analysis of the associated uncertainties and comparison with the relevant design requirements and safety standards... Any significant deficiencies in scientific understanding, data or analysis that might affect the results presented also have to be identified in the safety assessment [1]” (see Appendix II on post-closure safety assessment).

5.4. “Safety assessment has to provide input to ongoing decision making by the operator” [1], such as decision making relating to subjects for research, site characterization, facility design, allocation of resources and development of waste acceptance criteria. Safety assessment includes analyses to identify key uncertainties and processes relevant to safety. These analyses improve the understanding of the performance of geological disposal facilities and therefore contribute to the basis for the safety arguments presented in the safety case.

5.5. The safety case developed by the operator should be made available to other interested parties such as national and local governments so as to facilitate the relevant decision making processes that enable the operator to proceed to the next step of facility development or operation.

PREPARATION, APPROVAL AND USE OF THE SAFETY CASE AND SAFETY ASSESSMENT

Requirement 12 of SSR-5 (Ref. [1]): Preparation, approval and use of the safety case and safety assessment for a disposal facility

A safety case and supporting safety assessment shall be prepared and updated by the operator, as necessary, at each step in the development of a disposal facility, in operation and after closure. The safety case and supporting safety assessment shall be submitted to the regulatory body for approval. The safety case and supporting safety assessment shall be sufficiently detailed and comprehensive to provide the necessary technical input for informing the regulatory body and for informing the decisions necessary at each step.

5.6. A safety case has to be prepared early in the development of a geological disposal facility to guide activities in research and development, site characterization, design and planning [1]. The safety assessment process should involve calculations to evaluate the robustness of the proposed conceptual model(s) in terms of its potential to meet regulatory requirements and to determine the relevant radionuclides, pathways and release mechanisms for which further knowledge is necessary and on which the focus should be set. Scoping calculations are often based on limited data, for example, from searches of the literature, material specifications, laboratory studies and studies of natural analogues, preliminary site investigations and characterization of the waste. Acquisition of data will continue throughout the step by step process until the disposal facility is permanently closed or the proposed concept is determined to be unacceptable.

5.7. “The safety case has to be developed progressively and elaborated as the project proceeds” [1] to provide a basis for licensing applications at key steps in the development of the geological disposal facility (see Fig. 1). The regulatory body may require an update of, or revision to, the safety case prior to making a decision on proceeding to the next step in the development and operation of the geological disposal facility. The formality and level of technical detail of the safety case will depend on the stage of development of the project, the decision in hand, the audience to which it is addressed and specific national requirements.

SCOPE OF THE SAFETY CASE AND SAFETY ASSESSMENT

Requirement 13 of SSR-5 (Ref. [1]): Scope of the safety case and safety assessment

The safety case for a disposal facility shall describe all safety relevant aspects of the site, the design of the facility, and the managerial control measures and regulatory controls. The safety case and supporting safety assessment shall demonstrate the level of protection of people and the environment provided and shall provide assurance to the regulatory body and other interested parties that safety requirements will be met.

5.8. The results of a safety assessment should be presented in a way that provides a demonstration of the performance of individual system components. This is a worthwhile exercise that may be carried out easily if a modular approach to modelling is taken. Demonstration of the expected behaviour of each component and iterative improvement in component design or knowledge of a component's expected behaviour, to ensure its effective performance, will increase the level of confidence in the performance of the whole system.

5.9. The safety case for a geological disposal facility includes safety assessments for the operational period and for the post-closure period. For the safety case and supporting safety assessment for the operational period, safety of the facility will rely on active and passive measures, whereas for the post-closure safety case and supporting safety assessment, safety of the facility will rely solely on passive barriers. Additionally, the facility is subject to regulatory inspection and radiation monitoring for the entire operational period. Thus, differences exist both in the regulatory criteria and in the safety case and supporting safety assessments to be developed for demonstrating safety for the operational period and for the post-closure period.

5.10. The safety case for the operational period of a geological disposal facility should address all aspects of operation relevant to radiation exposure, including waste emplacement, any underground construction work carried out during emplacement and backfilling, sealing and closing of the facility. If it is intended that the facility could remain open for a long period after the conclusion of waste emplacement, the safety case for the operational period should include consideration of the refurbishment and replacement of equipment that would be necessary in this period. It might also be necessary to show that waste could be retrieved safely while the facility is open.

5.11. “Consideration has to be given to both occupational exposure and public exposure resulting from conditions of normal operation and anticipated operational occurrences... Accidents of a lesser frequency, but with significant radiological consequences (i.e. possible accidents that could give rise to radiation doses over the short term in excess of annual dose limits ...), have to be considered with regard to both their likelihood of occurrence and the magnitude of possible radiation doses” [1].

5.12. The safety case for the period after closure should address scenarios for the more likely evolutions of the geological disposal facility and its regional setting over very long time periods (e.g. a time period comparable to that over which the waste remains hazardous) and the less likely events that might affect the performance of the facility. For geological disposal facilities, to meet the requirements [1], it is necessary that the safety case and the supporting assessments:

- (a) Present evidence that the key features, events and processes that might significantly affect geological disposal system are sufficiently well understood that scenarios of possible evolutions are properly generated;
- (b) Provide estimates of the performance of the geological disposal system regarding compliance with all the relevant safety requirements;
- (c) Identify and present an analysis of the associated uncertainties.

5.13. The safety case for the period after closure should be based on quantitative analyses and should be further supported by qualitative arguments. It may include the presentation of multiple lines of reasoning based, for example, on studies of natural analogues and palaeohydrogeological studies. A major part of the safety case is concerned with demonstrating that consideration has been given to all the important uncertainties.

5.14. The regulatory body should stipulate or provide guidance concerning timescales for safety assessments. Comparison of calculated doses or risks to dose limits or risk limits specified in regulatory requirements may be required for at least several thousand years and may be extended to timescales beyond this, for example, to estimate peak dose. However, it is recognized that for timescales beyond several thousand years, uncertainty concerning future conditions of the geosphere and biosphere is such that reference calculations based on appropriate simplifying assumptions may be sufficient, with account taken of scenarios for evolution of the natural characteristics of the disposal system and ‘stylized’ approaches (i.e. under certain prescribed conditions) to human behaviour and characteristics, for example, using reference biospheres [15].