IAEA Safety Standards

for protecting people and the environment

Near Surface Disposal Facilities for Radioactive Waste

Specific Safety Guide

No. SSG-29

IAEA

International Atomic Energy Agency

IAEA SAFETY STANDARDS AND 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.

The publications by means of which the IAEA establishes standards are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety. The publication categories in the series are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides**.

Information on the IAEA's safety standards programme is available on the IAEA Internet site

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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: Vienna International Centre, PO Box 100, 1400 Vienna, Austria.

All users of IAEA safety standards are invited to inform the IAEA of experience in their use (e.g. as a basis for national regulations, for safety reviews and for training courses) for the purpose of ensuring that they continue to meet users' needs. Information may be provided via the IAEA Internet site or by post, as above, or by email to Official.Mail@iaea.org.

RELATED PUBLICATIONS

The IAEA provides for the application of the standards and, under the terms of Articles III and VIII.C of its Statute, makes available and fosters the exchange of information relating to peaceful nuclear activities and serves as an intermediary among its Member States for this purpose.

Reports on safety in nuclear activities are issued as **Safety Reports**, which provide practical examples and detailed methods that can be used in support of the safety standards.

Other safety related IAEA publications are issued as **Emergency Preparedness and Response** publications, **Radiological Assessment Reports**, the International Nuclear Safety Group's **INSAG Reports**, **Technical Reports** and **TECDOCs**. The IAEA also issues reports on radiological accidents, training manuals and practical manuals, and other special safety related publications.

Security related publications are issued in the **IAEA Nuclear Security Series**.

The **IAEA Nuclear Energy Series** comprises informational publications to encourage and assist research on, and the development and practical application of, nuclear energy for peaceful purposes. It includes reports and guides on the status of and advances in technology, and on experience, good practices and practical examples in the areas of nuclear power, the nuclear fuel cycle, radioactive waste management and decommissioning.

NEAR SURFACE
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-29

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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.

NOTE BY THE SECRETARIAT

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. The process of developing, reviewing and establishing the IAEA standards involves the IAEA Secretariat and all Member States, many of which are represented on the four IAEA safety standards committees and the IAEA Commission on Safety Standards.

The IAEA standards, as a key element of the global safety regime, are kept under regular review by the Secretariat, the safety standards committees and the Commission on Safety Standards. The Secretariat gathers information on experience in the application of the IAEA standards and information gained from the follow-up of events for the purpose of ensuring that the standards continue to meet users' needs. The present publication reflects feedback and experience accumulated until 2010 and it has been subject to the rigorous review process for standards.

Lessons that may be learned from studying the accident at the Fukushima Daiichi nuclear power plant in Japan following the disastrous earthquake and tsunami of 11 March 2011 will be reflected in this IAEA safety standard as revised and issued in the future.

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.

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

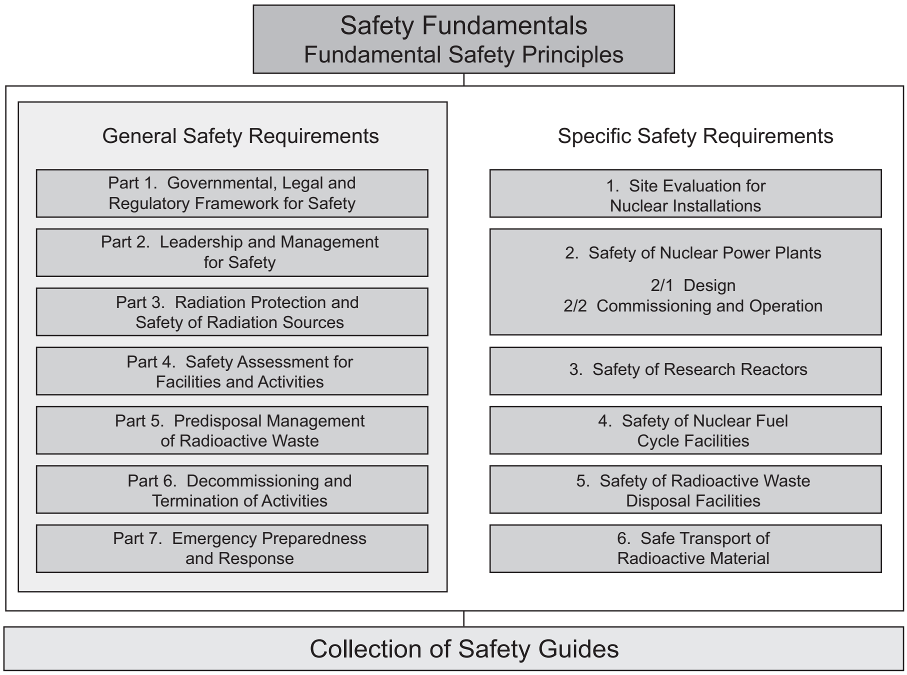

FIG. 1. The long term structure of the IAEA Safety Standards Series.

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 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

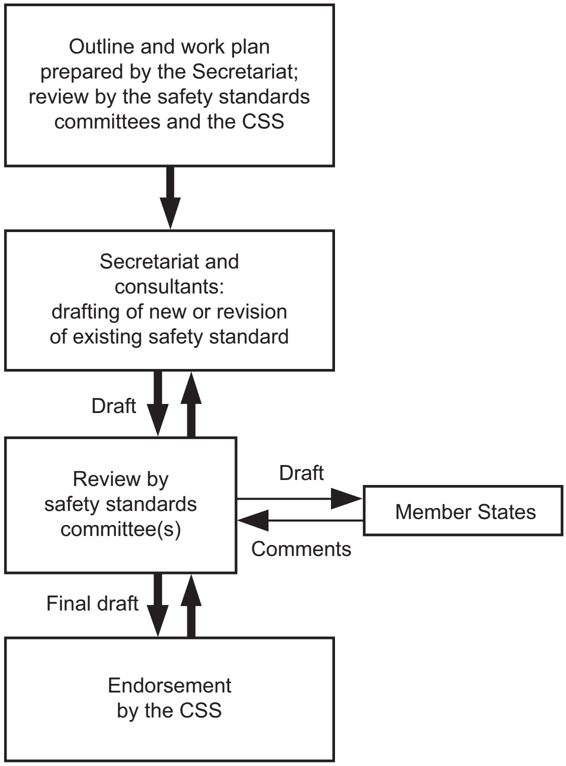

FIG. 2. The process for developing a new safety standard or revising an existing standard.

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 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 radioactive 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 (including activities in industry, research and medicine) 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 that any associated risks do not exceed acceptable levels.

1.2. The safety principles to be applied in all radioactive waste management activities are established in IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [1]. These principles form the technical basis for the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [2]. The relevant requirements for radiation protection are set out in IAEA Safety Standards Series No. GSR Part 3 (Interim), Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards (Interim Edition) [3]. The safety requirements for the disposal of radioactive waste, together with the safety objective and criteria for radiation protection in the post-closure period, are established in IAEA Safety Standards Series No. SSR-5, Disposal of Radioactive Waste [4]. The safety objective and criteria are replicated in Box 1.

1.3. As indicated in para. 1.8 of SSR-5 [4], the “term ‘disposal’ refers to the emplacement of radioactive waste into a facility or a location with no intention of retrieving the waste …. The term disposal implies that retrieval is not intended; it does not mean that retrieval is not possible.” A disposal facility is designed to contain the waste and to isolate it from the accessible environment to the extent demanded by the hazard of the waste. Although the radiological hazard presented by radioactive waste will reduce with time because of radioactive decay, the timescales over which the hazard remains significant can extend over many generations, depending on the radionuclides involved. The emphasis in radioactive waste disposal is therefore on the provision of long term safety through passive means.

BOX 1: RADIATION PROTECTION IN THE POST-CLOSURE PERIOD

Safety objective

The safety objective is to site, design, construct, operate and close a disposal facility so that protection after its closure is optimized, social and economic factors being taken into account. A reasonable assurance also has to be provided that doses and risks to members of the public in the long term will not exceed the dose constraints or risk constraints that were used as design criteria.

Criteria

(a) The dose limit for members of the public for doses from all planned exposure situations is an effective dose of 1 mSv in a year.[a] This and its risk equivalent are considered criteria that are not to be exceeded in the future.
(b) To comply with this dose limit, a disposal facility (considered as a single source) is so designed that the calculated dose or risk to the representative person who might be exposed in the future as a result of possible natural processes[b] affecting the disposal facility does not exceed a dose constraint of 0.3 mSv in a year or a risk constraint of the order of 10^{-5} per year[c].
(c) In relation to the effects of inadvertent human intrusion after closure, if such intrusion is expected to lead to an annual dose of less than 1 mSv to those living around the site, then efforts to reduce the probability of intrusion or to limit its consequences are not warranted.
(d) If human intrusion were expected to lead to a possible annual dose of more than 20 mSv (see Ref. [5], table 8) to those living around the site, then alternative options for waste disposal are to be considered, for example, disposal of the waste below the surface, or separation of the radionuclide content giving rise to the higher dose.
(e) If annual doses in the range 1–20 mSv (see Ref. [5], table 8) are indicated, then reasonable efforts are warranted at the stage of development of the facility to reduce the probability of intrusion or to limit its consequences by means of optimization of the facility's design.
(f) Similar considerations apply where the relevant thresholds for deterministic effects in organs may be exceeded.

Source: Paragraph 2.15 of SSR-5 [4].

[a] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).

[b] Natural processes include the range of conditions anticipated over the lifetime of the facility and events that could occur with a lesser likelihood. However, extremely low probability events would be outside the scope of consideration.

[c] Risk due to the disposal facility in this context is to be understood as the probability of fatal cancer or serious hereditary effects.

1.4. By contrast, “the term ‘storage’ refers to the retention of radioactive waste in a facility or a location with the intention of retrieving the waste” (para. 1.9 of Ref. [4]). Storage therefore anticipates future actions, such as to provide further conditioning or packaging of the waste, to maintain the facility in which storage takes place or to construct new facilities for further storage and ultimately disposal. The storage of radioactive waste is specifically dealt with in IAEA Safety Standards Series No. GSR Part 5, Predisposal Management of Radioactive Waste [6], and IAEA Safety Standards Series No. WS-G-6.1, Storage of Radioactive Waste [7].

1.5. The choice of a disposal system (i.e. the disposal facility and the environment in which it is sited) in any given circumstance will depend on a variety of factors, including the inventory of waste to be disposed of. In particular, the approach taken to meeting safety requirements should be commensurate with the hazard associated with the waste and the longevity of the hazard (i.e. the quantity and concentration of particular radionuclides), as well as with the environmental conditions at the site at which disposal will take place. For the types of waste that may be disposed of in near surface disposal facilities, there is a range of circumstances in which disposal programmes could be developed. For example, considerable volumes of very low level waste (VLLW) may arise from the decommissioning of nuclear facilities and clean-up of the sites or from the remediation of a site following an accident. In such cases, considerations of proximity may have an important bearing on the practicable choices for the disposal of such waste. By contrast, fairly small volumes of low level waste (LLW) may be generated from a large number of sources within a State or region, which may lead to the siting and development, operation and closure of a centralized facility.

1.6. This Safety Guide provides recommendations on how to meet the safety requirements of SSR-5 [4] and is concerned with the disposal of solid radioactive waste by emplacement in designated facilities at or near the land surface. Near surface disposal is primarily suitable for waste containing mainly short lived radionuclides (radionuclides with half-lives of less than about thirty years are considered to be short lived) and only low concentrations of long lived radionuclides. It has been practised in a number of States for several decades, and the experience gained has been taken into account in the development of this Safety Guide.

1.7. This Safety Guide is intended to provide guidance on the disposal of a wide range of radioactive waste appropriate for near surface disposal [8]. The guidance should be applied in accordance with a graded approach, consistent with the intrinsic hazard presented by the waste to be disposed of.

1.8. There is a notable difference in the approach to safety for a near surface disposal facility compared with the approach for a nuclear installation. This arises primarily because a nuclear installation, such as a fuel fabrication plant, a nuclear power plant or a reprocessing facility, is functional during its operating life and involves a production activity, such as electrical power generation. Nuclear installations rely upon operating limits and conditions for the active safety systems they employ. In contrast to a nuclear installation, the core function of a disposal facility for radioactive waste is to provide passive safety for long periods of time. However, operational limits and conditions will still be important for near surface disposal facilities to ensure operational safety and post-closure performance.

1.9. This Safety Guide supersedes the earlier publication Safety Series No. 111-G-3.1, Siting of Near Surface Disposal Facilities.[1]

OBJECTIVE

1.10. The objective of this Safety Guide is to provide guidance and recommendations relating to the development[2], operation, closure and regulatory control of facilities for the near surface disposal of radioactive waste to meet the safety requirements established in SSR-5 [4]. It is primarily intended for use by those involved with policy development and with the regulatory control and use of near surface disposal.

SCOPE

1.11. The term 'near surface disposal' is used in this Safety Guide to refer to a range of disposal methods, including the emplacement of solid radioactive waste in earthen trenches, above ground engineered structures, engineered structures just below the ground surface and rock caverns, silos and tunnels excavated at depths of up to a few tens of metres underground. This Safety Guide provides general guidance for the development, operation and closure of facilities of this

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[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Siting of Near Surface Disposal Facilities, Safety Series No. 111-G-3.1, IAEA, Vienna (1994).

[2] The term 'development' covers all stages before operation of a near surface disposal facility. It includes siting, design, construction and commissioning.

type that are suitable for the disposal of VLLW and LLW [8]. This Safety Guide does not apply to intermediate level waste (ILW) that will not decay to safe levels over a period of a few hundred years or to high level waste (HLW), as both are unsuitable for near surface disposal. This Safety Guide does not cover the disposal of waste from uranium mining and milling or waste containing only naturally occurring radioactive material (NORM) or borehole disposal of radioactive waste; these topics are dealt with in Refs [9, 10].

1.12. This Safety Guide is primarily concerned with activities associated with the development, operation and closure of near surface 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. The framework within which siting is conducted, and indeed the basis for policy decisions to adopt near surface disposal as a waste management option, will be specific to the societal context and approach to decision making in which the programme for disposal is being developed [11, 12]. General recommendations regarding the technical and scientific aspects of siting are provided in Appendices I and II.

1.13. The development of radioactive waste disposal facilities that incorporate design or operational provisions to facilitate reversibility, including the possible retrievability of waste packages, has been considered in several national programmes. It is conceivable that a requirement to provide such features could emerge as a result of specific processes for the engagement of interested parties. Paragraph 1.25 of SSR-5 [4] 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 near surface disposal facilities, irrespective of whether or not retrievability is incorporated into the design or operational plans.

1.14. The safety of waste transport to near surface disposal facilities is addressed in IAEA Safety Standards Series No. SSR-6, Regulations for the Safe Transport of Radioactive Material (2012 Edition) [13]. Some waste transported to a near surface disposal facility may require further treatment and conditioning prior to emplacement of the waste package into the disposal facility. Guidance for the safety of waste treatment and conditioning facilities that may be collocated with a near surface disposal facility is not provided in this Safety Guide. IAEA safety standards for fuel cycle facilities and for the predisposal management of waste apply for this type of facility [6, 14].

1.15. Nuclear security aspects of the disposal of radioactive waste in near surface facilities are outside the scope of this publication. However, this Safety Guide does identify where security measures are relevant for safety purposes. Guidance on addressing nuclear security aspects can be found in the Nuclear Security Series publications (see Refs [15, 16] and supporting guidance).

STRUCTURE

1.16. Section 2 provides an overview of near surface disposal and its implementation, and the step by step approach to developing a near surface disposal facility. Section 3 provides guidance on legal and organizational infrastructure. Section 4 discusses the safety approach and design principles, and Section 5 provides guidance for the preparation of the safety case and safety assessment. Section 6 presents guidance for specific steps in the development, operation and closure of a near surface disposal facility. Section 7 provides guidance on assurance for safety, and Section 8 deals with existing disposal facilities. Appendices I and II provide additional information and guidance concerning the siting of near surface disposal facilities, specifically concerning data needs.

1.17. SSR-5 [4] establishes 26 safety requirements that are applicable to the near surface disposal of radioactive waste. For convenience and traceability, the text of each requirement in SSR-5 [4] is reproduced in this Safety Guide and is followed by the related recommendations.

2. OVERVIEW OF NEAR SURFACE DISPOSAL AND ITS IMPLEMENTATION

2.1. Near surface disposal refers to the emplacement of solid, or solidified, radioactive waste containing predominantly short lived radionuclides in a disposal facility located at or near the land surface. The depth chosen for disposal, and the type of facility that is developed, will depend on a number of factors including, but not limited to, the nature of the waste and the local environmental conditions at the proposed site. An important feature of near surface disposal is the possible need to maintain institutional control over the site for a period following closure, owing to the need to prevent disturbance of the facility and its contents by human activities. However, as stated in para. 3.48 of SSR-5 [4], the "long term safety of a disposal facility for radioactive waste is required not to be dependent on active institutional control".

2.2. Concentration and containment of the waste and isolation of the waste from the biosphere is the accepted management strategy for most radioactive waste [4]. Containment and isolation can be provided through a series of complementary barriers, for example the waste form itself, waste containers, other engineered features associated with the facility design, and the local environment, each of which serves in some way to prevent the release of radionuclides from the waste form and/or to restrict the migration of contaminants from the facility to the accessible environment.

2.3. The overall programme for siting, construction and operation of a near surface disposal facility is likely to last an extended period, typically of the order of a few to several decades. In the context of radiation safety, it is conventional to identify three broad periods associated with the development, operation and closure of a near surface disposal facility: the pre-operational period, the operational period and the post-closure period [4]. While such terminology is convenient, it is also appropriate to recognize that, in the context of the development of waste disposal facilities, the whole development programme (including what is conventionally referred to as operation) is in fact contributing to the assembly of the final closed disposal facility, which is then expected to perform passively (essentially with no further active management or intervention) in order to contain and to isolate the waste for as long as necessary. Indeed, in the case of a near surface disposal facility, certain key components of the engineered barrier system may not be installed until closure of the facility.

2.4. With this in mind, the following phases can be identified:

(a) The **pre-operational period** includes the definition of concepts, site investigation and confirmation, safety assessment, design development and optimization, and construction. In the pre-operational period, site selection, detailed characterization and environmental impact assessment studies are typically conducted, together with the development of those aspects of the safety case for operational and post-closure safety that are required in order to obtain authorization to proceed with the construction of the near surface disposal facility and any commissioning activities prior to waste emplacement. Appendices I and II provide further recommendations on siting.

(b) 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. Experience has shown that the operational period is likely to run in parallel with the ongoing construction of the waste emplacement system and with data acquisition programmes. This provides flexibility, for example enabling the design of the facility to be modified in the light of experience or in accordance with regulatory processes. Monitoring and testing programmes, intended to provide evidence to support an eventual decision to close the disposal facility, can be expected to continue, and the safety case for the period of operation and for the period after closure will be further updated and developed. If considered necessary, the operational period may include extended performance monitoring and waste retrieval prior to closure. The operational period is completed following emplacement of the last waste package and the final closure of the facility.

(c) The **post-closure period** begins at the time when waste acceptance, handling and emplacement operations are concluded, any cap over the facility has been constructed and — in the case of disposal in rock caverns, silos and tunnels — the galleries and access routes from the surface have been sealed. After closure, the safety of the disposal facility is provided for by passive means inherent in the characteristics of the site and of the facility, although institutional control such as controls over access to, or use of, the site may be put in place or continue for a certain period. The higher the concentrations and total quantities of longer lived radionuclides in the waste, and the greater the vulnerability of the site to disruptive events, the longer such a period of control may need to be. However, for the purposes of the safety assessment, it is usually assumed that the period of active institutional control during which human intrusion is prevented lasts only for a limited time (typically a few hundred years) in order that, as soon as reasonably possible, safety will be provided by passive means.

2.5. The development, operation and closure of a near surface disposal facility is likely to last over many years. Given such timescales, and the large volume and diversity of information necessary to support the process (e.g. through the acquisition of data on waste and from engineering activities, site characterization and other activities that will support the safety case), it is appropriate to subdivide the programme into a series of steps involving formal stages at which the programme is reviewed and evaluations of safety are undertaken before decisions are made to progress [4]. Such a step by step approach allows confidence in safety to be increased in an iterative manner and helps to ensure that all key decisions are well founded. As a general rule, regulatory reviews at each key decision point also provide opportunities for independent technical review and involvement of interested parties. Figure 1 illustrates typical steps as the disposal facility progresses from the early decision making stage through to the post-closure period.

2.6. After site selection, consistent with the phases described above, a number of activities grouped in broad areas should be undertaken — namely, detailed site characterization and site confirmation that the site meets the selection criteria, design of the 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. The last three of these correspond to three important steps in the regulatory approval of a near surface disposal facility (see Fig. 1). Site characterization and design activities, as well as associated record keeping, may be expected to continue, at some level, up to facility closure. Key information on the disposal facility should also be placed in appropriate archives.

2.7. A step by step process also 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, operation and closure 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.

3. LEGAL AND ORGANIZATIONAL INFRASTRUCTURE

3.1. Development, operation and closure of a near surface 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.

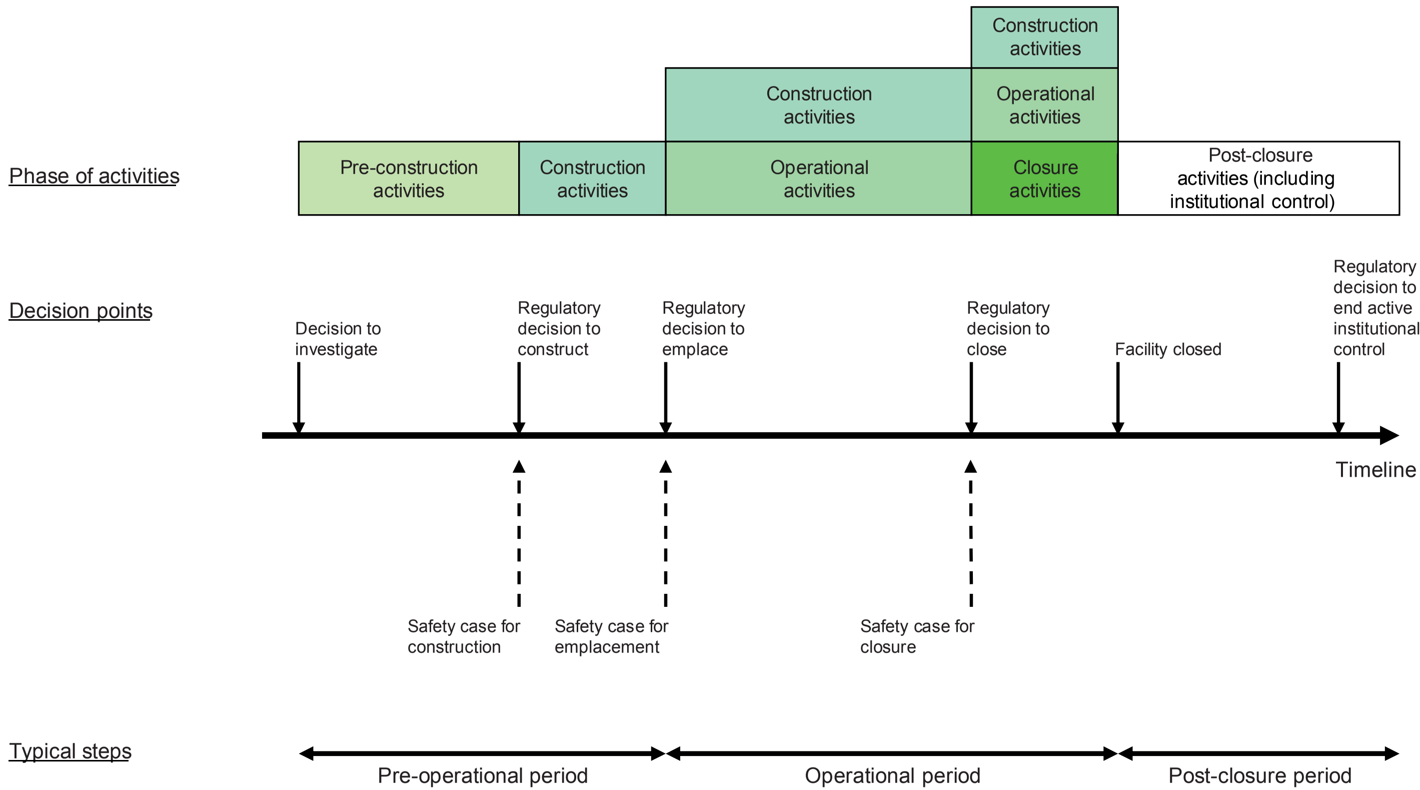

FIG. 1. *Timeline to illustrate the development, operation and closure of a near surface disposal facility.*

GOVERNMENT RESPONSIBILITIES

Requirement 1 of SSR-5 [4]: 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."

3.2. As stated in para. 3.7 of SSR-5 [4], the national legal and organizational framework for near surface disposal has to include the following:

(a) Defining the national policy and strategy 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, operation and closure of near surface 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 (siting, design and construction), operation and closure of near surface 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, operation and closure, independent 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 monitoring and arrangements that may be required for ensuring the security of the disposed of waste.

3.3. The government should ensure that the regulatory body is independent of the generator of the waste and the operator of the disposal facility. The regulatory body should possess the expertise to provide proper oversight and objectivity in evaluating waste management and disposal activities. Individuals working within the regulatory body should be sufficiently independent of influence from waste generators and from the operator of the disposal facility. The government should perform periodic reviews to evaluate the effectiveness of the regulatory body and its ability to fulfil its mission.

3.4. In accordance with national laws and preferences, the government should ensure that interested parties that are directly or indirectly affected by the outcome of the project are involved in making decisions at appropriate stages throughout the project. A clear, formal process identifying interested parties and decision makers should be established to facilitate a meaningful exchange of information and viewpoints. The ways in which interested parties are involved in decision making processes concerning the near surface disposal of radioactive waste will vary according to national laws, regulations and preferences. The involvement of interested parties in the development of frameworks for decision making can encourage public confidence in government actions, make the regulatory body more effective and improve the safety performance of operators [12].

RESPONSIBILITIES OF THE REGULATORY BODY

3.5. These recommendations refer to a single regulatory body, but it is recognized that, in practice, the regulation on safety of near surface disposal facilities could involve the participation of multiple regulatory bodies to address the concurrent activities of nuclear safety, industrial safety, environmental protection and radiological protection. The specific roles and responsibilities of the regulatory body in relation to waste management are established in IAEA Safety Standards Series No. GSR Part 1, Governmental, Legal and Regulatory Framework for Safety [17] and include the following:

- — Carrying out licensing, inspection and enforcement of regulations;
- — Providing independent advice to the government in the formulation of objectives in the national policy;
- — Issuing and updating rules, guidance and other regulatory criteria specific to near surface disposal facilities.

Requirement 2 of SSR-5 [4]: 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."

3.6. The regulatory body should provide guidance on the interpretation of the national legislation and regulatory requirements, including in particular the types of waste that can and should be disposed of in specific disposal facilities. Guidance should be provided on the expectations on the operator regarding the development, operation and closure, and licensing of each individual facility and, specifically, on the interaction between the regulatory body and the operator before the formal licensing process commences. The regulatory body should engage in dialogue with waste generators, the operator of the disposal facility and other interested parties to ensure that the regulatory requirements are appropriate and practicable and are clearly understood by the various parties.

3.7. The regulatory body should maintain competent staff and an appropriate management system, and should have access to independent assessment capabilities and participate in international co-operation as necessary to fulfil its regulatory functions.

3.8. In developing regulations, guidance and other regulatory criteria specific to near surface disposal facilities, the regulatory body should ensure consistency with the national policy and give due regard to the objectives and criteria set out in SSR-5 [4]. The regulations and guidance may include:

— Radiation protection criteria and environmental protection criteria for operational and post-closure safety;
— Requirements for the content of the safety case for a disposal facility, including the safety assessment and the management system;
— Criteria and requirements for the siting, design, construction, operation and closure of disposal facilities;
— Criteria and requirements for the waste, waste form, packaging, any backfill and sealing material and other components of the facility;
— Requirements for the involvement of interested parties.

3.9. The regulatory body has to establish and to document the procedures for evaluating the safety of a near surface disposal facility and the procedures that operators are expected to follow in the licensing process and in demonstrating compliance with the safety requirements [4]. The procedures established by the regulatory body should cover the following:

- Specification of the information to be supplied by the operator;
- Review of the required submissions and assessment of the compliance with regulatory requirements;
- Issuance of approvals and licences and setting of conditions in conformity with legislation and regulations;
- Guidance on the conditions of authorization;
- Inspection and audit of the operator’s data gathering, safety assessment, activities in construction and operation to ensure quality, and compliance with regulations and the terms of approvals and licences;
- Periodic reviews of approvals, licences and inspection procedures to determine their continued suitability or need for amendments;
- Involvement of interested parties;
- Requirements for termination of regulatory control.

3.10. The regulatory body should establish its own independent capability for reviewing safety cases and supporting safety assessments. This should be composed of qualified and competent individuals with the essential knowledge, skills and abilities to review and to evaluate critically the required submissions for applicants and licensees. The regulatory body should be capable of conducting, or arranging, independent research and assessments, if necessary with the involvement of technical support organizations, as required for the approval of licences for the development, operation and closure of near surface disposal facilities. The regulatory body should participate in international cooperation as necessary to fulfil its regulatory functions. Independent review capabilities can be established and maintained through formal agreements with academic institutions and national laboratories (where available) and through special commercial contracting agreements, where conflicts of interest may arise. 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 organization is undertaking appropriate research, that this research is of sufficient quality and that it is subject to independent expert review.

RESPONSIBILITIES OF THE OPERATOR

Requirement 3 of SSR-5 [4]: 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."

3.11. In developing the design of a safe near surface disposal facility, the operator should establish a safety strategy that will clearly set out how the facility is to comply with all the safety requirements. The strategy should indicate how the safety principles will be applied and should take into consideration the characteristics and quantities of the radioactive waste to be disposed of, the characteristics of the available site or sites, the available engineering techniques, and the national legal infrastructure and regulatory requirements. The safety strategy should also indicate how the management system will provide assurance of the necessary quality of work to be carried out and, among other things, it should establish the necessary frameworks for organization of the work (e.g. interaction between designers, assessors, site investigators and researchers). The safety strategy should be presented in the safety case for the facility, which the operator should develop in accordance with the detailed guidance provided in IAEA Safety Standards Series No. SSG-23, The Safety Case and Safety Assessment for the Disposal of Radioactive Waste [18].

3.12. In conducting the research necessary to support the understanding of the processes on which the safety of the near surface disposal facility depends, the operator has to carry out all the necessary investigations of the site and materials used in construction and operation (including packaging and other engineered barriers). The operator has to assess the suitability of materials for a given application and has to ensure the availability of other data required for the safety assessment [4].

3.13. The operator has to establish technical specifications to ensure that the disposal facility is constructed, operated and closed in accordance with the regulatory requirements and the safety case. This has to include the development and use of waste acceptance criteria and other controls and limits to be applied during construction, operation and closure [4].

3.14. The operator should identify and seek to prevent potential conflicts between efforts to address long term safety objectives and operational objectives: for example, operational expediency should not jeopardize long term safety functions, nor should site workers be subjected to undue risks in the interests of long term safety.

3.15. The operator should supply all information relevant to the safety case and the supporting safety assessment to the regulatory body, together with any other documents necessary to demonstrate safety and, through a process of iteration, demonstrate compliance with regulatory requirements and with the technical specification of the facility. Such information and records have to be retained by the operator until they are transferred to another organization that assumes this responsibility, such as at closure [4]. The need to preserve records for long time periods during operation and after closure should be taken into account in selecting the location, format and materials to be used for such records.

4. SAFETY APPROACH

4.1. The safety approach includes all the ways in which protection of people and protection of the environment are ensured throughout the lifetime of a near surface disposal facility. As the long term safety of a disposal facility for radioactive waste is required not to be dependent on active institutional control [4], the safety of a near surface disposal facility largely rests on the quality of the selected site and the capability of the design of the facility to contain and to isolate the waste. This emphasizes the importance that should be given to all steps in the development of a near surface disposal facility that precede the actual construction and operation of the facility.

4.2. Within the framework set by the national policy for near surface disposal of radioactive waste, the operator, in consultation with the regulatory body, should set out elements of the national policy in a formal safety strategy document that is produced as early as possible in the disposal programme and is updated periodically. The safety strategy is the high level integrated approach adopted for achieving safe disposal. It should include strategies to select a site and to design, construct, operate and close a disposal facility. In addition, it should include recommendations for the preparation and maintenance of the safety case for use in decision making and procedures for regulatory approval for the assumed duration of the period of institutional control (see Section 5). Throughout the whole process, safety should be the central and main consideration in all decisions taken in the development and operation of a near surface disposal facility.

4.3. The development and definition of a safety strategy should be the responsibility of the operator, which should develop and apply its safety strategy in line with the national policy for disposal. The operator should take into account the national regulatory framework, international standards and legal instruments and all relevant constraints posed by societal and economic factors. The regulatory body should review the operator's safety strategy for the near surface disposal facility at the early stage of its development and well in advance of the formal licensing steps.

4.4. The requirements in IAEA Safety Standards Series No. GSR Part 3 (Interim) [3] and the recommendations provided in the 1990 Recommendations of the International Commission on Radiological Protection [19] assume that, subject to the appropriate definition of exposed groups, the protection of people against the radiological hazards associated with a near surface disposal facility will also protect the environment against such hazards. The issues associated with the protection of the environment from harmful effects of ionizing radiation and the possible development of standards for this purpose are discussed in Refs [20, 21].

IMPORTANCE OF SAFETY IN THE DEVELOPMENT PROCESS

> **Requirement 4 of SSR-5 [4]: 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."**

4.5. As established in para. 2.15 of SSR-5 [4] (see Box 1):

> "The safety objective is to site, design, construct, operate and close a disposal facility so that protection after its closure is optimized, social and economic factors being taken into account. A reasonable assurance also has to be provided that doses and risks to members of the public in the long

term will not exceed the dose constraints or risk constraints that were used as design criteria.”

4.6. SSR-5 [4], when applied to near surface disposal facilities, requires that long term safety is to be ensured by:

(a) The capability of the features of the disposal facility to contain the waste and isolate it from the accessible biosphere;
(b) The capability of the features of the site to contribute to the containment and isolation of the waste;
(c) The limitations placed on the radiological inventory, mainly with regard to long lived radionuclides, that can be disposed of in the facility;
(d) The measures for surveillance and control of the disposal facility and its immediate surroundings that are applied to prevent or restrict any human activities that could disturb the facility barriers and lead to increased exposures.

4.7. Consequently, near surface disposal is an appropriate disposal option only for VLLW and LLW, while ILW and HLW, which contain larger quantities of long lived radionuclides, have to be disposed of in deeper geological disposal facilities. Whereas well sited and well designed geological disposal facilities aim at ensuring containment and isolation of radioactive waste over very long periods of time (tens to hundreds of thousands of years), the location of a near surface disposal facility at or near the surface makes it susceptible to processes and events that will degrade its containment and isolation capacity over much shorter periods of time (up to several hundreds of years). In near surface disposal, the facility is located in the biosphere where most human activities take place, and the possibility of human intrusion into a near surface disposal facility after the period of institutional control is considerably greater than in the case of geological disposal. Therefore, human intrusion after the period of institutional control has to be taken into account, and the adequacy of the limitations placed on the radioactive inventory should be assessed and confirmed, principally in terms of allowable quantities of long lived radionuclides in the waste packages.

4.8. The development, operation and closure of a near surface disposal facility involves an iterative process of site characterization and design and evolution of the safety case and supporting safety assessment to provide an optimized level of operational and post-closure safety (see the appendix to SSR-5 [4]). Throughout this process, all relevant characteristics of the waste to be disposed of should be identified and taken into account in the design of the facility and in the safety assessment. This iterative process may take several years, and key decisions, such as those on the choice of design concept, siting, detailed design, allowable inventory and construction of the facility, should be made in a step by step process as the project develops. In this process, optimization of the disposal facility and its safety performance through the evaluation and comparison of options should generally progress from more strategic considerations to detailed choices for design and operation. Optimization of the long term safety of a near surface disposal facility should mainly be achieved by means of decisions on the site and the design of the facility, and by a cautious approach followed in safety assessment to set adequate limitations on the inventory. Societal and economic factors, such as public acceptance of the disposal facility, and natural factors, such as surface geology, can constrain the available options for siting the facility. However, optimization of the design of the facility should take due account of all the favourable and unfavourable site characteristics and should be based on best practices.

4.9. Decisions should be made on the basis of the quantitative or qualitative information available at the time and the confidence that can be placed in that information. Therefore, a systematic identification and assessment of uncertainties that can affect the safety of the facility should be part of the development, operation and closure, and should be factored in at each major decision point that relates, directly or indirectly, to the safety of the facility. Facility development, operation and closure decisions are also influenced by external factors, such as national policy and preferences.

4.10. At each major decision point (siting, design, operation, closure and post-closure), an adequate level of confidence in safety should be developed so that the available options can be evaluated and the best protective options can be selected, with all relevant societal and economic factors taken into account. If more than one option is capable of providing the required and optimized level of safety, then factors other than safety also have to be considered. These factors could include public acceptability, cost, site ownership, existing infrastructure and transport routes [4].

4.11. Throughout the iterative process of site characterization, disposal facility design and safety assessment, the critical components for the safety of the disposal system should be identified. Different complementary approaches should be put in place to identify these critical components:

— In the design process, analysis of the safety function(s) of each component on the basis of the provision of defence in depth;

— In the iterative safety assessments, integration of all main safety relevant elements of the system and all available information (including a systematic analysis of uncertainties) regarding the performance and evolution of system components;
— Assessment of the technical feasibility of the operation of the system and its components in a manner that meets the functional requirements.

4.12. The critical components should be qualified, as appropriate and practicable, using standardized and appropriate testing methods to gain confidence in their ability to perform the required function(s) over the required timescale(s). If new techniques are employed, they should be developed and qualified in a time frame that is compatible with the project schedule. Research activities focusing on critical components should be used to improve further the understanding of system and component performance and should lead (a) to further optimization steps, even when development of the system has started, or (b) to improvement of the safety assessment to the extent that a more accurate assessment of system performance and safety can be made. A continued research programme on critical components of the disposal system is an important element of the safety strategy. However, the existence of such a programme should not be used to justify the taking of decisions early in the programme without an adequate level of confidence in the safety of the system. The balance between the level of confidence at a certain point and the prospects of additional insights from a continued research programme should be a central element in the process of interaction between the operator and the regulatory body.

4.13. Operational safety should be provided by means of active and passive control systems. Active systems could include operational controls (e.g. control of incoming waste for surface contamination or contact dose rate, and control of waste emplacement activities) and monitoring for radioactive releases, whereas passive systems could include engineered features such as shielding. Normal operating conditions, as well as anticipated operational occurrences and incident and accident conditions, should be considered in the development of operational safety systems. Both internal events (e.g. a fall of a waste package during waste handling operations) and external events (e.g. the risk of external explosion, strong winds, flooding and earthquakes) can lead to anticipated operational occurrences, incidents or accidents and should be assessed for the specific site and design of the facility. Where appropriate, the development of operational safety systems should make use of operational experience and technologies (e.g. techniques for waste handling) adopted from other types of nuclear facility. Consideration should be given to the fact that conventional risks may be more significant than radiological risks, especially if the waste to be disposed of is conditioned waste with only a small risk of dispersion of radioactive material.

4.14. Safety mechanisms for the post-closure period are distinct from those employed in the operational period, or for other types of facility. In the post-closure period, a near surface disposal facility is required to provide the necessary degree of containment and isolation, so that the migration of radionuclides from the waste into the biosphere is reduced to an acceptably low level and so that the likelihood of, and all possible consequences of, human intrusion are sufficiently reduced. This should be achieved primarily through passive means and using multiple safety barriers, supported by surveillance and control measures, as described in the following subsections.

4.15. The concept of near surface disposal covers a wide range of facilities (e.g. disposal at the surface in engineered vaults or trenches, or disposal at varying depths — from a few metres to a few tens of metres — in facilities with various types of engineered barriers). The components of the disposal system, both engineered and natural, that contribute to the containment and isolation of the waste after the facility is closed can therefore differ to a large extent. Throughout the development, operation and closure, an adequate understanding should be developed of the performance, durability and longevity of all the components that contribute to the overall system for containment and isolation of the waste. In order to develop an adequate understanding of the behaviour of the disposal facility, a focused effort should be made to characterize and to assess the system components in terms of their initial performance and the expected or possible evolution of their performance due to degradation or disturbing events and processes. The fact that the extent to which the engineered components of the system, or the natural components, or both, contribute to the overall containment and isolation can differ widely for different types of near surface disposal facility should be taken into account.

4.16. Through the process of optimization, all decisions should be taken with the aim of selecting the best protective options, in line with policy decisions (e.g. on the type of near surface disposal facility to be developed) and with account taken of societal and economic factors (e.g. expression of local acceptance or refusal for a particular site or sites). Once the type of disposal facility has been decided and the site selected, the main effort of optimization should be on making all the design choices with respect to the engineered components of the disposal system in a manner that all relevant characteristics of the site are correctly taken into account (e.g. chemical characteristics of the site that influence or determine the lifetime and performance of the engineered components, and mechanical and seismic characteristics of the site that can affect the stability and integrity of the engineered components). In order to design the facility in such a manner that the natural and engineered components of the disposal system are compatible and complementary, all relevant information with respect to the features of the site and the components of the facility should be used. When system specific information is lacking and generic information is used, a cautious and transparent approach to safety should be ensured.

4.17. Throughout the process of developing the disposal facility, its robustness should be evaluated in a systematic and structured manner to understand how disturbances that might be expected to occur or remaining uncertainties can affect the performance of the components and the safety of the disposal system. Both siting and design decisions should be made on the basis of an evaluation of robustness (e.g. the selection of sites that are less likely to be affected by external events such as floods or earthquakes) or the dimensioning of system components with a sufficient performance margin.

CONTAINMENT

Requirement 8 of SSR-5 [4]: 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."

4.18. For the purposes of this Safety Guide, the final sentence of Requirement 8 of SSR-5 [4] is not relevant, as heat generating HLW is not suitable for disposal in near surface disposal facilities [8].

4.19. Containment of radioactive waste implies that the disposal facility should be sited and designed to prevent or to minimize the release of radionuclides. As near surface disposal is only suitable for classes of waste containing mainly short lived radioactive waste and potentially with limited amounts of long lived radionuclides, the time frames over which containment has to be ensured are largely determined by the objective to limit the potential for a release of radionuclides from the waste to the biosphere. Absolute containment of long lived radionuclides is not possible — in particular in the long term — but should be aimed at for an appropriate period of time to allow for complete radioactive decay of the short lived radionuclides within the disposal system before they can reach the biosphere.

4.20. Containment can be provided by physical or chemical means. Physical containment relates to the prevention of radionuclide migration by means of physical barriers such as a metal container or barriers with low permeability to water. Chemical containment relates primarily to waterborne migration and refers to the retardation of the migration of radionuclides by reduction of their solubility and/or by sorption of radionuclides onto some immovable substrate material. Chemical containment is often provided by the use of cementitious waste forms and various facility components. In most environments, prevention and limitation of ingress of water, coupled with chemical containment, are key determinants of the safety of near surface disposal.

4.21. Depending on the type of near surface disposal facility, containment should be provided by a variety of means. The degree of containment provided by engineered barriers (i.e. the waste package, backfill and the facility structure including the final cap) and the natural environment (the geological surface layers within which the facility is situated or around the facility) can vary significantly. The overall system containment should be realized through a combination of engineered and natural barriers and should be compatible with the safety strategy and supported by scientific and technical arguments in the safety case. Designing for containment means that both the ingress of water into the facility towards the waste and the migration of radionuclides from the waste to the biosphere should be prevented or limited to the extent possible. The containment should prevent both the release of radionuclides in gaseous form (e.g. ^{3}H, ^{14}C and ^{129}I) as well as their release through migration in the liquid phase (i.e. via dissolution of radionuclides in the water that has entered the facility and their migration in the liquid phase to the biosphere). The construction of barriers with low water permeability around the waste, the slow dissolution of the waste form, and the physical and chemical characteristics of the engineered and natural barriers around the waste that favour sorption of the radionuclides in the solid phase should all contribute to containment of the waste and its radionuclides. External factors, such as low annual precipitation, that directly affect the containment capacity of a near surface disposal system should also be considered in the siting process.

4.22. The various components contributing to containment should be compatible with each other, in order to prevent interactions between components — for example, in the case of chemical processes — leading to a degradation of the containment capacity of one or more components. Especially, the physical and chemical characteristics of the waste should be systematically evaluated when selecting materials for the engineered barriers around the waste.

4.23. When natural barriers are important contributors to containment, their contribution should be evaluated on the basis of information obtained from site characterization. Uncertainties due to, for example, spatial variability of site characteristics or resulting from the techniques applied for field observation and measurement campaigns should be taken into account when assessing the containment capabilities of the natural components of the disposal system.

4.24. The contribution of the engineered barriers to containment will depend on:

(a) The way in which they are used in the design of the disposal facility (their location).
(b) Their relevant characteristics (such as low permeability to water or high sorption capacity).
(c) The evolution of these characteristics with time as a result of:
    (i) Physical and chemical processes (e.g. concrete degradation and erosion of the final cap);
    (ii) External events affecting these characteristics (e.g. seismic events, site flooding and mechanical instability of the site).

In the design and construction of the engineered barriers, attention should be paid to the lifetime of the barriers, both in terms of their expected lifetime (or in terms of the expected evolution of performance of the barriers with time) as well as in terms of demonstrability of their lifetime (or of the evolution of performance of the barriers). The activities of designing the engineered barriers and the supporting research activities necessary to characterize the barrier performance and its evolution with time should generate all the information necessary for the safety assessments of the performance of the engineered barrier within the overall system and its evolution with time. Account should be taken of the fact that an overly optimistic assessment of performance of the barriers will lead to an underestimation of future radiological consequences. An overly pessimistic or conservative assessment of the long term performance of the engineered barriers can lead to unnecessary restrictions on the amounts of waste that can be disposed of in the planned facility.

4.25. The safety case should integrate all the information on which the assumptions for safety assessment with respect to the performance of the components and its evolution is based (e.g. research results, modelling, natural evidence and from comparison with natural analogues).

4.26. The level of confidence in the containment provided by the individual components of the system, both engineered and natural, during their construction should be achieved by means of an adequate management system with suitable quality control and quality assurance procedures (including, e.g., component specifications, procedures for installation of the various components, and procedures for fabrication or construction) and by investigations (e.g. ongoing research activities into component behaviour). This information should be incorporated into the safety case and supporting safety assessment conducted during the pre-operational phase that reflects the properties of the disposed waste, the as-built properties of the engineered systems as well as the properties of the site.

ISOLATION

Requirement 9 of SSR-5 [4]: 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."

4.27. For the purposes of this Safety Guide, the part of Requirement 9 of SSR-5 [4] that refers to intermediate and high level waste is not relevant, as these classes of waste are not suitable for disposal in near surface disposal facilities [8].

4.28. For near surface disposal, isolation means retaining the waste and keeping its associated hazard away from the biosphere in a suitably located and appropriately designed disposal facility, with appropriate control in the post-closure period to prevent disturbance of the facility (e.g. prevention of inadvertent human access to the waste). The location and design of the facility should also take into account the potential impacts of external events.

4.29. The isolation capability of near surface disposal facilities should be ensured for periods of up to several hundreds of years. The isolation capability should be ensured mainly through passive means, in order neither to impose an excessive burden on future generations nor to rely on active measures to ensure safety over a period of time that is incompatible with the confidence placed in institutional and financial stability. As active means can be relied upon only for a limited period (up to a few hundred years), the possibility of human intrusion into the facility after such a period should be considered when assessing the safety of a near surface disposal facility.

4.30. The passive means that contribute to the isolation of the waste are mainly the durable physical barriers placed around the waste that make inadvertent intrusion into the waste more difficult without specific efforts (e.g. drilling into the facility). The isolation capability of a near surface disposal facility might be enhanced by locating the facility at some depth (a few tens of metres), as this can affect or limit the type of human activities that would be necessary to intrude into the facility and waste, as compared to a facility located at the surface.

4.31. The active means that contribute to the isolation of the waste are controls such as monitoring and surveillance of the facility and site in order to prevent human access to the waste and prevent disturbance of the facility by human activities. As long as active institutional controls are in place at the site, the potential for human intrusion into the facility can be assumed to be negligible. Therefore, a main element of the national policy and the safety strategy for near surface disposal should be to keep the facility under institutional control for as long as possible and reasonable. This intention should also be expressed in the licence of the disposal facility, and the periodic safety assessments of the closed facility during the period of institutional control should be used as a means to reconfirm this duration of institutional control. Active means can only be relied upon for a limited period, of a few hundred years at the longest, and the safety assessment for a near surface disposal facility and its licensing have to be based on the assumption that surveillance and control will cease after a certain period.

4.32. The general approach to the surveillance and control of a near surface disposal facility should broadly define how active institutional control of the facility under the nuclear regulatory system passes first to control of the site by a governmental organization (e.g. by restrictions on land use to ensure that activities that might disturb the facility are prevented) and subsequently to more passive institutional controls (e.g. the use of markers on the site, transfer of information on the facility to future generations through various means, archiving of information). Although passive means still might reduce the likelihood of human intrusion, a cautious approach should be followed and such passive means are not to be relied on in assessment of the safety of the facility and in setting activity limits for the waste that can be disposed of in the facility.

4.33. The siting of a near surface disposal facility should take into consideration the potential hazards to the facility posed by the disruptive effects of geomorphologic and meteorological processes such as erosion or seismic activity (see Appendix II). Location away from known areas of underground mineral, geothermal and groundwater resources will reduce the likelihood of inadvertent disturbance of the disposal facility.

4.34. In assessment of the safety of a near surface disposal facility, the treatment of human intrusion should be carried out on the basis of 'stylized' scenarios, which have been agreed with the regulatory body and meet the criteria set out in Box 1. This is because there is very limited scientific basis for defining human intrusion scenarios and the associated uncertainties (e.g. in timing, in the type of intrusion, in the number of potentially exposed people and in the likelihood of recognition of the radiation risk associated with the intrusion). In order to ensure safety after the period of active institutional control, when human intrusion can no longer be excluded, the amount of long lived radionuclides that can be disposed of in the near surface disposal facility should be limited. Through the assessment of the radiological consequences of stylized human intrusion scenarios, limits on the activity of long lived radionuclides can be set. The scope of the stylized human intrusion scenarios used in safety assessment is largely a matter to be agreed upon by the operator and the regulatory body.

MULTIPLE SAFETY FUNCTIONS

Requirement 7 of SSR-5 [4]: 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 shall be 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.”

4.35. The establishment of multiple safety functions, which should be fulfilled by various barriers and system features, provides for defence in depth. Defence in depth implies that safety is not unduly dependent: on a single element of the disposal system, such as the waste package; or on a control measure, such as verification of the inventory of waste packages; or on the fulfilment of a single safety function, such as containment of radionuclides or retardation of their migration: or on an administrative process such as procedures for controlling access to the site or for maintenance of the facility. Adequate defence in depth should be ensured by demonstrating that long term safety is provided by means of multiple safety functions.

4.36. In accordance with the application of a graded approach, the ability of a disposal system to provide containment and isolation of the waste is required to be commensurate with the hazard potential of the waste [3]. As a consequence, the type and number of barriers and features necessary to meet the requirements for containment and isolation will depend on the type of waste to be disposed of and on the hazard posed by the waste, which will change with time through radioactive decay. The required assessment of defence in depth should comprise an evaluation of the performance of the disposal system and its components and features in terms of their ability to perform the safety functions over time, both in situations that are expected to occur (such as the normal degradation of barriers) and in situations where disturbance of the system might occur.

4.37. In the safety case, all elements of the system design and all features of the disposal site that are important for demonstrating defence in depth of the planned disposal facility should be identified and assessed in a structured manner. Assessments should be performed to verify that a defect in one safety related characteristic, or a decrease of performance with time of one or more components, is compensated for by the performance of the safety functions or by a decrease of the hazard through radioactive decay. A systematic safety assessment of the various scenarios of evolution of the system and its components should be conducted to demonstrate that adequate defence in depth will be maintained. This assessment should also address how the increase in uncertainty with respect to the performance of components and the system for longer time frames is considered in the demonstration of safety and is taken into account in the design of the disposal facility.

4.38. The capability of the system as a whole to provide adequate containment and isolation is of prime importance, and the facility should be designed in a manner that is sufficiently flexible to take due account of the features of the site that can be considered less favourable. All relevant site features that could determine or influence the design of the facility should be systematically identified.

4.39. A safety function (e.g. the confinement of radionuclides to prevent or control their release) may be performed by means of a physical entity or a chemical property or process that contributes to containment of the radionuclides and/or isolation of the waste within the disposal system, such as impermeability or low permeability of a barrier to water, limited corrosion rate, and low solubility and high sorption capacity of radionuclides, which result in low leach rates.

4.40. A barrier means a physical entity, such as the waste, waste packaging, the backfill or liner and cap of the facility, the characteristics of which restrict (or, for a limited time, prevent) the migration of radionuclides or render direct access to the waste more difficult. A particular barrier may perform a number of safety functions, while a single safety function may be provided by a number of barriers. The use of a number of barriers and safety functions enhances both safety and confidence in safety and will ensure that the overall performance of the disposal system is not unduly dependent on a single barrier or safety function. Hence, even if a barrier or safety function does not perform fully as expected (e.g. owing to an unexpected process or an unlikely event), it should be demonstrated that the disposal facility is still safe.

4.41. The performance of a near surface disposal system is dependent on different barriers having different safety functions, the importance of which may vary over different time periods. The safety case should explain and justify the confidence attached to the safety functions provided by each barrier and should indicate the time periods over which they are expected to perform. The safety case should set out the scientific and technical arguments that support these claims and should also identify the complementary safety functions that will be effective if a barrier does not fully perform.

4.42. The disposal system should use a combination of natural and engineered characteristics to support efficient containment and isolation by maintaining integrity of the waste packages, by, for example, limiting the solubility of radionuclides and by minimizing the ingress of meteoric water (i.e. derived from precipitation). The importance of the contribution of the natural barriers and the engineered barriers to the containment and isolation of the waste will depend to a large extent on the type of near surface disposal facility (i.e. surface or subsurface) and on the characteristics of the site where the facility is to be located. In the long term, progressive degradation of the engineered barrier system cannot be ruled out, and consequently, radionuclides may be released to the geosphere or biosphere, depending on the type of near surface disposal facility. While radioactive decay is an important factor for the short lived radionuclides in limiting the magnitude of a potential release from a near surface disposal facility over time, other considerations are also important and should be considered. Factors limiting the ingress of water (which in turn may contribute to prolonging the integrity of waste packages) that should be considered include the use of durable barriers with low water permeability and design of the system so that it maintains low hydraulic gradients for the required period of time. The potential for a release of radionuclides to the biosphere should be further reduced by maintaining low flow rates as well as by means of the retardation and precipitation capability of the engineered barriers and the host environment. Materials used for the backfill or elsewhere in the engineered system should have properties that do not contribute to degrading unduly the safety functions of the other barriers.

PASSIVE SAFETY

> **Requirement 5 of SSR-5 [4]: 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."**

4.43. The role and importance of safety for the operational period of a near surface disposal facility is similar to that for any nuclear fuel cycle facility — that is, during the operational period, active control measures (such as control measures during waste handling and control of contamination and radiation levels in and around the facility) will be carried out. However, where possible, and necessary, passive safety measures should be applied, such as shielding of the waste during handling operations. For the post-closure period, the period of active management should be kept as short and as limited, in terms of effort and activities, as is practicable, consistent with the radionuclide content of the waste. After waste emplacement activities have ended, all steps should be undertaken to close the facility as soon as possible and to bring it to a passive state. This concludes the period of active management of the facility (namely, its construction, operation and closure). The steps taken towards closure of the facility may be determined to some extent by social and economic requirements and constraints, for example a decision may be taken to undertake a period of observation of the facility before it is completely closed, but this should not preclude the establishment of a strict plan for closure and the agreement on this plan by the parties involved (the operator, the regulatory body and other interested parties).

4.44. The safety of a disposal facility may depend on some future actions such as maintenance, surveillance and control, but this dependence should be minimized to the extent possible. In the case of a near surface disposal facility, such actions might be necessary for a period after closure of the facility (of a few decades up to a few hundred years). Measures taken during the period of active management might include, for example, repair to the cap of the disposal facility. Engineered structures that are necessary to provide safety in the post-closure period should have sufficient longevity as not to require maintenance during the post-closure period.

4.45. Closure of the disposal facility indicates the start of the period of institutional control. This period can be subdivided into active and passive phases, whose durations may be prescribed by regulation. Activities during the active phase of the period of institutional control will include preservation of knowledge, prevention of human intrusion, and monitoring and surveillance. If damage to, or deterioration of, the barriers is detected by means of monitoring or surveillance, remedial measures should be taken to restore any lost safety functionality to the parts of the disposal facility that remain accessible, at a minimum. However, the possible need for maintenance should not detract from the need to meet the requirement that safety is to be ensured primarily by passive means. In the passive phase of the period of institutional control, all active measures, including monitoring, surveillance and maintenance, cease (or, for the purposes of the safety assessment, are assumed to cease). Passive measures that continue may include the retention of records, the construction of durable warning markers and the control of land ownership. At the end of the period of active institutional control, it is assumed that, while further passive control is applied, inadvertent human intrusion becomes possible or even inevitable, although the site of the facility has been chosen to reduce the possibility to the extent possible.

4.46. In the case of near surface disposal, the period of active institutional control is required to be such that isolation of the waste is ensured for a period commensurate with the hazard posed by the waste. This period should also be used to increase confidence in the passive containment provided by the disposal system, by verifying the proper functioning of the components that are installed to contain the waste. Even if absolute confinement is not an attainable objective and some release of radionuclides to the biosphere might occur, such releases should at all times be sufficiently minimal as not to require any future corrective action. The safety case should provide all the elements and arguments necessary to support this claim.

SURVEILLANCE AND CONTROL OF PASSIVE SAFETY FEATURES

Requirement 10 of SSR-5 [4]: 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."

4.47. The long term safety of a near surface disposal facility depends on the quality of all the passive safety features that ensure long term containment and isolation, on the limitations placed on long lived radionuclides in the waste, and on the appropriate level of surveillance and control that has been applied to preserve and to protect the passive safety features. As the long term safety of a disposal facility is required not to be dependent on active institutional control, all passive safety features and the limitations on long lived activity in the disposed waste should be assessed and employed without assumption of surveillance and control beyond a period of a few hundred years at most.

4.48. For near surface disposal facilities, surveillance and control measures should be employed during active post-closure management of the disposal site, to provide assurance of the continued effectiveness of passive safety barriers. Surveillance and control should be achieved through monitoring and institutional control activities such as site protection and access restrictions; inspection of physical conditions coupled with retention of appropriate maintenance capabilities to address possible degradation of barriers; and monitoring as a method of confirming whether the continued performance of barriers is as specified. Since the safety of disposal facilities mainly relies on passive means, the intent of surveillance and monitoring is not to measure radiological parameters (e.g. radiological monitoring of the environment at the disposal site and in its surroundings), but to ensure the continuing fulfilment of safety functions [4].

4.49. Surveillance and control of the passive safety features should deal with both the features that contribute to the isolation capability of the system (such as the physical barriers separating the waste from the biosphere, the active control measures in place to restrict and to control access to the site, and the absence of events or processes of a geomorphological or meteorological nature that might disturb the facility) and the features that contribute to containment of the waste. The safety functions assigned to the different components of the system should be clearly described, and the possible degradation mechanisms of the system components should be identified and understood. The observations and measurements that will be performed to control possible or expected degradation of the system components and to monitor the evolution of component performance should be defined.

4.50. A programme should be designed for the surveillance and control of the continuing fulfilment of safety functions to monitor the ongoing adequacy of the passive safety features and should be conducted in a systematic, transparent and flexible manner. The programme should take into account the changing role of individual components over time to provide overall containment and isolation of the waste. The results and findings from this programme should be used to inform the safety case that will be presented to the regulatory body for the period after closure.

4.51. The use of passive measures, such as conservation of information in the form of markers and archives, including international archives, will reduce the risk of human intrusion over a longer period than is foreseen for active institutional controls, and should be considered. A more cautious approach with respect to likelihood of human intrusion is likely to be necessary for assessment of the consequences of human intrusion.

5. SAFETY CASE AND SAFETY ASSESSMENT

5.1. A safety case is a collection of arguments and evidence that demonstrates that the disposal facility is safe. Safety assessment is an essential part of safety case development and involves quantification of the radiation dose and/or risks that may arise from the disposal facility for comparison with dose and risk criteria set out in SSR-5 [4] (see Box 1). The safety case for a near surface disposal facility should address both operational safety and post-closure safety, although sometimes it is presented separately as an ‘operational safety case’ (i.e. a demonstration that the facility will be safe during operation) and a ‘post-closure safety case’ (i.e. a demonstration that the facility will be safe after it is closed). Comprehensive guidance on safety assessment is provided in IAEA Safety Standards Series No. SSG-23 [18].

PREPARATION OF THE SAFETY CASE

Requirement 12 of SSR-5 [4]: 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.”

5.2. A safety case is required to be prepared and updated to take into account new information acquired during the development of the disposal project (e.g. on the waste inventory, from site characterization, on engineering and facility design, and from monitoring) and at least for each major decision step in the lifetime of the facility (as shown, e.g., in Fig. 2). The safety case should be submitted to the regulatory body to obtain approval to proceed from one step to the next. The safety case has to be progressively enhanced as construction, operation and closure are carried out, so that all safety related issues are identified and the actions taken are recorded. At all times, up to date documentation of the safety case should be available that demonstrates that the facility is safe and can be expected to remain safe over the long term, and that guides the management and operation of the disposal facility.

5.3. Paragraphs 4.8 and 4.9 of SSR-5 [4] state that:

“4.8. The safety case has to include the output of the safety assessment …, 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 assessments and underlying assumptions.

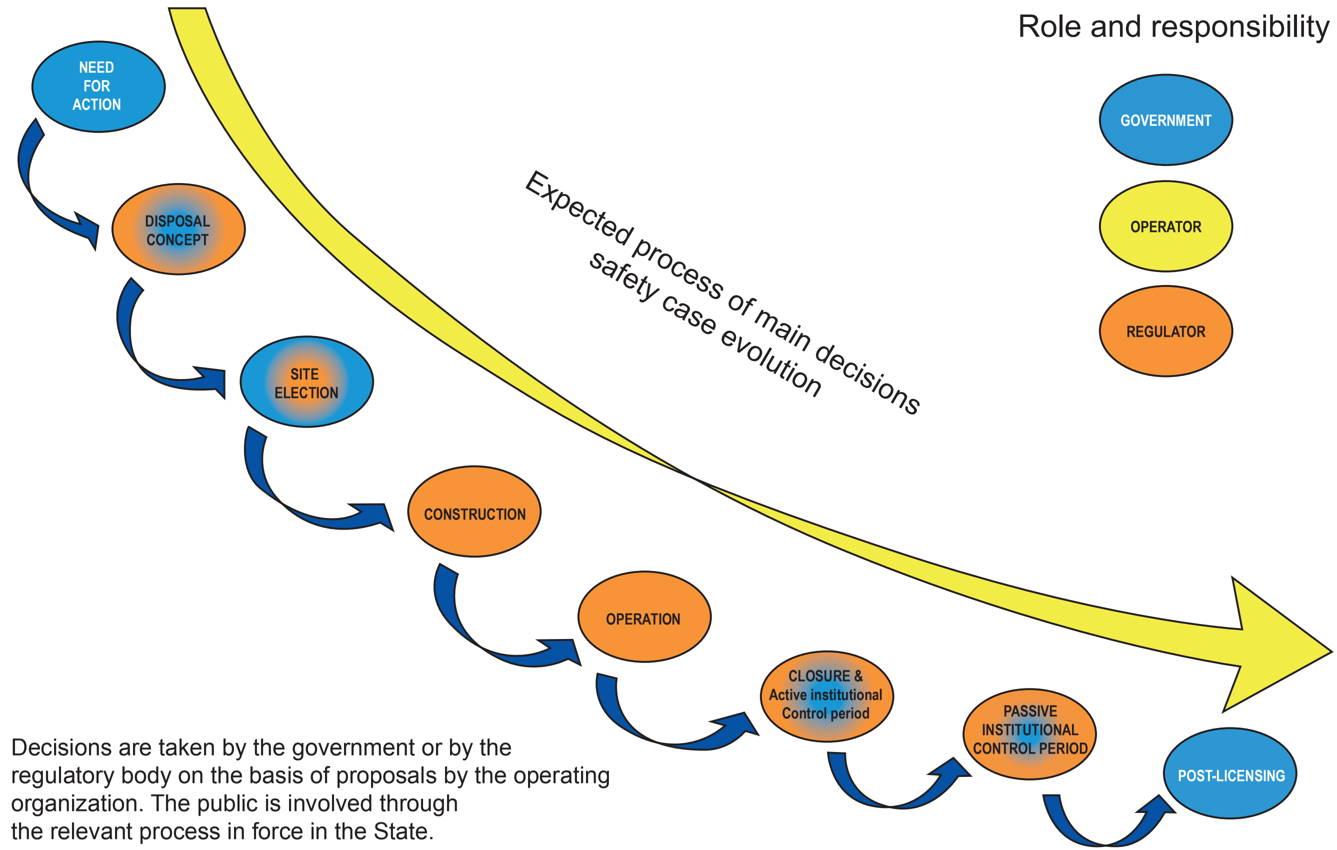

FIG. 2. Typical steps in the process of developing a near surface disposal facility.

> “4.9. The safety case may also include more general arguments relating to the disposal of radioactive waste and information to put the results of the safety assessment into perspective.”

Such arguments include comparisons of predicted radionuclide release with exposures to natural background concentrations and radiation levels. Remaining uncertainties and “[a]ny 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” (para. 4.9 of Ref. [4]). Further work to address unresolved issues is necessary if they have a significant impact on safety.

5.4. The primary audience for the safety case is typically the regulatory body, which will use it as a basis for regulatory decisions. However, the safety case and supporting safety assessment will also be of use and interest to others, and the needs of other audiences should be considered in its presentation. 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, operation or closure.

5.5. As stated in SSR-5 [4], the safety case and supporting safety assessment provide input to ongoing decision making by the operator, relating to subjects for research, site characterization, optimization of facility design, the allocation of resources and development of waste acceptance criteria. Safety assessment should involve the systematic assessment of radiation hazards and should provide an understanding of the behaviour of the disposal facility for a range of expected and less likely scenarios, including normal conditions and disruptive events, for the time frames over which the radioactive waste remains hazardous. Safety assessment should include structured uncertainty analyses. These uncertainty analyses should be designed to increase understanding of the behaviour and performance of the disposal facility and, therefore, to contribute to the basis for the safety arguments presented in the safety case. Sensitivity studies should be conducted to identify processes relevant to safety.

5.6. The safety case initially has to be prepared early in the development of a near surface disposal facility to guide all future activities [4]. At the early stages of development, the operator should plan the forthcoming process (e.g. of interacting with the authorities and interested parties) and the safety case should focus on the objectives to be achieved (e.g. the types of waste to be disposed of) and the safety strategy and disposal concept that may be used, as well as the identification of needs for further research and development. At such early stages, the operational safety case might be rather generic until there is a more developed facility design. The safety case should be progressively developed and elaborated as the programme proceeds to provide a basis for developing and managing the disposal facility, and to enable regulatory review and licensing at key steps in the development, operation and closure of the disposal facility (see Fig. 2). As time progresses and the safety case is revised and progressively enhanced, it should focus more on understanding and evaluation of the disposal system, and should be based on more detailed facility designs. Once the facility is operating, the safety case should be updated periodically to incorporate new information from site characterization, on the waste received and expected in the waste inventory, and on the as-built design of the facility. The safety case and supporting safety assessment should also reflect increasing knowledge (e.g. scientific and technical knowledge) on how the waste and the disposal facility and its surroundings may evolve.

5.7. 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, operation and closure of the disposal facility. The formality and level of technical detail of the safety case will generally reflect the level of hazard, the stage of development of the project, the decision in hand and specific national requirements. In some States, the regulatory body only becomes officially involved with the programme for development, operation and closure of a disposal facility at a later stage, for example on receipt of an application to construct the facility. In these cases, arrangements should be made that allow for earlier exchanges of information and views, prior to the official licensing steps.

5.8. The safety case and supporting safety assessment need to be sufficiently comprehensive and detailed to support the decision step being considered. Once fully developed, the safety case should include:

— A systematic description of the disposal system;
— Identification of the various features, events and processes that may affect how the facility will perform and evolve;
— Identification of scenarios for evolution of the site;
— Conceptual, numerical and computer models of relevant parts of the disposal system (e.g. the waste in the near field, the engineered barriers, the host rock and the surface environment of the facility).

The safety case should also document the data used and should provide results for relevant scenarios and exposure pathways in terms of the dose and/or the risk to relevant receptors (e.g. exposed and potentially exposed individuals and groups of people, and, in some cases, non-human species).

5.9. At early stages in the development of a near surface disposal facility, the safety case is rather generic and safety assessment calculations may necessarily be preliminary and simplified (making use of scope setting calculations) because the availability of site specific and waste specific data is limited. In such early stage assessments, data and models from the extensive literature on the subject should be used. If the disposal facility gains regulatory approval and proceeds to construction and operation, acquisition of additional data should continue throughout the step by step development process up until the withdrawal of active institutional control.

5.10. Depending on the purpose of the safety assessment, the results obtained should be compared with the relevant dose constraints and risk criteria, as established in national regulations. Different regulatory criteria may apply to different scenarios and exposures. For example, results from assessments of the potential consequences of human intrusion can be compared with the criteria provided in SSR-5 [4] and Box 1. As noted above, however, decision making on whether to proceed from one step to the next should not be based solely on such numerical comparisons and determinations of compliance with such quantitative criteria; wider judgement should be exercised and a range of factors should be considered, including qualitative criteria.

5.11. The level of detail required in the safety case for any particular decision step has to be decided in consultation with, and subject to the approval of, the regulatory body [4]. In any case, the operator should develop the safety case to a level of detail appropriate to demonstrate clearly the safety of the disposal facility. The regulatory body should require that the safety case provide sufficient information to allow a credible and critical review of the work performed. To facilitate this, the operator should aim to present the safety case and supporting safety assessment in a clear, comprehensive, traceable and transparent manner. In some cases, the regulatory body may decide to verify parts of the assessments by repeating certain calculations or may conduct its own assessments, for example to understand the behaviour of the disposal its, to address uncertainties or to assess alternative options.

SCOPE OF THE SAFETY CASE AND SAFETY ASSESSMENT

Requirement 13 of SSR-5 [4]: 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."

5.12. Figures 3 and 4 illustrate the main components of the safety case and safety assessment as described in IAEA Safety Standards Series No. SSG-23 [18]. The safety relevant aspects of the site and the design of the facility are indicated as the system description (Box C, Fig. 3). The managerial control measures relate to the double ended arrow on the right hand side of Fig. 3, which indicates the management system that is required to govern and apply to all aspects of the safety case and safety assessment. The regulatory controls are indicated as the limits, controls and conditions identified in Box G, Fig. 3.

5.13. The requirement to demonstrate the level of protection of people and of the environment relates to the integration of safety arguments (Box H, Fig. 3). Box H, together with the indication that the safety case is shared with the regulatory body and other interested parties (arrow on the left of Fig. 3), also indicates the requirement to provide assurance to the regulatory body and other interested parties.

5.14. The safety case and supporting safety assessment for operation and for the period after closure should address all of the regulatory requirements and criteria, and should include and make use of a variety of arguments and approaches to assessment. The safety case is also required to describe the managerial control measures that will be used to ensure compliance with the relevant regulatory controls.

5.15. For both operational safety and post-closure safety, there will be reliance on active and passive measures, but in the safety case for the period after closure, greater emphasis should be placed on the passive measures that achieve safety. Post-closure institutional control is nevertheless an important element in providing assurance of safety (see Section 7). Additionally, for the entire

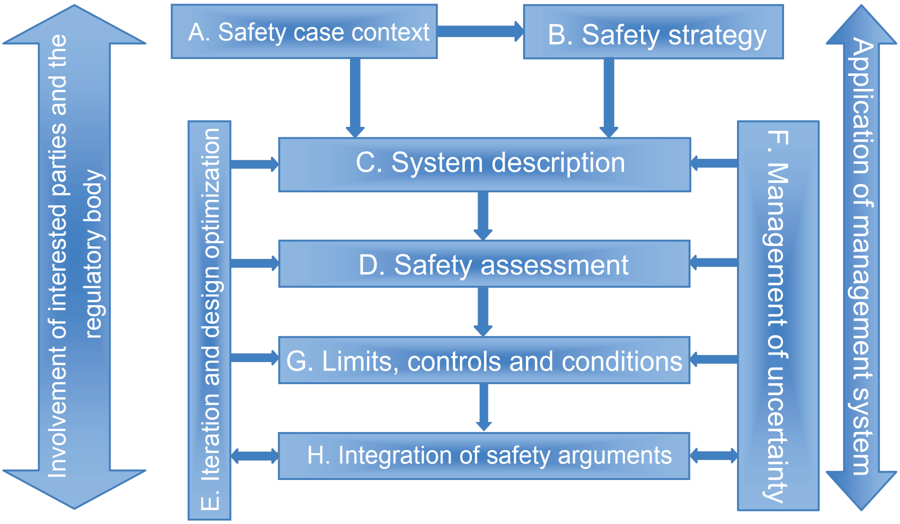

FIG. 3. The main components of the safety case, and application of the management system and the process for interaction with the regulatory body and interested parties.

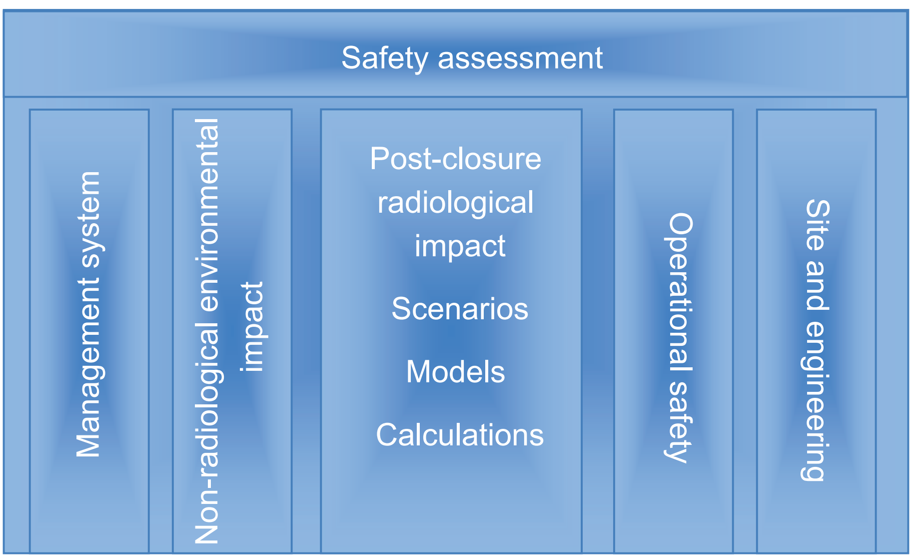

FIG. 4. Aspects included in the safety assessment.

operational period and, possibly, for part of the post-closure period (depending on the facility and on national regulations), the facility should be subject to surveillance and monitoring.

5.16. The operational safety case for a near surface disposal facility should consider all relevant aspects of operation that could lead to radiation exposure at or near the site. These include the receipt, characterization, handling, conditioning, packaging and emplacement of the waste, and any construction work carried out during facility operation and waste emplacement, as well as during any backfilling activities and during sealing and closure of the facility. The operational safety case should also consider any planned refurbishment work or replacement of equipment. It may also be necessary to show that waste can be retrieved safely while the facility remains operational (e.g. in the event that, after emplacement, non-compliant waste packages are discovered). Such retrieval would need to be performed safely and without significantly impairing the long term safety of the facility.

5.17. As stated in SSR-5 [4], consideration has to be given to both occupational exposure and public exposure resulting from conditions of normal operation and anticipated operational occurrences over the operating lifetime of the disposal facility. Similarly, consideration also has to be given to accidents with the potential for significant radiological consequences with regard to both the likelihood of occurrence and the magnitude of possible radiation doses. In some States, national regulations require that issues relating to chemical toxicity are considered and appropriate assessments are included in the safety case.

5.18. The post-closure safety case should specify a range of credible scenarios for the evolution of the disposal facility and its surroundings over the time period for which the waste represents a potentially significant hazard or as specified in national regulations, some of which prescribe the timescale for the assessment. Consideration should be given to expected scenarios (normal evolution scenarios) and to less likely scenarios. The scenarios should include processes that could affect the performance of the disposal system, such as degradation of the waste and the barriers and events (i.e. earthquakes, high rainfall, floods, landslides and erosion) that might affect the containment and isolation functions provided by the facility. The potential effects of human activities (i.e. inadvertent human intrusion events) and their consequences should also be considered. Such intrusive human activities are more likely to affect near surface disposal facilities than geological disposal facilities, and they may impose a significant restriction on the types and activities of waste that it is safe to dispose of in near surface disposal facilities. The consequences of human intrusion events should be assessed by considering a range of stylized scenarios based on the assumption that technology remains as it is at present. Such a ‘future states’ assumption is made because it is not possible to predict the details of future human behaviour and because it helps to avoid undue speculation as to the intrusive activities that may occur. Additional ‘what if’ scenarios should also be described to allow assessment of, for example, different waste inventories or alternative design options and disposal methods.

5.19. A formal approach to the development of scenarios should be adopted. Scenarios may be identified, constructed and described using several complementary methods. Such methods may begin with the development and consideration of lists of features, events and processes in which relevant events and processes can be combined to create scenarios (a ‘bottom-up’ approach), or may begin with a consideration of the safety functions of the key components of the disposal system (e.g. the facility cap) followed by the identification of the processes and events that might affect or impair the ability of the components of the disposal system to perform those safety functions (a ‘top-down’ approach).

5.20. The scenarios should be described in the safety case, and the performance of the disposal facility should be evaluated for a suitable set of scenarios in the supporting safety assessment. It may be possible to group similar scenarios to reduce the number of calculations necessary for the safety assessment. However, a sufficiently large range of scenarios should be assessed in the safety assessment in order to deal with the uncertainties associated with the future evolution of the disposal system. In practice, however, there may be no need to consider a large number of scenarios, provided that the scenarios considered ‘envelop’ the different situations that could potentially affect the disposal facility.

5.21. The post-closure safety case should include quantitative safety assessments that take into account uncertainties and qualitative arguments relating to the safety of the facility, given its waste inventory, design, siting and management. It should include multiple lines of reasoning based, for example, on evaluation of alternative conceptual models, alternative assumptions concerning the performance of barriers, alternative parameter values, as well as studies of appropriate natural analogues and simplified compliance calculations, among other things. A major part of the safety case should be to show that all the uncertainties relevant for safety and important to safety functions have been considered and will be managed appropriately.

5.22. Structured uncertainty analyses should be undertaken to gain an understanding of the performance of the disposal system and its components for a range of scenarios, conceptual models and parameter sets. Sensitivity analyses should also be conducted to identify the processes and parameters that have greatest influence on the performance of the disposal facility. Sensitivity analyses and uncertainty analyses should also be used to show that none of the parameters or processes would significantly impact safety when subjected to a relatively small change.

5.23. Calculations of potential doses and/or risks should be undertaken for a range of relevant exposure pathways (e.g. via gases and/or surface water and groundwater, depending on the waste and site under consideration) and for a range of exposed individuals or groups, in accordance with regulatory requirements. For very long time frames, when assumptions about human behaviour and biosphere characteristics are very uncertain, complementary arguments should be used to illustrate safety, for example by considering concentrations and fluxes of radionuclides of natural origin.

5.24. The results of safety assessment calculations should be presented in accordance with the relevant requirements of the regulatory body. The safety case should describe the relevant regulatory requirements and explain the approach that has been taken to comply with those requirements. In some States, it is necessary to combine the safety assessment results from different scenarios and to evaluate risk. It is acceptable to present and to consider the results of safety assessment calculations for scenarios involving human intrusion separately from the results of the safety assessment for other 'undisturbed' performance scenarios.

5.25. Comparison of safety assessment results with the dose or risk criteria specified in regulatory requirements may be required for several thousand years and may be extended to timescales beyond this, for example, to estimate peak dose. However, it is recognized that for very long timescales (i.e. beyond several tens of thousands of years) uncertainty concerning future conditions is such that more simplified calculations and comparisons may be sufficient.

5.26. The revisions of the safety case that are developed in parallel with the development, operation and closure of the disposal facility should include plans for waste management, facility development, facility closure and institutional control. For example, the closure plans should describe and demonstrate the feasibility of both the closure operations and the time schedule for them. The closure plans should be updated and refined as information is obtained during site characterization, design optimization, construction and operation of the disposal facility. An authorization to commence waste emplacement should include consideration of preliminary closure plans, although these plans may change as operations proceed.

5.27. The safety case and supporting safety assessment should become more detailed and comprehensive as development and operation of the near surface disposal facility proceed. The progressive development of the safety case and supporting safety assessment is illustrated in Table 1.

TABLE 1. FEATURES OF THE SAFETY CASE AND SUPPORTING SAFETY ASSESSMENT THROUGH THE LIFETIME OF A DISPOSAL FACILITY

Stage in the lifetime of the facility	Characteristics of the safety cases	Basis for safety assessment
Initial site investigation and preliminary facility design	Outline of the operational safety case Preliminary post-closure safety case based on the waste inventory One or more preliminary disposal concepts	Data from initial site investigations Preliminary design studies and closure plans Waste inventory, compendiums of data on behaviour of materials Data and observations from analogous systems, sites and processes
Site characterization	Interim operational and post-closure safety cases that are detailed enough to form the basis for the decision to proceed with 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 Closure plans
Construction	Final operational safety case and advanced post-closure safety case that are detailed enough to form the basis for the decision to define limits and conditions of operation and to begin operations	Site data gained during construction preparations Waste inventory, any trial waste emplacements, confirmed design Closure plans that will be tested during operations Detailed operational plans

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

Stage in the lifetime of the facility	Characteristics of the safety cases	Basis for safety assessment
Operation	Periodic updates to the safety case to provide the basis for waste acceptance and ongoing facility management (such updates should be made as required by national regulations or more regularly to facilitate facility management) Updates to the operational safety case as required, using experience and data from commissioning and operations and modifications to the facility, waste inventory or operating procedures	Data on the waste received, on the future waste inventory, on the as-built facility, from site characterization and monitoring, from developments in understanding of features, events and processes and scenarios addressed in safety assessments, and from refined plans for site development, closure and institutional control
Post-closure	Additional post-closure safety cases to provide ongoing assurance that system behaviour is as predicted	Updates of the post-closure safety assessment to reflect monitoring data and any new scientific evidence relevant to the safety case
Licence termination	Provision of assurance that the facility and site can be released from active institutional control to support licence termination	Update of the post-closure safety assessment to reflect the state of knowledge on all aspects of the safety case

DOCUMENTATION OF THE SAFETY CASE AND SAFETY ASSESSMENT

Requirement 14 of SSR-5 [4]: 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."

5.28. The needs of different interested parties for information should be considered, and this may necessitate the preparation of safety case documents at various levels of detail and in different styles.

5.29. Most modern safety cases include several levels of documentation (forming a hierarchy of documents), with a high level document providing an overview of the safety case written using relatively simple (as far as possible non-technical) language intended to be understandable by non-specialists within government and by members of the public. Such high level overview documents should convey the main messages from the safety case (e.g. that the disposal facility is and will be safely managed and will remain safe, causing only acceptably low doses and risks in the future).

5.30. The high level overview report should then be supported by layers of more detailed reports as necessary and appropriate to the facility and the decision making step in question. The layer of reports directly supporting the high level overview report should document the main components of the safety case, as set out in Figs 3 and 4[3], as well as independent peer reviews of the safety case and safety assessment work performed.

5.31. More detailed supporting reports should be provided that document various studies and work, such as engineering design studies, hydrological and geochemical modelling work, reports on software development and model verification studies, studies on degradation of waste and engineered barriers, studies on options for remedial action and expert studies. These documents should in turn be supported by records of laboratory and field studies documenting measurements that ultimately justify the parameter values used in the safety assessment, together with the scientific literature cited by the safety case.

5.32. The range and extent of safety case documentation required should depend on the level of hazard represented by the waste, the stage of development of the facility and the disposal, and local and national regulations and circumstances.

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[3] Examples include: the management system, including quality assurance arrangements; the system description, including the waste inventory, the facility design and engineering, the host rock and surrounding geology, and the surface environment; the safety assessment, including the scenarios, models, assumptions, data and parameters, exposure pathways and exposed and potentially exposed groups considered, and the calculations performed and their results; the relationship between the assessment results and the relevant regulatory limits, controls and conditions; and integrated conclusions relating to the overall safety and management of the disposal facility.

However, irrespective of how extensive the documentation of the safety case needs to be, it should present arguments, reasoning and supporting evidence in a convincing, traceable and transparent way. The documentation should facilitate an understanding of the models, data and assumptions used and of the supporting qualitative arguments. The results of the safety assessment should be presented in a manner that provides a demonstration of the performance of individual components of the system and of the overall system. Demonstration of the expected behaviour of key facility components increases confidence in the performance of the system as a whole. It also helps to identify any weaknesses in the design of components so as to assist iterative improvements.

5.33. Important considerations in documenting the safety case are justification of decisions, traceability of reasoning and clarity of information. Justification and traceability both require a well documented record of the decisions and assumptions made in the development and operation of a disposal facility, and of the models and data used in arriving at a particular set of results for the safety assessments. Ensuring justification, traceability and clarity will provide transparency, which is particularly important when documents are to be subject to review by experts or non-experts who are not involved directly 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 highly expert readers.

ADEQUATE UNDERSTANDING AND CONFIDENCE IN POST-CLOSURE SAFETY

> **Requirement 6 of SSR-5 [4]: 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."**

5.34. As described above, the operator should undertake an ongoing programme of assessment of safety of the disposal facility. The aim of the safety assessment should not be solely to evaluate the performance and radiological impact of the disposal system, but should also be to develop an understanding of how the disposal system (the facility and its surrounding environment) may behave and evolve. The process of the safety assessment as described above, involving the identification of features, events and processes and the development and modelling of appropriate scenarios, should be used to obtain an understanding of system behaviour. The performance of structured uncertainty analyses should identify the range of possible behaviours. Consideration should be given, as part of the safety case and safety assessment development, to conducting more detailed modelling studies for particular parts of the disposal system and for particular events and processes, in order to understand details, for example, of the surface environment, degradation of waste and barriers, and migration of radionuclides. Information from natural analogues may be used to increase understanding regarding the processes that could be important in the disposal system and to provide information relevant to longer timescales than those that can be accessed by experimentation. Sensitivity studies should be conducted to identify factors that are significant to safety.

5.35. The operator should define a logical and reasoned strategy for the development of an understanding of the disposal system and for the development of the safety assessment during the programme for development, operation and closure of the facility. What constitutes an adequate understanding of the components of the disposal system will depend on the role that the components are intended to play in fulfilling their safety functions.

5.36. An understanding of the disposal system and its dependence on features, events and processes that are internal and external to the facility will evolve as more data are accumulated and scientific knowledge is developed. Paragraph 3.30 of SSR-5 [4] states that:

> "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. Before the start of construction, during emplacement of waste and at closure of the facility, the level of understanding has to be sufficient to support the safety case for fulfilling the regulatory requirements applicable for the particular stage of the project."

5.37. The operator should openly acknowledge the uncertainties that exist at any stage in the development, operation and closure of the disposal system, and should develop and apply an approach to the management of uncertainties that ensures that the facility is developed and managed in a manner that will ensure operational and post-closure safety. The existence of uncertainties is in itself not a reason for not proceeding to the next step in facility development and management.

5.38. As the disposal programme proceeds, the safety case should be updated to reflect new data and lessons learned from the operating experience. Confidence in safety should be demonstrated, for example, by showing that the safety assessment is as comprehensive as possible and is based on good science and engineering practice and data, by showing that the disposal system is robust (i.e. its performance is not unduly sensitive to detrimental events and processes), by providing evidence regarding the appropriateness and effectiveness of controls such as waste acceptance criteria, and by providing information to demonstrate the feasibility and effectiveness of the engineered features of the facility.

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

STEP BY STEP DEVELOPMENT AND EVALUATION

> **Requirement 11 of SSR-5 [4]: 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, operation and closure of a near surface disposal facility can extend over many years or decades. The requirement to assess safety at key decision points in the development process, prior to commitment of additional resources, makes it necessary to divide the programme into a series of steps. While there may be many steps in the development, operation and closure of a disposal facility, the most important ones occur at regulatory or governmental decision points for the approval of construction of a near surface disposal facility (construction), the approval to receive and emplace waste (operations), the approval to close the facility (closure) and the decision to terminate active institutional control. At each of these steps, the safety case is required to be updated [4]. Reviews and updates should also be carried out at other stages in the programme for other reasons (e.g. to inform the operator's strategic choices in programme development). Such an approach provides multiple opportunities to assess the quality of the technical programme and the safety case supporting a decision making process, and thus enhances confidence. Confidence in the safety and feasibility of a near surface 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. For each step in the process, the operator should identify the decision that needs to be made and the information that is necessary to make the decision. The operator should also identify the appropriate interested parties and determine when and how to include them in the decision making process. Early involvement of the regulatory body and other relevant interested parties improves the quality of the decision making and provides clarity for the direction of the project.

6.3. The step by step approach also allows opportunities for independent technical reviews, regulatory reviews, and political and public involvement in the process. The nature of the reviews and the degree of involvement will depend on national practices and on the facility in question, but engagement of the regulatory body should take place at an early stage in the development process. Technical reviews by or on behalf of the operator and the regulatory body should focus on siting and design options, the adequacy of the scientific basis and the analyses conducted, and whether safety standards and requirements have been met. Alternative waste management options, the siting process and other aspects of public acceptability, for example, should be considered in wider reviews. Periodic reviews of safety should also be undertaken during all stages in the lifetime of a disposal facility. These reviews should verify the continuing adequacy of the safety case in the light of improvements in the understanding of the disposal system, developments in technology and regulatory guidance, and operational experience at the facility and at comparable facilities elsewhere.

6.4. Key supporting programmes (e.g. site characterization, design activities, environmental monitoring, safety assessment and record keeping) should be ongoing over a number of steps in the development, operation and closure of the disposal facility. As information matures and evolves with the safety case, design and site characterization, information from these key programmes should be shared across other aspects of the disposal project (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.

6.5. Additional steps should be introduced to facilitate the project management of facility design, commissioning, waste acceptance and operation, and post-closure elements, and should serve as supplementary points for review of the safety case or supporting safety assessments.

SITE CHARACTERIZATION

> **Requirement 15 of SSR-5 [4]: 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."**

6.6. In the siting process for a radioactive waste disposal facility, four stages should be recognized (see Fig. 5):

(1) The conceptual and planning stage;
(2) The area survey stage;
(3) The site investigation stage;
(4) The stage of detailed site characterization leading to site confirmation for construction of the disposal facility.

See Appendix I for further information concerning the first three stages, which should be read in conjunction with this section. Site investigations should progress from generalized studies at the early area survey stage to a programme of progressively more detailed characterization as candidate sites are identified, specific objectives are addressed and uncertain features are targeted. Detailed site characterization should be undertaken for site confirmation for construction of

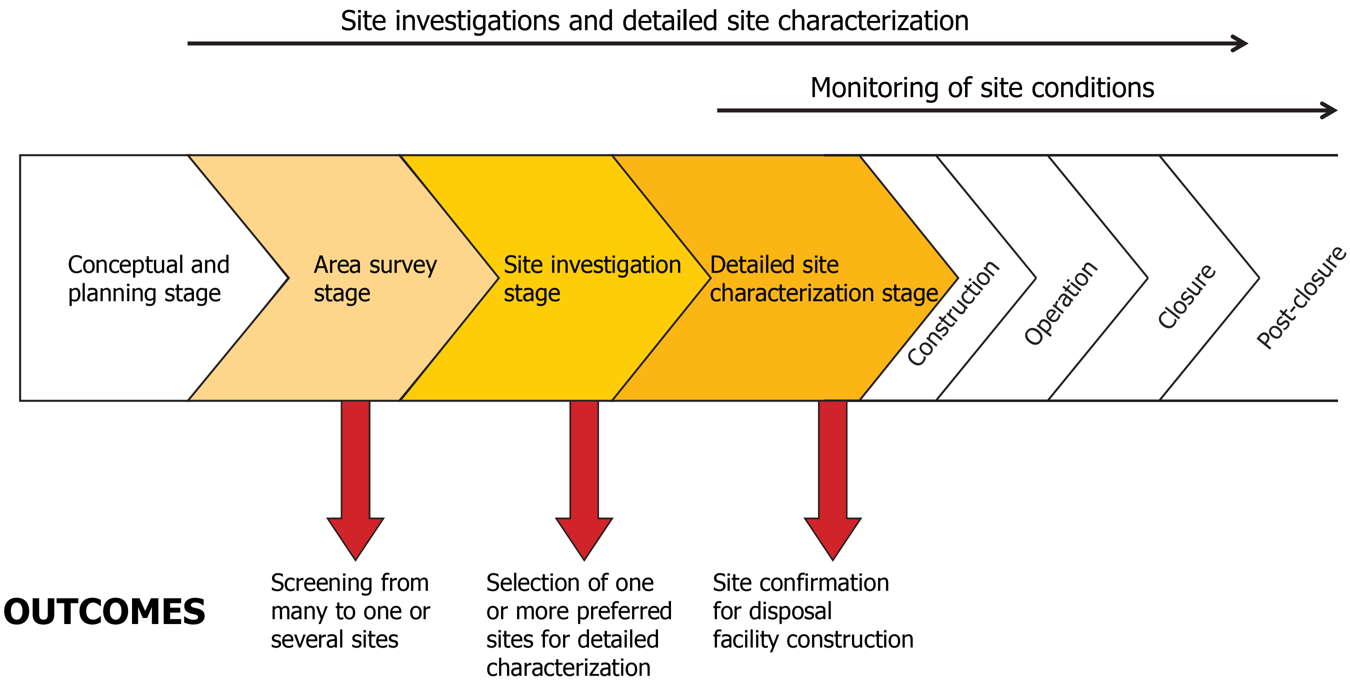

FIG. 5. Stages in the siting process.

the disposal facility and may continue through the phases of construction and operation.

6.7. The conceptual and planning stage of the siting process should take into consideration the fundamental limiting parameters for the disposal facility. The operator should address issues such as the types of waste that will be disposed of, the projected waste volumes, basic requirements for the site, and specific criteria that would disqualify a site from consideration. This information will help the operator develop a generic concept of the facility. Work completed at this step should serve as the foundation for the next step: the area survey stage.

6.8. At the area survey stage, the desirable features and possible limitations identified at the conceptual stage should be used to focus on one or more potential sites in a region of interest. The operator should narrow the region of interest by focusing on areas with appropriate features and characteristics that would accommodate the generic conceptual design for the facility. This step should lead to the elimination of unsuitable sites and the identification of potentially acceptable site locations. Next, the potential site(s) should be characterized to an appropriate level of detail to provide the necessary information to ensure that the disposal facility can meet the safety requirements for disposal of the intended type of waste.

6.9. An important part of characterization of the site lies in understanding how the site will behave over the long term. Site characterization should provide information on the effects the natural environment will have on the containment and isolation of radionuclides. Although the effects of many processes can be mitigated during operation, it is passive controls that will be relied upon in the post-closure period. Therefore, the potential effects of erosion, flooding, seismicity and other disruptive processes should be well understood.

6.10. 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 their spatial and temporal extent and variability. Site characterization should contribute to a comprehensive description of the site that is sufficient to support development of the safety case and its supporting assessments. For near surface disposal facilities, this description should include information concerning the surrounding populations and land use. The context in which site characterization is carried out and a clear understanding of objectives should be set down to define properly the extent and focus of the site characterization activities that are to be undertaken. Site characterization activities should comprise data acquisition (i.e. measurements of various types, sampling and monitoring) and the interpretation of the data to generate information and understanding.

6.11. Ultimately, an understanding of the disposal system on the basis of information gained from site characterization should provide a credible scientific description of the natural systems at the site and a demonstration of understanding of safety significant features, events and processes (relating to geology, hydrology, geochemistry, meteorology, etc.). This understanding is necessary to support confidence in the technical basis for safety assessments.

6.12. 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 containment and isolation of the waste within the disposal facility. Quantitative data should be obtained at a level of detail appropriate for their end use (in terms of the required degree of accuracy and precision of the data and their representative nature with regard to spatial variability). Appendix II provides guidance on the types of information that are expected from a programme for site investigation and characterization. However, the listing is not exhaustive and site specific circumstances will dictate what information is required and in what detail, in particular with respect to the site's containment and isolation capabilities.

6.13. Detailed investigations leading up to, and including, the site confirmation stage should be undertaken at the preferred site(s) to characterize the host environment in sufficient detail:

(a) To support or confirm the role of the site and its environment in the adopted safety strategy;
(b) To support or confirm the selection of the preferred site(s);
(c) To provide additional site specific information required for a detailed design of the facility;
(d) To provide additional site specific information for the safety assessment.

6.14. The objectives of each stage in a site characterization programme, in terms of what information is required and why, and how it will be provided, should be established at an early stage in the development process. A description should be included of how information collected in the programme will be used to inform future assessments and related decisions. At the same time, it should be recognized that the detailed aims and methods of data acquisition and interpretation may need to be amended in response to developments in understanding or changes in priorities identified through safety assessment modelling.

6.15. In addition to providing a description of the present day characteristics of a site, the site characterization programme should collate and interpret information from the past evolution of the site. Such information should be used to support the identification 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 components. However, scenarios for future evolution should also take account of expected differences between the future and the past, such as potential effects of human activities at present and in the foreseeable future. The timescale for consideration of past site evolution should be at least comparable to the future timescale of interest in the safety assessment.

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 original conditions of the site. This baseline record of the natural system would provide a reference 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.

6.17. The site characterization programme should be undertaken within an appropriate management system (see paras 7.20–7.33) in order to ensure the quality and long term usability of data, as well as their availability. The management system should take into account the fact 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.

6.18. A stage will be reached in the site investigations when the value of any additional data collected will not have a significant impact on safety and in particular on the safety assessments. A decision that site characterization is complete should relate to assurances that the objectives of the site characterization programme have been fulfilled, in terms of values of the parameters and the quantity and quality of data necessary to support safety assessment and facility design, or for providing additional confidence in the understanding of systems and processes. For example, sensitivity studies may indicate that key data uncertainties are manageable, that calculated dose and risks comply with relevant criteria, and that any further collection of data would not increase confidence in the safety case. Until such time, characterization activities should continue, including into the construction and operation stages, in order to provide further data and to reduce further any residual uncertainties in the safety case as necessary.

DESIGN

Requirement 16 of SSR-5 [4]: 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."

6.19. Near surface disposal facilities are expected to perform over much longer time periods than the time frames usually considered in engineering applications. Investigation of the ways in which analogous materials have behaved in nature, or how ancient artefacts and anthropogenic constructions have behaved over time, should be undertaken to contribute to the confidence in the assessment of long term performance of the facility. A technical justification to support the durability of materials over time should also be developed by means of testing that are appropriate for the material in the given application. Demonstration of the feasibility of the fabrication of waste packages and of the construction of engineered components and their features should be carried out in order to assess whether and to generate confidence that an adequate level of performance can be achieved. The feasibility of construction should also be demonstrated for novel, one-of-a-kind disposal facilities. Information on similar designs and the use of similar materials in other disposal projects should be provided to improve confidence in the safety case and supporting safety assessment.

6.20. The design of the facility is required to ensure safety during both the operational and post-closure periods. It should also consider requirements for monitoring, security, concurrent activities (excavation and waste emplacement), and, if requested, retrievability and reversibility. The closure arrangements for the facility and the measures for institutional control should be taken into consideration at an early stage of the facility design. The facility design 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 and becomes progressively more detailed over the phases of facility development, operation and closure, safety assessments should be updated to evaluate the effects of the design changes on compliance with regulatory criteria.

6.21. The design of the facility should take into account the waste that will be disposed of at the site. The types and quantity of waste for which the facility is developed should be identified at an early stage of the development process. Prior to the conceptual and planning stage, the national waste management policy and strategy should consider the type of waste (e.g. LLW and VLLW from the operation and/or decommissioning of nuclear power plants; radioactive waste generated in medicine, industry, agriculture, research and education), the quantities and characteristics of the waste, and the radioactive inventory of the waste proposed for disposal at the facility. In the course of design of the facility, information about the waste should be used to support the identification of a concept and the actual design.

6.22. The initial design of the facility should be used to validate the suitability of a candidate site for the disposal facility. The design of the facility, the physical characteristics of the site, and the characteristics of the waste or inventory are mutually interdependent and should be managed in such a way that a set of independent and complementary safety functions can be proposed in order to achieve the desired performance of the disposal system. The initial design of the facility should be used to demonstrate that the site, in combination with the design of the facility and the characteristics of the waste, will provide adequate containment and isolation of radionuclides for the necessary period of time. The initial design should be made subject to formal approval within the licensing process.

6.23. The design of the facility and the quality of its construction should also be compatible with the foreseen duration of institutional control and with the post-closure needs. The need to maintain and to repair accessible elements of the disposal facility (such as the final cap) during the period of institutional control should be minimized in accordance with the principles of relying, as far as practicable, on passive controls and of not imposing undue burdens on future generations.

6.24. The design of the facility should accommodate the proposed operational activities and radiation protection practices (i.e. access control and zoning), which should be determined based on the estimated radiation exposure conditions and the potential for contamination. As noted in Section 4, design of the facility for operational safety may include both active and passive systems and should rely on radiation protection related and industrial best practices and techniques.

6.25. Means for radiation monitoring during operation should be designed with consideration given to anticipated operational occurrences, incidents and postulated accidents. A monitoring programme, including monitoring devices, should be established on the basis of likely receptor locations and should reflect realistic pathways. Exposure pathways may be different for workers and for members of the public, and differences in exposure pathways should be reflected in the types and locations of radiation monitoring stations. Appropriate monitoring stations should be established for measuring external radiation levels, airborne contamination and water contamination (groundwater and surface water, as appropriate). The programme should include measurement points within controlled and non-controlled areas on the site and off the site to account for public exposure pathways.

6.26. The process for facility design should be made subject to an appropriate management system that also provides for configuration change control (see paras 7.20–7.33). Design attributes of the engineered barriers for operational safety and post-closure safety should be characterized to ensure that the management system applies a degree of control commensurate with the significance to the safety of such barriers.

6.27. Although disposal is defined as the emplacement of waste in an appropriate facility without the intention of retrieval, in some national systems it may nevertheless be required that retrievability (design for safe removal of waste) of the waste be allowed at any period before closure. If the ability to retrieve waste is a design requirement, it should be considered in the conceptual design and in the subsequent 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. Although retrievability can be envisaged for all phases of development, operation and closure of the facility, post-closure retrievability should be considered an exceptional condition.

6.28. The design of the facility for safety in the period after closure should meet the precepts of robustness, simplicity, technical feasibility and passive operation of barriers. The disposal facility should be designed and operated to achieve long term stability of the disposal site and to eliminate, to the extent practicable, the need for ongoing active maintenance of the disposal site following closure. The design of the facility should take the intrinsic features of the host environment into account (including the potential for erosion, flooding, seismicity and other disruptive phenomena). However, the relative importance of these processes will vary from site to site, and the design of the facility should focus on those processes that pose the most substantial challenge to meeting the performance objectives and regulatory requirements.

WASTE ACCEPTANCE

Requirement 20 of SSR-5 [4]: 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."

6.29. The types of waste that will be disposed of in any radioactive waste disposal facility will be the prime determinant of the potential hazard that the facility and its operation could present to workers and the public. Consequently, the characteristics of the waste intended for disposal, both its activity levels and other characteristics, should be considered in the design of the facility and the safety assessment. When waste is emplaced in a disposal facility, the operator should ensure through a waste acceptance process that the waste packages and, if applicable, unpackaged waste comply with the waste acceptance criteria for the facility. This waste acceptance process should ensure that:

— The disposal facility will be safely operated (e.g. through the safe handling of waste packages in both normal operation conditions and in anticipated operational occurrences).
— The waste form and waste packaging will fulfil their attributed safety functions for the operational phase and, if applicable, for the post-closure phase.
— The waste emplaced in the facility complies with all limitations on radionuclide concentrations and/or total activity.
— The characteristics of the waste will not negatively affect other components of the system to the extent that this would lead to failure or to a significant decrease of performance of safety functions.

6.30. Waste intended for near surface disposal should be characterized to provide sufficient information to ensure compliance with waste acceptance criteria. Arrangements should be put into place to verify that the waste and waste packages received for disposal comply with these criteria, and if not, to ensure that corrective measures will be taken by the responsible party, either the waste generator or the operator of the disposal facility. Waste characterization activities should take place early in the process of waste management (i.e. at the stage of waste generation and waste processing). The quality controls applied to waste packages should be determined on the basis of records of the waste treatment, preconditioning testing (e.g. of containers) and control of the conditioning process. Post-conditioning testing and the need for corrective measures should be limited to the extent practicable.

6.31. The waste acceptance process established by the operator should take into account the steps of waste generation and waste processing. Depending on national responsibilities, the waste generator, the waste management organization or the operator of the disposal facility should establish and/or apply waste acceptance criteria and technical specifications and procedures for controlling waste generation, waste processing and waste characterization. This should ensure that there will be mechanisms (e.g. procedures and controls) in place during the process of waste generation and management that will ensure that the waste acceptance criteria for disposal can and will be met. As part of the waste acceptance process, the operator should carry out verifications and controls when waste is received for disposal. The major elements of the waste acceptance process should be presented to the regulatory body for approval, for example as part of the safety case for the application of a licence.

6.32. In the development of the waste acceptance criteria, emphasis should be given to the fact that near surface disposal is intended for short lived radioactive waste containing only limited amounts of long lived radionuclides and that, generally, longer lived waste needs greater levels of containment and isolation that cannot be provided by near surface disposal. The national policy for radioactive waste management should ensure that these limitations on long lived radionuclides are respected and that waste with higher concentrations of long lived radionuclides is disposed of in facilities designed to accept such waste.

6.33. Waste acceptance criteria should be developed by the operator of the disposal facility as part of a process of iterative dialogue between the parties involved, including the waste generator, any other waste management organizations and the regulatory body. They should be developed as part of the safety case, with account taken of the waste generating processes, the waste processing options, the resulting anticipated inventory for disposal, and both operational safety (including transport safety) and long term safety of the disposal facility. The approach adopted for the development of the waste acceptance criteria in respect of long term safety should take into account both scenarios of radionuclide releases from the disposal facility and scenarios for human intrusion, and should make use of the dose and risk constraints for normal evolution and for natural disturbing processes and the possibility of human intrusion.

6.34. The waste acceptance criteria should include the waste characteristics important for safety in the operational and post-closure period, and should specify the following:

— Allowable levels of activity in each package and allowable levels of long lived radionuclides in each package;
— Allowable surface dose rate and surface contamination;
— The permissible range of chemical and physical properties of the waste and the waste form;
— Substances or properties that are not permissible in waste for disposal;
— The permissible dimensions, mass and other manufacturing specifications of each waste package;
— Limitations on allowable uncertainties in respect of waste characterization;
— Requirements for accompanying documentation.

As stated in para. 2.26 of IAEA Safety Standards Series No. GSG-1, Classification of Radioactive Waste [8], restrictions on levels of activity concentration for long lived radionuclides in individual waste packages may be complemented by restrictions on average levels of activity concentration or by operational techniques such as emplacement of waste packages with higher levels of activity concentration at selected locations within the near surface disposal facility.

6.35. The properties of the waste actually disposed of influence the arrangements that will need to be put in place at the end of facility operation, such as the arrangements for closure, the planned or foreseen time frame for licence termination and the post-closure activities, including both active and passive institutional controls. Various factors should be considered when closing the facility and putting in place a control programme for the closed facility, and determining the minimum time period until termination of the licence and for subsequent institutional controls. Example factors include the presence of considerable amounts of mobile radionuclides that could reach the biosphere in the time frame of the control period, the possibility of the generation of non-radioactive gases and the total inventory of long lived radionuclides.

6.36. Optimization of a near surface disposal system from the perspective of the radioactive waste inventory should mainly be dealt with by means of a cautious approach adopted to limit the activity, especially the activity of long lived radionuclides, that can be disposed of in the facility and through an adequate waste acceptance process. If further steps of optimization are considered, a broad view should be taken in respect of the different steps of radioactive waste management (e.g. additional separation of waste at the point of waste generation, waste processing and the feasibility of lowering the amounts of long lived radionuclides present in specific waste streams to be disposed of in the near surface disposal facility). In taking such a broad view, the gain in safety for the near surface disposal facility should be put in perspective with any increase in occupational exposures in waste management facilities and with economic factors.

6.37. In accordance with a graded approach and the assumptions made in the safety case, modelling and/or testing of the behaviour of waste forms should be undertaken to ensure the physical and chemical stability of the different waste packages and unpackaged waste under the conditions expected in the disposal facility, and to ensure their adequate performance in the case of accidents, incidents or abnormal conditions.

6.38. Records of the receipt and disposal of waste should be structured to accommodate the information associated with waste acceptance.

CONSTRUCTION

Requirement 17 of SSR-5 [4]: 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."

6.39. Construction of the facility should proceed in accordance with the approved facility design and any approved design modification that may be necessary after commencing construction. Construction of the systems and components that are important to the safety of the facility should not commence until the construction of the facility is approved in accordance with the requirements of the regulatory body.

6.40. Prior to construction, appropriate documentation should be in place and maintained by means of an efficient document management system. Detailed design and construction drawings, technical specifications and fabrication techniques, among other things, should all be developed and maintained. Applicable codes and standards for all buildings (structures), systems and components should be identified.

6.41. Manufacturing plans should be available and all material specifications should be known before starting construction or manufacturing. Such plans should identify material criteria, specifications and quality assurance standards. An adequate management system with appropriate quality assurance and quality control programmes is essential to ensure that the safety related systems, structures and components are designed, manufactured and constructed in a manner that ensures that they will perform their safety function as required. Checks and verification steps should be taken during pre-construction and active construction stages. This process should ensure that the facility complies with the approved design presented in the safety case or with 'as-built' modifications that have been evaluated and approved by the regulatory body.

6.42. Documents submitted to the regulatory body should be written in a detailed manner. The regulatory body should provide guidance to assist applicants in the preparation of licence applications; in some States, such guidance is provided in the form of a standard review plan. Following these plans and guides will increase the likelihood that applications and supporting documentation submitted to the regulatory body will meet expectations and reduce the possibility that they will include structural weaknesses or deficiencies that could result in delays in review, approval and construction of the project.

6.43. The initial construction phase of the facility includes a variety of activities, such as site preparation, construction of buildings, construction and installation of equipment and utilities, and construction of associated support systems. Disturbances to the host environment, such as the development of unnecessarily extensive excavation or excessive disturbed zones, and the introduction of chemically adverse substances into the local environment, should be avoided or limited during the construction of the disposal facility. Best practices for construction techniques should be identified and incorporated into construction procedures. All construction activities should be performed in such a way that the intrinsic containment and isolation features of the host environment are preserved to the greatest extent practicable.

6.44. Emphasis should be given to control of the quality of safety related activities (namely, those activities that have to be identified in the safety case and approved by the regulatory body) performed during construction in order to ensure that the realization of the facility complies with the design as set out in the safety case or that ‘as-built’ modifications have been evaluated and shown to have no effect on the safety case.

6.45. At the end of the initial construction phase, the systems and components should be subjected to a series of commissioning tests to determine whether they function in accordance with the approved design and have met the required performance criteria. A commissioning period should be used to perform these tests and to evaluate the adequacy of the design and the operating procedures.

6.46. Construction activities may continue during the operation of the facility as waste disposal cells and trenches are opened and closed. Operational activities, which include ongoing construction and waste emplacement, should be performed in a manner that ensures occupational health and safety. The management and performance of all activities should reflect a combination of best practices in radiation protection, industrial safety and civil engineering. The safety of facility construction activities should rely on up to date safety practices analogous to those at existing nuclear or industrial facilities. Best practices in radiation protection should be adopted and followed for operational activities taking place during the construction of the facility to protect both workers and the public.

OPERATION

Requirement 18 of SSR-5 [4]: 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), and prior to the receipt of the first waste at the facility, the operator should satisfy the applicable regulatory requirements to demonstrate the adequacy of the facility structures, systems and components. In addition, the operator should also verify that the required services, functions and procedures are in place. This demonstration should be performed for normal and abnormal events and for emergency conditions. A commissioning programme should be used to evaluate the operability of safety related equipment and the adequacy of operating procedures, including procedures to safely handle, emplace and, if necessary, retrieve waste as part of normal operations.

6.48. The operator should revise and update the safety assessment and the safety case to demonstrate that hazards and risks to workers and the public under normal conditions of operation and under abnormal conditions have been reduced to levels that are as low as reasonably achievable. Active control of safety should be maintained for as long as access to the facility remains necessary. This may include an extended period after the emplacement of waste has finished and before the final closure of the facility. Hazards and risks associated with operations (e.g. fire and floods) should be identified in the safety case. Policies, practices and procedures should be put in place to manage the hazards and risks.

6.49. Policies and procedures should be developed for all activities necessary for the safe operation of the facility. Procedures should be formally documented and maintained as part of the document management system for the facility. Explicit instructions, formal training and certification of workers should be provided to ensure that workers can adequately carry out their work.

6.50. Operations should be conducted in accordance with approved procedures providing for occupational radiation protection [3, 21]. The operator is responsible for ensuring that such procedures and instructions are followed by workers at the facility.

6.51. The operator should develop training programmes that ensure that activities relating to the safe operation of the disposal facility can be accomplished properly and safely. Training programmes should be established to ensure that personnel at all levels have the required competences. The training programmes should provide knowledge and practical experience for activities and should facilitate the development of a safety culture. The training programmes and associated procedures should be regularly updated to incorporate experience gained from the analysis of feedback from the operating experience.

6.52. Operating procedures (including procedures for the receipt, handling and emplacement of waste) should be put in place, tested and periodically reviewed and updated to enhance safety. The operator should ensure that such procedures and instructions are followed by workers at the facility. Training and certification of workers should be employed to ensure that written procedures and practices are well known, are documented and are followed.

6.53. Maintenance procedures should be put in place to ensure that structures and equipment continue to perform their intended function (safety and non-safety related) throughout the lifetime of the facility. Items important to safety (e.g. equipment for waste handling or waste management) should be inspected, tested and maintained in accordance with the established procedures. Periodic maintenance for support equipment (mechanical, civil and electrical structures, systems and components) should also be conducted in accordance with established policies and procedures.

6.54. As a near surface disposal facility will operate for long periods before its final closure, a programme to manage ageing (e.g. a programme of preventing maintenance) should be put in place for both active and passive systems. Active components should be the focus of the maintenance programme. An ageing management programme should also be put in place for passive structures (e.g. engineered features) that are required to maintain integrity in the operational phase as well as in the post-closure period. Ageing management programmes should be designed to detect problems in construction and operation that might not otherwise be discovered until after closure.

6.55. Quality assurance procedures should be put in place to allow the operator to validate the competence of the workers, to assess the effectiveness of the training and certification programmes, and to promote a safe working environment. The purpose of such procedures is to ensure that activities at the facility are being conducted in accordance with standard operational procedures, and that a graded approach is applied to safety which focuses resources on the aspects of the facility operations that are associated with the highest risk and that present the greatest hazard.

6.56. Emergency procedures should be established to address emergencies that may arise and have on-site or off-site consequences [22]. The safety case should give an indication of what factors could contribute to a scenario that would result in significant on-site and/or off-site consequences. The resultant scenarios should reflect operating reality but should also consider analysis of worst case situations. Emergency plans should be developed to address these cases or scenarios. The emergency plans should be tested at appropriate intervals in accordance with national regulations.

6.57. Access to areas in which waste is handled, stored or emplaced should be controlled to ensure safety and the physical protection of the waste. Provisions should be put in place for detecting any unauthorized intrusion and for taking countermeasures promptly.

6.58. Maintenance of mechanical, civil and electrical structures and equipment should be carried out in accordance with a schedule for preventive maintenance. Elements important to safety (e.g. equipment for waste handling and waste lifting) should be inspected, tested and maintained in accordance with the maintenance schedules for the disposal facility. Disposal units (e.g. vaults, trenches and areas of the facility) that have already been closed, as well as those that are still open, during the operational phase should be included in the maintenance schedule. There should be clear and thorough documentation of all changes and modifications to equipment, procedures and conditions; and, where required, such changes and modifications should be justified in the safety case.

6.59. Modifications to the design and improvements in processes are inevitable parts of facility operation. A system for configuration control and management should be developed to document and to allow for approval of modifications and to track changes at the facility. A near surface disposal facility may need design modifications for a number of reasons, including internal and external influences. Process improvements originate from the need for better human resource management or improved management of exposures. For example, the monitoring of occupational exposure rates and releases of radioactive material may suggest the need for design changes, including revisions in procedures that could result in improved performance, decreased exposure and reductions in off-site releases of radioactive material. Similarly, environmental monitoring (e.g. groundwater monitoring) might give an indication whether processes and features modelled in the safety assessment are performing as anticipated.

6.60. The period between the emplacement of the last waste package and the closure of the last disposal cell or trench should be as short as possible, in order to take full advantage of the passive safety features as soon as possible.

6.61. The control of access to the site and radiologically controlled areas is an important part of ensuring that exposure to workers and the public is as low as reasonably achievable.

CLOSURE

Requirement 19 of SSR-5 [4]: 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."

6.62. Closure of a near surface disposal facility should include the decommissioning of operational systems and components, and the placing of the facility in a State that has been demonstrated to provide the safety functions necessary for long term safety.

6.63. The process of facility closure should be documented in a plan for facility closure. Typically, portions or segments of the site may be closed as waste is emplaced and disposal units become full. Elsewhere at the facility, disposal activities may be ongoing until waste capacities are reached and final site closure activities are completed. The facility closure plan should be developed during the operation of the facility and should provide order and structure to planned disposal activities. The facility closure plan should take into account factors such as the type of waste that will be disposed of at the facility, the timing of disposal actions, annual estimates of waste volumes, the location of waste within the facility if retrieval may be required (especially with regard to the emplacement of waste of higher levels of activity concentration at selected locations), and the phased interim closure of individual disposal units (vaults, cells or trenches). Finally, the facility closure plan should describe the installation of final engineered barriers and site markers (if applicable) and how the facility will be transferred into the period of institutional control. The regulatory body should review the facility closure plan for approval. The facility closure plan should also serve as a tool for communication with the public, by informing them of long term plans and how those plans might impact on the local community.

6.64. The facility closure plan should form part of the safety case for post-closure safety. The post-closure safety of a disposal facility depends on design, construction and operation of the facility. Requirements for the period after closure should be considered in the design of the facility, and design of the closure features should be updated as the design of the facility is developed. The performance of the facility in the period after closure should be considered when updating the safety case and the updated safety case should provide evidence that the closure system will be effective and that safety of the disposal facility after closure will be ensured.

6.65. Before construction activities commence and disposal units are filled, there should be sufficient evidence available that the closure features will function as intended. As disposal activities begin, goals for post-closure performance should be used to inform decisions on operational factors such as waste placement and the interim design of the cap. Closure activities should commence early in the lifetime of the facility as disposal units are filled. The impact of the closing of individual disposal units on the safety case for the entire facility should be well understood and adequately documented.

6.66. Closure activities for each disposal unit will collectively determine the post-closure performance of the facility. There should be sufficient evidence that the performance of engineered barriers of the disposal units (e.g. backfilling, sealing and capping) will function as intended to meet the design requirements. Over the course of operations, the design of disposal units may be modified as a result of many factors, such as improvements in materials and in construction techniques, improved information on site features and characteristics, and changes in waste characteristics or waste forms. A record keeping system should be put in place to document these changes and to verify, through updates to the safety case, that performance requirements will continue to be met. Information management systems should be put in place to track any change that could potentially impact the post-closure performance of the facility.

6.67. The closure plan should be maintained and updated periodically. The closure plan should include or provide reference to the collation of all the information recorded in previous phases that may be necessary for corrective actions in the future, or for reassessing the safety of the disposal facility in the future, if necessary. The closure plan should include the type of waste disposed of, its radionuclide content, its location in the facility and the materials used for backfill.

6.68. The closure plan should describe any controls intended for the post-closure period. Such controls may include the radiation monitoring plan and the surveillance programme. A description of the record keeping system and provisions for any control on the use of the site should also be included, together with the means for enforcing any restrictions on access to, or use of, the site. The various organizations responsible for the actions and controls described in the post-closure plan should be identified.

6.69. The minimum duration of institutional controls to contribute to safety should be defined in the arrangements for closure and should be justified in the safety case. Active institutional controls should remain in place until the consequences of human intrusion will not exceed the criteria specified in SSR-5 [4]. Beyond this period, consideration should be given to the type of passive control necessary and, in particular, the site may be placed under the jurisdiction of the local planning authority for land use. The institutional control measures put in place should include the following:

— The prevention of unauthorized use of the site and human intrusion into the disposal facility;
— Monitoring and surveillance of the disposal system;
— Maintenance and remedial actions, if required;
— The transfer of knowledge to future generations.

6.70. The closure method, including the materials and techniques to be used, as well as the expected performance of the components used in closure, should be outlined in the closure plan. The closure method should be optimized in the light of available materials and techniques in order to provide the degree of post-closure performance required from the disposal system throughout the period of institutional control and beyond. The proposed closure method should be described in the safety case developed for obtaining authorization to close the disposal facility.

6.71. The effectiveness of the closure system should be demonstrated by developing an understanding of the natural evolution of the site and by in situ testing, data analysis and modelling. Testing the actual in situ behaviour of the closure system should be carried out to provide an insight into performance and to reduce the uncertainty in models and in the safety assessment. Information that cannot be determined through site specific analysis should be obtained through the use of suitable analogues, including experience with similar systems either within the State or elsewhere.

6.72. Closure of the facility should also include plans for final closure of the disposal units, final physical preparation of the site (e.g. installation of the cap), institutional controls and decommissioning of the facilities on the site. In closing the disposal units and preparing the site for closure, consideration should be given to requirements for post-closure monitoring and commitments in respect of the licensing process, as well as to design features relied upon in the safety case for long term performance.

6.73. Facility closure should also include decommissioning of the parts of the facility which are not part of the disposal system itself (e.g. administrative buildings, and components and equipment used for operating the disposal facility) and any environmental restoration needed, and should consider measures to prevent or to reduce the likelihood of human actions. The disposal facility should ultimately be closed in accordance with the conditions set for closure by the regulatory body in the licence for the facility, with particular consideration given to any changes in responsibility that may occur at this stage.

7. ASSURANCE OF SAFETY

MONITORING PROGRAMMES

Requirement 21 of SSR-5 [4]: 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."

7.1. Monitoring means continuous or periodic observations and measurements of engineering, environmental and radiological parameters important to safety. Monitoring should begin as soon as possible in the development of the disposal facility and, in any case, prior to the construction of the disposal facility to establish background levels and to assist in site characterization. The monitoring programme provides input to safety assessments, the continuing assurance of operational safety of the facility, and the subsequent confirmation that actual conditions are consistent with the assumptions made for post-closure safety. Comprehensive guidance on the monitoring of radioactive waste disposal facilities is provided in IAEA Safety Standards Series No. 31, Monitoring and Surveillance of Radioactive Waste Disposal Facilities [23].

7.2. The monitoring programme should be defined prior to construction and in coordination with development of the safety case. A baseline survey of the site, including characteristics of the host environment, should be conducted before commencing construction activities. The monitoring programme should be revised periodically to reflect new information gained during construction, operation and closure.

7.3. The monitoring programme should define monitoring methods (e.g. sampling of soil, vegetation, water and air), measurement techniques, requirements, limits and tolerances, monitoring and measuring frequencies and reporting requirements, including the retention of monitoring and measurement results.

7.4. The programme of monitoring should be included as part of the safety case and should be refined with each revision of the safety case. As such, the monitoring programme should be made subject to audit and independent verification by the regulatory body. 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 radiological protection [3]. Technical and scientific data obtained from the results of monitoring and measurement may also be used to improve the assumptions and models for safety assessments.

7.5. For the post-closure period, the near surface disposal facility 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 safety functions of the facility. Monitoring for non-radiological contaminants, which may be of concern, may also be necessary. The operator of the facility should consider such contaminants when designing its monitoring programme.

POST-CLOSURE AND INSTITUTIONAL CONTROLS

Requirement 22 of SSR-5 [4]: 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."

7.6. Institutional controls following closure should be considered as a means of providing additional assurance of the safety of the disposal facility. Institutional controls may contribute to safety by preventing or reducing the likelihood of human actions that could inadvertently interfere with the waste or degrade the safety features of the disposal system. Institutional controls may also contribute to increasing public acceptability of a near surface disposal facility.

7.7. Paragraph 5.6 of SSR-5 [4] states that: "The long term safety of a disposal facility for radioactive waste has not to be dependent on active institutional control." However, the radionuclide inventory in a near surface disposal facility may be such that institutional control needs to be maintained over the facility (e.g. to prevent human intrusion) for a certain period after closure of the facility.

7.8. The operator should prepare plans for institutional controls to be put in place in consultation with the regulatory body and any local, regional or national authority responsible for the administration of the area where the site is located. The plans should define the intended function of the institutional controls, describe how they will be effected, state their assumed period of effectiveness, and provide arguments and evidence that they can be relied upon. The plans may initially be flexible and conceptual in nature, when the facility is first constructed, but they should be developed and refined progressively as closure of the facility and release of the site from regulatory control approaches.

7.9. Institutional controls may be active (i.e. controls requiring active maintenance by the operator) or passive (i.e. measures that may persist without future actions by the operator or others). Active institutional controls may include measures to prevent members of the public from having access to the site (e.g. maintaining a site fence and security personnel) and monitoring activities with respect to the radionuclide concentration in environmental media as well as to the integrity and performance of engineered barriers. Passive institutional controls may include the placing of information about the disposal facility in local, national or international records and archives (to enable future generations to make decisions on the disposal facility and its safety), the use of durable markers at the site [4], and the placing of legal restrictions on the use of the land.

7.10. The operator should distinguish clearly between plans for the institutional controls to be put in place and any assumptions concerning the duration and effectiveness of institutional controls made for the purposes of the safety assessment. An assumption in a safety assessment that, for example, active institutional controls will be effective in preventing human intrusion for 100 years, does not necessarily mean that active institutional controls will actually be removed after 100 years. The decision to release a site from regulatory control and to move from the period of active to passive institutional control is a decision that will need to be taken in the future by the operator in conjunction with the regulatory body, with account taken of the views of relevant interested parties.

7.11. The safety assessment and safety case should not place reliance on institutional controls being effective (e.g. in preventing human intrusion) for an indefinite period.

7.12. The results of the safety assessment may provide input to decisions on the plan for institutional controls, but they should not be the only factor considered; rather, the views of all interested parties should be taken into account to provide a strong and well supported safety case. The possibility of disruptive events that could affect the facility should also be considered in developing plans for institutional control. In general, radioactive decay will cause the hazard posed by the waste and the associated doses and risks to decrease over time. However, in some cases (e.g. near surface disposal facilities that contain appreciable quantities of long lived radionuclides), assessed doses may remain relatively constant with time, or even increase slightly, because of growth in the content of daughter radionuclides.

7.13. For some near surface disposal facilities, dose assessments for human intrusion scenarios provide a quantitative indicator for a decision on the period of active institutional control necessary after closure of the facility in order to meet the criteria presented in the safety requirements for the disposal of radioactive waste [4], as set out in Box 1. Other exposure pathways and scenarios (e.g. releases via, and exposures from, the gas or groundwater pathways) may also influence the need for a period of institutional control and its duration. Plans for institutional control should not be based solely on such numerical comparisons; wider judgement should be exercised and a range of factors should be considered.

7.14. The operator should justify any claims made in the safety case and in the plan for institutional controls regarding the duration of effectiveness of institutional controls. Typically, the safety case and supporting safety assessment should assume that institutional controls will remain effective for no more than a few hundred years.

7.15. Different organizations are likely to be responsible for different institutional control activities. The operator will often be responsible for active institutional control, while State organizations may be responsible for activities such as the archiving of records and land use controls. At an appropriate stage, regulatory approval may be sought for a transfer of responsibility for the site from the operator to, for example, the government.

STATE SYSTEM OF ACCOUNTING FOR AND CONTROL OF NUCLEAR MATERIAL

> **Requirement 23 of SSR-5 [4]: Consideration of the State system of accounting for, and control of, nuclear material[9]**
>
> **"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 … .**
>
> "[9] State systems of accounting for, and control of, nuclear material are required by IAEA nuclear safeguards agreements." [24–26]

7.16. Materials or waste subject to nuclear material accountancy and control measures are unlikely to be a concern in relation to the development of most near surface disposal facilities. However, where nuclear material accountancy and control requirements do apply, they will need to be integrated into the programme for development, operation and closure of the disposal facility. Physical protection measures may also have to be taken for nuclear material and nuclear facilities, and are addressed in IAEA Nuclear Security Series No. 13, Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5) [15].

7.17. If nuclear material accountancy and control measures are required for a closed near surface disposal facility, then intrusive methods, which might compromise post-closure safety, should be avoided. To the extent practicable, IAEA nuclear safeguards might, in practice, be applied by remote means (e.g. satellite monitoring, aerial photography, microseismic surveillance and administrative arrangements).

SECURITY

Requirement 24 of SSR-5 [4]: 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.”

7.18. 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, 15, 27].

7.19. The level of nuclear security has to be commensurate with the level of radiological hazard and the nature of the waste. Security requirements will be the most rigorous where nuclear safeguards requirements apply [4] (see also paras 7.16–7.17).

MANAGEMENT SYSTEMS

Requirement 25 of SSR-5 [4]: Management systems

“Management systems[12] 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.

“[12] 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).”

7.20. Requirements on the management system are established in IAEA Safety Standards Series No. GS-R-3, The Management System for Facilities and Activities [27], general recommendations are provided in IAEA Safety Standards Series No. GS-G-3.1, Application of the Management System for Facilities and Activities [28] and detailed recommendations on the management system for the disposal of radioactive waste are provided in IAEA Safety Standards

Series No. GS-G-3.4, The Management System for the Disposal of Radioactive Waste [29].

7.21. The first particular aspect that should be considered when the operator and the regulatory body develop the management system for a near surface disposal facility for radioactive waste is that, after termination of the active institutional controls in the post-closure phase, safety and environmental protection will depend on a passive system that has to ensure adequate containment and isolation of the waste. Depending on the type of near surface disposal facility (on the surface or at a shallow depth, with highly engineered vaults or a more simple trench design), passive containment and isolation of the waste will rest on engineered barriers, natural barriers, when present, and favourable features of the natural environment of the disposal facility (e.g. its long term stability). This reliance on a passive system affects the development and application of the management system, in which the performance, stability, complementarity and longevity of all components contributing to the containment and isolation of the waste should be given systematic attention from the design phase until the moment of termination of institutional controls on the site.

7.22. A second specific aspect that should be considered is that, after closure of the disposal facility and before termination of active institutional control takes place, a long period of institutional surveillance and control (a few decades up to a few hundred years, largely depending on the activity of long lived radionuclides in the emplaced waste) is necessary to ensure that the passive system put in place is not disturbed by human activities that could lead to inadvertent intrusion into the disposal facility. During this long period, surveillance of the site to restrict access to the facility and control of the passive functioning of the system will take place. The management system should give particular emphasis during the development, operation and closure of the disposal facility to the recording of information about both what has been done and the reasons why decisions were taken. This should be done to meet the challenge of managing all relevant knowledge and information of the disposal system over such a long period, in order to enable a step by step decision making process until termination of all control activities at the site.

7.23. A third specific aspect that should be considered is the requirement to ensure appropriate limitation of the waste inventory in terms of the activity, mainly of long lived radionuclides, that can be disposed of. A waste acceptance process should therefore be put in place that integrates all elements (waste characterization, and a management system for the waste acceptance for disposal) that are necessary to ensure that this limitation is complied with during waste emplacement activities.

7.24. The management system should define the role of management and the organizational structure for processes for all safety related activities. It should also define the responsibilities and authorities of the various individuals and organizations involved in managing, applying and assessing the quality of the processes.

7.25. The financial resources that will be available to the operator to develop and to operate the disposal facility should be demonstrated to be adequate and secure. The regulatory body should verify the adequacy of the financial resources periodically and should review, for approval, the mechanism put in place to ensure that funds will be preserved and made available for the intended purpose at the time when required.

7.26. For all development phases and activities, the operator should determine its staffing requirements, should recruit and train suitably qualified personnel, and should foster and maintain a safety culture. The operator should take the necessary steps to maintain competence and a safety culture throughout the facility development programme and through training, education and transfer of knowledge. Further information on maintaining competence and on safety culture can be found in Refs [30–32].

7.27. The elements of the management system that provide assurance of the quality of safety related processes should take into account uncertainties in the host environment. The host environment, while important for safety, cannot be designed or manufactured but only characterized to a certain level of detail. Furthermore, a disposal facility is developed through several sequential steps in design, characterization and assessment, with an increasing degree of detail and accuracy. However, a degree of uncertainty will always remain, and the management system should ensure that these uncertainties are appropriately taken into account in the demonstration of safety.

7.28. The management system for a disposal facility should ensure the production and retention of documentary evidence to illustrate that the necessary quality of data has been achieved, that components have been supplied and used in accordance with the relevant specifications, and that the waste packages and unpackaged waste comply with the established requirements and criteria and have been properly emplaced in the disposal facility. The management system should also ensure the collation of all the information recorded at all steps of the development, operation and closure of the facility, and the preservation of information that could be important to safety and for any reassessment of the facility in the future.

7.29. The operator's management system should comply with national standards on management systems, and nationally or internationally recognized codes, regulations and standards should be used whenever possible [27–29]. An appropriate management system, which integrates safety, health, environmental, security, quality and economic elements, contributes to the confidence that the relevant requirements and criteria for site characterization, design, construction, operation, closure and post-closure safety are being met. The relevant activities, systems and components should be identified on the basis of the results of systematic safety assessments, and the application of the management system should be graded in accordance with their importance to safety.

7.30. The management systems of the waste generator and of the operator should be part of the safety case and should be reviewed and be acceptable to the regulatory body. The management system should be endorsed by senior management of the operating organization, with a commitment to ensuring that it is fully applied throughout the organization.

7.31. 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.

7.32. The management system and its integrated quality assurance programme should, for the near surface disposal facility, provide for the production, retention and preservation of objective evidence (e.g. monitoring samples and documentary evidence).

7.33. Consideration should be given to the physical and electronic forms of records to ensure that information remains available and is archived appropriately for the benefit of future generations. Records describing the precise location and nature of the waste should be protected appropriately.

8. EXISTING DISPOSAL FACILITIES

Requirement 26 of SSR-5 [4]: 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.”

8.1. Periodic safety assessment and updating of the safety case should be undertaken to provide an overall assessment of the status of protection and safety of the facility. These should include an analysis of the operational experience acquired and possible improvements that could be made, with account taken of the prevailing situation, new technological developments or new regulatory circumstances.

8.2. Some existing near surface disposal facilities were not designed or sited, or have not been operated, in accordance with modern standards for post-closure safety. At some existing facilities, in the early years of operation the waste acceptance criteria were either not in place or were used very differently from criteria that would be considered acceptable for such facilities today. As a result, these facilities may contain waste, or types of waste packages, that are now not regarded as suitable for near surface disposal. Decisions as to whether or not to reopen and retrieve and/or redesign and rebuild such disposal facilities need to be informed through studies that allow the judgement of risks to workers and the public of the choices at hand: to leave the facility alone, or wholly, or partially, renovate or move it.

8.3. In the event that safety regulations are changed, the implications for existing disposal facilities should be evaluated by reviewing and, if necessary, revising the safety assessment. If the facility is still operating, the safety assessment should be based on current plans for its continued operation, eventual closure and any post-closure institutional controls. If the facility has been closed, the safety assessment should assume that present active institutional controls are not continued beyond a few hundred years.

8.4. The periodic reassessment of safety should be based on, and should update, the existing safety case and safety assessment, and the methodological approach used should be the same as that described in Section 5.

8.5. The collection of additional site characterization data may be necessary. Much of this can be conducted on the site, but off-site investigations will typically be necessary as well (e.g. to characterize regional groundwater flow patterns). Monitoring data should be used in the development and calibration of models, and, if enough independent datasets are available, in model validation. If the assessment shows that the facility meets modern standards for post-closure safety, no further action is necessary. If it does not meet modern standards, then the next steps should depend on whether the facility is still operating or has been closed.

8.6. If an operating near surface disposal facility fails to meet current standards for new facilities, a decision should be taken as to whether the facility should be closed or be allowed to continue operation with some modification, or whether remedial actions need to be taken and the facility closed or allowed to continue operation following remediation. These decisions should be taken on the basis of results of the safety assessment, but will also necessarily entail broader economic and social considerations that are outside the scope of this Safety Guide. It will therefore be necessary to assess and to compare options for possible remedial actions, changes to current waste acceptance criteria, operational and maintenance procedures, closure plans and planned post-closure institutional controls. Remedial actions could include new drains or controls on groundwater pathways, improved features to prevent rain or groundwater ingress to the facility or, in the extreme, removal of some or all of the waste. New monitoring and surveillance procedures may also be required, either during operation and/or after closure.

8.7. The main radiation protection principle applied in decisions regarding remedial actions or changes to operating plans and procedures at an operating site is that of optimization [3]. Input to the decision should be obtained by comparing different possible actions and changes on the basis of various factors, such as their effects on radiological impacts on people and the environment, their non-radiological impacts on people and the environment, their societal impacts, and their financial costs. Feasibility studies and demonstration programmes should be carried out to assist the decision making process.

8.8. In the case of a closed near surface disposal facility, it should be determined whether remedial action should be carried out and, if so, what would be the best action to take. In radiation protection terms, the principles involved are those of justification, and then optimization [3]. Justification involves a comparison of the implications of possible remedial actions with the taking of no action, and then a decision as to which, if any, actions would provide an overall net benefit. When remedial actions have been identified that would be justified, these should then be compared in order to provide input to a decision on the preferred action. The comparison should include all the factors required to identify and to defend the recommended option for remediation.

8.9. The options for remedial actions at a closed facility are more limited than at an operating facility. It may be possible to add further engineered barriers in order to restrict water ingress (e.g. a new cap), repair engineered barriers or extend planned periods of institutional control to prevent human intrusion for longer. Installation of new drainage systems under vaults will not usually be possible. Opening up the facility to remove some, or all, waste will generally be feasible but would likely entail a significant commitment of resources and radiation exposures and risks to workers, which should be considered against the benefits that retrieval of the waste might be expected to bring.

8.10. In addition, the timing of any remedial action should be considered. Early action could have advantages and disadvantages. On the one hand, less degradation of the waste forms and waste packages will have occurred, so it will be easier to remove waste from the facility. On the other hand, however, less decay will have occurred so radiation exposure to workers will be higher. Thus, for remedial actions to be considered justified, the benefits that they yield are required to outweigh the radiation risks to which they give rise.

Appendix I

SITING OF NEAR SURFACE DISPOSAL FACILITIES

INTRODUCTION

I.1. Siting is a fundamentally important activity in the disposal of radioactive waste. In the siting process for a radioactive waste disposal facility, four stages may be recognized:

(1) A conceptual and planning stage;
(2) An area survey stage, leading to the selection of one or more sites for more detailed consideration;
(3) A site investigation stage of detailed site specific studies and site characterization;
(4) 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 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 and 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 disposal facilities. During the initial stages of site selection, site specific information (e.g. geological and hydrogeological 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 near surface 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 to retard the movement of radionuclides from the disposal system to the accessible environment can be effected. This evidence needs to be tested in subsequent detailed site effected, characterization and associated safety assessment modelling.

I.2. Detailed site investigations and characterization span the final stages of a siting process — stages 1 and 2 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's development process. The purpose of the conceptual design and planning stage is to develop an overall plan for the site selection process and to identify, using available data and 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 concern is 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, for example 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 to target progressively areas that may include 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 better determine 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.

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 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. The analysis in this phase will rely mostly on available information (e.g. geological data from previous exploration, historical seismicity data and remote sensing data).

Site screening phase

I.10. In the screening 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. national parks and 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, 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 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 a 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 investigations 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 about their ability to meet all safety requirements and about their acceptability for construction of the disposal facility.

I.15. At the conclusion of the 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[4], as specified by appropriate national authorities, may be conducted at this stage. 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 is also expected that the regulatory body will review the results and decide whether the preferred site(s) is (are) 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.

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[4] Environmental impact assessments are not defined in the IAEA safety standards, although they are included in many international instruments and national legislations and regulations. In the context of a Safety Guide in preparation on radiological environmental impact assessment for facilities and activities, the definition from the Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention) is adopted. According to Article 1 of the Espoo Convention, ‘environmental impact assessment’ means a national procedure for evaluating the likely impact of a proposed activity on the environment, while ‘impact’ means any effect caused by a proposed activity on the environment, including human health and safety, flora, fauna, soil, air, water, climate, landscape and historical monuments or other physical structures, or the interaction among these factors. It also includes effects on cultural heritage or socioeconomic conditions resulting from alterations to those factors.

Appendix II

GUIDANCE AND DATA NEEDS FOR SITE INVESTIGATION AND SITE CHARACTERIZATION

GENERAL

II.1. 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 to host 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.

II.2. 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 use 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.

II.3. Guidance can be helpful in the overall decision making process, but it 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.

II.4. Paragraphs II.6–II.34 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 commences 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 process, 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.

II.5. 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.

GEOLOGY

II.6. The geology of the disposal site should contribute to the isolation of waste and the limitation of release of radionuclides to the biosphere. It should also contribute to the stability of the disposal system and should provide sufficient volume and favourable properties (geological, mechanical, geochemical, hydrogeological, etc.) for disposal. Preference should be given to sites with a uniform and predictable geology, which can be readily characterized through geological investigative techniques.

II.7. In the area survey stage, the geological information should include identification of the approximate geological structure and stratigraphy, possibly with the depth, thickness and lateral extent of the surface formation and surrounding units. In the site characterization stage, information to be collected should include the following:

- — Stratigraphy, lithology and mineralogy;
- — Geological structure characteristics;
- — Geotechnical characteristics.

In the site confirmation stage, extensive geological investigations should be undertaken to characterize fully the geology to the level needed for detailed safety assessment, modelling and final facility design.

HYDROGEOLOGY

II.8. The hydrogeological characteristics of the host site should include low groundwater flow paths and long flow paths in order to restrict the migration of radionuclides. Expected changes in important hydrogeological conditions (e.g. gradient) due to natural events and the construction of the disposal facility should be evaluated. Preference should be given to sites with a simple geological setting that could make characterizing or modelling of the hydrogeological system easy and reliable. The dispersion characteristics of the hydrogeological system may also be important and should be evaluated.

II.9. In the area survey stage, hydrogeological characteristics of an area or site may not yet be available in sufficient detail. In situations where hydrogeological maps are lacking, the information analysed should encompass:

— Data on existing and projected major water uses;
— Identification of major discharge and extraction points;
— An estimate of groundwater flow velocity and direction.

For the site characterization stage, the following information should be considered:

— The location and extent of and the interrelationship between the important hydrogeological units in the region;
— Average flow rates and prevailing directions of the groundwater flow;
— Information on recharge and discharge of the major hydrogeological units;
— Information on regional and local water tables and their seasonal fluctuations.

The site confirmation stage may require detailed information on the hydrogeological characteristics of the site selected. The type of data should, in general, express quantitatively the characteristics indicated above, with the aim of defining travel times of radionuclides along the likely flow paths from the waste to the biosphere.

GEOCHEMISTRY

II.10. The geochemistry of groundwater and the geological media should contribute to limiting the release of radionuclides from the disposal facility and should not significantly reduce the longevity of engineered barriers. Preference should be given to sites where geochemical conditions promote sorption and precipitation and co-precipitation of radionuclides that could be released from the disposal system, and inhibit the formation of chemical compounds of radionuclides that migrate readily.

II.11. In the consideration of the likely chemical interactions within the disposal system, the following should be evaluated:

- Corrosive action of groundwater on the engineered barriers;
- Processes or conditions influencing the solubility and the sorption of radionuclides;
- Eh and pH of the groundwater;
- Processes or conditions involving the presence of natural colloids and organic materials;
- Potential gas generation by the disposal system.

II.12. The information necessary to estimate the potential for migration of radionuclides to the biosphere should include a description of the geochemical and hydrochemical conditions at the site, the surrounding geological and hydrogeological units, and the paths of potential groundwater flow. This information should include:

- The mineralogical and petrographical composition of the groundwater flow system and its geochemical properties;
- Groundwater chemistry.

II.13. This information is unlikely to be available at the area survey stage for the selection of candidate sites. However, it should be collected as part of the investigation programme carried out during the site characterization and site confirmation stages.

TECTONICS AND SEISMICITY

II.14. The site should be located in an area of low tectonic and seismic activity such that the isolation capability of the disposal system will not be endangered.

Areas of low tectonic and seismic activity should be selected in the regional analysis. Preference should be given to areas or sites where the potential for adverse tectonic, volcanic or seismic events is sufficiently low that it would not affect the ability of the disposal system to meet safety requirements.

II.15. In the application of site selection criteria, the following conditions should be considered:

— Recent or historic evidence of active faulting, tectonic processes or igneous activities;
— Historical earthquakes of such magnitude and intensity that, if they recurred, could adversely affect isolation of the waste;
— The potential for natural events such as subsidence or volcanic activity that could change the regional hydrogeological system;
— Evidence of soil liquefaction in seismic loads.

II.16. The distance to sites from areas with high seismicity, or from known or suspected capable faults, may be used as a screening factor at the area survey stage for the selection of candidate sites.

II.17. The design of the disposal facility should take into account tectonic stability and seismic activity of the site that could adversely affect the proposed disposal system. The following information should be analysed at the site confirmation stage:

— Historical seismicity at the site;
— The occurrence of quaternary faults at the site and the age of latest movement;
— Evidence of active tectonic processes, such as volcanism;
— Estimates of the maximum potential earthquake within the geological setting.

SURFACE PROCESSES

II.18. It should be verified that surface processes such as flooding of the disposal site, landslides or erosion do not occur with such frequency or intensity that they could affect the ability of the disposal system to meet safety requirements. The disposal site should be generally well drained and free of areas of flooding or frequent ponding. Accumulation of water in upstream drainage areas due to precipitation or snowmelt and the failure of water control structures, channel obstruction or landslides should be evaluated and minimized so as to decrease the amount of runoff that could erode or inundate the facility. Preference should be given to areas or sites with topographical and hydrological features that preclude the potential for flooding.

II.19. In the area survey stage, areas and sites subject to flooding should be evaluated. Potential sites can be screened on the basis of the severity of effects of flooding. Surface geological processes such as erosion, landslides or weathering should be evaluated in regard to their frequency and capacity to affect the safety of the disposal system. In the site characterization and site confirmation stages, the following information should be collected:

- The topography of the site, showing actual drainage features;
- The location of existing and planned surface water bodies;
- A definition of areas of landslides and other potentially unstable slopes, and of materials of low bearing strength or high liquefaction potential;
- A definition of areas containing poorly drained materials;
- Data on the flood history of the region;
- Upstream drainage areas.

METEOROLOGY

II.20. The meteorology of the site area should be characterized such that the effects of unexpected, extreme meteorological conditions can be adequately considered in the design and licensing of the disposal facility. The potential for extreme meteorological events should be evaluated. Potential sites may be screened on the basis of the severity of the effects of such events.

II.21. In the site selection process, consideration should be given to the following conditions:

- Precipitation (rain and snow);
- Dispersion conditions for potential atmospheric releases of radioactive material;
- The potential for extreme weather phenomena, such as tropical and extratropical cyclones and hurricanes, tornadoes, severe winter storms and sandstorms.

II.22. In the area survey stage, data on extreme weather conditions that may adversely affect facility safety should be mapped on a national or regional scale.

In the site characterization and site confirmation stages, information should be obtained on the meteorological conditions, as determined from the closest recording station(s), in order to predict potential effects of extreme precipitation on the hydrological and hydrogeological systems at the site, and to evaluate the radioactive releases to the environment during operation of the disposal facility. The types of information should include:

— Characteristics of wind and atmospheric dispersion;
— Precipitation characteristics;
— Extreme weather phenomena.

EVENTS RESULTING FROM HUMAN ACTIVITIES

II.23. The site should be located so that activities carried out by present, or future, generations at or near the site will not be likely to affect the isolation capability of the disposal system. Areas in the immediate vicinity of major hazardous facilities, airports or transport routes carrying significant quantities of hazardous materials should be evaluated. In addition, areas or sites should be evaluated for valuable geological resources or potential future resources, including groundwater suitable for irrigation or drinking water, that are likely to give rise to interference activities resulting in a release of radionuclides in quantities beyond the acceptable limits. A site should be considered less suitable where previous or future activities could create significant release pathways between the waste and the biosphere. Screening of potential sites should include consideration of the distance from such facilities and the associated impacts.

II.24. In the area survey stage, known valuable geological resources, including groundwater, should be mapped as part of the process of defining the region of interest. In the site characterization and site confirmation stages, in order to estimate any adverse impact that off-site installations might have on the projected disposal system, the following information should be collected:

— The location of nearby hazardous installations, such as oil refineries, chemical plants, storage depots, pipelines and other facilities, that could have an impact on site operations;
— The location of airports and important air traffic corridors and flight frequencies;
— The location of transport routes with frequent movement of hazardous material.

II.25. In the site characterization and site confirmation stage, in order to evaluate whether past or future exploration and recovery of resources could negatively affect the disposal system, the following information should also be collected:

— Known occurrences of energy and mineral resources, including groundwater, and estimates of their present and projected quality and value and the potential for their use;
— Records of past and present drilling and mining operations in the vicinity of the site.

TRANSPORT OF WASTE

II.26. The site should be located so that the access routes will permit the transport of waste with minimal risk to the public. Parameters including radiation exposure and the potential for an accident associated with the transport of waste to the disposal site should be taken into account.

II.27. To evaluate existing or required access routes, the information to be collected should include the following:

— A description of existing routes in the vicinity of the site and analysis of their adequacy for handling waste shipments;
— Anticipated improvements in the existing transport network;
— Estimates of the overall costs and risk of waste transport;
— Analysis of emergency response requirements and capabilities relating to transport.

LAND USE

II.28. Land use and ownership of land should be considered in connection with foreseeable development and regional planning in the area of interest. Future uses of the land in the vicinity of the proposed site should be evaluated for any potential impact on the operation and performance of the disposal facility. The impact of the disposal facility's operation on the future use of the land in the vicinity of the proposed site should also be evaluated.

II.29. Jurisdiction over the land, or land ownership, may be a significant factor in some States with respect to the financial viability and public acceptance of the disposal facility. Early control or ownership of the site by the operator or government would simplify the site planning and evaluation efforts, shorten the time required until the facility is brought into operation and reduce the problems associated with the withdrawal of land from other uses.

II.30. The data collected should include the following:

— Existing land resources and uses and jurisdiction over them;
— Foreseeable development of land in the area of interest.

POPULATION DISTRIBUTION

II.31. Consideration should be given to avoiding areas of high population density. The selection of candidate sites should be performed on the basis of appropriate suitability factors, with account taken of the likelihood of future disturbances and radiation protection of people who could be affected by the release of radionuclides from the disposal facility.

II.32. At the area survey stage, large scale maps should be prepared showing major population centres and regions with population density as a function of distance. At the site characterization stage, more detailed data should be collected on the basis of the most recent census, and extrapolated as appropriate.

PROTECTION OF THE ENVIRONMENT

II.33. The site should be located so that the environment will be adequately protected for the entire lifetime of the facility and so that potential adverse impacts can be mitigated to an acceptable degree, technical, economic, social and environmental factors being taken into account. Near surface disposal facilities should comply with the requirements for protection of the environment. Possible adverse effects that a near surface disposal system may have on the environment include the following:

— Disturbance of the environment due to the construction and operation of the disposal facility;
— Impact on areas of significant public value;
— Disturbance of public water supplies;
— Impact on endangered species.

II.34. To estimate potential impacts on the environment, the types of information collected should include the following:

- — Locations of national parks and areas with historical monuments and archaeological findings;
- — Existing surface water and groundwater resources and their quality;
- — Existing terrestrial and aquatic vegetation and wildlife, particularly endangered species.

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