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

IAEA SAFETY RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish or adopt standards of safety for protection of health and minimization of danger to life and property, and to provide for the application of these standards.

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The site provides the texts in English of published and draft safety standards. The texts of safety standards issued in Arabic, Chinese, French, Russian and Spanish, the IAEA Safety Glossary and a status report for safety standards under development are also available. For further information, please contact the IAEA at PO Box 100, 1400 Vienna, Austria.

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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
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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 measures[1] 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

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

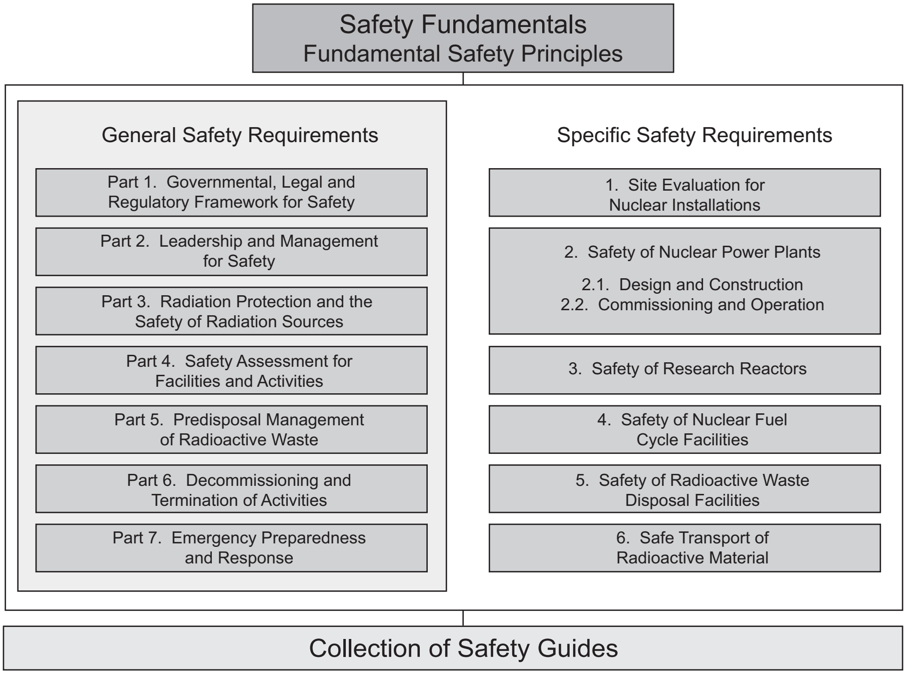

FIG. 1. The long term structure of the IAEA Safety Standards Series.

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

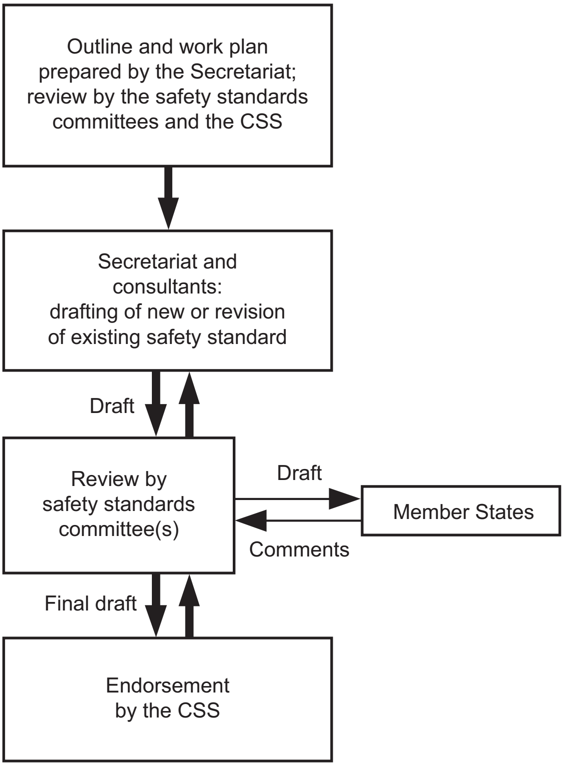

FIG. 2. The process for developing a new safety standard or revising an existing standard.

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.

CONTENTS

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.

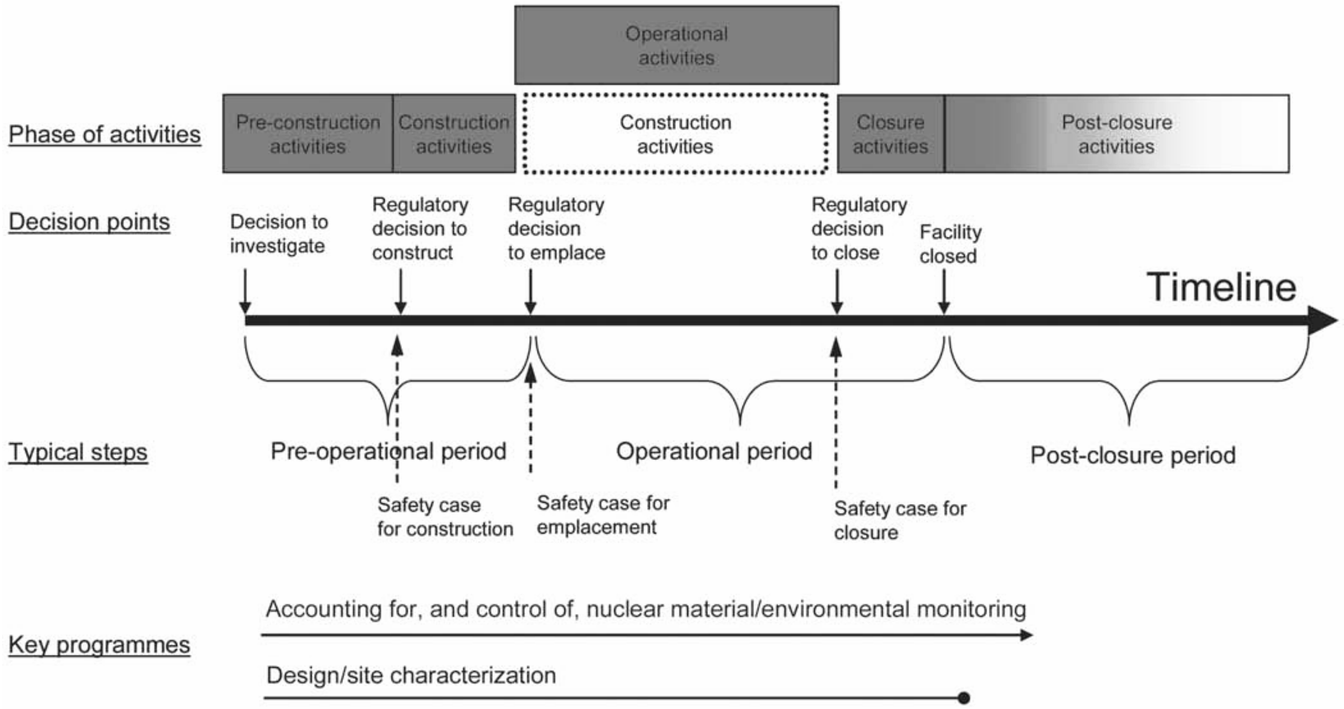

FIG. 1. Timeline to illustrate the development of a geological disposal facility.

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].

5.15. In safety assessment for the post-closure period, the performance of the geological disposal system under the expected evolution and under certain specific, but less likely, evolutions and events is analysed. Sensitivity analyses and uncertainty analyses should be undertaken to obtain an understanding of the performance of the geological disposal system and its components under a range of evolutions and events. Low probability scenarios that have a potential for major consequences should be explored to understand the robustness of the disposal system. The safety assessment should include some stylized calculations of the consequences of inadvertent human intrusion into the closed disposal facility [1].[1] Similarly, a stylized approach could be taken for biosphere calculations (see Appendix II on post-closure safety assessment for further details regarding development of the safety assessment).

5.16. Where appropriate, the need to consider complex processes in the post-closure evolution of the disposal system should be reduced to the extent possible. Whereas passive features are not necessarily free from complexity, in the choice of site and design features complex processes should be avoided to the extent possible. Avoidance of complex processes may reduce the need to couple processes in the models developed for safety assessment; furthermore, it may be possible to restrict consideration of other factors that could affect the evolution of the disposal system in more complex settings. The spatial and temporal variability of features, events and processes [16] that need to be taken into account could also be more clearly presented for a relatively simple environment if complex processes are avoided. In this way, the number of key parameters to be included in the safety assessments may be reduced and simpler models could be used to assess safety. Although simplicity is a desirable feature, the containment and isolation capabilities of the site afforded by its natural characteristics are of primary importance and these should be the deciding criteria employed in the choice of a site.

5.17. Calculations of doses and/or risks will be undertaken over the time periods and for the exposure scenarios specified in regulatory requirements. Regulatory criteria will typically specify characteristics of exposed groups or individuals to be used in dose calculations (the concepts of critical group and average member of the critical group have been used in some States in specifying exposure

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[1] An IAEA TECDOC on the use of human intrusion scenarios in safety assessment of radioactive waste disposal is in preparation.

scenarios). For very long timescales for which dose estimates can be very uncertain, complementary arguments may be useful to illustrate safety, for example, safety indicators, such as concentrations and fluxes of radionuclides of natural origin [17].

5.18. The safety case should include plans for closure of the facility. These should be updated and refined as information is gained during site characterization and construction and operation of the disposal facility. An authorization to begin waste emplacement in a facility will include approval of preliminary closure plans, while recognizing that these plans will be updated as operations proceed. If possible, closure designs and plans in should be tested under conditions that are relevant for the facility.

5.19. The safety case and supporting safety assessments should become more detailed and comprehensive as development and operation of the geological disposal facility proceeds. The progressive development of the safety case and supporting safety assessments is illustrated in Table 1.

DOCUMENTATION OF THE SAFETY CASE AND SAFETY ASSESSMENT

> **Requirement 14 of SSR-5 (Ref. [1]): Documentation of the safety case and safety assessment**
>
> **The safety case and supporting safety assessment for a disposal facility shall be documented to a level of detail and quality sufficient to inform and support the decision to be made at each step and to allow for independent review of the safety case and supporting safety assessment.**

5.20. The scope and structure of the documentation setting out the safety case and supporting safety assessment depend on the step reached in the project for the geological disposal facility and on national requirements. This includes consideration of the needs of different interested parties for information. Important considerations in documenting the safety case are justification of decisions, traceability of reasoning and clarity of information. Depending on the needs of the different interested parties, documents may need to be prepared at various levels of detail and in different styles.

TABLE 1. FEATURES OF THE SAFETY CASE AND SUPPORTING SAFETY ASSESSMENTS THROUGHOUT THE LIFETIME OF A DISPOSAL FACILITY

Stage in lifetime of the facility	Characteristics of the safety case[a]	Basis for safety assessment
Initial site investigation and preliminary facility design	Outline of operational safety case, preliminary post-closure safety case.	Data from initial site investigations; preliminary design studies and closure plans; waste inventory, compendia of data on behaviour of materials; data and observations from analogous sites and processes.
Site characterization and confirmation	Interim operational and post-closure safety cases that are detailed enough to form the basis for the decision for construction.	Detailed site investigation data from surface and subsurface investigations; detailed plans for facility design and construction; waste inventory, site specific data on behaviour of materials; operational plans and closure plans. Regulatory decision on construction.
Construction	Final operational safety case and advanced post-closure safety case that are detailed enough to form the basis for the decision for commissioning and operation.	Site data gained during construction; waste inventory, any trial waste emplacements, as-built design; closure plans that will be tested during operations; detailed operational plans. Regulatory decision on operation.
Operation	Periodic updates of operational safety case may be provided as required, using experience and data from commissioning and operations. Final post-closure safety case to form the basis for the decision for closure.	Updates of operational and post-closure safety assessments using experience and data from commissioning and operations (including information from in situ testing, monitoring and experiments and testing of closure plans). Regulatory decision on closure.

TABLE 1. FEATURES OF THE SAFETY CASE AND SUPPORTING SAFETY ASSESSMENTS THROUGHOUT THE LIFETIME OF A DISPOSAL FACILITY (cont.)

Stage in lifetime of the facility	Characteristics of the safety case[a]	Basis for safety assessment
Post-closure	Optional additional post-closure safety cases to provide ongoing assurance that behaviour of the disposal system is as predicted.	Optional update of post-closure safety assessment if new scientific evidence relevant to the safety case emerges.

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[a] The safety case that may be developed during each phase in the facility development programme.

5.21. The level of detail provided in the safety case documents should be such that arguments, reasoning and supporting evidence are presented in a convincing, transparent and traceable way. Similarly, the documentation relating to safety assessment should facilitate understanding of the models, data, assumptions and qualitative arguments.

5.22. Transparency is particularly important when documents are to be subject to review by experts or non-experts who are not directly involved in developing, operating or regulating the disposal facility. Key arguments, decisions and assumptions should be set out in high level documents rather than being provided only in very detailed technical documents intended for a small number of very expert readers.

5.23. Traceability is important for quality assurance, especially when changes are made to designs, procedures, models, data or assumptions. It is also essential so that the regulatory body, independent reviewers and others can gauge the strength of arguments and the quality of key data.

5.24. The number of safety case and safety assessment documents and their length will increase throughout the lifetime of the disposal facility. This should be borne in mind when devising the structure for the documentation and setting out guidance for preparing and archiving documents. A complex hierarchy of documents and lack of attention to brevity can cause increasing problems as development of the facility proceeds.

UNDERSTANDING AND CONFIDENCE IN SAFETY

Requirement 6 of SSR-5 (Ref. [1]): Understanding of a disposal facility and confidence in safety

The operator of a disposal facility shall develop an adequate understanding of the features of the facility and its host environment and of the factors that influence its safety after closure over suitably long time periods, so that a sufficient level of confidence in safety can be achieved.

5.25. Understanding of the performance of the disposal system and its dependence on features, events and processes that are internal and external to the facility evolves as more data are accumulated and scientific knowledge is developed. “Early in the development of the concept, the data obtained and the level of understanding gained have to assure sufficient confidence to be able to commit resources for further investigations” [1] (see Appendix II, paras II.61–II.71). Before the start of construction, during emplacement and at closure of the facility, the level of understanding has to be adequate to support the safety case that can facilitate the process to make decisions and gain regulatory approvals to proceed.

5.26. Identifying and addressing uncertainties is a major part of post-closure assessments. A range of techniques should be used to evaluate uncertainties in post-closure performance of the facility. Detailed models of particular parts of the disposal system and of particular events and processes should be used to investigate behaviour and to decide how to handle system components and features, events and processes in the overall safety assessment. Sensitivity analysis, uncertainty analysis and bounding calculations can be used at the detailed level and at the system level. Probabilistic and deterministic calculations can be made for both time varying and steady state situations. The aim is to reduce uncertainties concerning safety where possible, and where this is not possible, to characterize uncertainties quantitatively or qualitatively. Care should be exercised in applying criteria for periods of time for which the uncertainties are such that the criteria may no longer be appropriate as a basis for decision making.

6. ELEMENTS IN A STEPWISE APPROACH TO THE DEVELOPMENT OF A GEOLOGICAL DISPOSAL FACILITY

STEP BY STEP DEVELOPMENT AND EVALUATION

Requirement 11 of SSR-5 (Ref. [1]): Step by step development and evaluation of disposal facilities

Disposal facilities for radioactive waste shall be developed, operated and closed in a series of steps. Each of these steps shall be supported, as necessary, by iterative evaluations of the site, of the options for design, construction, operation and management, and of the performance and safety of the disposal system.

6.1. The development of a geological disposal facility can take decades. The goal of assessing safety at key decision points in the development process, prior to commitment of additional resources, makes it practical to divide the programme into a series of steps. Typical steps should be set at regulatory or governmental decision points for the approval of construction of a geological disposal facility (construction), the approval to receive and emplace waste (operations) and the approval to close the facility permanently (closure). At each of these steps, the safety case is required to be updated [1]. Such an approach provides multiple opportunities to assess the quality of the technical programme and the safety case supporting the decision making process and thus provides confidence in these. Confidence in the safety and feasibility of a geological disposal facility is enhanced through the step by step process and by the maturing safety studies as the project progresses. Figure 1 illustrates a development timeline for a disposal facility, including specification of decision points and phases of activities.

6.2. Key programmes (e.g. site characterization, design activities, accounting for, and control of, nuclear material and environmental monitoring, safety assessment) will be ongoing over a number of steps in the development of the disposal facility (see Fig. 1). As information matures and evolves with the safety case, design and site characterization, information from these key programmes should be shared among other relevant programmes (e.g. the safety case should inform the site characterization and design programmes of the relevance of uncertainties; performance monitoring should be used to provide confirmation of assumptions made in the safety case). The step by step process is an iterative process that should maximize the value of information as it evolves over the series of steps.

6.3. Additional steps may be introduced to facilitate the project management of facility design, commissioning, waste acceptance and operation, and post-closure elements, and may serve as supplementary points for review of the safety case or supporting safety assessments. The nature of the reviews will depend on national practices and the facility in question.

SITE CHARACTERIZATION

Requirement 15 of SSR-5 (Ref. [1]): Site characterization for a disposal facility

The site for a disposal facility shall be characterized at a level of detail sufficient to support a general understanding of both the characteristics of the site and how the site will evolve over time. This shall include its present condition, its probable natural evolution and possible natural events, and also human plans and actions in the vicinity that may affect the safety of the facility over the period of interest. It shall also include a specific understanding of the impact on safety of features, events and processes associated with the site and the facility.

6.4. In the siting process for a radioactive waste disposal facility, four stages may be recognized (Fig. 2): (i) the conceptual and planning stage, (ii) the area survey stage, (iii) the site investigation stage and (iv) the stage of detailed site characterization leading to site confirmation for construction of the disposal facility (see Appendix I for information concerning the first three stages, which should be read in conjunction with this section). Site investigations progress from generalized studies at the early area survey stage to a programme of progressively more detailed characterization as specific objectives are addressed and uncertain features are targeted. Detailed site characterization is required for site confirmation for construction of the disposal facility and may continue through the phases of construction and operation.

6.5. Site characterization is an activity undertaken in order to understand the natural features, events and processes at a site (at the present time, in the past and potentially in the future) and to describe adequately their spatial and temporal extent and variability. Site characterization contributes to a comprehensive description of the site, which may include information concerning anthropogenic characteristics (e.g. land use and transport infrastructure for environmental studies). There should be a clear understanding of the context and of the objectives for any site characterization in order to define properly the degree and focus of the site characterization activities that will be necessary. Site characterization will comprise data acquisition (i.e. mensuration, sampling and monitoring) and the interpretation of that data to generate information and

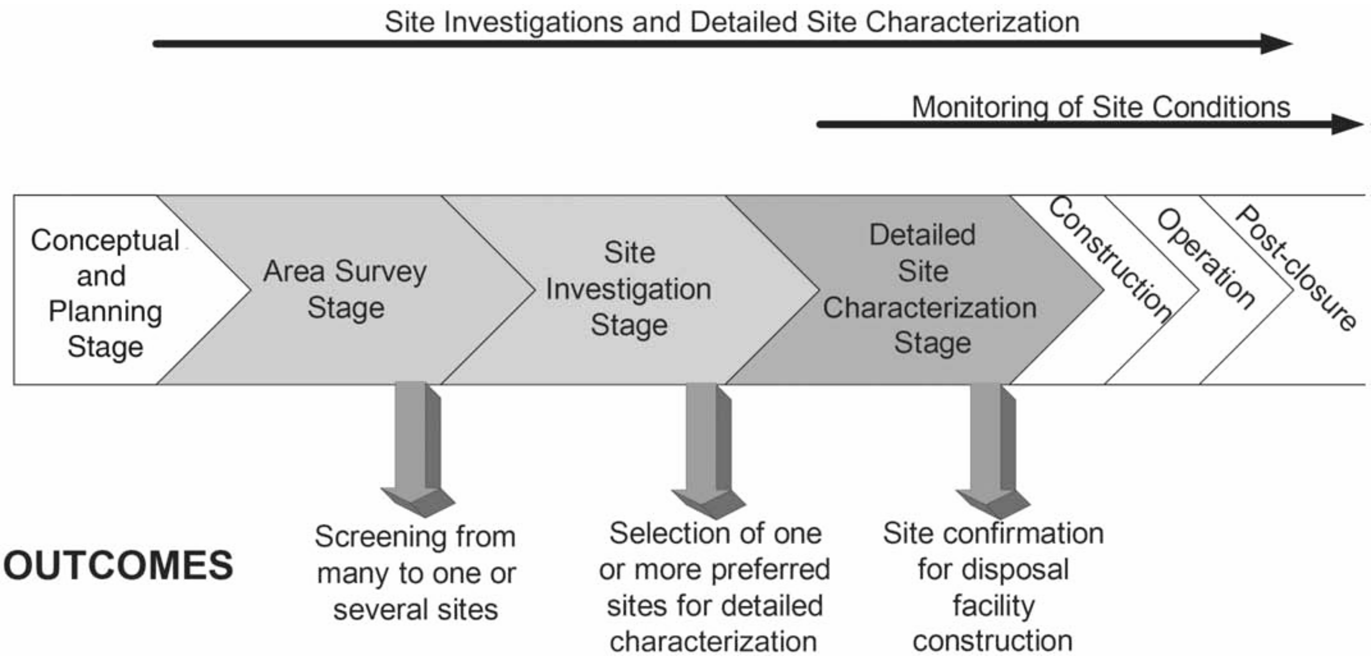

FIG. 2. Stages in the siting process.

knowledge. Site characterization will essentially begin at the earliest stage of the investigation of a site and is expected to become more intensive as the facility development programme progresses through to confirmation of the site and commencement of construction.

6.6. Detailed investigations leading up to and including the site confirmation stage should be undertaken at the preferred site (or sites) to characterize the geological and hydrogeological system in sufficient detail to:

(a) Support or confirm the selection of a preferred site (or sites);
(b) Provide additional site specific information required for detailed design, safety assessment, environmental impact assessment and for licensing of the disposal facility.

6.7. Site characterization should comprise both surface based investigations and underground investigations. The latter may be undertaken as a precursor to commencing construction of the disposal facility, whereby characterization and in situ experiments could be carried out in an underground laboratory or rock characterization facility at the potential disposal site. Alternatively, underground investigations might be carried out as an integral and early part of disposal construction, in which case authorization for construction (but not operation) is based only on results from surface based investigations. Surface based investigations should include, but not be limited to, remote sensing (e.g. satellite monitoring, aerial photography, seismic surveillance) and airborne surveys, geological and geochemical mapping and sampling of outcropping strata, surface based and borehole geophysical investigations, borehole sampling, logging and hydrogeological testing.

6.8. The objectives of a site characterization programme, in terms of what information is required, why it is required and how it will be provided, should be established at an early stage in the development process, recognizing that the detailed aims and methods of data acquisition and interpretation may be amended in response to developing understanding or changes in priorities identified through the development of the safety case and supporting safety assessments.

6.9. A detailed programme of site characterization should be carried out to provide the site specific data necessary to support the technical basis for safety assessments of the long term isolation and containment of the waste within the excavated portion of the geological disposal facility. Quantitative data of a level of detail sufficient for their end use should be obtained (in terms of accuracy and precision of the data and their representative nature with regard to spatial and temporal variability). Appendix I provides additional guidance on the types of information that are expected from a programme for site investigation and characterization. However, the listing may not be exhaustive and site specific circumstances will ultimately dictate what information is required and in what detail.

6.10. Ultimately, knowledge from site characterization will be necessary to provide a credible scientific description of the natural characteristics at the site and a demonstration of understanding concerning safety significant processes (e.g. geological, hydrological, geochemical, mechanical processes). This knowledge will be necessary to provide confidence in the technical basis for safety assessments of the geological disposal system.

6.11. In addition to providing a description of the present day characteristics of a site, the site characterization programme should collate and interpret information in support of models describing the past evolution of the site. This should include an investigation of the long term stability of the geosphere in response to past environmental and climatic changes at the surface and the effects of tectonics, including faulting, rock fracturing and volcanism. Palaeohydrogeological studies are particularly relevant in this regard. The timescale for consideration of such changes should be at least comparable to the future timescale of interest in the safety assessment. Such information may be used in support of scenarios for the future natural evolution of the site and for evaluating the relevance of features, events and processes that could affect the performance of the disposal system, including interactions between the natural and engineered elements.

6.12. The site characterization programme should be conducted at spatial and temporal scales and of a scope sufficient to acquire an adequate understanding of the phenomena that could affect site safety for the time periods of interest and also to develop credible physical process models.

6.13. Site characterization should be undertaken in an iterative manner with safety assessment, as it provides input to, and is, in turn, guided by, the development of the safety case.

6.14. Details of the site and its surroundings should be obtained through the use of additional field, laboratory and subsurface studies. Such studies should permit modelling radionuclide transport on the basis of site specific data, contribute to the establishment of the detailed engineering characteristics of the site and contribute to the development of the design of the facility.

6.15. A detailed programme of site characterization should be implemented in order to provide the site specific data necessary to support the technical basis for the detailed disposal design. The necessary information will include geoscientific parameters and will provide an understanding of factors affecting inflow characteristics relevant to the disposal facility design. The site characterization should enable confirmation of the volume of rock available for disposal of waste, for construction of tunnels and galleries and their optimal layout. The detailed programme of site characterization should also provide the site specific data necessary to support any environmental impact assessments that might be required and should provide input into any regulatory licensing decisions concerning the construction and operation of the disposal facility.

6.16. The site characterization programme should identify the site conditions to be monitored in the pre-construction, construction and operational phases and should establish the required level of detail of measurement (e.g. accuracy and precision) to ensure a suitable baseline record of the natural systems of the site against which the results of future site monitoring can be compared to determine any changes brought about by the construction and operation of the facility. Baseline monitoring information may include, for example, hydraulic pressure measurements, chemical constituents of groundwater and surface waters, surface water flows and natural background radioactivity. The sampling timescale interval should be selected to provide sufficient resolution to allow early notification of any significant changes in site conditions brought about by construction and operation of the facility. Information from disturbances caused by construction could also be used to test and develop models of the site.

6.17. If it is decided to carry out post-closure monitoring, for example, to demonstrate and provide assurance that site behaviour is as predicted, the requirements for this should be specified in advance.

6.18. The site characterization programme should include a management system for ensuring the quality and long term usability of data, as well as their availability. The management system should take into account that site characterization data include spatially distributed information and time series data and that such information is necessary to support the establishment of a baseline for future monitoring.

6.19. The management system should accommodate the integration and coordination of multidisciplinary activities that support multiple objectives (i.e. scientific, engineering and safety objectives). Activities carried out as part of site characterization should minimize, where possible, any impacts on the natural features of the site, to ensure that long term safety is not compromised.

6.20. Information from site characterization activities will likely be used to inform various decision making mechanisms. Confirmation of the suitability of site conditions will provide support for regulatory approvals to progress to the next phases of the development programme, namely, construction and/or operation of the disposal facility. Site characterization should continue as long as is necessary, including into the operational period, to provide the basic data for a specific understanding of the disposal area, to support continuing excavation activities, to contribute further to an adequate baseline for future monitoring, to contribute to the confirmation of assumptions made in earlier safety assessments and to support the post-closure safety case.

6.21. Criteria should be established to indicate and justify when an operator should proceed from one stage to the next stage of site characterization (e.g. to move from surface based investigations to underground investigations), under what conditions a site may be confirmed as suitable for disposal facility construction or operation and when investigations may be considered complete.

6.22. A key requirement for decision making, and possibly one of the most difficult to justify, will relate to the sufficiency of site information. Ultimately, the decision on when the site characterization is complete will need to be based on confirmation that its objectives have been met in terms of the quantity and quality of data necessary to support safety assessments, disposal design and environmental impact assessments or for providing additional confidence in understanding the system and processes. As part of the site investigations, the quantity and quality of data to support safety assessments and the post-closure safety case will be considered sufficient when the value of any additional data collected will not significantly impact on safety. For example, sensitivity studies may indicate that key data uncertainties are manageable, that calculated dose and risks remain within the bounds of regulatory limits, constraints or a target and that any further collection of data would not increase confidence in the safety case. This may be a useful basis for the decision regarding when site investigations for safety assessments may be considered complete (although it is noted that continued monitoring may be of value).

6.23. The site confirmation stage will generally consist of detailed studies and investigation of the preferred site prior to the start of full scale construction of the disposal facility. Careful comparisons with all relevant criteria should be made to confirm that the disposal system, if constructed and operated as designed, will perform as required. Upon confirmation of the suitability of the site, a proposal is submitted to the regulatory body with sufficient information to permit decisions to be made regarding approval for construction of the facility. This proposal will include a safety assessment based on the results obtained from the site investigation, characterization and confirmation activities. Site confirmation studies are reviewed by the regulatory body regarding the decision on the suitability of the site following its review of all information. If all necessary requirements are met, approval (in the form a licence, an authorization for construction, or other form of permission) to begin construction of the disposal facility may be issued. Characterization activities are normally expected to continue into the construction and operational phases in order to provide further data and further reduce any residual uncertainties in the safety case.

6.24. An environmental impact assessment, as required by appropriate national authorities, should be carried out in conjunction with the site characterization for safety purposes. Depending on relevant national laws, the environmental impact assessment may be very broad and may include an evaluation of the effects of the proposed disposal facility on public health and safety and on the environment. It may also include a discussion on avoiding or mitigating such effects and other local or regional impacts of locating the disposal facility at the site.

DESIGN

> **Requirement 16 of SSR-5 (Ref. [1]): Design of a disposal facility**
>
> **The disposal facility and its engineered barriers shall be designed to contain the waste with its associated hazard, to be physically and chemically compatible with the host geological formation and/or surface environment, and to provide safety features after closure that complement those features afforded by the host environment. The facility and its engineered barriers shall be designed to provide safety during the operational period.**

6.25. The facility design is required to provide safety during both the operational and post-closure periods and should take account of any requirements for monitoring, accounting and control of nuclear material, concurrent underground activities (such as excavation, waste emplacement and equipment maintenance, refurbishment and replacement) and retrievability of the waste or reversibility.

6.26. Whilst disposal is defined as the emplacement of waste in an appropriate facility without the intention of retrieval, in some situations, it may, nevertheless, be required that retrievability (design for the safe removal of waste) of the waste be allowed at any period of time before closure. If the ability to retrieve waste is a design requirement, it should be considered as early as possible in the design process in such a way as not to compromise the safety of the facility after closure. As with meeting any design requirement, an optimized approach should be adopted that is consistent with the design principles.

6.27. Although retrievability can be envisaged for all phases of facility development, after closure of the facility, retrievability is considered an exceptional condition. However, in some States, post-closure retrievability is a legal requirement and constitutes a boundary condition on the options available, which must always satisfy the safety requirements for disposal.

6.28. The design of the facility should be of sufficient detail and accuracy to enable the effect of the design requirements to be appropriately evaluated in the assessments of operational and post-closure safety. As the facility design evolves over the phases of facility development, safety assessments are updated to evaluate the effect of design changes on compliance with regulatory criteria.

6.29. The design of the facility for safety in the period after closure should meet the precepts of robustness, simplicity, technical feasibility and passivity; as noted in Section 4, facility design for operational safety will include both active and passive systems. Facility design for the safety of surface based activities associated with the operational period (waste handling and storage) should reflect state of the art radiation protection and industrial safety practices, analogous to existing nuclear facilities. Facility design for the safety of possibly concurrent underground activities (excavation and waste emplacement) should reflect a combination of the best radiation protection, industrial, mining and civil engineering safety practices [2, 4, 18].

6.30. The design of the geological disposal facility for safety in the post-closure period should make optimal use of the intrinsic features of the host geological environment and includes engineered barriers that complement the natural barrier system. Disposal facilities for both high level and intermediate level waste are expected to perform over much longer time periods than those usually considered in industrial applications. Investigation of the ways in which analogous natural materials have behaved in geological settings in nature, or how ancient artefacts and anthropogenic constructions have behaved over time, may contribute to confidence in the assessment of long term performance of the facility. It is important to demonstrate that both the fabrication of waste containers and the construction of engineered barriers are feasible (e.g. in underground laboratories) in order to gain confidence that an adequate level of performance can be achieved.

6.31. The geological disposal facility should be designed so that fissile material, when present, will remain in a subcritical configuration during the operational period. Assessment of the possible evolutions of the disposal system in the post-closure period should also address the criticality issue and should provide confidence that a subcritical condition will be maintained.

6.32. Operational activities should be classified on the basis of estimated radiation exposure conditions and the potential for contamination. Rooms requiring radiation control or with the potential for contamination should be located within a specified area of the facility to allow appropriate access control. In meeting operational requirements to control access, a zoned approach, working inwards towards areas requiring more stringent control, could be applied, where appropriate.

6.33. Radiation monitoring in the operational period should be designed with consideration given to both anticipated operational conditions and postulated accidents. Monitoring stations should be established for measuring, for example, external radiation levels and air and groundwater contamination, as necessary. Such stations should be installed in the radiation controlled areas of the site and the non-controlled areas on-site and should be located selectively in the vicinity of the disposal facility, outside the site boundary.

6.34. To maintain the assurance of robust safety assessment and safety case, the facility design process should be conducted within a management system providing for configuration change control. Design attributes of the engineered barriers for operational safety[2] and post-closure safety should be classified to ensure application of design requirements is graded in accordance with the safety significance of the barrier.

6.35. As with the management system requirements for data integrity, documentation of the facility design relevant to safety should be transparent and should be archived for the benefit of future generations.

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[2] Engineered barriers for operations are often referred to as ‘systems, structures and components important to safety’.

WASTE ACCEPTANCE

Requirement 20 of SSR-5 (Ref. [1]): Waste acceptance in a disposal facility

Waste packages and unpackaged waste accepted for emplacement in a disposal facility shall conform to criteria that are fully consistent with, and are derived from, the safety case for the disposal facility in operation and after closure.

6.36. The proposed waste inventory and the waste acceptance criteria should be developed as part of the safety case and should be submitted to the regulatory body for approval of operations. The operations will ensure the safe handling of waste and the fulfilment of the safety functions by the waste form and waste packaging with regard to long term safety.

6.37. The final waste inventory received and emplaced should be tracked, submitted to the regulatory body for approval of facility closure and included in the safety case.

6.38. The waste characteristics important to the safety of the operational and post-closure periods are part of the relevant safety case. Waste acceptance criteria may be developed by means of an iterative dialogue between regulatory body, the operator of the facility and the generator of the waste. The criteria should include the waste characteristics important to safety in the operational period and the period after closure and typically specify the following:

(a) The permissible range of chemical and physical properties of the waste and the waste form;
(b) The permissible dimensions, weight and other manufacturing specifications of each waste package;
(c) Allowable levels of radioactivity in each package;
(d) Allowable amounts of fissile material in each package;
(e) Allowable surface dose rate and surface contamination;
(f) Requirements for accompanying documentation;
(g) Allowable decay heat generation for each package.

Generators of waste and operators of facilities may wish to consider additional waste acceptance criteria, such as the waste conditioning method adopted in the treatment process, the potential for gas generation (e.g. through radiolysis, corrosion or the influence of microorganisms) or the composition of the waste (e.g. presence of free liquids, void volumes, organic content).

6.39. Waste intended for geological disposal has to be characterized to provide sufficient information to ensure that the waste packages received for disposal comply with the waste acceptance criteria or, if not, that corrective measures are taken by the generator of the waste or the operator of the disposal facility [1]. The decision on acceptance of waste packages is based mainly on records, preconditioning tests and control of the manufacturing and conditioning processes. Owing to the risk of potentially high doses from waste packages, "post-conditioning testing and the need for corrective measures have to be limited as far as practicable" [1].

6.40. The management systems for records should be structured to accommodate the information associated with waste acceptance, including the data indicated in the previous paragraph, and records on waste generation and processing.

6.41. The proposed waste acceptance criteria should be published at the earliest opportunity, to facilitate compatibility of the waste generated and its safe management at the waste generation sites prior to its emplacement in the disposal facility.

CONSTRUCTION

> **Requirement 17 of SSR-5 (Ref. [1]): Construction of a disposal facility**
>
> **The disposal facility shall be constructed in accordance with the design as described in the approved safety case and supporting safety assessment. It shall be constructed in such a way as to preserve the safety functions of the host environment that have been shown by the safety case to be important for safety after closure. Construction activities shall be carried out in such a way as to ensure safety during the operational period.**

6.42. Construction of a geological disposal facility commences only after the safety case for facility construction is approved in accordance with the requirements of the regulatory body. If it is proposed that an underground rock characterization or experimental facility will constitute a part of the disposal facility, adequate documentation should be available to demonstrate that the construction and operation of the characterization facility conforms with regulatory requirements for the disposal facility itself.

6.43. Construction of the facility should proceed in accordance with the approved facility design and any approved design modifications that may be necessary after commencing construction. The layout of the disposal facility will be constrained by host rock conditions and consequently design modifications are likely to be necessary as the construction proceeds. During the construction process, host rock investigations should be performed to verify the suitability of the layout of the disposal facility.

6.44. Excavation and construction of the facility has to be carried out in a manner that avoids unnecessary disturbance of the geological environment, such as the development of unnecessarily extensive disturbed zones due to excavation, the introduction of chemically adverse substances into the host rock and the introduction of hydrogeological and geochemical transients into the host rock. The intrinsic isolation and containment features of the host rock should be preserved as far as practicable.

6.45. Construction of a geological disposal facility could continue after the commencement of operation of part of the facility and the emplacement of waste. To ensure the safety of the underground activities associated with facility construction, consideration will need to be given to the possibly concurrent activities of excavation and waste emplacement, and construction should reflect a combination of the best radiological, industrial and civil engineering safety practices [2, 4, 18].

6.46. The safety of surface based construction activities should rely on state of the art industrial safety practices, analogous with existing nuclear or industrial facilities.

OPERATION

Requirement 18 of SSR-5 (Ref. [1]): Operation of a disposal facility

The disposal facility shall be operated in accordance with the conditions of the licence and the relevant regulatory requirements so as to maintain safety during the operational period and in such a manner as to preserve the safety functions assumed in the safety case that are important to safety after closure.

6.47. As an element of obtaining approval for operation (the licence), the operator is required to demonstrate, prior to commencement of operations involving radioactive material, the adequacy of the facility structures, systems, components, services, functions and procedures for the safe receipt, emplacement and, if necessary, retrieval of waste packages, including for off-normal events and emergency conditions. A commissioning period should be used to evaluate the adequacy of the design, including operating procedures, for the safe handling, emplacement and, if necessary, retrieval of waste as part of normal operations.

6.48. Following approval for commencement of operations involving radioactive material, the facility should be operated in accordance with the terms and conditions of the operating licence and relevant regulatory requirements to provide for adequate radiation protection of workers, the public and the environment. Operations should be conducted in accordance with approved procedures providing for safety [4, 18, 19].

6.49. Access to areas in which waste is handled, stored or emplaced should be controlled to ensure safety and the physical protection of material. Provision should be made for detection of any unauthorized intrusion and for the prompt taking of countermeasures (see also paras 6.69–6.74).

6.50. Closure activities are a part of the operational period of the facility and should be subject to separate approval by the regulatory body; the safety case should be periodically updated to reflect these closure activities. Some parts of the disposal facility, such as disposal tunnels, may be backfilled as soon as practicable in order to minimize the disturbance to the host rock. Such stepwise closure actions should be subject to regulatory approval.

6.51. Consideration should be given to the possibility for concurrent construction and waste emplacement. These activities should be conducted in accordance with the requirements for radiation protection, excavation safety and industrial safety, as appropriate for the specific activity.

6.52. Geological disposal facilities are likely to be operated for several decades for emplacement of waste from power plant operations or decommissioning. Operating procedures should cover maintenance and possibly refurbishment or replacement of equipment over this period of operation. Documentation of changes in equipment, procedures and conditions, and, where required, the safety case for them, should be clear and thorough.

6.53. Monitoring of worker exposures and releases of radioactive material (primarily to the air) in the operational period should be used to inform design changes, including changes in procedures, to minimize releases and to keep exposures as low as reasonably achievable.

6.54. As part of the demonstration of safety in the operational phase, the operator should analyse the consequences of various external events (e.g. fire, flooding, explosions) on the safety of the disposal facility and the safety of workers.

6.55. In some geological disposal programmes, it is envisaged that the facility could remain open for some considerable time after waste emplacement has ceased. This would extend the operating period even further, thus providing increasing amounts of monitoring data relevant to the performance of the facility after closure (e.g. corrosion of waste packages, wetting of backfill materials, changes in hydrological conditions). Procedures should be developed for the evaluation of monitoring data with respect to the impact of the extended operating period on the post-closure safety of the facility (e.g. re-evaluation of safety on the basis of the monitoring data). Documentation of the monitoring data, of any relevant changes from baseline conditions and, as necessary, of the impact of the extended operating period on post-closure safety should be clear and thorough.

CLOSURE

> **Requirement 19 of SSR-5 (Ref. [1]): Closure of a disposal facility**
>
> **A disposal facility shall be closed in a way that provides for those safety functions that have been shown by the safety case to be important after closure. Plans for closure, including the transition from active management of the facility, shall be well defined and practicable, so that closure can be carried out safely at an appropriate time.**

6.56. Closure of a geological disposal facility involves activities such as backfilling and sealing of the underground openings of the disposal facility. The purpose of closure is to try to restore, as far as practicable, the initial natural conditions of the host rock before any excavation is started.

6.57. Post-closure performance of a geological disposal facility should be considered in the initial design and in subsequent updates to the safety case. Prior to regulatory approval for facility closure, the safety case should be updated to provide sufficient evidence that the closure system will be effective and that the safety of the geological disposal facility after closure will be in accordance with regulatory requirements. The effectiveness of the closure system could be shown by demonstrating an understanding of the natural evolution of the site, by in situ testing, by data analysis and modelling and by the use of suitable natural analogues.

6.58. “The disposal facility has to be closed in accordance with the conditions set for closure by the regulatory body in the facility’s authorization, with particular consideration given to any changes in responsibility that may occur at this stage. Consistent with this, the installation of closure features may be performed in parallel with waste emplacement operations. Backfilling and placement of seals or caps may be delayed for a period after the completion of waste emplacement, for example, to allow for monitoring to assess aspects relating to safety after closure or for reasons relating to public acceptability. If such features are not to be put in place for a period of time after the completion of waste emplacement, then the implications for safety during operation and after closure have to be considered in the safety case” [1].

6.59. Closure of a geological disposal facility should also include decommissioning of surface facilities and undertaking any environmental restoration necessary, and may include the construction of durable markers.

MONITORING PROGRAMMES

Requirement 21 of SSR-5 (Ref. [1]): Monitoring programmes at a disposal facility

A programme of monitoring shall be carried out prior to, and during, the construction and operation of a disposal facility and after its closure, if this is part of the safety case. This programme shall be designed to collect and update information necessary for the purposes of protection and safety. Information shall be obtained to confirm the conditions necessary for the safety of workers and members of the public and protection of the environment during the period of operation of the facility. Monitoring shall also be carried out to confirm the absence of any conditions that could affect the safety of the facility after closure.

6.60. Monitoring means continuous or periodic measurement of radiological or other parameters or determination of the status of a structure, system or component. “Monitoring has to be carried out at each step in the development and in the operation of a disposal facility” [1]. Monitoring provides input to safety assessments, continuing assurance of operational safety of the facility and confirmation that actual conditions are consistent with the assumptions made for safety after closure.

6.61. The monitoring programme should be defined prior to construction and in conjunction with development of the safety case. A baseline survey of the site, including the characteristics of the host rock, should be conducted before commencing construction activities. The monitoring programme should be revised periodically to reflect new information gained during construction and operation. A discussion of monitoring activities that could be conducted during the pre-operational and operational periods is provided in Ref. [20].

6.62. A programme of monitoring should be included as part of the safety case and should be refined with each revision of the safety case. During the operational period, the monitoring programme should be used to demonstrate compliance with the regulatory requirements and licence conditions for operation, including compliance with safety requirements for environmental and radiation protection [4].

6.63. The monitoring programme should be subject to audit and independent verification by the regulatory body or other recognized organizations.

6.64. For the post-closure period, the geological disposal facility should be of a passively safe design and should not require or rely on a post-closure monitoring programme to provide assurance of safety. Post-closure monitoring may be performed to provide public assurance, if required, by the government or the regulatory body, but should not compromise the passively safe design.

SURVEILLANCE AND CONTROL OF PASSIVE SAFETY FEATURES

> **Requirement 10 of SSR-5 (Ref. [1]): Surveillance and control of passive safety features An appropriate level of surveillance and control shall be applied to protect and preserve the passive safety features, to the extent that this is necessary, so that they can fulfil the functions that they are assigned in the safety case for safety after closure.**

6.65. In the context of this Safety Guide, the term ‘surveillance’ refers to the physical inspection of a disposal facility in order to verify its integrity to protect and preserve the passive safety features (barriers). Surveillance should focus on elements of the performance of barriers that are directly related to key safety functions of the disposal system. “For geological disposal... the passive safety features (barriers) have to be sufficiently robust so as to not require repair or upgrading” [1] to fulfil their required safety functions. Surveillance activities should not compromise the safety of the facility after closure.

6.66. Geological disposal facilities are designed to be passively safe and, following closure, should not rely on intervention, surveillance or control for the assurance of safety.

THE PERIOD AFTER CLOSURE AND INSTITUTIONAL CONTROLS

Requirement 22 of SSR-5 (Ref. [1]): The period after closure and institutional controls

Plans shall be prepared for the period after closure to address institutional control and the arrangements for maintaining the availability of information on the disposal facility. These plans shall be consistent with passive safety features and shall form part of the safety case on which authorization to close the facility is granted.

6.67. Geological disposal facilities are designed to be passively safe in the post-closure period (i.e. not requiring intervention to ensure safety) and “The long term safety of a disposal facility for radioactive waste is not to be dependent on active institutional control” [1].

6.68. Passive institutional controls should be established to prevent or reduce the likelihood of inadvertent human actions that could interfere with the waste or degrade the safety features of the geological disposal facility. Institutional controls may include the construction of durable markers, the posting of facility records in national and international archives accessible to future populations and the transfer of responsibility for the facility to a successor organization. A suitable mechanism may need to be developed for the transfer of responsibility from one generation to the next.

CONSIDERATION OF THE STATE SYSTEM OF ACCOUNTING FOR, AND CONTROL OF, NUCLEAR MATERIAL

> **Requirement 23 of SSR-5 (Ref. [1]): Consideration of the State system of accounting for, and control of, nuclear material**
>
> **In the design and operation of disposal facilities subject to agreements on accounting for, and control of, nuclear material, consideration shall be given to ensuring that safety is not compromised by the measures required under the system of accounting for, and control of, nuclear material [21–23].**

6.69. The system of accounting for, and control of, nuclear material applies to materials that contain significant quantities of fissile material in potentially extractable form [21–23]. The objective of IAEA nuclear safeguards is the timely detection of the diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or other nuclear explosive devices or for purposes unknown and the deterrence of such diversion by the risk of early detection. Geological disposal provides long term passive nuclear security, consistent with the objective of IAEA nuclear safeguards.

6.70. Where IAEA nuclear safeguards requirements apply, they will apply for all three periods of development of a geological disposal facility (see para. 2.3). Whereas formal IAEA guidance for the application of safeguards in geological disposal facilities is still under development, physical protection guidelines have been issued by the IAEA, which will have to be taken into account for such facilities.

6.71. Certain information that is required for safety can also serve the purposes of IAEA safeguards. Complementary and shared information should be identified early in the development of the disposal facility and could include:

(a) Monitoring data to provide baseline information for later safety assessments, to provide assurance of operational safety and performance of the facility and to confirm conditions consistent with long term safety;
(b) Information from IAEA safeguards measurements on nuclide composition of spent fuel, which could be used for calculations to assess subcriticality and heat generation;
(c) Measurements of releases of radionuclides and environmental monitoring data, which can contribute to assurance of the absence of undeclared activities at the site in relation to fissile material.

6.72. During the pre-operational period, IAEA nuclear safeguards authorities will require information about the original undisturbed site preferably before excavation begins, draft plans of the facility and operations, a description of intended exploratory underground works and general information on the region (e.g. local mining activity). Early access to design information and any pre-existing or baseline data is necessary so that the IAEA can assess nuclear safeguards requirements and suggest any changes to the design that may make it easier to safeguard. This information is also used for the planning of safeguards measures to ensure that they will not compromise the safe construction and operation of the facility.

6.73. During the operational period, IAEA safeguards are aimed at ensuring continuity of knowledge as regards fissile material and the absence of any undeclared activities at the site in relation to such material. Continuity of knowledge is maintained by the State system for accounting and control and the IAEA. The operator will be required to keep records sufficient for the needs of the State and the IAEA.

6.74. IAEA policy for geological disposal facilities is that safeguards requirements will continue even after the waste has been sealed in a geological disposal facility. In the post-closure period, IAEA nuclear safeguards might, in practice, be applied by remote means (e.g. satellite monitoring, aerial photography, microseismic surveillance) although simpler administrative arrangements could also be adequate. “Intrusive methods, which might compromise safety after closure, have to be avoided” [1]. Continuation of the application of safeguards measures could increase confidence in the longevity of administrative controls designed to prevent inadvertent disturbance of the geological disposal facility. In this respect, nuclear safeguards could improve confidence in safety after closure.

NUCLEAR SECURITY MEASURES

Requirement 24 of SSR-5 (Ref. [1]): Requirements in respect of nuclear security measures

Measures shall be implemented to ensure an integrated approach to safety measures and nuclear security measures in the disposal of radioactive waste.

6.75. “Where nuclear security measures are necessary to prevent unauthorized access by individuals and to prevent the unauthorized removal of radioactive material, safety measures and nuclear security measures have to be implemented in an integrated approach” [1, 2, 24].

6.76. “The level of nuclear security has to be commensurate with the level of radiological hazard and the nature of the waste” [1].[3] Security requirements will be the most rigorous where nuclear safeguards requirements apply (see also paras 6.69–6.74).

MANAGEMENT SYSTEMS

Requirement 25 of SSR-5 (Ref. [1]): Management systems

Management systems[4] to provide for the assurance of quality shall be applied to all safety related activities, systems and components throughout all the steps of the development and operation of a disposal facility. The level of assurance for each element shall be commensurate with its importance to safety.

6.77. Reference [25] establishes requirements for the establishment, implementation, assessment and continual improvement of a management system within every organization. A management system designed to fulfil the requirements integrates safety, health, environmental, security, quality and economic elements. Safety is the fundamental principle upon which the management system is based. The management system defines the organizational structure for implementing processes. It also defines the responsibilities and authorities of the various personnel and organizations involved in designing, implementing and assessing the processes and how the activities will be executed. The management system should be applied to all processes, activities, systems and components throughout all the steps of the development and operation of a geological disposal facility.

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[3] Technical guidance on physical protection of radioactive waste is in preparation.

[4] The term ‘management system’ includes all the initial concepts of quality control (controlling the quality of products) and its evolution through quality assurance (the system for ensuring the quality of products) and quality management (the system for managing quality).

6.78. The operator's management system should comply with national standards on management systems and internationally recognized codes, regulations and standards should be used whenever possible [25–27]. An appropriate management system that integrates safety, health, environmental, security, quality and economic elements contributes to confidence that the relevant requirements and criteria for site characterization, design, construction, operation, closure and post-closure safety are met. The relevant activities, systems and components should be identified on the basis of the results of systematic safety assessments and application of the management system requirements should be graded in accordance with their importance to safety.

6.79. The operator's management system should be acceptable to the regulatory body and appropriately qualified certifying organizations. The management system should be endorsed by the senior management of the operating organization with a commitment to ensuring that it is fully implemented throughout the organization.

6.80. The operating organization should be periodically assessed by appropriate external bodies to ensure compliance with the procedures in place as part of the management system.

6.81. Because geological disposal utilizes both natural and engineered barriers, the management system should be designed to accommodate the fact that uncertainties are inherent in natural systems and that special procedures may be required to deal systematically with such uncertainties in long term safety assessments.

6.82. The management system and its integrated quality assurance programme should, for a geological disposal facility, provide for the production, retention and preservation of objective evidence (e.g. samples of materials as well as documentary evidence) that the required quality objectives have been achieved.

6.83. Consideration should be given to the physical and electronic forms of the records to ensure that information remains available and is archived appropriately for the benefit of future generations (see also para. 6.68).[5]

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[5] A Safety Report containing further information on the maintenance and preservation of such records is in preparation.

6.84. For all development phases and activities, the operator should determine its staffing requirements, should recruit and train suitably qualified persons and should foster and maintain a safety culture. Recognizing that a disposal facility may operate for decades, the operator should implement measures to maintain competency and safety culture through training, education and transfer of knowledge.

EXISTING DISPOSAL FACILITIES

Requirement 26 of SSR-5 (Ref. [1]): Existing disposal facilities

The safety of existing disposal facilities shall be assessed periodically until termination of the licence. During this period, the safety shall also be assessed when a safety significant modification is planned or in the event of changes with regard to the conditions of the authorization. In the event that any requirements set down in this Safety Requirements publication are not met, measures shall be put in place to upgrade the safety of the facility, economic and social factors being taken into account.

6.85. Currently, there are no existing disposal facilities for high level radioactive waste and only a limited number of existing geological disposal facilities for intermediate level waste. Older facilities that were not constructed to current safety standards may not meet all the safety requirements established in Ref. [1].

6.86. Post-closure safety assessment needs to be carried out for existing facilities in order to determine whether they meet current standards for post-closure safety. For a facility that is operating, the assessment should be based on current plans for its continued operation, eventual closure and any post-closure institutional controls.

6.87. If the assessment shows that the facility meets current standards for post-closure safety, no further action is necessary. If it does not meet current standards, then the next steps depend on whether the facility is still operating. The collection of additional information on site characterization may be required.

6.88. If existing facilities that fail to meet standards are to continue operating safely and, subsequently, to be closed safely, they have to be brought up to an appropriate level of safety performance. It will, therefore, be necessary to assess and compare options for possible remedial actions, changes to current waste acceptance criteria, operational and maintenance procedures, and closure plans. New monitoring and surveillance procedures may also be necessary.

6.89. It may be necessary to determine whether remedial actions should be carried out and, if so, what the best action to take would be. In radiation protection terms, the principles involved are the principles of justification and optimization [4]. Justification involves comparing the implications of possible remedial actions with the implications of taking no action, and then deciding which, if any, actions would do more harm than good. When the types of remedial action that would be justified have been identified, they should then be compared to one another in order to provide input to a decision on the preferred action. This comparison should include all the factors required to identify the optimum option (i.e. the remedial action that would do most good).

6.90. The main radiation protection principle involved in decisions concerning remedial actions or changes to operating plans and procedures at an operating facility is the principle of optimization [4]. Input into decision making should be obtained by comparing the various proposed actions and changes on the basis of their radiological impacts on people and the environment after closure, their non-radiological impacts on people and the environment, their social impacts, their financial costs and other factors. Feasibility studies and a programme of demonstrations may support the decision making process. Because of the wide range of issues that need to be considered, there are advantages in involving interested parties other than the regulatory body (e.g. the local community) in assessments and comparisons of proposed remedial actions and operational changes at existing facilities.

6.91. The options for remedial actions at a closed facility (or closed areas of a geological disposal facility) are more limited than at an operating facility. Opening up the facility (or a portion of the facility) to undertake remedial action will likely entail significant commitment of resources and significant radiation exposure of, and risks to, workers.

6.92. In addition, there is the question as to the appropriate timing of remedial actions. Early action could have advantages and disadvantages. For example, less degradation of the waste form and waste packages will have occurred so it will be easier to remove waste from a facility, but less decay will have occurred and therefore the radiation exposure workers could be higher. One way to deal with the issue of timing is to carry out an optimization exercise and include remedial actions at various times as separate options. As with operating facilities, there are advantages in involving interested parties in decision making on remedial actions at closed facilities.

Appendix I

SITING OF GEOLOGICAL DISPOSAL FACILITIES

INTRODUCTION

I.1. Siting is a fundamentally important activity in the geological disposal of radioactive waste. In the siting process for a radioactive waste disposal facility, four stages may be recognized: (i) a conceptual and planning stage; (ii) an area survey stage, leading to the selection of one or more sites for more detailed consideration; (iii) a site investigation stage of detailed site specific studies and site characterization and (iv) a site confirmation stage. In site selection, one or more preferred candidate sites are selected after the investigation of a large region, the rejection of unsuitable sites and the screening and comparison of the remaining sites. From several, possibly many, prospective sites identified at the start of a siting process, a selection is made of one or more preferred sites on the basis of geological setting and with account taken of other factors. Sociopolitical factors are an important consideration in any site selection process (e.g. demographic conditions, transport infrastructure, existing land use). Decision making in the site selection process may involve various levels of involvement of the public and local communities, including the use of veto and volunteerism. The national preferences expressed will vary from State to State and hence cannot be addressed within international guidance for the safety of geological disposal facilities. During the initial stages of site selection, geological and hydrogeological site specific information may be sparse or lacking. Nevertheless, such data that are available and expert judgement should be used in support of a decision to select one or more locations as a prospective underground disposal site. A promising site should display evidence of favourable natural containment and isolation characteristics for the waste types under consideration and should provide indications that all necessary engineered barriers to prevent or retard the movement of radionuclides from the disposal system to the accessible environment can be implemented. This evidence needs to be tested in subsequent detailed site investigation, characterization and associated safety assessment modelling.

I.2. Detailed site investigation and characterization span the final stages of a siting process (stages iii and iv) and Section 6 of this Safety Guide provides recommendations particularly for the detailed site characterization stage leading to site confirmation. This Appendix provides a brief overview of some important points concerning the conceptual and planning stage, the area survey stage and the site investigation stage. This is followed by further guidance on the types of data expected from an investigation and characterization programme.

Conceptual and planning stage

I.3. As the first stage of siting relates to concept design and planning in advance of site selection, it is necessarily undertaken early in the disposal facility development process. The purpose of the conceptual design and planning stage is to develop an overall plan for the site selection process and identify, using available data, the types of rock and geological formation, which can be used as a basis for the area survey stage. The guiding principles of the siting process should be established by the operator early in this planning stage. The necessary financial and human resources, materials, equipment and time should be estimated to the extent practicable, and responsibilities for the entire siting study should be specified. It is possible that the organization charged with responsibility for selecting a site can be the same as the organization that characterizes the site(s) in detail or that constructs and operates the disposal facility. Such decisions as to allocation of responsibilities will be made at a national level. However, the siting process should proceed in accordance with a specified plan, which is likely to require periodic updating and which should be developed in consultation with the regulatory body. The plan should include:

(a) Specification and description of general tasks to be performed;
(b) Sequence diagrams for various tasks;
(c) Any guidance or criteria adopted for site characteristics;
(d) An outline of procedures for applying this guidance or criteria;
(e) A comprehensive schedule;
(f) Cost estimates;
(g) How long term safety concerns are considered in design optimization;
(h) The reasons for which proposed sites may be excluded or have been excluded.

I.4. At the start of the conceptual and planning stage, key decision points should be defined, on the basis of the needs and timing for the disposal facility. The types and quantities of waste to be emplaced in the disposal facility should be specified and characterized. The projected waste volumes and activities should be quantified. Using this information, the generic disposal facility design concept should be developed.

I.5. The key geoscientific criteria that will be used in support of judgements concerning the potential suitability of a site should be developed by the operator, in accordance with national regulatory requirements. Such criteria might include requirements or preferences for the host rock and surrounding geosphere, e.g. tectonic setting, rock characteristics and groundwater properties. From these criteria, screening guidance should be established for the selection of suitable areas and host rocks and later for the selection of the preferred site(s). It is recognized that, as knowledge improves, the criteria, or any limits placed on the criteria, may change during the siting process. Furthermore, it is also recognized that consideration of the criteria could be enhanced using the results of preliminary assessments of the total system.

Area survey stage

I.6. The purpose of an area survey stage is to identify regions and progressively target areas that may contain suitable sites, after the relevant siting factors identified in the previous stage have been considered. This process of site selection may be accomplished by the stepwise screening of a region of interest, which results in the identification of suitable small areas. If some small areas have already been designated as possible locations, studies can be conducted at this stage to gather the regional scale information necessary to determine better the boundary conditions.

I.7. The area survey stage generally involves two phases:

(1) A regional mapping or investigation phase to identify areas with potentially suitable sites;
(2) Screening to select one or more potential sites for further and more detailed evaluation.

(a) Regional mapping or investigation phase

I.8. A typical stepwise screening approach starts with defining the criteria to be used to choose regions of interest. The criteria include geographical, geological and hydrogeological attributes beneficial for the disposal concept. In general, it is the performance of the entire system that will be important, although factors may be identified that are critical to the success or otherwise of a specific disposal concept. The regional mapping or investigation may, for example, cover the whole territory of a region defined by natural or political boundaries, or it may be restricted to lands adjacent to major waste generators in a State. Subsequent activities should focus on successively smaller and increasingly more suitable areas. The process should permit selection of one or more potential sites.

I.9. The choice of siting factors for use in the regional mapping phase should be based on the type of disposal facility intended, the ability to apply simple guidance and the ready availability of the necessary data. Any specific regulatory requirements should also be considered, for example, requirements in respect of proximity to major geologically active faults and centres of igneous activity. This analysis in this phase will rely mostly on available information (e.g. geological data from previous exploration, historical seismic data, remote sensing data).

(b) Site screening phase

I.10. In the next phase, potential sites are identified within the suitable areas. The screening of potential sites may involve some factors not considered in the regional mapping phase, including sociopolitical criteria if not previously used. For example, in the regional analysis and the subsequent screening of potential sites, many national laws and regulations will need to be considered (e.g. important groundwater resources, national parks, historical monuments). These are, in general, clearly defined and therefore no specific regulatory decisions will be necessary.

Site investigation stage

I.11. The site investigation stage involves the detailed study of one or several of the potential sites identified in the area survey stage, to determine whether they are acceptable in various respects, and in particular from the safety point of view. The information necessary to develop a preliminary site specific design should be obtained at this stage.

I.12. The site investigation stage requires more detailed studies than in the regional mapping stage, in order to obtain site specific information to establish the characteristics and the ranges of the parameters of a site with respect to the location of the intended disposal facility. This will require site reconnaissance and investigations to obtain evidence on actual geological, hydrogeological and environmental conditions at the site. This would involve on-site surface and possibly subsurface (e.g. borehole) investigations supplemented by laboratory work. Other data relevant to wider understanding of the site and a site description, such as transport access, demography and social considerations, should also be gathered. Site investigation may progress in a number of stages that involve acquiring and interpreting consecutively more information, in order to select one or more preferred sites for detailed characterization.

I.13. A preliminary safety assessment should be carried out at a relatively early stage to indicate whether a site is potentially suitable for a disposal facility. The preliminary safety assessment should include the results of the preliminary site investigation and a description of the decision process used.

I.14. If several sites are under consideration, a reasonable comparative evaluation may be made between sites on the basis of judgements made about their ability to meet all safety requirements and about their acceptability for construction of the disposal facility.

I.15. At the conclusion of this site investigation stage, the preferred site or sites will have been identified. A report on the entire process should be prepared, with documentation of all data and analytical work, including the preliminary safety assessment. It is expected that the final site selection will also involve judgements based on socioeconomic and political considerations. An environmental impact assessment, as specified by appropriate national authorities, may be conducted at this stage. It is also expected that the regulatory body will review the results and decide whether the preferred site is likely to be suitable for construction of a disposal facility and whether the planned site confirmation studies are likely to result in a licence application.

SITE INVESTIGATION AND CHARACTERIZATION GUIDANCE AND DATA NEEDS

General

I.16. Owing to the predominance of factors and processes that may be highly site specific and interactive, only general guidance can be provided on determining the suitability of potential sites for hosting a disposal facility. In particular, sociopolitical factors will be highly dependent on national priorities and circumstances and therefore detailed advice or guidance is not provided in this Safety Guide.

I.17. The sequence of the subject matter considered in this Appendix does not imply any order of priority, nor is it intended to be totally comprehensive, since the relevance of the various aspects to the site investigation process can vary in specific cases. It is necessary, therefore, that implementation of this guidance and the development of any subsidiary criteria in a siting process be done in consideration of long term safety, technical feasibility and social, economic and environmental concerns. Criteria developed in this manner should be such that technical and institutional concerns can be translated into practical measures.

I.18. Guidance can be helpful in the overall decision making process but is not necessarily intended to be used to set strict preconditions. To assess whether a disposal system meets its performance goals, the system of natural and engineered barriers has to be considered as a whole. Flexibility in the design of the disposal system is important and the possibility to compensate for uncertainties in the performance of one component by placing more reliance on another should be retained.

I.19. Paragraphs I.21–I.52 provide examples of the types of information that will be required from site investigations and characterization. The information could be used to support safety assessments, disposal facility design studies or environmental impact assessments or to provide additional confidence in the chosen disposal option. By definition, site characterization begins as soon as the characteristics of a site begin to be understood as a result of geological, hydrogeological and other scientific investigations. Characterization of a site will continue at least until construction of the disposal facility and may continue into the operational phase. Data needs will vary during the different stages of the siting and construction processes, in terms of the detail required and the scope. At the outset, during the area survey and preliminary investigation stages, data and knowledge will be assessed against the various siting factors that will have to be considered in a siting process. Some or all of these factors could be developed into specific criteria upon which decisions and judgements may be made on selection of a site. The following paragraphs are not meant to specify a complete set of information needs, nor are they associated with any particular weighting. In determining the relevance of these information needs and their application, account should be taken of the options available, the specific site characteristics and the regulatory conditions existing within each State. Further, the types of information specified in this guidance should not be considered in isolation but should be used in an integrated fashion for an overall optimization of site selection and confirmation.

I.20. A comprehensive site description includes additional information over and above geoscientific and environmental data to support decisions on site selection and site confirmation. For example, land use, transport infrastructure and a consideration of other human impacts on a site all have a role to play. Consequently, some broad guidance on these issues is also provided.

Geological setting

I.21. The geological setting of a disposal facility should be amenable to overall characterization and should have favourable geometrical, physical and chemical characteristics for hosting the disposal facility and for inhibiting the movement of radionuclides from the disposal facility to the surface environment during the time periods of concern.

I.22. The depth and dimensions of the host rock should be sufficient for hosting the disposal facility. Uniform rock formations in comparatively simple geological settings are preferred because they are likely to be more easily characterized and their properties are likely to be more predictable. Similarly, formations with few major structural features or potential transport pathways whose impact on performance can be readily assessed are also preferred. However, it is appreciated that as investigations and characterization proceed, seemingly simple environments might prove to be more complex than first expected.

I.23. The mechanical properties of the host rock should be favourable for the safe construction, operation and closure of the disposal facility and for ensuring the long term stability of the geological barrier surrounding the disposal facility. For heat generating waste, the thermal and thermo-mechanical properties of the host rock also need to be considered. Depending on the potential for gas generation by the disposal system, the gas transport properties of the geological barrier should also be considered in assessing its suitability for disposal.

I.24. The information that should be assembled to obtain an appropriate level of understanding of the geological setting include regional and local structural and stratigraphic data of the rocks, sediments and soils, and their chemical and physical properties, including mechanical and, where appropriate, thermal properties.

Future natural changes

I.25. The host rock should not be liable to be affected by future geodynamic phenomena (e.g. climate change, neotectonics, seismicity, volcanism, diapirism) to such an extent that these could unacceptably impair the containment and isolation capabilities of the overall disposal system.

I.26. Climate evolution represented by glacial cycles may result in fundamental changes in the hydrosphere, such as fluctuations in sea level, changes in erosion or sedimentation processes and rates, changes in glacial or periglacial conditions, and variations in the surface and subsurface hydrological balance. Geodynamic effects such as ground motion associated with earthquakes, land subsidence and uplift, volcanism and diapirism may also induce changes in crustal conditions and processes. Such types of event, which in some cases can be interrelated, may affect the overall disposal system through disturbances in the site integrity or modifications of groundwater fluxes and pathways. A preliminary assessment of the predictability and effects of these phenomena should be made for the required periods of time at an early stage of the siting process. The site should be located in a geological and geographical setting where these geodynamic processes or events will not be likely to lead to unacceptable releases of radionuclides.

I.27. The response of the geosphere to environmental changes at the surface tends to decrease with depth. Factors that impact the stability of the geosphere should be assessed. The information necessary to support any evaluations includes:

(a) Climatic history (local and regional) and expected long term future trends at regional and more global scales;
(b) Tectonic history and framework of the geological setting at a local and regional scale and its historical seismicity;
(c) Evidence of active (Quaternary and possibly late Tertiary) neotectonic processes, such as uplift, subsidence, tilting, folding and faulting;
(d) Presence of faults in the geological setting (e.g. their location, length, depth and information on the age of latest movement);
(e) The in situ regional stress field;
(f) Estimates of the characteristics and maximum intensity of earthquake that would be possible at the site on the basis of its seismotectonic context;
(g) Estimates of the geothermal gradient and evidence of thermal springs;
(h) Evidence of active (Quaternary and possibly late Tertiary) volcanism;
(i) Evidence of diapirism;
(j) Palaeohydrology.

The above information may not be available at the area survey stage. However, it should be collected in the site investigation, characterization and confirmation programmes.

Hydrogeology

I.28. The hydrogeological characteristics and the setting of the geological environment should tend to restrict groundwater flow within the disposal facility and should support the safe containment and isolation of waste for the required times. The groundwater system should be well enough understood to provide confidence that any radionuclides that might migrate from the disposal facility environment would be retarded due to limited connectivity or would be dispersed in the geosphere, resulting in sufficiently long travel times that reduce their concentration at the surface.

I.29. Such an evaluation of the mechanisms of groundwater movement, as well as an analysis of the direction and rate of flow, will be an important input to the safety assessment of any site because the most likely mode of radionuclide release is by groundwater flow. Irrespective of the nature of the waste or the disposal option, a geological environment capable of restricting flow to, through and from the disposal facility will contribute to preventing unacceptable radionuclide releases. Natural features such as aquifers or fracture zones are potential release pathways for radionuclides. Such paths should be limited in the disposal facility host rock so that the protective functions of the geological and engineered barrier systems remain compatible. The dilution capacity of the hydrogeological system may also be important and should be evaluated. Siting should be optimized in such a way as to favour long and slow moving groundwater pathways from the disposal facility to the environment.

I.30. Possible consequences for the hydrogeology resulting from processes caused by the disposal of radioactive waste (e.g. thermal and radiation effects, increased hydraulic conductivity due to excavation) should be taken into account.

I.31. Data needs for hydrogeology include:

(a) Hydrogeological evaluation of local and regional geological units and characterization and identification of aquifers and aquicludes in sufficient detail;
(b) Identification and characterization of important hydrogeological units in the region (e.g. their location, extent, interrelationship);
(c) Recharge and discharge estimates into and out of the major local and regional hydrogeological units (location and water budget);
(d) Hydrogeological characteristics of the host rock (e.g. distribution of porosity, hydraulic conductivity, hydraulic head gradients);
(e) Groundwater flow (average flow rates and prevailing directions) of all hydrogeological units in the geological environment;
(f) Physical and chemical characteristics of the groundwater and host rock in the geological environment;
(g) Investigation of the palaeohydrogeological evolution of the site.

Geochemistry

I.32. The physicochemical and geochemical characteristics of the geological and hydrogeological environments should tend to limit the release of radionuclides from the disposal facility to the accessible environment or at least to restrict their migration.

I.33. The choice of a host rock and of a surrounding geological environment that has suitable geochemical characteristics and good retardation properties for long lived radionuclides is particularly important in geological disposal. In a formation where groundwater movement through fractures and pores occurs, retardation by minerals both within the rock matrix and on the fracture surfaces could be important in supporting the long term performance of the disposal system. The geochemical retention or retardation processes that govern the consequent rate and quantity of radionuclide migration include processes such as diffusion, precipitation, sorption, ion exchange and chemical interaction. The ability of groundwater to transport radioactive colloids may be important and should also be taken into account. Biogeochemistry is another factor that may have significance for specific sites.

I.34. The information necessary to estimate the potential for migration of radionuclides to the accessible environment should encompass the description of geochemical and hydrochemical conditions of the host rock and the surrounding geological and hydrogeological units and their flow systems. This information should include:

(a) Mineralogical and petrographical composition of the geological media and their geochemical properties;
(b) Groundwater chemistry.

I.35. The range of chemical and physicochemical interactions between the waste form, the container and backfill material and the disposal facility environment should be evaluated. To assess migration of radionuclides to the accessible environment resulting from rock–water–canister interactions followed by corrosion of the canister and leaching of radionuclides from the waste, information should be collected on:

(a) The chemical, radiochemical and mineralogical composition of the rocks (including the fracture infilling materials);
(b) Sorption capacities of the minerals and rocks for ionic species of important radionuclides;

(c) Radionuclide content and chemical composition of the groundwater, including pH and Eh;
(d) Effects of radiation and decay heat on the rock and the groundwater chemistry;
(e) Effects of organic, colloidal and microbiological materials;
(f) Pore structure and mineral surface characteristics of the rock (including cracks);
(g) Effective diffusion rates of nuclides in the rock units;
(h) Solubility and speciation of radionuclides.

Events resulting from human activities

I.36. The siting of a disposal facility should be carried out with consideration of actual and potential human activities at or near the site. The likelihood that such activities could affect the containment and isolation capabilities of the disposal system and cause unacceptable consequences should be minimized.

I.37. In the assessment of a host rock for a disposal facility, valuable or potentially valuable alternative uses of the host rock, such as for resource exploitation or the construction of storage cavities, should be considered. For example, the possible presence of gas or oil deposits and valuable mineral deposits and any significant geothermal energy potential should be taken into account to minimize the potential for human intrusion into the geological disposal system. Preference should be given to sites located in areas that minimize the likelihood that the host rock would be exploited for such uses.

I.38. Pre-existing boreholes and excavations in the host rock and surrounding rocks exhibiting actual or potential hydraulic connectivity should be identified where they may impact on safety. In such cases, the boreholes and other structures that could represent potential migration pathways for radionuclides should be sealed.

I.39. Surface characteristics that could lead to flooding of the disposal facility as a result of failure of existing or planned surface water impoundments should be carefully considered and evaluated. In the regional analysis, potential sites can be selected on the basis of the severity of the effects of flooding. Facilities constructed in the vicinity of slopes should be evaluated in the context of slope failure and rock slides potentially resulting from human activities such as deforestation.

I.40. The information necessary to evaluate how actual and potential human activities might affect the disposal system includes:

(a) Records of past and present drilling and mining operations in the vicinity of the site;
(b) Information about occurrences of energy and mineral resources in the area around the site;
(c) Evaluation of actual and potential future use of the surface water and groundwater at the site;
(d) Location of existing and planned surface water bodies.

Construction and engineering conditions

I.41. The surface and underground characteristics of the site should permit application of an optimized plan of surface facilities and underground workings and the construction of all excavations in compliance with appropriate safety regulations.

I.42. Overall construction or excavation strategies should be prepared and applied to the development of underground workings to ensure that they comply with national regulations for the construction of underground structures and that concurrent excavation and waste emplacement activities do not interfere with one another. The excavation works should be carried out in such a way that they do not create changes in the surrounding rock that would represent unacceptable preferential pathways from the disposal facility to the biosphere. Rock spoil generated by sinking shafts, driving tunnels and excavating rooms may be evaluated, for example, with a view to its use as backfill in the proposed disposal system. Where this is not possible, consideration should be given to using rock spoil for landscaping to enhance the natural environment. Proximity to appropriate sources of aggregate or water for construction activities may also be a consideration.

I.43. The data necessary for evaluation of construction and engineering conditions include:

(a) Detailed geological and hydrogeological data on the host rock and its overburden;
(b) Topography of the site and the surrounding area;
(c) Flood history of the area;
(d) Specification of areas susceptible to landslides, potentially unstable slopes or materials of low bearing strength or of high liquefaction potential;

(e) Potentially adverse conditions arising during excavation (high rock temperature, high gas concentration, high rock stress to strength ratio, existing shear zone);
(f) Historical seismicity of the region;
(g) Geomechanical and thermal properties of the host rock.

Protection of the environment

I.44. The site should be located such that the quality of the environment will be adequately protected and potentially adverse impacts can be mitigated to an acceptable degree, taking into account technical, economic, social and environmental factors.

I.45. Geological disposal facilities, as with any other major industrial facility, have to comply with the requirements of protection and conservation of the environment and other relevant regulations of non-radiological concern. Among possible adverse effects a geological disposal system may have on the environment, the following may be mentioned:

(a) Degradation of the environment due to excavation activities and other industrial operations in the area of interest. Such degradation may comprise noise or visual effects or a physical impact, such as from spoil leachates.
(b) Impact on areas of significant public value.
(c) Degradation of public water supplies.
(d) Impact on plant and animal life, particularly endangered species.

I.46. To estimate potential impacts on the environment, the types of information required will relate to data needs for environmental impact assessments and should include consideration of:

(a) Location of national parks, wildlife areas, sites of special scientific or cultural interest and historical areas;
(b) Existing surface water and groundwater resources;
(c) Existing terrestrial and aquatic vegetation and wildlife.

Land use

I.47. In the selection of suitable sites, land use and ownership of land should be considered in connection with possible future development and regional planning in the area of interest. The jurisdiction over the land, or ownership, will in most States be a significant factor with respect to economics and public acceptance. Existing ownership of the land by the operator of the proposed facility or the government could simplify the site planning and evaluation efforts and could reduce the problems associated with the withdrawal of land from other uses. Information collected for siting purposes should include details of existing land resources and their jurisdiction, and land use plans for the areas of interest.

Transport of waste

I.48. For siting purposes, information should be gathered on: (a) alternative modes of transport and the infrastructure to support waste movements, (b) alternative transport routes and (c) population densities along proposed transport routes.

I.49. Transport of radioactive waste to a geological disposal facility involves a potential for exposure of the public to ionizing radiation. The potential for exposure may increase with increasing distance over which the waste is to be transported. Consideration of transport of waste to the disposal facility could be a factor in obtaining public acceptance of a disposal facility location.

I.50. In some instances, new access routes will need to be constructed or existing ones improved. Access routes are more difficult and expensive to construct where unsuitable terrain conditions, such as steep gradients and natural obstacles, exist. For these reasons, preference may be given to sites requiring shorter transport distances and a limited amount of additional construction, and where access routes are not required to traverse difficult terrain. However, the construction of new roads or other transport infrastructure, in totality or partly, may allow the operator to optimize the transport network, for example, to bypass inhabited or sensitive zones or to support the creation of transport links for the local community.

Social impacts

I.51. The construction and above ground operations such as receiving and handling the waste containers, decontamination and repackaging as required, as for any large industrial activity, should not take place in densely populated areas. On the other hand, the site should be located in an area capable of absorbing the project related population fluctuations and demands for necessary services, such as construction labour and operating staff, housing, hostels and restaurants, supporting service industry and established civic and cultural organizations. In general, preference should be given to sites away from highly populated areas, but which are capable of absorbing expected changes in the infrastructure and have a workforce available.

I.52. To estimate the social impacts that might result from the development of a disposal system at a site, the types of information gathered should include data on:

(a) Population composition, density, distribution and trends;
(b) Employment distribution and trends in the economic sector;
(c) Community services and infrastructure, including recreational utility;
(d) Housing supply and demands;
(e) The industrial base and expectations in the region;
(f) The agricultural base and expectations in the region.

Appendix II

POST-CLOSURE SAFETY ASSESSMENT

INTRODUCTION

II.1. Safety assessment is a procedure for evaluating the performance of a disposal system and, as a major objective, its potential radiological impact on human health and the environment. Potential radiological impacts after closure of a disposal facility may arise from gradual processes, such as degradation of barriers, and from discrete events that may affect the containment and isolation of the waste. The potential for inadvertent human intrusion can be assumed to be negligible while active institutional controls are considered fully effective, but may increase afterwards. The technical acceptability of a disposal facility will greatly depend on the waste inventory, the engineered features of the disposal facility and the suitability of the site. It should be judged on the basis of the results of the safety assessments, which should provide a reasonable assurance that the disposal facility will meet the design objectives, performance standards and regulatory criteria. These are specified in the Safety Requirements [1] and further described in this Safety Guide. Many of the concepts presented in this Appendix are derived from the Safety Guide for Safety Assessment for Near Surface Disposal of Radioactive Waste [28]. Despite obvious differences between near surface disposal and deep geological disposal, many of the principles for developing safety assessments are similar. For example, many elements of the safety assessment approaches described in the IAEA Coordinated Research Programme for Improved Safety Assessment Methodologies for Near Surface Disposal have been adapted with little modification for use for geological disposal programmes [29, 30].

II.2. This Appendix summarizes important considerations in assessing the safety of a disposal facility and recommends the steps to be followed in performing post-closure safety assessment. Operational activities at a geological disposal facility are discussed only in the context of their potential impact on post-closure safety. Although radioactive waste may contain potentially hazardous non-radioactive components, this Appendix considers explicitly only the radiological hazard associated with the waste. However, most of the information for performing safety assessments for releases of radioactive material to the environment will be applicable for releases of many types of non-radiological contaminant.

GENERAL CONSIDERATIONS FOR SAFETY ASSESSMENT

Safety issues

II.3. For the post-closure phase of geological disposal facilities, the major safety issue is the possibility of radiation exposure and environmental impacts over time periods far into the future. Some effects may be assumed to occur, for example, through the gradual leaching of radionuclides into groundwater and subsequent migration through environmental media and transfer to humans. Assessments may, therefore, need to project the behaviour of the site and the facility for time periods of the order of thousands of years and potentially longer. Thus, post-closure assessments take account of particular events that occur very infrequently (e.g. once every thousand years) but which may result in significant consequences, such as major seismic events and climate changes. The aim of post-closure assessments is to obtain reasonable assurance that the disposal system will provide a sufficient level of safety, rather than to predict its future performance in any specific way.

II.4. A key issue in safety assessments for a disposal facility is to develop confidence in the results of modelling. A conceptual model of the disposal facility is a description in terms of the general features present and their detailed characteristics. Among the most important features are those that identify the relative significance of possible migration pathways for radionuclides. A description of a particular set of features, events and processes used to represent the behaviour of the disposal facility performance over time is termed a scenario. Scenarios can include gradual processes (e.g. corrosion of the waste package, transport of radionuclides in groundwater) and discrete events (e.g. disruption of the waste package owing to seismic activity). Safety assessment for the disposal facility should be robust, i.e. tolerant to uncertainties. The results of the assessment, including identification of uncertainties, should be compared with the design goals and regulatory criteria, with account taken of other lines of reasoning and considerations contributing to the acceptability of the disposal facility.

Uses of safety assessments

II.5. Safety assessments serve different purposes at different stages in the development of a disposal facility. At an early stage, safety assessments should be used to determine the feasibility of major disposal concepts, to direct site investigations and to assist in initial decision making. Their use is of greater importance in the stages following early concept development and site selection.

Such assessments should then be developed to assist in system optimization and facility design by carrying out comparative assessments for various items such as alternative waste package designs and closure measures. Safety assessments should be carried out periodically throughout disposal facility planning, construction and operation and prior to closure, and are used to develop and progressively update the safety case. The post-closure safety case is the synthesis of evidence, analyses and arguments that quantify and substantiate a claim that the disposal facility will be safe after closure and beyond the time when active control of the facility can be relied on (see Section 5 and Ref. [11]).

II.6. The completeness and robustness of the safety assessment will, in turn, depend on the extent and quality of the data in terms of all relevant information on waste characterization, site characterization, waste package performance and the function and performance of other engineered barriers. Close coordination of the safety assessment and the supporting data acquisition programmes is, therefore, necessary, with the safety assessment being a valuable means of identifying and prioritizing supporting research and development work.

II.7. A principal function of the safety assessment is in the licence application and approval process. This includes both radiological and environmental aspects. Such safety assessments for regulatory purposes may be required at various stages in the licensing process, including approval to construct, operate and close the disposal facility, and whenever there are significant changes in the state of the disposal facility. The safety assessment, therefore, should be performed and updated throughout all relevant stages of development of the disposal facility by using appropriate models and data.

II.8. Results of safety assessments are an important means of confirming the acceptability of inventory levels and provide one way of developing waste acceptance requirements for the disposal facility. Acceptable waste forms and packages are usually dependent on the analysis of scenarios of radionuclide release to the environment and transfer along environmental pathways. Although geological disposal has as a primary focus, the disposal of significant inventories of long lived radionuclides and large quantities of short lived radionuclides with high activities often present in the waste may cause concerns for post-closure safety with regard to heat generation. In addition, safety assessments should also be used to determine the levels of chemical substances in the waste that could cause degradation of the engineered barriers or enhance radionuclide solubility.

II.9. The safety assessment and the associated licence conditions determine, to a large extent, some of the principal controls and requirements on the disposal facility. For example, in establishing waste acceptance requirements for the disposal facility, the safety assessment could be used to determine requirements for waste packages, both for individual packages and for the facility in total. The safety assessment should also be used in evaluating potential exposure pathways and in establishing and reviewing the environmental monitoring programme for the site and the surrounding area. The safety assessment should be based on design(s) actually used or proposed for the disposal facility, including closure plans.

GUIDANCE FOR SAFETY ASSESSMENT

General

II.10. Safety assessment requires the development of both qualitative and quantitative arguments, depending on site characterization results, waste characteristics, design data and mathematical modelling. The results from assessments, in their turn, provide necessary input for decisions throughout the development of disposal facilities. The assumptions and judgements on which the safety assessment is based need to be robust and readily communicable to a wide range of interested parties in order to achieve confidence in the safety assessment results.

II.11. The safety assessment process should involve scoping calculations to evaluate the robustness of the proposed conceptual model (in terms of its potential to meet regulatory requirements) and to focus on the relevant radionuclides, pathways and release mechanisms on which further knowledge is required. Scoping calculations are often based on limited data, for example, from literature searches, material specifications, laboratory studies and studies of natural analogues, preliminary investigations on the site and characterization of the waste. Acquisition of data will continue throughout the step by step process until the disposal facility is accepted or the studied concept is determined to be unacceptable.

II.12. During the safety assessment process, relevant scenarios should be identified [16, 31]. Determining the relevance of each scenario to the evaluation of the disposal facility may need supporting studies and additional data collection and require further iterations of the safety assessment process. Such studies and analyses may also be useful in reducing uncertainties when attempting to quantify the events and phenomena that lead to the release and transport of radionuclides. Even if safety assessments are robust, namely, they rely, for example, on clearly identified conservative assumptions and are approved as such by the regulatory body, uncertainty is inevitably attached to long term predictions.

Iterative approach to safety assessment

II.13. A schematic presentation that illustrates the iterative approach to safety assessment is shown in Fig. 3. This approach involves the following activities, which usually iterate and/or overlap:

(a) Definition of the objectives of the assessment, safety requirements and performance criteria;
(b) Acquisition of information and description of the disposal system, including waste form, site characteristics and engineered structures;
(c) Identification of features, events and processes that might influence long term performance;
(d) Development and testing of conceptual and mathematical models of the behaviour of the system and its components;
(e) Identification and description of relevant scenarios;
(f) Identification of the pathways potentially leading to the transfer of radionuclides from the disposal facility to humans and to the environment;
(g) Conduct of the assessment by conceptual and mathematical modelling;
(h) Evaluation of the robustness of the assessment;
(i) Comparison of the assessment results with the assigned safety requirements;
(j) Additional considerations.

II.14. Characterization of the system and description of the pathways require the acquisition of appropriate data through field and laboratory experiments. Scenario analysis requires the identification and definition of phenomena that could initiate or enhance the release of radionuclides from the disposal facility and result in exposure to humans. Throughout the iterative process of safety assessment, additional data collection may be required that is focused on the parameters identified as important for the safety of the disposal facility.

Defining objectives

II.15. Safety assessment plays a central role in the development of a disposal facility and may be used for multiple purposes. Since these various uses may require different levels of detail of analysis and imply different data needs, or the presentation of results to different interested parties such as technical specialists

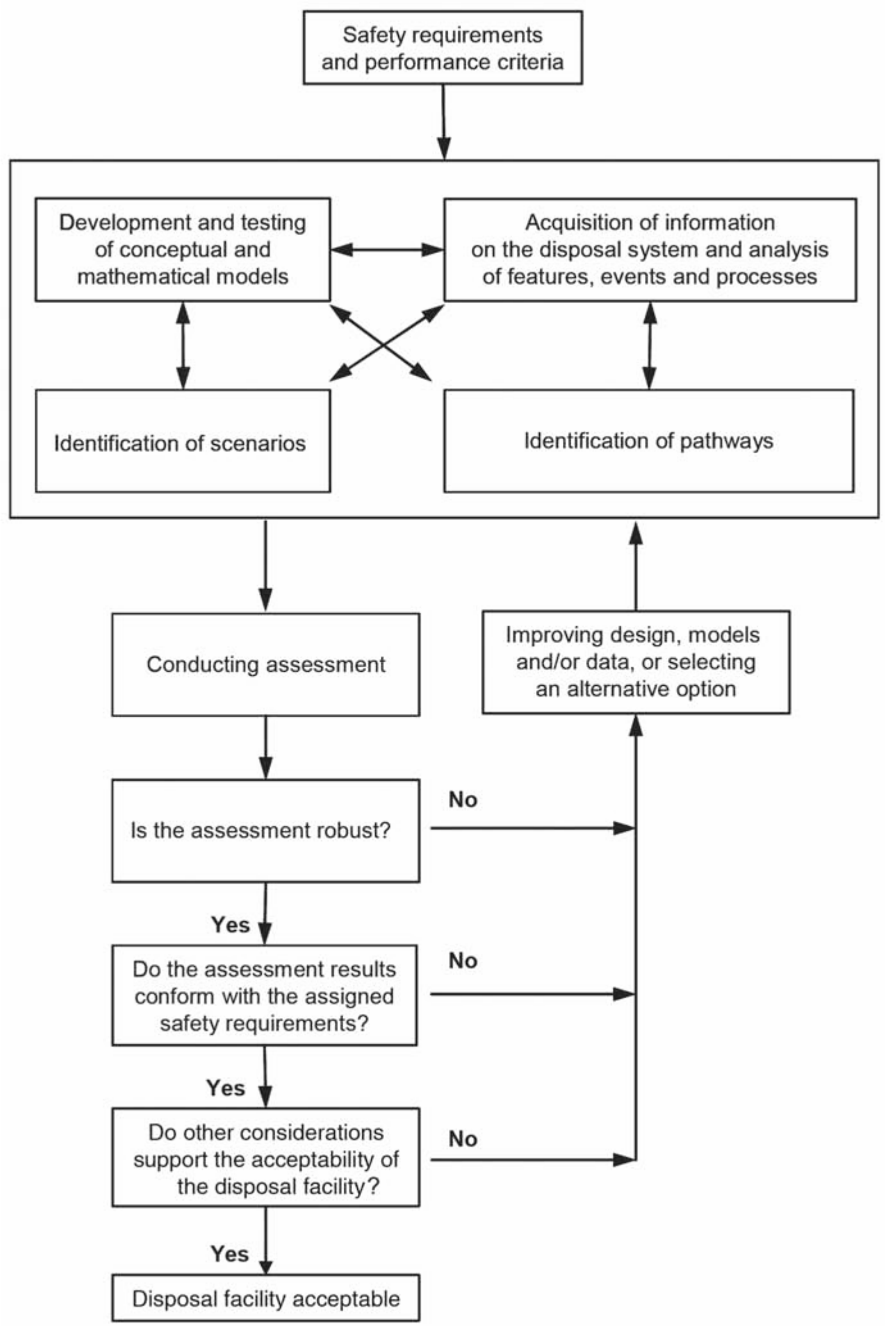

FIG. 3. Example of the iterative approach to safety assessment.

and lay persons, the objective of the safety assessment should be clearly defined in accordance with the particular application.

II.16. One output of assessments consists of numerical results used to compare projected system performance with established criteria. This requires proper identification and, on the basis of relevant data, thorough examination of all significant features, events and processes. Understanding the behaviour of a disposal system and its interaction with the environment is aided by the development of a set of models. Quantitative evaluations require mathematical modelling supported by the use of computer codes. Models are simplified to a certain extent, depending on the purpose for which the model was developed. The necessary complexity of a model should be carefully considered, in view of the fact that the most complex and detailed model is not necessarily the best one for a particular purpose.

DATA REQUIREMENTS FOR SAFETY ASSESSMENT

II.17. The amount and the quality of data required will depend on the purpose of the assessment. Preliminary assessments will probably require only simple models using data that are readily available. The results will normally only be used as a guide to future studies. In this case, only a limited appreciation of the uncertainties associated with the results is needed. While finalizing the design and licensing stages of the disposal facility, the operator should support the application with an assessment based on sufficient, quality assured data describing the site, the design and the waste characteristics. Although management systems should be established (and followed) for data collection as early as possible in the process, it is recognized that a similar quantity and quality of data may not be necessary at an early stage in the design and scoping stages of the disposal facility. The operator should plan the data acquisition programme carefully to ensure that the objectives are achieved in a cost effective way.

II.18. Data will be needed from several sources, with levels of detail and uncertainty that depend on the objective of the particular safety assessment. Data on the following are typically required:

(a) Waste characteristics (radionuclide composition as a function of time; total inventory; physical, chemical and thermal characteristics; mass transfer parameters under disposal conditions);
(b) Container characteristics (mechanical and chemical performance under disposal conditions);

(c) Disposal facility characteristics (dimensions, backfill/buffer material, structural material, engineered features);
(d) Site characteristics (geology, hydrogeology, geochemical properties, climatic conditions);
(e) Biosphere characteristics (natural habitat, atmospheric conditions, aquatic conditions);
(f) Demographic and socioeconomic characteristics (land use, food habits, population distribution).

II.19. Early scoping and screening data needs are normally met through literature searches, collection of material specifications and very limited site or design specific investigations. These data may be used to make preliminary analyses and to develop preliminary designs. The initial conceptual model(s) of the disposal facility will be developed on the basis of these data. A preliminary safety assessment, at this stage, may be carried out as a check on the potential of the system to perform adequately. Since only few data of limited detail are usually available at this stage of the safety assessment, simple models are appropriate.

II.20. Data collection activities should be targeted to defined data needs on the basis of the conceptual design, the current knowledge of the site and the results of the preliminary safety assessment of the disposal facility. On the basis of the preliminary design, the information available on site characteristics and the preliminary assessment, it should be possible to start to determine the amount of detail required to provide a basis for assurance of safety in compliance with regulatory requirements. Direct links between safety assessment and collection of site characterization data should be established in a data acquisition programme. For example, if fractures play a role in groundwater transport predictions, appropriate detail of the fracture system such as transmissivity, connectivity and orientation could be required.

Pre-operational monitoring data

II.21. Ambient conditions should be defined for the site as a baseline to measure performance during operations and for any monitoring programme. Background measurements are normally carried out for radionuclides and for certain other ‘indicator’ parameters. These may include data relating to surface and subsurface hydrology, or groundwater chemistry. Pre-operational monitoring data may provide a benchmark against which models can be tested.

II.22. Site parameters that are expected to vary with time, such as those used to calibrate hydrological flow models or atmospheric transport models used for safety assessment, should be measured with a regularity that allows estimation of their variability. For some parameters, it may be important to estimate the extremes of the range of variation. Owing to the long period of time associated with geological disposal facilities, plans should be made to continue measurements of time varying parameters throughout this period, where appropriate, to increase the reliability of the available information.

Operational and post-closure monitoring data

II.23. Operational monitoring data may indicate differences from predicted or assumed conditions. The reasons for these differences should be identified and used to improve the understanding of the system. Where significant deviations from predicted conditions are observed, a new safety assessment might be required to confirm that the regulatory criteria continue to be satisfied.

II.24. Post-closure monitoring, if performed, should be used to verify the absence of unacceptable radiological impact and to provide added assurances confirming the behaviour of the disposal system barriers. For example, monitoring of groundwater chemistry may be carried out in support of waste package corrosion rates. However, national programmes do not commonly plan to use post-closure monitoring data to provide confirmation data, owing to the long period of time during the development of the disposal facility during which data will have been collected to confirm system behaviour and the very long time frames (e.g. thousands of years and longer) projected for future releases to the biosphere.

SYSTEM DEFINITION

II.25. Safety assessment of a disposal facility is based on a multidisciplinary approach to system definition and on systematic analysis of possible sets of events and processes that may affect the performance of the disposal system [16]. The description of the disposal facility requires information on waste characteristics, disposal facility design and site properties and constitutes the basis for the development of a conceptual model of the waste disposal system, scenarios of its possible behaviour and assessment of potential radionuclide migration pathways.

Development of the conceptual model

II.26. The ultimate goal of the development of the conceptual model is to provide a framework that will permit judgements to be made about the behaviour of the total disposal system. If possible, the model should have enough detail that mathematical models can be developed to describe the behaviour of the system and its components so as to provide an estimate of the performance of the system over time. Different levels of detail will be required at different stages as the iterative safety assessment is conducted and leading, eventually, to a licensing decision being made. The model should be as simple as possible but should include enough detail to represent the system's behaviour adequately for the purpose of ensuring compliance with safety requirements.

II.27. Development of a conceptual model should include the following steps:

(a) *Identification and characterization of the waste in terms of inventory, form and package.* This information should be sufficiently detailed to allow adequate modelling of radionuclide releases, i.e. the source term. As a minimum, information should be provided as a basis for the justification of a simple release model, such as by assuming that the release rate is constant or that a fixed proportion is released each year. The conceptual model of the source term may be refined by iteration as more information on the waste and the disposal facility is obtained.

(b) *Characterization of the disposal site by the necessary parameters, including geology, hydrogeology, geochemistry, tectonics and seismicity, volcanic activity, surface processes, meteorology, ecology and the distribution of local populations and their social and economic practices.* This site information is needed to define pathways and receptors and thus to develop a conceptual physical, chemical and biological model of the site.

(c) *Specification of facility design.* Before the assessment starts, the design should be specified in terms of the material used and the components of the system. Changes in the design, either on the basis of the safety assessment or otherwise, may require that the safety assessment be updated.

(d) *Increased knowledge of the site.* This might suggest that one or more feasible alternative conceptual models exist and need to be considered. Where alternative models have been considered and discounted, the reasons should be clearly documented and, where appropriate, identified in the safety assessment.

Development of the mathematical model

II.28. Developing the mathematical model from the conceptual model is an important step in which the conceptual model is expressed quantitatively through mathematical equations in a calculational model. The general procedures used to develop such models are well accepted, and predictive mathematical models, varying in both level of detail and complexity, have been developed in key areas. They should be used to describe individual processes, subsystems and overall system performance. In the transition from conceptual models to mathematical models, and finally to implementation using calculation techniques, errors may be introduced owing to the simplifications, approximations, bias, modelling assumptions or the mathematical approaches used. Therefore, models used in performance assessment should be tested and updated not only on the basis of comparisons of their outputs with empirical data, but also in the process of their development on the basis of peer review, inter-code comparisons, comparisons with other performance assessments, results of experiments carried out to test specific aspects of conceptual and numerical models and comparisons with cases for which analytical solutions exist.

Analysis of features, events and processes

II.29. Systematic examination of actual and potential features, events and processes should be used to identify the factors that might influence the long term safety of a disposal facility and thus aid development of an appropriate safety assessment model [15]. The safety assessment model can be built either through scenario analysis or by some alternative technique such as sampling parameter space.

II.30. The first step in identifying which of the many phenomena are relevant to the safety assessment should be to establish a checklist. More recently, information on the features, events and processes has been assembled at the international level by working groups of the OECD Nuclear Energy Agency [16]. In developing a suitable list of scenarios, events and processes of natural origin, and processes attributable to the waste itself or to features of the disposal facility, should be considered.

Scenario analysis

II.31. Scenarios depend on the characteristics of the environment and of the disposal facility, and on events and processes that could either cause initial release of radionuclides from waste or influence their fate and transport to humans and to the environment. The choice of appropriate scenarios and associated conceptual models should be a subject for the special attention of both operator and regulatory body as this may strongly influence subsequent analysis of the disposal facility. In some States, scenarios are specified by the regulatory body, although the operator may also choose to consider others. In other States, the operator may select the scenarios but be required to justify the selection to the regulatory body.

II.32. Normal evolution scenarios are usually based on extrapolation of existing conditions into the future and incorporate changes expected to occur with the passage of time. Since there may be a range of possible evolutions, a set of normal evolution scenarios should be developed to provide a reasonable basis for the anticipated evolution of the disposal facility. Events that are less likely to occur may introduce significant perturbations to the system and require the development of alternative scenarios. Some of these scenarios can be handled by using the same models, but with revised parameters. Other scenarios may require new models. The intended design will probably be based on the normal evolution scenario, but may need to be modified to account for the results of the assessment based on other, less likely, scenarios.

II.33. A range of scenarios should be considered and documented so as to develop as complete an understanding of the system as possible. However, where there are options, those scenarios that are most likely to occur should be selected for detailed assessment or those that are relatively unlikely but which could have major consequences. The selection of scenarios for detailed assessment should be clearly justified in the safety assessment documentation and, where appropriate, supporting evidence should be provided. This selection is to ensure the effective use of extensive assessment efforts and to ensure that the design of the disposal facility is developed in a way that protects human health and the environment.

II.34. Scenario development should lead to a systematic focusing of the safety assessment on the important conditions and phenomena relating to performance of the disposal facility. Expert judgement, fault and event tree analyses, process influence diagrams and other techniques can be used to focus on the important scenarios [29]. The process, the judgements made and the factors considered should be documented.

Identification of pathways

II.35. The important pathways for radioactive material released from the disposal facility to the environment for both undisturbed (normal) conditions and disturbed (non-normal) conditions should be identified from a comprehensive set of potential pathways. Experience shows that only a few pathways are likely to be important for the undisturbed performance of a disposal facility. They include groundwater transport, soil, land plants, land animals, surface waters, aquatic animals and gaseous pathways. For disturbed performance (e.g. human intrusion scenario), the major addition to this list is likely to be suspended radioactive material and direct exposure.

CONSEQUENCE ANALYSIS

Model calculations

II.36. Once all relevant scenarios and pathways to humans have been identified, the next stage in the safety assessment process is consequence analysis. This involves the development and application of transport and exposure models to evaluate the potential impact of releases from the disposal facility on humans and on the environment.

II.37. It may be very helpful to use a modular systems approach to model the potential release and transport of radionuclides to humans via selected environmental pathways. This will ensure that individual submodels can be made available for inspection to assist in understanding how estimated doses were determined. The model may consist of the following discrete submodels: groundwater flow into the disposal facility, degradation of waste packages, near field transport within and near disposal areas, groundwater transport, surface water transport, atmospheric transport, uptake by plants and animals, and dose to humans. A modular approach also allows flexibility and the concentration of effort on those parts of the system that need sophisticated modelling in order to ensure that the results are technically acceptable. The benefits of this approach can be significant when sophisticated models are used to provide added assurance that the disposal facility will perform in an acceptable manner.

II.38. The source term used in the models should be representative of potential releases of radionuclides from various waste forms under the identified range of environmental conditions and degradation of engineered barriers, such as waste containers and backfill materials, should be considered. Early models are likely to be simple, but as understanding of the system develops it may become necessary to employ more detailed models to ensure that the system is adequately represented. However, the models should be simple enough to be compatible and commensurate with available data. Expert judgement should be used here to ensure a proper balance between using simple models and existing data and more detailed models that may need some data that are not readily available. This does not preclude the use of more complex models of parts of the system to improve the understanding of the phenomena involved. Examples of such sophisticated models are the use of numerical groundwater models or geochemical speciation models to assess hydrological boundary conditions and temporal variability of groundwater chemistry if the physical characteristics or groundwater monitoring suggest the need to understand changes in the system at a more sophisticated level.

II.39. Reasonable conservatism that can withstand scientific scrutiny should be built into the safety assessment modelling from the beginning. A simple modelling approach is likely to be more efficient, easily understandable and justified. Assumptions should be formulated on the basis of available data and knowledge of the system or similar systems and selected so that they are not likely to underestimate the release and transport of radionuclides. Since acceptance of the results can be the most difficult aspect of an assessment, any approach to make that acceptance easier will be a long term benefit. An approach which balances simplicity, conservatism and realism is likely to be the best starting point for assessments.

II.40. The chosen model should be consistent with the assessment objective, easy to use (considering the complexity of the system) and the one for which the data can be obtained. The model should be appropriate for the application, the accuracy of the algorithms should be demonstrable, the assumptions should be reasonable and the input data should be representative.

II.41. The modelling approach selected should be fully and clearly documented together with the matters considered as it is developed. The documentation should provide a traceable record of all the assumptions and decisions made during the development and application of the modelling approach. This should include the reasons for disregarding any alternative models considered in the process of developing the modelling approach.

Sources of uncertainty

II.42. Safety assessment results need to be considered with respect to uncertainties in input data for models, assumptions within the different parts of the models, assumptions about the interfaces between the individual parts of the overall model and uncertainties relating to the long term evolution of the disposal systems. All of these uncertainties should be investigated by sensitivity and uncertainty analyses supplemented by other means of building confidence and, where appropriate, by expert judgements.

II.43. Uncertainty is inherent in any safety assessment. Sensitivity and uncertainty analyses have the important goal of extending understanding and reducing, where possible, the uncertainty in some of the results of the safety assessment by directing attention to a better definition of those parameters that most affect the results and their uncertainty. The analyses of sensitivity and uncertainty are closely related. Sensitivity analysis should be used to identify those parameters, system components or processes that produce significant effects on the predicted disposal facility performance. Identification of sensitive conceptual model components and important scenarios is usually done through application of systematic parameter variation. Each scenario may require its own distribution of parameters. Often, bounding values for the expected case are used to investigate system behaviour under uncertainty. Statistical techniques may also be employed to explore the whole range of expected parameter variation [32].

II.44. Broadly, two main sources of uncertainty should be considered in safety assessment. One is the degree to which the model represents the real system. This uncertainty is associated with the model inputs, which represent the description of the disposal system, the site characteristics, the engineered features of the disposal facility and their interaction with the environment, and the modelling itself. The other source of uncertainty is related to the unpredictability of the evolution of the facility and its environment over long periods of time. Each of these uncertainties, to varying degrees, is affected by variability in the disposal system and limitations in the knowledge of how the system will perform.

II.45. The first source of uncertainty should be reduced by improving the quality of site characterization and waste data, the design details of the facility, the conceptual model and the scenario selection. The goal should be to estimate and reduce this uncertainty to a level either deemed acceptable or shown to be unimportant in the context of the performance of the disposal facility. The second source of uncertainty should be examined to understand the potential changes to the performance of the disposal facility due to the occurrence of potentially disruptive future events. The results of such an examination may provide a reasonable assurance that the disposal system will be safe even though model outcomes may be uncertain. Thus, the primary importance of the sensitivity and uncertainty analyses for regulatory decisions is in using them as tools for assessing compliance with safety requirements in the face of uncertainty. It stands to reason that, if compliance with the safety standards can be shown by some other means, for example, by using a demonstrably conservative model, the uncertainty analysis may not be required.

II.46. A major source of uncertainty in scenario development stems from the potential for missing an important scenario. Peer review of the scenarios chosen can help and should be used to reduce such uncertainty.

II.47. Similarly, uncertainty in development of the conceptual and numerical models of the site should be evaluated by peer review. The general trend is to use simple models for ease of explanation and for computational efficiency. The uncertainty associated with the simplification existing in building the conceptual and numerical models can often be determined by additional modelling studies and data collection. Again, the modular approach and careful analysis of intermediate computational results can lead to a more detailed understanding of the system. This, in turn, can lead to an overall reduction in model uncertainty.

II.48. Inherent uncertainty arises from the attempt to project future events. Some of these uncertainties can be disregarded following careful examination of extreme or bounding scenarios or of the results of probabilistic assessments, but only if they have little effect on the performance of the disposal system. Other uncertainties, particularly those associated with human actions dictated by future socioeconomic conditions or major changes in climatic conditions in the far future, are not as amenable to rigorous quantified projections. In such circumstances, stylized calculations can be performed to understand the potential impact on the disposal facility. Safety assessment is based on a conceptual model whose prime purpose is to provide a framework to allow analysis to proceed. Where suitable mathematical models can be derived and where the data exist, the assessment can be quantitative. If this is not the case, then qualitative assessment should be made. This does not invalidate the assessment process but renders it more dependent on the qualitative judgements of the experts, supported, where possible, by calculation. Within this framework, however, the basis for the judgements should be carefully documented for examination as part of the safety assessment. Care should also be taken with respect to the reliability of the available information that is reflected in the level of calculational detail provided in the assessment and in the interpretation of results, which should, therefore, change according to the length of time into the future being considered.

Sensitivity analysis

II.49. The system should be analysed to determine how and to what degree the predicted behaviour of the disposal facility depends on the conceptual model used, the scenarios that are applicable to the model and the variation in the parameters used to describe the system as input to the model. If the results are sensitive to initial and boundary conditions, then more extensive data may have to be generated. The process should examine the model's sensitivity to different scenarios and exposure pathways. If it is determined that the assessment is sensitive to these parameters, consideration should be given to their further evaluation.

II.50. Single parameter variation or variation of combinations of a few parameters should be considered as a starting point for sensitivity analysis in safety assessments. Consideration should be given to extreme but reasonable variation of some parameters because this may change the relative importance of different pathways and make the model no longer applicable.

II.51. Different methods for varying parameter values can be used for this task, but the analysis should be structured with care to ensure that the combinations that are chosen by the computer code are physically reasonable. In addition, the analysis should be structured to preserve the information needed to determine the sensitive combinations and to identify sensitive parameters.

II.52. Sensitivity analysis should guide the iterative process used for improvement of the model formulation, scenario development and gathering of additional data. Sensitivity analysis results should be used to indicate where design features should be effectively improved to yield better performance. In addition, the identification of key parameters arising from sensitivity analysis could be used to focus research directions to reduce uncertainties. Furthermore, sensitivity analysis could be used to identify processes and associated parameters that do not significantly impact on safety assessment results so that further research on these topics can be excluded.

Uncertainty analysis

II.53. Parameters can be used in safety assessments to represent uncertainty due to variability (e.g. variation in the permeability of the host rock) as well as what may happen in the future (e.g. location, timing and magnitude of an earthquake). Uncertainty analysis should be performed by concentrating on those parameters that are shown by sensitivity analysis to be important for defining the result of the safety assessment. Methods commonly used are related to the sensitivity analysis techniques of single variable or multivariable variation with the goal of developing bounds for the estimated performance of the disposal facility. Simple bounding analysis should generally produce fully adequate information on the range of performance but it should be noted that, since the systems are so complex, extreme values, on a parameter by parameter basis, may not always yield the bounding behaviour of the system. Monte Carlo analysis can also provide distributions of expected results based on the statistical analysis of estimates of input parameter variation. When developing the input distributions for the Monte Carlo analysis and correlation between the parameters, use of expert judgement may be necessary and should be elicited in a formal and recorded manner. Additionally, care should be exercised in developing the range of values for an input parameter or combinations of parameters so as not to introduce unwarranted dilution of risks (e.g. arbitrarily increasing the range of values for an input parameter beyond what is supported by data may be considered a conservative approach for setting the parameter range, but could lead to a reduction in the estimated dose and, thus, inappropriately reduce or dilute the risk).

PRESENTATION OF THE RESULTS OF THE SAFETY ASSESSMENT

General

II.54. The presentation of the safety assessment results is important for enhancing understanding and gaining acceptance. These results will be used for various purposes. In the decision making process, they are used principally for comparison with the regulatory standards. The need to build a consensus that the disposal facility is a safe disposal option for the designated waste for a long time into the future adds an important dimension to the safety assessment and the presentation of its results.

II.55. Since safety assessment results normally provide the basis for establishing requirements on waste acceptance and disposal facility design, it is important to provide information on the performance of system components, particularly to the system designers and, ultimately, to the regulatory body, in order to illustrate the levels of protection provided by the various parts of the disposal facility. The outputs of the models used in safety assessments are not actual predictions, but are, in fact, indicators of what might happen under certain conditions that may prevail in the future. Conveying this and the complexity of a geological disposal facility composed of both natural and engineered parts, as reflected in safety assessment models, to different interested parties is very important; therefore, presentation of results should be carefully prepared.

Comparison with regulatory standards

II.56. The most common use of safety assessment results is to demonstrate compliance with regulatory requirements. For this purpose, to substantiate the outcome of the safety assessment, the following items are required:

(a) A clear description of the site, the selected design and the waste inventory for disposal;
(b) A thorough discussion of the conceptual model and the physical basis for the model;
(c) A discussion of alternative models and the reasons for disregarding such models;
(d) The basis for selecting or developing scenarios and pathways;
(e) Documentation of assumptions and justifications of simplifications used;
(f) A summary of the inputs to the models;
(g) The actual data used, their source and justification;
(h) The interpretation of results.

The documentation of the results of the safety assessment should include information on uncertainty and the conclusions of any sensitivity and uncertainty analyses.

Performance of system components

II.57. 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 which is easily carried out if a modular approach to modelling is taken. Showing the expected behaviour of each component and the iterative improvement in component design or knowledge of the component's expected behaviour, to ensure its effective performance, increases the level of confidence in the performance of the whole system.

Future radiological impacts

II.58. The results of a safety assessment should be presented in a way that allows consideration of variations in projected impacts with time. This approach can be particularly useful since the projections are only indications of performance and showing the evolution of the disposal facility generated impacts over time can contribute to the credibility of the safety assessment results. In any case, it may be useful to show how the effect of radioactive decay generally leads to decreasing impact with time. Such an approach should also be followed when long term radiological impacts are compared with natural radiation levels, for example, to demonstrate, in a relative way, the effect of disposing of long lived radionuclides.

Level of presentation

II.59. In order to represent the complexities of the geological disposal facility, complex models are often necessary. Presenting and explaining these models may be difficult, particularly when dealing with the general public. In addition, the licensing of disposal facilities may form the basis of legal action. Since discussing the results of complex modelling in a judicial context may be very difficult, efforts should be made, for explanatory purposes, to supplement the sophisticated modelling approach with a less complex model.

II.60. While simplification may cause loss of detail, demonstration of consistency of the results of simple and complex methods may be possible if it can be shown that simplification has actually focused the safety assessment on the critical factors relating to system safety. This is often referred to as robust modelling of the system. Robust assessments should be demonstrated to provide good estimates of system behaviour using simple models and a minimum of data. Satisfactory simplification generally requires a very good understanding of the disposal facility and its performance. Provided that this understanding can be demonstrated, simple robust models and safety assessment methods using limited data are easier to explain to the public than complex models requiring large amounts of data.

CONFIDENCE BUILDING

II.61. Safety assessments provide a basis for rational and technically sound decisions in the process of establishing waste disposal facilities. As discussed in the preceding paragraphs, safety assessments play a role in different stages of the process. Preliminary assessments can be used in site selection to identify uncertainties and focus research needs. Safety assessments should provide inputs to disposal facility design and allow the definition of waste acceptance requirements on a disposal facility specific basis. Finally, licensing of a disposal facility should, at least in part, be based on the outcome of a safety assessment.

II.62. Scientists, regulatory bodies, decision makers and other interested parties should all have confidence in the information, insights and results provided by safety assessments. Activities contributing to confidence building include: (i) verification, calibration and, if possible, validation of models;

(ii) investigation of relevant natural analogues; (iii) quality assurance and (iv) peer review [33].

Verification, calibration and validation of models

II.63. Safety assessments are based on models of the disposal facility and of its natural surroundings. These models are used to simulate the evolution of the system and to provide an indication of the consequences of a number of scenarios. The modelling effort comprises the development of conceptual models and mathematical models and the corresponding computer codes or other methods of calculation. Confidence in the modelling results depends on two questions. First, does the method of calculation solve accurately the mathematical equations that constitute the model? The process of verification is used to answer this question. Second, does the model reproduce sufficiently accurately field and/or experimental results? Calibration and validation using different data sets are used to answer this question.

Verification

II.64. Verification of the method of calculation is achieved by solving test problems designed to show that the equations in the mathematical model are solved satisfactorily. Through the use of test problems and feedback from diversified use of the method, it is possible to achieve a high level of confidence in the correctness of the mathematics and that the equations are correctly encoded and solved. Comparison of the results of different methods in solving the same problem and using the same input parameters is also an effective approach. Therefore, verification of the methods of calculation is feasible and should be used for confidence building in safety assessments.

Calibration

II.65. Calibration aims to reduce uncertainty in conceptual and numerical models and parameters and is performed by comparing model or submodel predictions with field observations and experimental measurements. Calibration is, therefore, a site specific procedure, whereby a set of site specific input data is used to compare predictions and observations at that site. In practice, if a model can be calibrated successfully for a variety of site specific conditions, an increased level of confidence can be placed in the model's ability to represent those aspects of system behaviour and therefore to estimate their effects in situations in which they cannot be measured. However, one difficulty that is often encountered in the calibration process is that different conceptual models and their associated sets of input data produce results which show equally good agreement with the observed data. This limits the reduction in uncertainty that can be achieved.

Validation

II.66. As far as possible, modelling output should be shown to be valid, that is, to correspond to empirical data obtained in an actual situation. In contrast to calibration, which is a more site specific model adjustment process, validation has more to do with producing credible results at a variety of different sites or under a wide range of conditions. Although the validation of models for the long term evolution of a specific site is not possible over the relevant timescales, limited validation may be possible through the use of data from natural analogue studies or climate analogues. It may also be useful to compare modelling outputs with observations on the behaviour of certain components of the disposal system, for example, data sets obtained with in situ experiments, or with measurements performed during site characterization and during the operational phase.

Natural analogues

II.67. Natural analogues have been studied so that the results of observations made in nature may be compared with the performance of components or processes expected in a disposal system [34]. The analogy between natural analogues and a waste disposal facility is not perfect since in most cases only the end results of the naturally occurring processes can be observed, and there is significant uncertainty about initial conditions and their evolution over time.

II.68. To date, it has proven difficult to use natural analogue studies in a quantitative way to calibrate/validate models or to provide values for the parameters used in these models. However, some relevant processes such as degradation of package materials, radionuclide transport by groundwater or transfer of elements from soil to biota could be investigated in appropriate natural analogues with an adequate level of detail and with sufficient control of boundary conditions to allow some model testing. Therefore, despite some reservations, natural analogues should be used to build confidence in the various processes and materials used for the disposal system. The use of information derived from natural analogue studies could be particularly useful for increasing the decision makers’ and the public’s confidence in the assessment.

Management systems

II.69. Management systems provide a planned and systematic set of procedures to document the various steps in a process and to provide confidence that the results of the process are of good quality. These procedures have been, or are being, introduced into many areas of radioactive waste management [27]. The need to generate confidence in the results of safety assessments requires that procedures be applied to the various elements of the assessment, and in particular to data acquisition, design activities, development of models and methods of calculation, from the earliest stage. Management systems provide a framework in which safety assessment activities are performed and recorded, attesting to compliance with the procedure. In this way, it can be shown that reliable and traceable sources of information have been used. As a result, confidence in the results of the safety assessment will be enhanced.

Peer review of safety assessments

II.70. In scientific activities, confidence in the validity of results depends to a great extent on the outcome of the peer review process. Scientific work and results relevant to safety assessment should be published in the open literature in order that they are available for detailed scrutiny by other experts active in the same field, as well as by anyone interested in the subject.

II.71. The peer review process for work that constitutes the basis for safety assessments should include forms other than the typical peer review of scientific publications and programme results. National radioactive waste management programmes should have provision for the technical review of important activities. The regulatory body should develop an independent capability for reviewing safety assessments. In some cases, the operator of the disposal facility organizes, or the competent authorities organize, critical reviews by independent bodies. Such reviews can additionally make use of the expertise of natural and social scientists and can be effective in raising the level of confidence in the assessment.

ADDITIONAL CONSIDERATIONS

II.72. Since the safety assessment of geological disposal facilities involves consideration of hypothetical future events and their consequences, there is no expectation that particular projections will become reality. The only realistic objective is a reasonable degree of assurance, based on evaluating all appropriate evidence, including professional judgements and mathematical modelling, that the disposal facility will perform within acceptable safety bounds.

II.73. It should be borne in mind that implementing a geological disposal facility programme depends not only on scientists, regulatory bodies and decision makers being confident of its safety, but also on public acceptance. For the purpose of gaining the confidence of the public, the process of developing a waste disposal facility should incorporate a number of features aimed at promoting openness, public involvement and the effective and widespread dissemination of information. A well-designed safety assessment using simple, robust performance assessment techniques applied to an adequately grounded conceptual model may help foster public understanding and acceptance of the geological disposal facility. International intercomparisons and peer reviews are important aids in gaining public acceptance.

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