IAEA
International Atomic Energy Agency

IAEA SAFETY STANDARDS

No. SSG-1 (Rev. 1)

for protecting people and the environment

Borehole Disposal Facilities for Disused Sealed Radioactive Sources

SPECIFIC SAFETY GUIDE

IAEA SAFETY STANDARDS AND RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

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BOREHOLE DISPOSAL FACILITIES FOR DISUSED SEALED RADIOACTIVE SOURCES

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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-1 (Rev. 1)

BOREHOLE DISPOSAL FACILITIES FOR DISUSED SEALED RADIOACTIVE SOURCES

SPECIFIC SAFETY GUIDE

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FOREWORD

by Rafael Mariano Grossi
Director General

The IAEA's Statute authorizes it to "establish…standards of safety for protection of health and minimization of danger to life and property". These are standards that the IAEA must apply to its own operations, and that States can apply through their national regulations.

The IAEA started its safety standards programme in 1958 and there have been many developments since. As Director General, I am committed to ensuring that the IAEA maintains and improves upon this integrated, comprehensive and consistent set of up to date, user friendly and fit for purpose safety standards of high quality. Their proper application in the use of nuclear science and technology should offer a high level of protection for people and the environment across the world and provide the confidence necessary to allow for the ongoing use of nuclear technology for the benefit of all.

Safety is a national responsibility underpinned by a number of international conventions. The IAEA safety standards form a basis for these legal instruments and serve as a global reference to help parties meet their obligations. While safety standards are not legally binding on Member States, they are widely applied. They have become an indispensable reference point and a common denominator for the vast majority of Member States that have adopted these standards for use in national regulations to enhance safety in nuclear power generation, research reactors and fuel cycle facilities as well as in nuclear applications in medicine, industry, agriculture and research.

The IAEA safety standards are based on the practical experience of its Member States and produced through international consensus. The involvement of the members of the Safety Standards Committees, the Nuclear Security Guidance Committee and the Commission on Safety Standards is particularly important, and I am grateful to all those who contribute their knowledge and expertise to this endeavour.

The IAEA also uses these safety standards when it assists Member States through its review missions and advisory services. This helps Member States in the application of the standards and enables valuable experience and insight to be shared. Feedback from these missions and services, and lessons identified from events and experience in the use and application of the safety standards, are taken into account during their periodic revision.

I believe the IAEA safety standards and their application make an invaluable contribution to ensuring a high level of safety in the use of nuclear technology. I encourage all Member States to promote and apply these standards, and to work with the IAEA to uphold their quality now and 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.

Safety Guides

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it

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

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

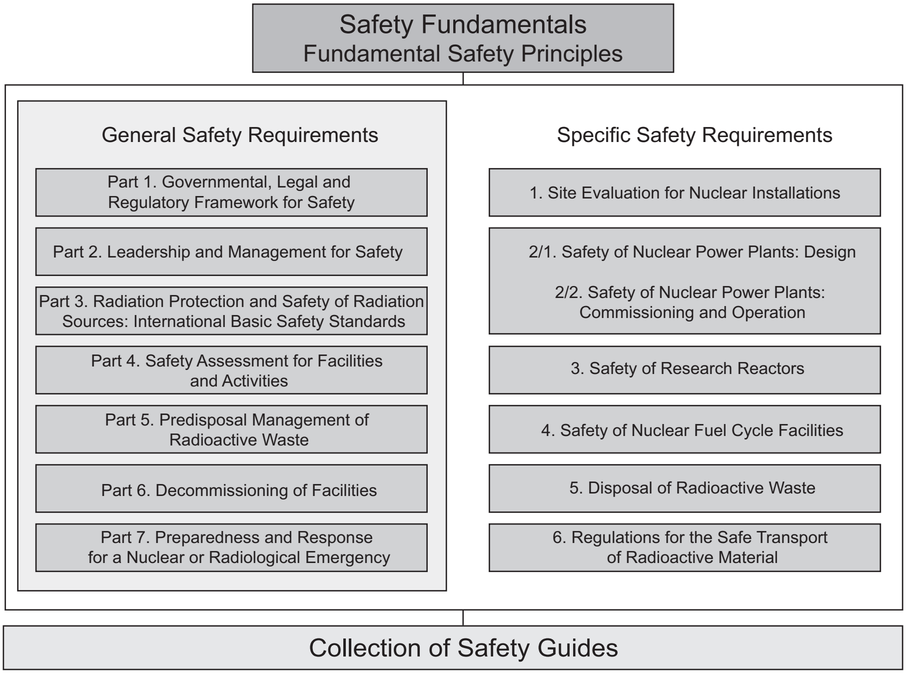

FIG. 1. The long term structure of the IAEA Safety Standards Series.

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 five Safety Standards Committees, for emergency preparedness and response (EPReSC) (as of 2016), nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on Safety Standards (CSS) which oversees the IAEA safety standards programme (see Fig. 2).

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

A management system has been established for the processes of planning, developing, reviewing, revising and establishing the IAEA safety standards.

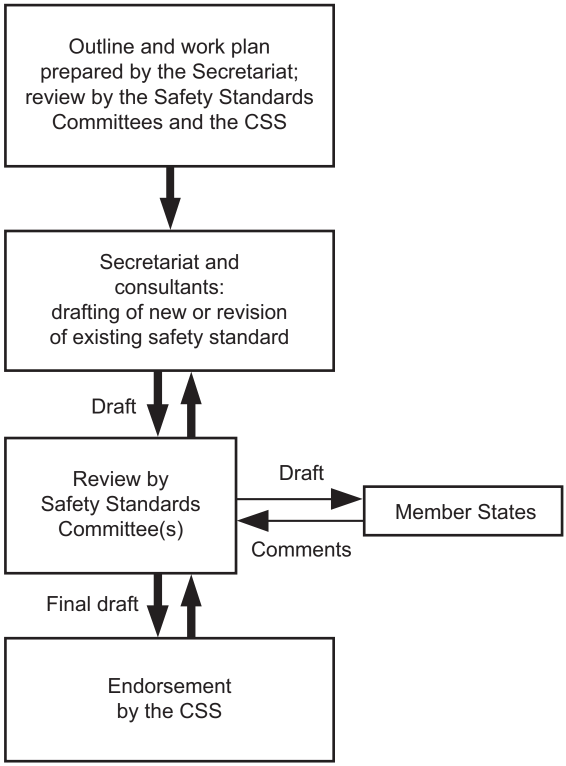

FIG. 2. The process for developing a new safety standard or revising an existing standard.

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 they appear in the IAEA Nuclear Safety and Security Glossary (see https://www.iaea.org/resources/publications/iaea-nuclear-safety-and-security-glossary). 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. This Safety Guide provides recommendations on the development (i.e. site selection and evaluation, and facility design and construction), commissioning, operation, closure, institutional control and regulation of borehole disposal facilities for radioactive waste to fulfil the safety principles established in IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [1], and relevant safety requirements, in particular those established in IAEA Safety Standards Series Nos GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [2]; GSR Part 5, Predisposal Management of Radioactive Waste [3]; and SSR-5, Disposal of Radioactive Waste [4]. The types of radioactive waste considered in this Safety Guide are disused sealed radioactive sources[1] that have been declared as radioactive waste, and small volumes[2] of low and intermediate level secondary waste generated during the management of these sources.

1.2. This Safety Guide supersedes IAEA Safety Standards Series No. SSG-1[3], which was published in December 2009. Since its publication, the relevant Safety Requirements have been revised, and significant further research and development has been conducted on the borehole disposal of disused sealed radioactive sources in preparation for the implementation of such disposal by Member States. The borehole disposal of disused sealed radioactive sources has been licensed in one Member State, pilot borehole disposal projects are under way elsewhere, and several more States are actively interested in developing their own borehole disposal facilities for disused sealed radioactive sources. It is timely, therefore, to provide revised recommendations that properly reflect the current IAEA safety

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[1] A disused sealed radioactive source is a radioactive source, comprising radioactive material that is permanently sealed in a capsule or closely bonded and in a solid form (excluding reactor fuel elements), that is no longer used, and is not intended to be used, for the practice for which an authorization was granted [5].

[2] At a borehole disposal facility having one narrow diameter disposal borehole, the total volume of this secondary waste is expected to be less than 1 m^3 that is, small enough that it could be disposed of in just a few waste packages. The disposal of secondary waste in the same borehole disposal facility is intended to give States with small inventories of disused sealed radioactive sources the option to dispose of all their waste in one place and thereby avoid leaving a potential legacy comprising a small volume of waste with no disposal route.

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Borehole Disposal Facilities for Radioactive Waste, IAEA Safety Standards Series No. SSG-1, IAEA, Vienna (2009).

standards and the state of knowledge regarding borehole disposal of the types of radioactive waste described in para. 1.1.

1.3. The modifications incorporated into this Safety Guide reflect recent research and development, studies and pilot projects on borehole disposal of the radioactive waste described in para. 1.1. The Safety Guide has also been updated for consistency with current IAEA safety standards. The Safety Guide is consistent with the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [6], with the Code of Conduct on the Safety and Security of Radioactive Sources [7] and with the supplementary Guidance on the Management of Disused Radioactive Sources [8].

OBJECTIVE

1.4. The objective of this Safety Guide is to provide recommendations on the development, commissioning, operation, closure, institutional control and regulation of borehole disposal facilities for disused sealed radioactive sources that have been declared as radioactive waste and small volumes of low and intermediate level secondary waste generated during the management of these sources, to fulfil the safety requirements contained in GSR Part 3 [2], GSR Part 5 [3] and SSR-5 [4]. This Safety Guide can also be used as a basis for reassessing and, where appropriate, upgrading the safety of existing borehole disposal facilities.

1.5. This Safety Guide complements IAEA Safety Standards Series Nos SSG-29, Near Surface Disposal Facilities for Radioactive Waste [9], and SSG-14, Geological Disposal Facilities for Radioactive Waste [10].

SCOPE

1.6. This Safety Guide provides recommendations on borehole disposal facilities for disused sealed radioactive sources that have been declared as radioactive waste and small volumes of low and intermediate level secondary waste generated during the management of these sources. This Safety Guide does not provide recommendations on the borehole disposal of other low and intermediate level waste that was not generated during the management of the disused sealed radioactive sources or on high level waste.[4]

1.7. The borehole disposal of the radioactive waste described in para. 1.1 could be a sensible component of any State's national policies and strategies for achieving the fundamental safety objective of protecting people and the environment from harmful effects of ionizing radiation. Borehole disposal is particularly suitable, however, for States (or regional groupings of States) that have limited amounts of waste.

1.8. There is potential to develop safe borehole disposal facilities of various designs and employing various waste processing and conditioning methods, for example facilities with various numbers of boreholes or boreholes with various diameters. The Safety Guide does not prescribe the disposal methods to be used but provides for flexibility in the development, commissioning, operation, closure and institutional control of a borehole disposal facility to suit the particular waste and the circumstances faced, as long as safety is ensured and demonstrated in the facility safety case. However, in providing recommendations on borehole disposal, this Safety Guide does describe a reference borehole disposal concept that involves the conditioning and disposal of the radioactive waste described in para. 1.1 using cement based and stainless steel engineered barriers and narrow diameter boreholes (see paras 2.12–2.19). Furthermore, in the light of experiences in various States, this Safety Guide focuses on borehole disposal at depths that are sufficient, in conjunction with other factors, to avoid adverse effects on safety owing to inadvertent human intrusion.[5]

1.9. In this Safety Guide, it is assumed that the transport of radioactive material as defined in IAEA Safety Standards Series No. SSR-6 (Rev. 1), Regulations for the Safe Transport of Radioactive Material, 2018 Edition [12], is conducted in accordance with the requirements established in SSR-6 (Rev. 1).

1.10. This Safety Guide addresses the predisposal management of the waste described in para. 1.1 and its disposal in borehole disposal facilities along with the

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[4] In IAEA Safety Standards Series No. GSG-1, Classification of Radioactive Waste [11], spent fuel that has been declared as radioactive waste is included in high level waste. Annex III to GSG-1 indicates that highly active disused sealed radioactive sources (e.g. 1 PBq Cs-137 sources) would not be classified as high level waste and so are within the scope of this Safety Guide.

[5] Radioactive waste disposal facilities comprising rock caverns, silos and tunnels at depths of up to a few tens of metres underground are near surface disposal facilities [4], and recommendations on these are provided in SSG-29 [9].

interdependences between the two. The Safety Guide addresses both operational safety and post-closure safety at borehole disposal facilities.

1.11. It is recognized that radioactive waste disposal is carried out within a wider context that involves consideration of financial, economic and social issues; issues of conventional safety, security and planning; and aspects of environmental protection not related to protection from exposure to ionizing radiation. Although these wider issues are not specifically addressed in this Safety Guide, some information is provided in para. I.7 of Appendix I.

1.12. This Safety Guide is intended for use by persons involved in the implementation and regulation of the safe disposal of radioactive waste, as described in para. 1.1, in borehole disposal facilities.

STRUCTURE

1.13. Section 2 provides an overview of borehole disposal and describes a reference borehole disposal concept for the waste identified in para. 1.1. Section 3 provides recommendations on fulfilling the requirements on the legal and organizational infrastructure. Sections 4 and 5 focus on how an adequate level of safety may be achieved and demonstrated. Section 6 provides recommendations on developing a borehole disposal facility. Section 7 provides recommendations on measures to give additional assurance of safety. Section 8 addresses existing borehole disposal facilities. The two appendices complement the main text with respect to siting and site characterization for borehole disposal facilities and generic post-closure safety assessment for borehole disposal facilities. The two annexes address other borehole disposal concepts and disposal depth.

2. OVERVIEW OF BOREHOLE DISPOSAL AND ITS IMPLEMENTATION

BOREHOLE DISPOSAL OF DISUSED SEALED RADIOACTIVE SOURCES

2.1. Paragraph 1.6 of SSR-5 [4] states:

> "The preferred strategy for the management of all radioactive waste is to contain it (i.e. to confine the radionuclides to within the waste matrix, the packaging and the disposal facility) and to isolate it from the accessible biosphere."

2.2. Paragraph 1.10 of SSR-5 [4] states (footnote omitted):

> "The specific aims of disposal are:
>
> (a) To contain the waste;
> (b) To isolate the waste from the accessible biosphere and to reduce substantially the likelihood of, and all possible consequences of, inadvertent human intrusion into the waste;
> (c) To inhibit, reduce and delay the migration of radionuclides at any time from the waste to the accessible biosphere;
> (d) To ensure that the amounts of radionuclides reaching the accessible biosphere due to any migration from the disposal facility are such that possible radiological consequences are acceptably low at all times."

2.3. The IAEA safety standards provide recommendations on three options for the disposal[6] of radioactive waste: near surface disposal[7], borehole disposal and geological disposal. Safety is achieved through a combination of natural and engineered barriers that provide sufficient containment and isolation of the waste to fulfil the safety requirements, thereby ensuring an adequate level of protection of people and the environment.

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[6] Disposal is the emplacement of waste in an appropriate facility without the intention of retrieval [5].

[7] Near surface disposal facilities include disposal facilities at the surface and at depths of up to a few tens of metres underground (see SSG-29 [9]).

2.4. In borehole disposal, containment and isolation should be provided by a multi-barrier system, each element of which fulfils one or more safety functions over different timescales. The host geological environment and the depth of disposal should be chosen so that the disposal facility provides the necessary containment and isolation. For example, a waste disposal zone should not be located in an aquifer (see para. 6.44). Isolation should be provided inter alia by reducing the probability of inadvertent human intrusion.

2.5. Borehole disposal facilities have to comply with the requirements and standards of safety that apply to all disposal facilities. In accordance with SSR-5 [4], the operating organization[8] is required to develop a site specific safety case, including safety assessments, to evaluate and demonstrate facility safety, and to determine the types and amounts of radioactive waste that can safely be disposed of at the facility. The safety assessments have to comply with the requirements established in SSR-5 [4] and in IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Facilities and Activities [13].

2.6. Borehole disposal offers flexibility concerning the possible depth of waste disposal (see paras 4.33–4.36); the range of depths that may be accessed by boreholes can reach from the surface down to and beyond the depths typically associated with geological disposal facilities[9]. The depth chosen for the disposal of radioactive waste in a particular facility should be determined, taking account of factors including the need to reduce the probability of inadvertent human intrusion (e.g. by a period of post-closure institutional control), the nature of the waste (e.g. activities and half-lives of radionuclide present, durability of waste package and waste form), the suitability of the host geology, the hydrogeological and hydrogeochemical conditions, the possible influence of climatic and other surface related processes (e.g. erosion) and the results of the safety assessments. The previous version of this Safety Guide relied on a 1987 report [14] in setting a recommended minimum depth of 30 m for disposal of radioactive waste in a

[8] The operating organization is any organization or person applying for authorization or authorized to operate an authorized facility or to conduct an authorized activity and responsible for its safety. This includes, inter alia, private individuals, governmental bodies, consignors or carriers, licensees, hospitals and self-employed persons [5]. The licensee is the holder of a current licence. The licensee is the person or organization having overall responsibility for a facility or activity [5]. Although the operating organization does not have to be the licensee (e.g. the operating organization could be a supply chain organization), in practice, for an authorized facility, the operating organization is normally also the registrant or licensee. However, the separate terms are retained to refer to the two different capacities [5].

[9] Geological disposal involves disposal in a facility at least a few hundred metres below ground level (see SSR-5 [4]).

borehole disposal facility. At that time, 30 m was regarded as the depth beyond which human intrusion was limited to drilling and significant excavation activities, such as tunnelling, quarrying and mining [14]. Since Ref. [14] was published, however, significant developments have been made in the construction of high-rise buildings and other infrastructure, and other types of excavation deeper than 30 m have become commonplace. In the light of these developments and of practices and experiences in Member States (see Annex II), and given that it is easy and inexpensive (in comparison with the total cost of a waste disposal programme) to drill narrow diameter boreholes, this Safety Guide recommends a minimum depth for borehole disposal of many tens of metres[10].

2.7. A borehole disposal facility at a specific site can include one or more boreholes. The number of boreholes should be determined, taking into consideration the inventory of waste to be disposed of (the number and total length of waste packages and their spacing in the borehole) and the factors identified in para. 2.6. Each borehole should be fitted with a casing, which is sealed at the bottom of the borehole to provide a suitable and well defined disposal volume. More information on the casing of disposal boreholes is given in Ref. [15] and in paras 2.14, 6.34, 6.44 and 6.46 of this Safety Guide. The spacing between boreholes should be optimized, taking account of the characteristics of the site, the practicalities of drilling and operations, the potential for interactions between boreholes and the results of safety assessment.

2.8. A waste package is the product of conditioning the waste and includes one or more waste containers. The operating organization should use waste packages that are suitable for the borehole disposal facility. The size of the waste packages for disposal, the diameter of the borehole and the size of the disused sealed radioactive sources should be compatible. Backfill material should be used to fill spaces inside the waste packages, spaces in the boreholes outside the waste packages, and, as appropriate, spaces between borehole casing and the host geology. The waste package, backfill, host geological environment and surrounding rocks should provide a multi-barrier system that ensures a safe and sustainable management solution for the radioactive waste.

2.9. In accordance with Requirement 5 of SSR-5 [4], the safety of a disposal facility is required to be ensured by passive means to the fullest extent possible and the need for actions to be taken after closure of the facility is required to

[10] A precise, single value for minimum depth cannot be provided. The phrase ‘many tens of metres’ is used here to convey that the recommended minimum depth is greater than both ‘a few tens of metres’ (e.g. 30–50 m) and ‘several tens of metres’ (e.g. 50–80 m).

be minimized. The operating organization should design the borehole disposal facility in such a way that safety is provided by passive means through the inherent characteristics of the components of the disposal system (i.e. the waste package, backfill materials and the host geological environment) and no actions need to be taken to ensure safety after the release of the site from regulatory control. Recommendations on monitoring at a borehole disposal facility are provided in Section 7.

2.10. When planning waste disposal, consideration should be given to the volumes of waste that need to be disposed of and to the capacities and dimensions of existing and planned disposal facilities. Borehole disposal facilities are constructed by drilling and, therefore, have a geometry that is generally suitable for relatively small volumes of radioactive waste as compared with the volumes that can be disposed of in near surface or geological disposal facilities.[11]

2.11. The operating organization should optimize the design of a borehole disposal facility so that, in combination with appropriate facility siting (see paras 6.14–6.21 and Appendix I) and disposal at a sufficient depth, it is improbable that radioactive waste disposed of in a borehole will be affected by inadvertent human intrusion (see para. 5.10 of SSR-5 [4]) or other potential causes of the waste returning to the surface.

Reference concept for borehole disposal of disused sealed radioactive sources

2.12. This section outlines a reference concept for the disposal of the radioactive waste described in para. 1.1, which involves one or more vertical boreholes drilled using widely available drilling technology. Other borehole disposal concepts are described in para. 2.29 and Annex I. The dimensions and materials described in this section are for the reference borehole disposal concept; they can and should be adapted to meet the safety requirements for other borehole disposal concepts. More details on the reference borehole disposal concept are provided in Refs [15, 17–20].

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[11] The volume capacity of borehole disposal facilities to receive conditioned radioactive waste is limited by the diameter and length of the borehole in host rocks suitable for safe disposal. The term ‘small volumes’ here means volumes that are significantly smaller than the thousands to hundreds of thousands of cubic metres of waste that are disposed of in near surface disposal facilities. It cannot necessarily be assumed that radioactive waste created as a result of an accident with disused sealed radioactive sources (e.g. the accident that occurred in Goiânia, Brazil, which generated approximately 3500 m^3 of radioactive waste [16]) can be disposed of by borehole disposal.

2.13. Reference [15] introduces a concept for the disposal of disused sealed radioactive sources in boreholes. The concept was designed as a viable option for States that do not have extensive nuclear programmes or large radioactive waste disposal programmes (e.g. including the development of large geological disposal facilities), recognizing the associated security issues, States' obligations under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [6] and the recommendations of the Code of Conduct on the Safety and Security of Radioactive Sources [7] to implement a safe disposal solution and thereby protect people (both current and future generations) and the environment. While the borehole disposal concept has been improved since Ref. [15] was published (see Refs [17, 18]), it remains essentially the same and has become a reference borehole disposal concept. In summary, the reference borehole disposal concept entails the emplacement of disused sealed radioactive sources that have been declared as radioactive waste, and possibly a small volume of low and intermediate level secondary waste generated during the management of these sources, in a suitably located borehole disposal facility drilled and operated from the surface.

2.14. In the reference borehole disposal concept, the borehole is assumed to be vertical and straight, and to have a diameter of 260 mm, which should be large enough to accommodate the borehole casing, backfill and waste packages. Drilling rigs that can drill a 260 mm diameter hole are widely available because boreholes of this size are often used for water abstraction. In the reference borehole disposal concept, the borehole is cased to full depth using high density polyethylene tubing whose purpose is to facilitate operations such as emplacement of the waste packages into the borehole. In the reference borehole disposal concept, centralizers are placed between the borehole side wall and the casing to ensure that the casing stays in the centre of the borehole and to provide a uniform gap into which to emplace backfill grout (cement slurry) [15]. In the reference borehole disposal concept, the bottom of the casing is sealed with a cement based plug; this, together with the cement based backfill in the annulus between the borehole side wall and the outside of the casing, prevents the ingress of groundwater and, thus, facilitates the waste emplacement operations. The cement based material used in the reference borehole disposal concept comprises a sulphate-resistant Portland cement and sand with a maximum particle size of 4 mm. Alternative materials (e.g. for the casings, cements or backfills) can be used, but in all cases the operating organization should justify the choice of material, taking account of its intended purposes, safety functions and performance in the conditions of the disposal system.

2.15. In the reference borehole disposal concept, disused sealed radioactive sources are placed inside a stainless steel disposal capsule, which is closed by fully welding on a stainless steel lid [15]. The thickness of the weld should be at least as thick as the disposal capsule walls and the weld should be tested for leaks. In the reference borehole disposal concept, the sealed disposal capsule containing the radioactive sources is then placed inside a precast cement based insert inside a stainless steel waste container. In the reference borehole disposal concept, the cement based insert comprises two pieces: a larger body part and a lid. The lid of the insert is fixed to the insert body using a small amount of liquid grout (cement slurry), which will set and solidify. In the reference borehole disposal concept, the waste container is closed by fully welding on a stainless steel lid [15]. The weld should be at least as thick as the waste container walls. Low and intermediate level secondary waste generated during the management of the disused sealed radioactive sources is placed inside a stainless steel waste container, and the waste container is closed by welding on a stainless steel lid. The weld should be at least as thick as the waste container walls. Alternative materials and designs (e.g. for the capsules, inserts or containers) may be used, but in all cases the operating organization should justify the choice of material and the design of disposal facility components, taking account of their intended purposes, safety functions and performance in the conditions of the disposal system. Disposal capsules, inserts and waste containers should be made in diameters and lengths that accommodate the sizes of the sources to be disposed of and taking account of the diameter of the borehole and casing.

2.16. The composition of the stainless steel used for the disposal capsules and containers and their lids should be the same to avoid the possibility of processes such as galvanic corrosion. The type of stainless steel described in Ref. [15] is a 316L stainless steel. The choice of stainless steel and other materials for the disposal capsules and containers should be appropriate for the disused sealed radioactive sources and radioactive waste to be disposed of (e.g. in terms of their potential to generate heat and to cause radiolysis of water; see Appendix II).

2.17. In the reference borehole disposal concept, the waste packages are emplaced in the borehole, and the spaces around the waste packages in the borehole are filled using cement based backfill. The operating organization should determine the total length of disposal zone needed by considering the number and lengths of the waste packages and the amount of space between them. The operating organization should determine the number of boreholes and disposal zones needed, as well as the locations and depths of the disposal zones, by considering the total length of disposal zone needed and the characteristics of the host rocks.

2.18. Figure 1 illustrates an example of a disposal facility for disused sealed radioactive sources with two boreholes; the inset highlights the components present in the disposal zone.

2.19. In the reference borehole disposal concept, a steel deflection plate (shown as a red triangle in Fig. 1) should be inserted into the borehole above the uppermost waste package. This deflection plate (referred to as an anti-intrusion plate in Ref. [15]) should be designed and emplaced to prevent a drill bit from running into the waste packages if someone were to drill into the borehole. In other borehole disposal concepts, the operating organization should consider installing a deflection plate and or other engineered components, as necessary, to reduce the probability of human intrusion. In the reference borehole disposal concept, the section of the borehole above the deflection plate is filled with cement based backfill to within a few metres of the ground surface, and the top section of the borehole above the backfill is filled with soil so that the borehole is undetectable without special equipment [15]. Different materials and depth intervals can be used, but in all cases the operating organization should justify the choice of material and the design of disposal facility components, taking account of their intended purposes, safety functions and performance in the conditions of the disposal system. For example, depending on site specific conditions, the operating organization could consider using clay based backfills.

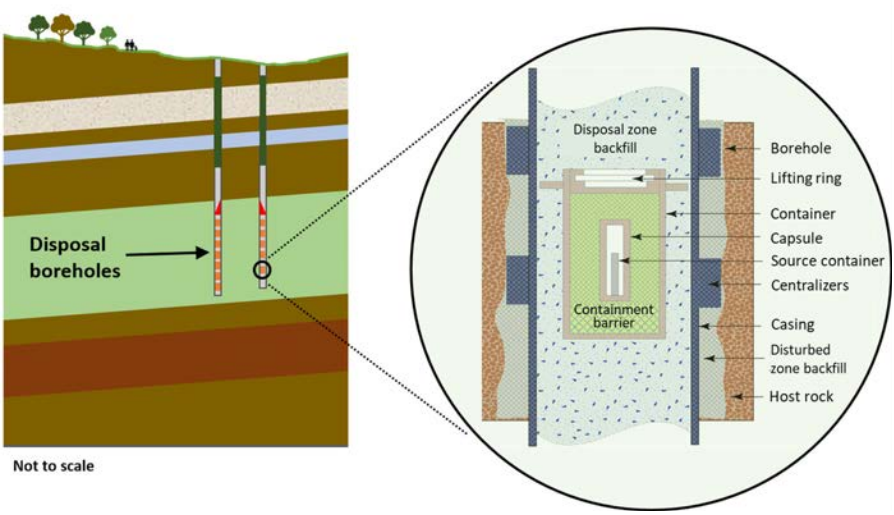

FIG. 1. Example of a borehole disposal system for disused sealed radioactive sources.

Periods in borehole disposal of disused sealed radioactive sources

2.20. In accordance with Requirement 11 of SSR-5 [4], a step by step approach is required to be followed in developing a disposal facility. It is probable that a programme for developing a borehole disposal facility (including site characterization and selection, safety case development, interactions with interested parties and authorization) will take several years to a decade to implement. Once the necessary authorization processes are completed, however, the operation and closure of a disposal borehole is not likely to last more than a few months to a year. The step by step approach should include formal stages at which the programme is reviewed and evaluations of safety are undertaken before decisions are made to progress. Such a step by step approach allows confidence in safety to be increased gradually and helps to ensure that decisions are well founded. The regulatory body should undertake reviews at each major decision point. These reviews also provide opportunities for independent technical review and the involvement of interested parties.

2.21. The operating organization should ensure that the step by step process of facility development is flexible enough for the disposal programme to be adapted in response to new scientific and technical information that becomes available. Throughout the development, commissioning, operation, closure and institutional control of a borehole disposal facility, the operating organization and the regulatory body should follow a graded approach so that the effort expended and the controls applied are commensurate with the hazard and the level of risk associated with the waste. Information on how the graded approach can be applied to post-closure safety assessment for borehole disposal is provided in Ref. [20].

2.22. It is convenient to group the development, commissioning, operation, closure and institutional control of a radioactive waste disposal facility into three periods, namely the pre-operational (or development) period, the operational period and the post-closure period (see para. 1.22 of SSR-5 [4]). Various activities take place during these three periods depending, inter alia, on the disposal concept. The subsections below describe the activities that should take place during these periods for borehole disposal.

Pre-operational period

2.23. The pre-operational period includes all of the activities that can be conducted before waste is received at the site. The extent of these activities should reflect the situation in the State and may include waste characterization; the definition of the inventory of waste for disposal; disposal site investigation, characterization and selection; site specific disposal facility design; development of the safety case and security plan; regulatory review and authorization; and construction. Waste characterization and processing for storage and disposal may occur at authorized facilities at other sites in the State. In this period, the operating organization should develop its management system and those aspects of the safety case for the disposal facility site necessary to obtain an authorization for the borehole disposal facility. The operating organization should conduct environmental impact assessment studies as necessary and should develop a safety case for the facility that includes appropriate safety assessments (including operational and post-closure safety assessments) in accordance with the national, legal and regulatory framework.

Operational period

2.24. The operational period begins after an authorization has been obtained. As waste management activities could result in radiation exposures during this period, these activities are required to be authorized by the regulatory body and are subject to controls in accordance with the requirements for radiation protection and safety of radiation sources established in GSR Part 3 [2] and GSR Part 5 [3]. The operating organization should conduct predisposal management activities in accordance with the recommendations provided in IAEA Safety Standards Series Nos WS-G-6.1, Storage of Radioactive Waste [21], and SSG-45, Predisposal Management of Radioactive Waste from the Use of Radioactive Material in Medicine, Industry, Agriculture, Research and Education [22].

2.25. In some cases, the waste received at the site has already been processed. Once it has passed through the applicable waste acceptance procedures and undergone the necessary period of buffer storage, this waste can be emplaced immediately. If the waste received at the site has not already been processed, the operating organization should undertake the necessary predisposal management activities (e.g. dismantling of devices containing disused sealed radioactive sources, removal of the disused sealed radioactive sources, conditioning), using appropriate facilities and following appropriate procedures. The operating organization should design and conduct the waste processing activities in such a way as to avoid any discharges[12]. If discharges cannot be avoided, the operating organization should ensure that they meet established standards and requirements. Processing facilities may be fixed or mobile. IAEA Safety Standards Series No. RS-G-1.9, Categorization of Radioactive Sources [23], recognizes five

[12] Discharges are planned and controlled releases of (usually gaseous or liquid) radioactive substances to the environment [5].

categories of radioactive sources. Hot cell facilities, such as the one described in Ref. [24], typically have sufficient shielding to be used for the processing of disused sealed radioactive sources in all five categories. The processing of disused sealed radioactive sources in Categories 3–5 can be done safely with less shielding than for sources in Categories 1 and 2 and can be performed using a facility such as the one described in Ref. [24]. Whichever facilities are used, the operating organization should provide sufficient shielding to ensure protection of workers appropriate to the nature of the waste, including shielding from both gamma and neutron sources, if necessary. The operating organization should provide appropriate storage facilities at the site to facilitate the waste management process.

2.26. The operation of a borehole disposal facility includes handling of waste packages, emplacement of waste packages in the borehole, emplacement of engineered barriers (e.g. borehole backfill, seals, anti-intrusion barriers) and facility closure. The operating organization has to conduct all of these activities in accordance with the requirements established in SSR-5 [4].

2.27. To comply with the requirements established in IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [25], all operations should be conducted in accordance with an appropriate management system by suitably qualified and experienced personnel, trained in accordance with clear operating procedures (see also IAEA Safety Standards Series No. GSG-16, Leadership, Management and Culture for Safety in Radioactive Waste Management [26]). Traceable records should be created that describe and characterize the site, the facilities, the radioactive waste and the waste management activities undertaken. The range of information and the level of detail to be recorded should be specified in the management system, taking account of the graded approach. Important safety related information concerning radioactive waste management should be retained and controlled. Facilities other than the boreholes that were used during operations are required to be decommissioned in accordance with IAEA Safety Standards Series No. GSR Part 6, Decommissioning of Facilities [27].

Post-closure period

2.28. The post-closure period begins immediately after the borehole disposal facility has been closed. In accordance with Requirement 5 of SSR-5 [4], after facility closure, the safety of the borehole disposal facility is required to be provided by passive features inherent in the characteristics of the site and the facility. Some forms of institutional control can continue after closure; initially these may be active controls (e.g. maintenance of site security, monitoring (see para. 7.14)), but active controls cannot be maintained indefinitely, so passive institutional controls become more relevant later. Passive institutional controls may include, for example, administrative restrictions on land use that provide additional assurance that inadvertent human intrusion will be improbable. The authorization for the disposal facility should be terminated when the relevant technical, legal and financial requirements have been fulfilled.

OTHER BOREHOLE DISPOSAL CONCEPTS

2.29. Several other concepts have been developed, involving the use of boreholes for radioactive waste storage or disposal, and some of these have been implemented for various types of radioactive waste (see Annex I). In accordance with the objectives and scope of this Safety Guide, the borehole disposal concepts described in Annex I for waste types other than those identified in para. 1.1 are not considered in further detail, although the information provided may be of general interest. The recommendations provided in this Safety Guide, particularly those provided in Section 8, should be considered as a basis for reassessing and, where appropriate, upgrading the safety of existing borehole disposal facilities that contain waste of the types identified in para. 1.1.

3. LEGAL AND ORGANIZATIONAL INFRASTRUCTURE FOR A BOREHOLE DISPOSAL FACILITY

3.1. Responsibilities for the development, commissioning, operation, closure and institutional control of a borehole disposal facility are distributed among three types of organization: the national government, the appointed regulatory body (or bodies) and the operating organization of the facility.

RESPONSIBILITIES OF THE GOVERNMENT

3.2. The government is required to establish a national policy and strategy for safety, as set out in Requirement 1 of IAEA Safety Standards Series No. GSR

Part 1 (Rev. 1), Governmental, Legal and Regulatory Framework for Safety [28]. Further, Requirement 2 of GSR Part 5 [3] states (references omitted):

> "**To ensure the effective management and control of radioactive waste, the government shall ensure that a national policy and a strategy for radioactive waste management are established. The policy and strategy shall be appropriate for the nature and the amount of the radioactive waste in the State, shall indicate the regulatory control required, and shall consider relevant societal factors. The policy and strategy shall be compatible with the fundamental safety principles and with international instruments, conventions and codes that have been ratified by the State. The national policy and strategy shall form the basis for decision making with respect to the management of radioactive waste.**"

3.3. In establishing a national policy and a strategy for radioactive waste management, the government has responsibilities including the following:

(a) To establish and implement a decision making process for designating a disused sealed radioactive source as radioactive waste (see Ref. [8]).
(b) To develop and maintain a comprehensive national inventory of radioactive waste (including disused sealed radioactive sources declared as radioactive waste).
(c) To ensure that the preferred options for radioactive waste management are identified (see para. 3.5 of GSR Part 5 [3]).
(d) To ensure that due consideration is given to interdependences between the various steps in waste management.
(e) To ensure that the long term storage of disused sealed radioactive sources that have not been declared as radioactive waste is avoided.
(f) To develop a disposal programme for disused sealed radioactive sources designated as radioactive waste that is compatible with the State's overall radioactive waste management programme[13] (see Ref. [8]).
(g) To ensure that consideration is given to the national need for one or more radioactive waste disposal facilities and to the type(s) of facility that might

[13] In a radioactive waste management programme, a group of related waste management projects is managed in a coordinated way and with a particular long term aim in order to obtain benefits and control not available from managing the projects individually.

be the most appropriate, depending on the inventory of disused sealed radioactive sources and other radioactive waste for disposal in the State.[14]

(h) To ensure that safety is paramount among the factors considered when selecting appropriate types of disposal facility for disused sealed radioactive sources and other radioactive waste. Other factors that should be considered include the inventory of disused sealed radioactive sources and other radioactive waste for disposal in the State, the potential need for transport of radioactive material, and relevant socioeconomic factors.

(i) To ensure that the resources devoted to safety by the licensee, and that the scope and stringency of regulations and their application, are commensurate with the magnitude of the radiation risks and their amenability to control (see para. 3.24 of SF-1 [1]).[15]

3.4. Requirement 1 of SSR-5 [4] states:

"**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.**"

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[14] For example, in some States a national strategy for the disposal of disused sealed radioactive sources might include the use of one or more borehole disposal facilities, in other States it might include near surface disposal for low level waste and borehole disposal for disused sealed radioactive sources, while in yet other States it might include near surface disposal for low level waste and some short lived disused sealed radioactive sources, and geological disposal for other disused sealed radioactive sources and waste.

[15] The number of disused sealed radioactive sources in States varies from just a few sources in some States, to well over 100 000 sources in other States. The volume of packaged radioactive waste envisaged to result from the conditioning of disused sealed radioactive sources is estimated to vary from less than ten cubic metres in typical small States to several hundred cubic metres in some large States. Although these volumes are relatively small in comparison to the volumes of other waste types present in some States, the hazard associated with some disused sealed radioactive sources can be very high.

3.5. In accordance with Requirements 1–3 of SSR-5 [4], the governmental, legal and regulatory framework has to include the following:

(a) Establishing or identifying legally responsible organizations for the development, commissioning, operation, closure and institutional control of borehole disposal facilities;
(b) Setting clearly defined legal, technical and financial responsibilities for organizations that are to be involved in the development, commissioning, operation, closure and institutional control of borehole disposal facilities;
(c) Ensuring the adequacy and security of financial provisions, for example by requiring the operating organizations of borehole disposal facilities to establish funds for facility closure and any subsequent controls for which they are responsible;
(d) Defining the overall process for the development, commissioning, operation, closure and institutional control of borehole disposal facilities, including the legal and regulatory requirements at each step, and the processes for decision making and the involvement of interested parties;
(e) Defining legal, technical and financial responsibilities and, if necessary, providing for any institutional arrangements that are envisaged after disposal facility closure, including monitoring and ensuring the nuclear security of the disposed waste;
(f) Establishing a regulatory body with appropriate responsibilities for oversight of predisposal waste management facilities and borehole disposal facilities;
(g) Ensuring that the necessary scientific and technical expertise (e.g. from national institutes for health, radiation protection, geology, hydrology and other relevant disciplines) is available to both the operating organization and the regulatory body.

3.6. Requirement 4 of GSR Part 1 (Rev. 1) [28] states:

> "**The government shall ensure that the regulatory body is effectively independent in its safety related decision making and that it has functional separation from entities having responsibilities or interests that could unduly influence its decision making.**"

3.7. To fulfil this requirement, the government should ensure that the regulatory body possesses the expertise to provide proper oversight and objectivity in evaluating predisposal waste management and disposal activities at borehole disposal facilities and that individuals working within the regulatory body are sufficiently independent of influence from waste generators and from operating organizations. The government should perform periodic reviews to evaluate the effectiveness of the regulatory body and its ability to fulfil its mission.

3.8. The government should ensure that interested parties that are directly or indirectly affected by borehole disposal facilities and activities are involved in making decisions at the appropriate stages. A clear, formal process for identifying interested parties and decision makers should be established to facilitate a meaningful exchange of information and views. The ways in which interested parties are involved in decision making processes concerning the borehole disposal of the radioactive waste described in para. 1.1 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 operating organizations.

RESPONSIBILITIES OF THE REGULATORY BODY

3.9. The regulatory body is required to ensure that a comprehensive national register of sealed radioactive sources is developed and maintained (see para. 4.63 of GSR Part 1 (Rev. 1) [28]).

3.10. Requirement 3 of GSR Part 5 establishes general requirements regarding the responsibilities of the regulatory body for radioactive waste management facilities and activities, while Requirement 2 of SSR-5 [4] states:

> "**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.**"

3.11. The regulatory body should develop and implement an effective process for establishing regulatory requirements for the development of a borehole disposal facility and should involve interested parties in that process. The regulatory requirements should be established well in advance of any authorization application. The regulatory requirements should cover all stages in the development, commissioning, operation, closure and institutional control of borehole disposal facilities and activities; should specify which principles, requirements and criteria will be used in regulating the facilities and activities; and should require the operating organization to establish arrangements for what should happen in the case of non-compliance, events and accidents. Model regulations for borehole disposal are provided in Ref. [29].

3.12. The regulatory body should provide guidance on how the regulatory requirements will be implemented, on the procedures that the operating organization should follow in making applications for authorization and safety case submissions, and on the probable timescales for regulatory review and assessment of safety cases and applications for authorization. The regulatory body should ensure that the regulatory requirements are both comprehensive and commensurate with the scale and potential hazard of the facilities and activities under regulatory control.

3.13. The regulatory body should define and follow a step by step approach to authorization for borehole disposal facilities. The regulatory body should encourage the operating organization, as far as possible, to describe the disposal programme in its entirety in the safety case and at each step in its application for authorization so that early steps in the disposal programme can be seen to be compatible with later ones and the regulatory body is informed of the long term safety of the facility when reviewing applications for initial steps in the facility development process.

3.14. The regulatory body should not grant an authorization for borehole facility construction, commissioning or operation until it has completed its regulatory review and assessment of the relevant applications for authorization and of the safety case. It should also first determine that the application is complete and the safety case has presented sufficient evidence to provide reasonable assurance that the safety requirements will be fulfilled and that funds are, or will be, available to finance the waste disposal programme through all of the relevant steps (e.g. development, commissioning, operation, closure and institutional control).

3.15. The regulatory body should ensure that the authorization has sufficient flexibility to accommodate changes (e.g. in disposal facility design) through a change control process. In the authorization, the regulatory body should specify the conditions under which the operating organization can make changes to the disposal system without needing to apply to the regulatory body for a new authorization. The burden imposed by the change control process should be commensurate with the scale of the changes and their potential implications for safety.

3.16. The regulatory body should develop and implement processes and procedures through which it sets conditions for the development, commissioning, operation, closure and institutional control of each borehole disposal facility. These processes and procedures should cover, but not be limited to, the regulatory review and assessment of the safety case for the facility and authorization with appropriate conditions.

3.17. The regulatory body should undertake an independent review and assessment of the safety case for the borehole disposal facility. The regulatory body should consider critically the available evidence and the level of confidence that can be held in each aspect of the safety case, for example in the effectiveness of the institutional controls assumed in the safety case.

3.18. General recommendations on regulatory review and assessment are provided in IAEA Safety Standards Series No. GSG-13, Functions and Processes of the Regulatory Body for Safety [30]. The scope of a regulatory review and assessment should not be restricted solely to the documented safety case, but should consider a wide range of aspects, including the following:

(a) Whether the operating organization has the necessary competences and resources (e.g. human, financial);
(b) Whether the site is suitable;
(c) Whether all aspects of the facility design and the limits and controls are adequate;
(d) Whether the operating organization uses an appropriate safety management system;
(e) Whether the safety assessments are adequate;
(f) Whether there are additional requirements or conditions that should be imposed and, if these have already been imposed, whether they have been fulfilled.

3.19. The regulatory body should develop a plan for managing the regulatory review and assessment process in relation to borehole disposal facilities; this plan should cover staffing and resources, the objectives and scope of the review and assessment, timescales and scheduling, the allocation of responsibilities, the training of personnel, the processes and procedures to be followed, monitoring of progress, meetings with the operating organization, the role of technical advisors, and interactions with the public and other interested parties. Recommendations for the regulatory body on interacting with interested parties are provided in IAEA Safety Standards Series No. GSG-6, Communication and Consultation with Interested Parties by the Regulatory Body [31].

3.20. Regulatory reviews and assessments of borehole disposal facility safety cases should reflect the scale and potential hazard of the facilities and activities. The regulatory body should prioritize issues according to their importance to safety.

3.21. The regulatory body should ensure that it has sufficient capability and capacity to perform and manage programmes for the review and assessment of borehole disposal facility safety cases in order to determine whether the facility is and will remain safe and the conditions of authorization that should be specified and attached to the authorization. Regulatory review and assessment of the safety case and authorization application may be undertaken in various ways and may include the use of independent external experts in accordance with the recommendations provided in IAEA Safety Standards Series No. GSG-12, Organization, Management and Staffing of the Regulatory Body for Safety [32].

3.22. The regulatory body should check that the operating organization exercises adequate control over the borehole disposal facility. The regulatory body should verify that the conditions of authorizations are being met, including by checking that the operating organization is properly developing and complying with waste acceptance criteria and by conducting appropriate regulatory inspection and enforcement activities.

3.23. The regulatory body should develop a regulatory inspection plan for activities important to safety, such as construction, operation and closure (see GSG-13 [30]). The regulatory inspections should involve verifying the operating organization's compliance with the authorization, safety case and operating procedures and assessing the safety culture of the operating organization's staff and contractors (see GSG-16 [26]).

Radiation protection in the operational period

3.24. In accordance with GSR Part 3 [2], the regulatory body is required to establish appropriate requirements for radiation protection. In accordance with SF-1 [1], protection must be optimized to provide the highest level of safety that can reasonably be achieved. Paragraph 3.22 of SF-1 [1] states:

> "To determine whether radiation risks are as low as reasonably achievable, all such risks, whether arising from normal operations or from abnormal or accident conditions, must be assessed (using a graded approach) a priori and periodically reassessed throughout the lifetime of facilities and activities."

3.25. The following key requirements apply in the operational period of a borehole disposal facility:

(a) In relation to justification, Requirement 10 of GSR Part 3 [2] states that “**The government or the regulatory body shall ensure that only justified practices are authorized.**” As indicated in para. 2.5 of GSR Part 5 [3], radioactive waste management is part of the ‘practice’ giving rise to the waste and as such does not require separate justification.
(b) In relation to optimization, Requirement 11 of GSR Part 3 [2] states that “**The government or the regulatory body shall establish and enforce requirements for the optimization of protection and safety, and registrants and licensees shall ensure that protection and safety is optimized.**”
(c) In relation to dose limits, Requirement 12 of GSR Part 3 [2] states that “**The government or the regulatory body shall establish dose limits for occupational exposure and public exposure, and registrants and licensees shall apply these limits.**”
(d) In relation to dose and risk constraints, para. 3.120 of GSR Part 3 [2] states that “The government or the regulatory body shall establish or approve constraints on dose and constraints on risk to be used in the optimization of protection and safety for members of the public.” Dose and risk constraints are established at levels below those of the corresponding limits because exposures could be received from more than one source. Risk here refers to the risk of all cancers and the risk of hereditary effects.

3.26. Predisposal radioactive waste management activities may lead to planned exposures. Radioactive waste disposal activities may lead to planned exposures of workers and the public in the operational period of the borehole disposal facility. Schedule III of GSR Part 3 [2] sets out the following key dose limits that apply to radioactive waste management (footnotes omitted):

> “For occupational exposure of workers over the age of 18 years, the dose limits are:
>
> (a) An effective dose of 20 mSv per year averaged over five consecutive years (100 mSv in 5 years) and of 50 mSv in any single year;
>
> …….

“For public exposure, the dose limits are:

(a) An effective dose of 1 mSv in a year;
(b) In special circumstances, a higher value of effective dose in a single year could apply, provided that the average effective dose over five consecutive years does not exceed 1 mSv per year”.

Radiation protection in the post-closure period

3.27. The fundamental safety objective established in SF-1 [1] is to protect people and the environment from harmful effects of ionizing radiation. Paragraph 2.15 of SSR-5 [4] states:

> “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.”

3.28. Radioactive waste disposal may lead to planned potential exposures of the public in the post-closure period; however, planned potential exposures are not certain to occur. The following key criteria apply in the post-closure period of a borehole disposal facility:

(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 [2]. This and its risk equivalent are considered criteria that are not to be exceeded in the future (see para. 2.15(a) of SSR-5 [4]).
(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 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 (see para. 2.15(b) of SSR-5 [4]).
(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 (see para. 2.15(c) of SSR-5 [4]).

(d) If human intrusion is expected to lead to a possible annual dose of more than 20 mSv (see table 8 of Ref. [33][16]) to those living around the site, then alternative options for waste disposal are to be considered (para. 2.15(d) of SSR-5 [4]).
(e) If annual doses in the range 1–20 mSv (see table 8 of Ref. [33]) 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 (see para. 2.15(b) of SSR-5 [4]).
(f) The International Commission on Radiological Protection considers that a dose rising towards 100 mSv will almost always justify protective action (see para. 241 of Ref. [33]).
(g) The International Commission on Radiological Protection indicates that exposures above 100 mSv incurred either acutely or in a year would be justified only under extreme circumstances, either because the exposure is unavoidable or in exceptional situations such as the saving of life or the prevention of a serious disaster. No other individual or societal benefit would compensate for such high exposures (see para. 236 of Ref. [33]).

RESPONSIBILITIES OF THE OPERATING ORGANIZATION

3.29. Requirement 4 of GSR Part 5 [3] establishes general requirements in relation to the responsibilities of the operating organization for the safety of radioactive waste management facilities and activities. Requirement 3 of SSR-5 [4] states:

> "**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.**"

3.30. The operating organization has prime responsibility for the safety of facilities and activities; this responsibility cannot be delegated and extends throughout all stages in the lifetime of facilities and the duration of activities until the end of regulatory control. If the operating organization employs contractors to perform

[16] The recommendations provided by the International Commission on Radiological Protection in Ref. [33] are not accepted by regulatory bodies in all Member States.

work, the operating organization retains the prime responsibility for safety and for ensuring compliance with legal and regulatory requirements (see paras 2.14 and 2.15 of GSR Part 1 (Rev. 1) [28]).

3.31. In accordance with Requirements 12–14 of SSR-5 [4], the operating organization of a borehole disposal facility is required to develop and maintain a safety case, including relevant safety assessments, on the basis of which decisions on the authorization and development, commissioning, operation, closure and institutional control of the facility will be made. The operating organization is required to submit the safety case to the regulatory body for approval. The operating organization should include in the safety case information on site selection and evaluation, design, construction, operation, closure and, if necessary, surveillance after closure. Recommendations on the safety case and safety assessment for the predisposal management of radioactive waste are provided in IAEA Safety Standards Series No. GSG-3, The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste [34]. Recommendations on the safety case and safety assessment for the disposal of radioactive waste are provided in IAEA Safety Standards Series No. SSG-23, The Safety Case and Safety Assessment for the Disposal of Radioactive Waste [35]. Detailed information specific to safety assessment for predisposal waste management is contained in Ref. [36]. Detailed information specific to post-closure safety assessment at borehole disposal facilities for disused sealed radioactive sources is contained in Refs [19, 20].

3.32. In accordance with Requirement 15 of SSR-5 [4], the operating organization has to conduct or commission investigations of sites as necessary to assess their suitability to host a borehole disposal facility and to inform decisions on site selection. The operating organization should use the safety case to plan site investigations and should integrate the results of the site investigations into the safety case.

3.33. The operating organization should seal site investigation boreholes to prevent them from acting as pathways for groundwater or gas flow and for radionuclide migration. The site investigation boreholes should be sealed in a timely manner, before the disposal facility is commissioned, and in accordance with the authorization and the safety case. The operating organization should seal site investigation boreholes in such a way that the sealed boreholes are no more permeable than the surrounding intact rocks. Further recommendations on site characterization are provided in Section 6 and Appendix I.

3.34. The operating organization should take full responsibility for radioactive sources and radioactive waste at the borehole disposal facility site. The operating organization should verify that the radioactive sources and radioactive waste are described correctly and sufficiently in the accompanying documentation. For disused sealed radioactive sources, the description should include the following information:

(a) The radionuclide, and its half-life and activity at a specified date;
(b) The nature of radiation emitted and the dose rate at contact and 1 m distance;
(c) The size of the unshielded source;
(d) Whether the source is known to be leaking;
(e) The physical and chemical form of the source;
(f) The container materials and thickness.

3.35. Where possible, the information recorded for each disused sealed radioactive source should include the following:

(a) Manufacturer;
(b) Source type and model;
(c) Serial number;
(d) Date of manufacture;
(e) Date of import;
(f) Date of receipt by the operating organization of the borehole disposal facility;
(g) Previous owners;
(h) Name and type of device in which the source was used and the use to which it was put.

3.36. The operating organization should attempt to fill significant gaps in the information available, consulting the manufacturers and users of the sources, the waste generators, the IAEA's International Catalogue of Sealed Radioactive Sources and Devices[17] and other information sources as appropriate.

3.37. The operating organization is responsible for processing the radioactive sources and radioactive waste, for producing waste packages suitable for borehole

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[17] The IAEA's International Catalogue of Sealed Radioactive Sources and Devices may be accessed by authorized users through the following link: https://www.iaea.org/resources/databases/international-catalogue-of-sealed-radioactive-sources-and-devices

disposal and for disposing of the waste packages. To fulfil this responsibility, the operating organization should undertake the following activities:

(a) Provide the facilities and equipment necessary for these activities and develop and follow appropriate operating procedures;
(b) Provide radiation shielding appropriate to the nature of the radioactive sources and radioactive waste to be processed;
(c) Remove the sources from the devices in which they were used and place them in appropriate capsules for temporary storage;
(d) Retrieve the sources from temporary storage and condition them for disposal;
(e) Condition waste for borehole disposal and dispose of the waste packages.

3.38. The operating organization is responsible for safety throughout all of the activities and should ensure that the activities are optimized and performed by suitably qualified and experienced personnel who have been trained in the procedures to be followed. The operating organization should ensure that interdependences in the waste management process are taken into account (e.g. that the disposal capsules and waste packages are suitable for emplacement in the borehole disposal facility).

3.39. The operating organization is responsible for all steps in the borehole disposal of the radioactive waste described in para. 1.1. The operating organization should not begin construction of the disposal borehole(s) or other activities that could significantly affect baseline (e.g. hydrogeological) conditions at the site (see IAEA Safety Standards Series No. SSG-31, Monitoring and Surveillance of Radioactive Waste Disposal Facilities [37]) until an authorization has been granted. The operating organization should engage with the regulatory body from an early stage in the process leading to the authorization and development of a borehole disposal facility. The operating organization should ensure that construction and disposal activities are performed in accordance with the approved safety case.

3.40. The operating organization is responsible for establishing limits, controls and conditions (e.g. technical specifications) on the basis of the safety assessments and the safety case to ensure that the borehole disposal facility is constructed and operated in accordance with both the safety case and the authorization conditions. The operating organization should exercise due control over the receipt, processing and emplacement of waste and should implement and maintain appropriate security measures.

3.41. The operating organization should assess the implications for safety of changes to the types or volumes of waste or to the design or operation of the facility as part of a change control process.

3.42. The operating organization is responsible for all steps necessary for the safe and sustainable decommissioning of the authorized predisposal management facilities and activities. Decommissioning is required to be conducted in accordance with the requirements established in GSR Part 6 [27].

3.43. In accordance with paras 3.15 and 3.16 of SSR-5 [4], the operating organization is required to record and retain information relevant to the safety of the borehole disposal facility, including inspection records and other assessments of compliance with regulatory requirements, the operating organization's management system and the operating procedures (see also GSG-16 [26]). If responsibility for the facility is transferred between organizations, the operating organization should provide the newly responsible organization with information relevant to the safety of the facility. In accordance with para. 3.16 of SSR-5 [4], the operating organization is required to cooperate with the regulatory body and supply all the information that the regulatory body may request to ensure safety and fulfil its responsibilities.

4. SAFETY APPROACH FOR A BOREHOLE DISPOSAL FACILITY

IMPORTANCE OF SAFETY IN THE DEVELOPMENT AND OPERATION OF A BOREHOLE DISPOSAL FACILITY

4.1. Principle 5 of SF-1 [1] states that: "**Protection must be optimized to provide the highest level of safety that can reasonably be achieved**". To fulfil this principle, the operating organization should reduce doses and risks to as far below the relevant dose and risk criteria set by the regulatory body as can be reasonably achieved, taking account of economic and social factors. The operating organization should also ensure that it has effective leadership, fosters and maintains an effective culture for safety and undertakes radioactive waste management activities in compliance with an appropriate management system (see GSG-16 [26]). Decisions on whether protection has been optimized are judgemental because of the need to consider what is reasonable and to balance information on a wide range of quantitative and qualitative factors, including present-day and potential future doses and risks, technical practicalities, costs, uncertainties and the views of interested parties. The optimization of protection should be considered at every step in the development and operation of a borehole disposal facility and discussed with interested parties in the light of the particular situation.

4.2. The operating organization should consider the following in optimizing protection at a borehole disposal facility:

(a) Arrangements for above ground operations (e.g. waste handling and transport);
(b) Provision of appropriate radiation shielding;
(c) Control of working environments;
(d) Design of predisposal waste management facilities and activities (e.g. waste processing);
(e) Design of facilities and activities to avoid discharges;
(f) Separation of facility construction activities (e.g. drilling) from waste emplacement operations;
(g) Establishment and use of procedures for operating the disposal facility (e.g. waste emplacement procedures, borehole backfilling procedures);
(h) Use of remote techniques as necessary (e.g. for waste handling and emplacement);
(i) Reduction of the possibility of accidents and minimization of their potential consequences;
(j) Minimization of the need for maintenance activities in radiation and contamination areas.

4.3. The operating organization should determine the arrangement of radioactive sources and waste in the disposal capsules and containers on the basis of the radionuclides present, the sizes of the sources and the volume of waste. The operating organization should consider using suitable information systems and/or software to help refine plans for the arrangement of sources in disposal capsules and containers.

4.4. When optimizing the protection provided in the post-closure period at a borehole disposal facility and when judging whether optimization has been achieved, the operating organization and the regulatory body should consider the following aspects, among others:

(a) Whether due attention has been paid throughout the facility development process to the post-closure safety implications of possible options, including those relating to the design and siting issues discussed in paras 6.14–6.21 and Appendix I, in particular the following:

(i) Selecting a suitable site for the borehole disposal facility;

(ii) Designing the facility in such a way that it can accommodate the volume of waste to be disposed of (e.g. by choosing an appropriate number and diameter of boreholes);

(iii) Locating the disposal zone(s) appropriately within the geological environment, taking due account of the geology, hydrogeology and geochemistry;

(iv) Providing sufficient isolation of the waste to minimize the probability of inadvertent human intrusion;

(v) Selecting appropriate borehole drilling techniques, in particular to avoid creating pathways for radionuclide migration along or close to the borehole walls.

(b) Whether the assessed potential doses and risks fall below the relevant dose and risk criteria.

(c) Whether the probability of events that might give rise to potential doses or risks above the relevant dose and risk criteria has been reasonably reduced by means of siting or design.

(d) Whether the programmes for siting, design, construction, operation and closure have been conducted in accordance with a suitable management system to ensure the necessary level of quality in safety related aspects of the project (see GSG-16 [26]).

4.5. Requirement 4 of SSR-5 [4] states:

“**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.**”

4.6. An option for the safe, secure and sustainable management of waste of the types identified in para. 1.1, including long lived and high activity disused sealed radioactive sources and their shielding materials, is to isolate the waste from the surface environment in a borehole disposal facility at depths deeper than the recommended minimum depth (see Annex II). Another safe, secure and sustainable management option for the aforementioned waste types is geological disposal (see para. 1.14(d) of SSR-5 [4]), which is being pursued in many States.

4.7. Options for the safe, secure and sustainable management of some short lived disused sealed radioactive sources might be borehole disposal at depths shallower than the recommended minimum depth or near surface disposal together with low level waste, but this is conditional on there being sufficient confidence in the ability to maintain effective active institutional control and effective engineered barriers at the disposal facility site until the hazard has reduced to safe levels. In the case of waste disposal at depths shallower than the recommended minimum depth, even if the post-closure safety assessment suggests that assessed potential doses and risks will be below relevant dose and risk criteria, this alone might not provide sufficient confidence that the disposal facility will be safe in the long term. In the safety case, the operating organization should therefore complement the results of the safety assessments with other arguments to show that the disposal facility will provide a safe, secure and sustainable solution for short lived disused sealed radioactive sources.

4.8. In developing a borehole disposal facility, the operating organization should address questions such as the following:

(a) What are the types and volumes of waste to be disposed of? What hazards are associated with the waste and how will these hazards evolve?
(b) Where should the facility be sited?
(c) How can the facility layout be designed to take advantage of the natural characteristics and barrier potential of the host environment?
(d) How should predisposal waste management operations be performed?
(e) How many boreholes should be constructed?
(f) In what depth range should waste be disposed of?
(g) What type of borehole casing should be used?
(h) Within the chosen disposal concept, are there other options that could be considered (e.g. for waste conditioning, for waste emplacement) and what would be the safety implications of these options? For example, could alternative materials be used for the engineered barriers?
(i) How can quality control be ensured throughout the management of the disused sealed radioactive sources and waste?
(j) What monitoring might be needed?
(k) What institutional controls should be put in place?

4.9. In making decisions about such questions, the operating organization should adopt a questioning attitude as part of its culture for safety and, for example, should ask if there is a safer way for things to be done. The operating organization should conduct safety assessments and demonstrate that a range of options has been considered and that the safety implications of the available options have been assessed and understood. The operating organization should document its assessments of the available options clearly, with the aim of increasing confidence in the process followed and the safety of the disposal system. At all stages, the operating organization should provide reasonable assurance of safety to the regulatory body and other interested parties.

4.10. For the reference borehole disposal concept described in Section 2, much of the documentation needed to demonstrate an optimized level of protection and safety is already available, such as the following:

(a) A generic design including the use of stainless steel and cement based engineered barriers (see Section 2);
(b) Procedures for, and a demonstration of, operational safety;
(c) A generic safety assessment (see Ref. [19]) — although this does not remove the need for a site specific assessment, the generic safety assessment does provide reasonable assurance that the disposal concept is capable of providing the necessary levels of safety in a wide range of environments.

4.11. The operating organization should follow a graded approach in applying the safety requirements in relation to the development and operation of a borehole disposal facility. The operating organization should strive to comply with the safety requirements in a way that is commensurate with the hazard and the level of risk associated with the waste to be disposed of. Further recommendations on the use of a graded approach are provided in paras 5.25–5.45.

PASSIVE MEANS FOR THE SAFETY OF A BOREHOLE DISPOSAL FACILITY

4.12. Requirement 5 of SSR-5 [4] states:

> "**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.**"

4.13. The operating organization should develop, operate and close a borehole disposal facility so that, after closure, the safety of the facility does not depend on active systems or on actions by future operating organizations, governments or generations. The assurance of safety through institutional controls in the period after closure is addressed in paras 7.12–7.21.

4.14. The operating organization should promote passive safety by taking the following measures:

(a) Siting the borehole disposal facility at a location that has stable geological conditions, low potential for the abstraction of water and/or the extraction of minerals, oil, gas or other resources (thus a low probability of inadvertent human intrusion) and groundwater that is chemically compatible with the structures, systems and components of the facility.
(b) Designing the borehole disposal facility in such a way that the waste is disposed of in solid waste forms that are chemically and physically stable, using waste packages and other structures, systems and components that are chemically and physically stable, ensuring that the waste, waste forms and structures, systems and components are compatible with each other and with the host rock; and in such a way that the waste is disposed of at depths deeper than the recommended minimum depth. The design should be consistent with the hazard posed by the waste and the degree of containment and isolation shown to be necessary in the safety case for the facility.
(c) Keeping the operational period short (e.g. a few months to a year) and avoiding keeping a borehole open for an extended period; this should be achieved by drilling and constructing a borehole and emplacing waste and backfill only when sufficient waste has been collected to allow this sequence of activities to be conducted as a reasonably sized disposal campaign (e.g. sufficient waste to fill the disposal zone in a disposal borehole). The operating organization should provide sufficient storage capacity for waste before and between disposal campaigns. During predisposal management, waste is required to be processed into a safe and passive form for storage or disposal as soon as possible; the processing is required to be consistent with the type of waste, the possible need for its storage, the anticipated disposal option, and the limits, conditions and controls established in the safety case and in the assessment of environmental impacts (see paras 4.13 and 4.14 of GSR Part 5 [3]).
(d) Closing the borehole disposal facility in such a way that does not involve subsequent maintenance of the structures, systems and components.
(e) Implementing passive institutional controls, such as the archiving of records of the borehole disposal facility, controls on land ownership and restrictions on land use. Such passive institutional controls should be designed to reduce the possibility of future inadvertent human intrusion and provide additional assurance and confidence in the safety of the facility.

UNDERSTANDING OF A BOREHOLE DISPOSAL FACILITY AND CONFIDENCE IN SAFETY

4.15. Requirement 6 of SSR-5 [4] states:

> "**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.**"

4.16. The operating organization of a borehole disposal facility should develop and demonstrate to the regulatory body and, as appropriate, to other interested parties an adequate understanding of the borehole disposal system and of the factors that could affect safety. The operating organization should define a logical and reasoned strategy for the development of this understanding that includes the conduct of systematic safety assessments in accordance with the requirements established in GSR Part 4 (Rev. 1) [13], and the recommendations provided in SSG-23 [35] and in this Safety Guide. The safety assessments should cover predisposal management activities, disposal operations and the post-closure period; they should be based on a systematic and comprehensive analysis of the features, events and processes that could affect the disposal system and on analyses of the safety functions of the structures, systems and components of the borehole disposal facility.

4.17. The operating organization should use the safety assessments to develop an understanding of how the borehole disposal facility and its surrounding environment might behave and evolve in the future under different conditions or scenarios. A generic list and analysis of features, events and processes relevant to the post-closure safety of borehole disposal facilities are contained in Ref. [19]; the operating organization should consider this information when identifying features, events and processes as well as scenarios for a borehole disposal facility at a specific site.

4.18. To provide reasonable assurance of safety, the operating organization should develop a safety case that includes safety assessments showing that the disposal system's features, events and processes and their possible interactions have been identified and are sufficiently well understood, taking account of uncertainties. The operating organization should also perform uncertainty analyses to identify the range of possible disposal system behaviours and should consider conducting more detailed modelling and sensitivity studies for the parts of the disposal system that are significant to safety. Uncertainty analysis through the use of scenarios and features, events and processes in safety assessment is covered further in GSR Part 4 (Rev. 1) [13], GSG-3 [34], SSG-23 [35] and Refs [19, 20].

4.19. The operating organization should acknowledge openly the uncertainties that exist at each stage in the development, commissioning, operation, closure and institutional control of the borehole disposal facility, and should develop and apply an approach to the management of uncertainties that ensures that the facility is developed and managed in a safe manner. The existence of uncertainties should not prevent advancement to the next step in facility development and management.

4.20. The operating organization should update the safety case and the safety assessments as the borehole disposal programme proceeds, to reflect new data and experience. An understanding of the behaviour of the disposal system will evolve as more data are accumulated and as scientific knowledge develops. Early in the development of the disposal concept, the data and understanding should be sufficient to give the confidence necessary to commit resources to further investigation. Before the start of construction, during emplacement and at closure, the understanding gained from safety assessment and compiled in the safety case should be sufficient to give reasonable assurance of safety and assurance that the relevant regulatory requirements will be satisfied.

4.21. Confidence building should be an integral part of safety assessment and of the safety case development process. The operating organization should present in the safety case documentation a series of arguments intended to build confidence in the safety of the borehole disposal system. The operating organization may seek to build confidence in the safety of the borehole disposal system in various ways, including the following:

(a) By showing that the safety assessment is as comprehensive as possible and is based on good science and engineering practice and high quality data;
(b) By showing that the disposal system is safe and robust (i.e. its performance is not unduly sensitive to individual detrimental events or processes);
(c) By providing evidence regarding the appropriateness and effectiveness of controls such as waste acceptance criteria (see paras 6.58–6.66);
(d) By providing information to demonstrate the feasibility of, and build confidence in, the effectiveness and durability of the engineered components of the facility.

4.22. The operating organization should develop further confidence building arguments as appropriate, for example relating to defence in depth, engineered safety features, multiple lines of reasoning, institutional control, monitoring, information from natural analogues or the use of conservative approaches.

MULTIPLE SAFETY FUNCTIONS

4.23. Requirement 7 of SSR-5 [4] states:

> "**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.**"

4.24. The operating organization should develop a safety strategy for the borehole disposal facility that includes multiple safety functions. A safety function is a specific purpose that must be accomplished for safety [5]. A safety function is usually attributed to a particular structure, system or component and could be provided by a physical or chemical quality of that structure, system or component.

4.25. The operating organization should ensure that safety functions are provided by a combination of engineered and natural barriers. The operating organization should ensure that the borehole disposal system is designed in such a way that the number and complexity of the barriers and safety functions are commensurate with the hazard and risk associated with the waste.

4.26. Examples of barriers and safety functions in borehole disposal systems include the following:

(a) Host rocks with low permeability, where the rate of groundwater movement and the degree of radionuclide sorption onto the rocks together ensure that any radionuclides migrating from the waste will take many thousands of years to migrate to the biosphere;

(b) Waste containers that are resistant to corrosion under the conditions in the disposal system, for example containers made of particular stainless steels for the disposal of different types of disused sealed radioactive source [17];
(c) Waste in solid form that has low solubility and that releases radionuclides slowly under the relevant geochemical conditions;
(d) Engineered barrier materials that retard radionuclide migration, for example a cement based backfill between the container and the borehole casing, which creates high pH conditions that limit solubility and promote sorption, thus providing containment.

4.27. The operating organization should ensure that the performance of the borehole disposal system is not unduly dependent on one safety function or barrier and that the barriers are not unduly dependent on each other. The operating organization should provide reasonable assurance that if one barrier does not perform as expected, or if one safety function is not fulfilled, then the disposal system will still be safe. The operating organization should design the disposal facility in such a way that the loss of performance of one barrier does not lead directly to the loss of performance of other barriers.

4.28. The operating organization should design the engineered components of the disposal system in such a way that they are compatible with each other and with the natural barriers. Examples of incompatible components include the following:

(a) Ordinary Portland cement for backfill when the surrounding groundwater or geology has high levels of sulphate, which is common in some types of clay;
(b) Swelling clays (e.g. bentonite) for containment in highly saline environments or in groundwater with high levels of potassium.

CONTAINMENT OF RADIOACTIVE WASTE

4.29. Requirement 8 of SSR-5 [4] states:

> “**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.**”

4.30. Containment is defined as methods or physical structures designed to prevent or control the release and the dispersion of radioactive substances [5]. In the context of waste disposal, the containment of the radionuclides associated with the waste is through the provision of engineered barriers and natural barriers [5].

4.31. The operating organization should pay particular attention to providing containment of the radionuclides in the waste during the initial period after borehole disposal, when the level of activity is highest. The containment should be sufficient to allow the vast majority of radionuclides to decay without reaching the biosphere. The operating organization is not required, however, to provide absolute containment of all radionuclides for all time, as this cannot be demonstrated and is not necessary for safety. The operating organization should demonstrate in the safety assessment that potential doses and risks arising from any radionuclide releases that do occur are below the relevant dose and risk criteria.

4.32. Although some disused sealed radioactive sources generate heat as a result of radioactive decay, this does not preclude their disposal in a borehole disposal facility if the operating organization can prepare a convincing safety case. The operating organization should provide sufficient containment for such waste by selecting or designing suitable waste containers and waste packages. The operating organization should take account of the characteristics of, and processes associated with, high activity disused sealed radioactive sources, including, where relevant, heat generation, the emission of neutrons and the radiolysis of water. The operating organization should ensure that the design of the waste package includes suitable barriers that are compatible with the other barriers in the disposal system (e.g. the borehole backfill, the host rocks) and that will work together with the other barriers to contain the radionuclides through a combination of physical and chemical functions.

ISOLATION OF RADIOACTIVE WASTE

4.33. Requirement 9 of SSR-5 [4] states:

> “**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.**”

4.34. Isolation is defined as the physical separation and retention of radioactive waste away from people and from the environment [5]. Not only is isolation a requirement for safe waste disposal, it is also important for providing and maintaining nuclear security over certain types of disposed waste. Paragraph 3.43 of SSR-5 [4] states:

> "For near surface facilities, isolation has to be provided by the location and the design of the disposal facility and by operational and institutional controls. For geological disposal of radioactive waste, isolation is provided primarily by the host geological formation as a consequence of the depth of disposal."

4.35. When siting a borehole disposal facility, the operating organization should give due consideration to events and processes that might bring disposed waste closer to the surface environment, leading to a loss of isolation and causing people to become exposed to radiation. Such events and processes include erosion, tectonic uplift, glaciation, permafrost melting and inadvertent human intrusion. To minimize the probability of inadvertent human intrusion, the operating organization should site borehole disposal facilities away from areas with resources such as minerals, oil, gas, geothermal energy and water. Further information on the siting of borehole disposal facilities is contained in Appendix I.

4.36. In designing a borehole disposal facility, the operating organization should select an appropriate depth range for the waste disposal zone(s), taking account of the waste characteristics and of the requirements for isolation and nuclear security. For waste that will have significant activity at the end of the period of active institutional control[18] (e.g. long lived disused sealed radioactive sources that have been declared as waste and intermediate level waste generated during the management of these sources), the operating organization should locate the disposal zone(s) deeper than the recommended minimum depth (see Annex II). Disposal at depths shallower than the recommended minimum depth could be a safe and appropriate option for some short lived disused sealed radioactive sources and low level waste that are not subject to safeguards (see paras 7.22–7.27), but the operating organization has to demonstrate that sufficient isolation and nuclear security would be provided. The operating organization should take account of the characteristics (e.g. permeability) of the host rocks and the geochemistry of the groundwater when deciding on the depth of the disposal zone(s) in a borehole disposal facility (see Section 6).

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[18] For example, fig. 3 of Ref. [15] shows that some sealed radioactive sources containing ^{137}Cs will not decay to exemption levels for more than 1000 years, while sources containing ^{226}Ra can remain potentially dangerous for tens of thousands of years.

4.37. In selecting a site and designing a borehole disposal facility, the operating organization should give due consideration to further enhancing confidence in the isolation provided, including confidence in the choice of disposal depth, by incorporating mechanically strong and heavy engineered anti-intrusion barriers (e.g. deflection plates, concrete slabs).

SURVEILLANCE AND CONTROL OF PASSIVE SAFETY FEATURES

4.38. Requirement 10 of SSR-5 [4] states:

> "**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.**"

4.39. In the context of a disposal facility for radioactive waste, surveillance refers to the physical inspection of the facility to verify its integrity and the capability to protect and preserve passive barriers [5]. Although there may only be relatively limited possibilities to directly observe the passive safety features of a borehole disposal facility, the operating organization should inspect the disposal system periodically throughout the period of authorization to check that there have not been unexpected changes to conditions or human activities at or near the site that could significantly affect the structures, systems and components of the facility. If such changes have occurred, the operating organization should reassess the safety of the facility and update the safety case. The government or regulatory body, as appropriate, should check periodically that any passive institutional controls that have been implemented remain in place and are effective.

STEP BY STEP DEVELOPMENT AND EVALUATION OF BOREHOLE DISPOSAL FACILITIES

4.40. Requirement 11 of SSR-5 [4] states:

> "**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.**"

4.41. The development, commissioning, operation and closure of a borehole disposal facility may take place over a shorter period than that for a near surface or geological disposal facility. Nonetheless, the operating organization should follow a step by step approach to the development, commissioning, operation and closure of a borehole disposal facility that includes iterative evaluations (e.g. assessments) of the site and of the various options for the facility.

4.42. The most important steps in the development, commissioning, operation and closure of a borehole disposal facility should coincide with regulatory or governmental decision points. These decision points are typically the selection of a site, approval of the design concept, authorization of the start of construction, authorization of commissioning and operation, authorization of facility closure, and the decision to release the site from regulatory control. The regulatory body should establish and follow a step by step approach to the authorization of a borehole disposal facility (see Section 3).

4.43. The operating organization should engage with interested parties and the regulatory body at the start of the development process to ensure a common understanding on the direction of the disposal programme and to facilitate inclusive and consensual decision making.

4.44. Decisions on site selection, facility design, start of construction, commissioning and operation, closure and release of the site from regulatory control should be made as the project proceeds on the basis of the information available at the time and the confidence that the borehole disposal facility will fulfil the requirements and provide acceptable safety and security. In making decisions on whether to proceed from one step to the next, the operating organization should take account of factors such as national policies and strategies, and the views of interested parties.

4.45. The operating organization should follow an iterative approach to assessing the safety of the borehole disposal system and should update the safety case as needed before a decision is made to progress to, and commit resources for, the next step. By following a step by step approach, the operating organization should progressively build confidence in the safety of the borehole disposal facility as the disposal programme proceeds.

4.46. The iterative approach to safety assessment and safety case development should include the collection, analysis and interpretation of relevant scientific and technical data and the development of designs and operational plans and procedures, and should cover both the operational and post-closure periods (see para. 1.18 of SSR-5 [4]). The operating organization should use the step by step approach as a framework in which to develop and demonstrate sufficient confidence in the technical feasibility and safety of the borehole disposal facility. For each step in the process, the operating organization should identify the decision that needs to be made and the information that is necessary to make the decision. The operating organization should also identify the appropriate interested parties and determine when and how to include them in the decision making process.

4.47. As information becomes available it should be used to update the safety case and inform decisions regarding facility design and further data gathering to reduce uncertainties. The operating organization should undertake additional iterations of safety assessment as appropriate to facilitate management of the disposal facility.

4.48. The operating organization and the regulatory body should conduct or commission independent technical and regulatory reviews at appropriate steps and decision points. The nature of these reviews and the degree of involvement of interested parties at each step and decision point will depend on national practices and the borehole disposal facility in question.

5. SAFETY CASE AND SAFETY ASSESSMENT FOR A BOREHOLE DISPOSAL FACILITY

5.1. The safety case is a collection of scientific, technical, administrative and managerial arguments and evidence in support of the safety of a facility, covering the suitability of the site and the design, construction and operation of the facility, the assessment of radiation risks and assurance of the adequacy and quality of all of the safety related work associated with the facility. Safety assessment is an integral part of the safety case. Safety assessment involves quantification of radiation dose and radiation risks that may arise from the facility, for comparison with the relevant dose and risk criteria.

5.2. In addition to safety assessments, the collection of arguments and evidence compiled in an operating organization’s safety case should include the following:

(a) Descriptions of the safety case context, the safety strategy and the disposal system;
(b) Demonstrations of optimization and the management of uncertainty;

(c) Evidence of independent review and the involvement of interested parties in the development of the safety case;
(d) A statement of the limits, controls and conditions to be applied during facility development;
(e) The management system and evidence that it has been applied to ensure the quality of safety related work and activities (see GSG-16 [26] and paras 4.60 and 4.61 of SSG-23 [35]).

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

5.3. Requirement 12 of SSR-5 [4] states:

> "**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.**"

5.4. The operating organization should start to prepare the safety case, including appropriate safety assessments, early in the development of the borehole disposal facility. The operating organization should include the safety case in the information provided to the regulatory body to request authorization.

5.5. The operating organization should use the safety case and safety assessments to guide all steps and decisions in the development, commissioning, operation, closure and institutional control of the borehole facilities and activities and as a basis for communication with interested parties (see GSG-3 [34] and SSG-23 [35]). The operating organization should regard the safety case as a living document, updating it to take account of new information at each step and as required in the authorization issued by the regulatory body. Figure 2 illustrates the progressive updating of the safety case during the development, commissioning, operation, closure and institutional control of a disposal facility and the typical sequence of decisions that are made. The operating organization should use the safety case to guide the activities undertaken in the development, commissioning, operation, closure and institutional control of the borehole disposal facility, including research and development, site characterization, facility design and optimization.

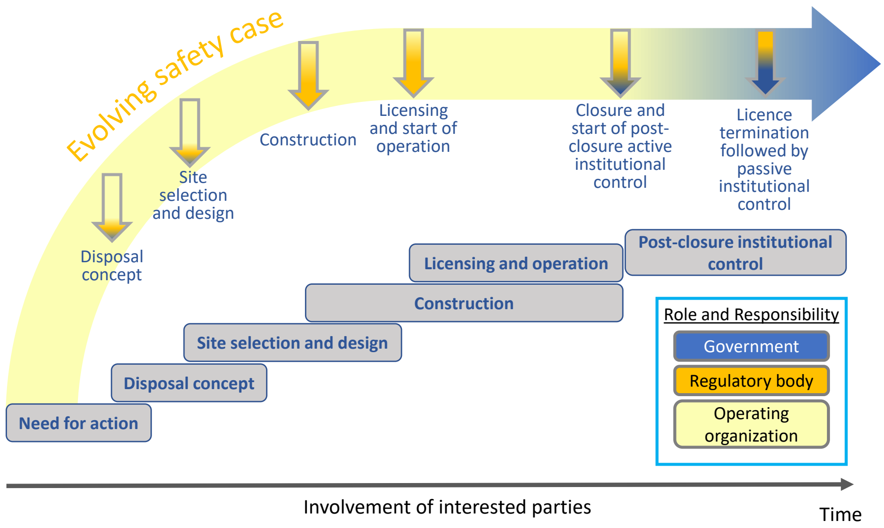

FIG. 2. The typical sequence of decisions made in the development, commissioning, operation, closure and institutional control of a disposal facility for radioactive waste. Depending on the national legislation, the licence may be terminated at the end of the period of active institutional control or at a later time.

The operating organization should also provide information from the safety case to assist in regulatory decisions on the release of the site from regulatory control.

5.6. For a borehole disposal facility, some of the periods in the step by step development approach may be significantly shorter than those for near surface and geological disposal facilities. For example, at a borehole disposal facility comprising one disposal borehole, the operational period may be just a few months to a year long. The regulatory body should define its requirements for provision of information and updating of the safety case, taking account of the national regulatory approach, the size of the facility and the hazard posed by the disposed waste. The regulatory body should be prepared to review the safety case in a timely manner to support closure so that disposal boreholes do not remain open for extended periods.

5.7. When preparing the safety case, the operating organization should consider the regulatory body to be the primary audience but should also take account of the needs of other interested parties. The operating organization should make safety case information available to the public except where this is prevented for legal reasons or for reasons related to security or commercial confidentiality. As the safety case that has been developed to support authorization may be highly technical, the operating organization should also provide a description of the safety case that is readily understandable by the public.

5.8. The operating organization should make the safety case sufficiently detailed and comprehensive that it provides the information needed by the regulatory body to decide whether the regulatory requirements have been, or have the potential to be, fulfilled and therefore whether the project can proceed from one step to the next. Early in the borehole disposal programme, the safety case might have weaknesses or gaps in some areas owing to incomplete knowledge; in such cases, the operating organization should acknowledge the lack of data or information in the safety case and should describe the potential significance of the uncertainties and how the uncertainties will be managed.

5.9. The operating organization should use the safety case to guide decisions concerning, for example, the objectives and allocation of resources for research and development, site characterization, facility design, optimization, the development of waste acceptance criteria and the operation, closure and institutional control of the borehole disposal facility.

5.10. The operating organization should follow a graded approach in preparing the safety case and conducting safety assessments. A programme for the development, commissioning, operation, closure and institutional control of a borehole disposal facility is typically significantly smaller than that for a near surface or geological disposal facility. In developing a site specific safety case for a borehole disposal facility, the operating organization should consider the available information, including that in Refs [15, 19, 20, 24].

SCOPE OF THE SAFETY CASE AND SAFETY ASSESSMENT

5.11. Requirement 13 of SSR-5 [4] states:

> "**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. The operating organization should define clearly and justify the scope of the safety case and the safety assessments so that they are appropriate to the stage in the disposal programme (i.e. the development, commissioning, operation, closure or institutional control of the borehole disposal facility). For example, the scope of an initial assessment of the feasibility of a disposal concept will differ from the scope of a later assessment performed for regulatory approval, commissioning, operation or closure purposes.

Scope of the safety case

5.13. The scope of the safety case for a borehole disposal facility should include all relevant facilities and activities. Figure 3 illustrates the structure and main components of the safety case as described in SSG-23 [35] and Ref. [38]. In the safety case, the operating organization should describe and assess all safety relevant aspects of the borehole disposal site, facility and activities, both during operations and following the closure of the facility, and should demonstrate that appropriate and effective management controls will be applied. The operating organization should work in accordance with the management system throughout the development of the safety case and throughout the development, operation, closure and institutional control of the borehole disposal facility (see GSG-16 [26]). Paragraphs 5.14–5.24 address the safety case components identified in Fig. 3.

5.14. As part of the safety case development, the operating organization and the regulatory body should engage in appropriate formal dialogue from an early stage; this dialogue should include discussion of regulatory requirements, guidance and expectations regarding the scope and content of the safety case.

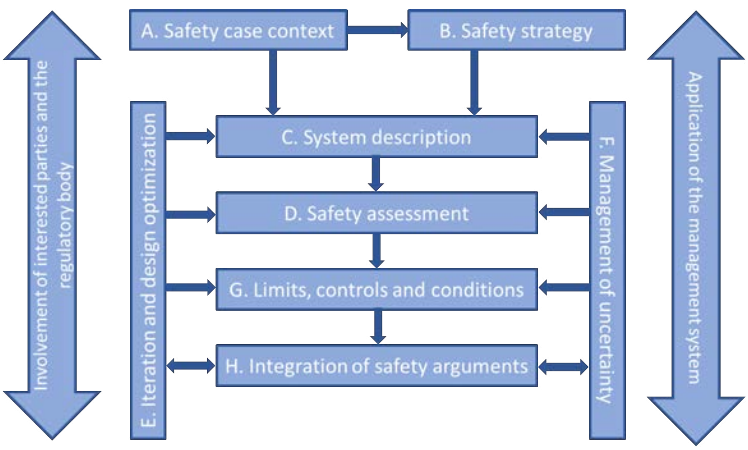

FIG. 3. The main components of the safety case, application of the management system and the process for interaction with the regulatory body and interested parties. [35]

Detailed technical discussion may also be needed on the safety assessments and on other aspects relating, for example, to the design of the facility or to plans for its operation, closure and monitoring. The dialogue should be broadly framed so that it can include aspects other than those relating to radiological safety, such as environmental protection, which may lead to requirements or constraints on facility development.

5.15. The operating organization should also establish and lead a programme of dialogue with interested parties about the disposal facility. This programme of dialogue should be appropriate to the situation in the State and locally at the site. As part of the dialogue, the operating organization should use information from the safety case to provide assurance that safety requirements will be met. The programme of dialogue should also be designed to enhance trust in the transparency, competence and behaviour of the operating organization and the regulatory body. In addition to discussing the plans for the disposal facility and its safety, the benefits resulting from use of the radioactive sources should be described. Further recommendations on interactions with interested parties on radioactive waste management are provided in GSG-16 [26]. Recommendations on the role of the regulatory body in such dialogue are provided in GSG-6 [31].

5.16. The operating organization should describe the safety case context, including information on the following aspects:

(a) The legal and regulatory framework for the management of the waste, which may include international commitments (e.g. the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [6] and the Code of Conduct on the Safety and Security of Radioactive Sources [7]) and national laws, regulations, policies and strategies on radioactive waste management, along with a description of their application to borehole disposal.
(b) The purpose of the safety case at this stage within the context of the step by step approach to the development of the borehole disposal facility, possibly supplemented with specific supporting objectives (e.g. relating to proposed changes to operations).
(c) The scope of the safety case at this stage, including the features, events and processes that are included in the safety case and those that are excluded, along with justifications for these decisions. The scope of the safety case might be influenced by aspects such as the site selection process, public engagement and acceptance, environmental and social impact assessment, operational and post-closure time frames, and the application of a graded approach to safety case development.

(d) The target audience for the safety case and how interested parties will be involved during the development of the safety case.

5.17. Early in the safety case development process, the operating organization should define a safety strategy establishing the approach that will be taken to comply with the fundamental safety objective, safety principles, protection criteria and regulatory requirements identified in the safety case context and to ensure that good science and engineering practices are adopted. The safety strategy should address the following:

(a) How the waste is to be contained and isolated from the biosphere using borehole disposal;
(b) The inclusion of passive safety features in the borehole disposal system;
(c) The robustness of the borehole disposal system;
(d) The approach to management of uncertainties and interdependencies and the application of the graded approach.

5.18. The operating organization should include in the safety case a description of the borehole disposal system containing detailed information on the following:

(a) The inventory of waste, how the inventory was derived and the level of confidence in the inventory;
(b) The characteristics of the site and its surrounding environment;
(c) The predisposal facilities and activities (e.g. hot cell or other facility for conditioning of waste);
(d) The operating procedures;
(e) The disposal facilities and activities (e.g. configuration and construction of waste packages and boreholes, commissioning activities, waste emplacement operations) and the closure activities;
(f) The safety functions associated with the engineered and natural components of the borehole disposal system and how these are expected to be fulfilled over time.

5.19. The operating organization should include in the safety case for a borehole disposal facility any safety assessments needed to address aspects that are relevant to the safety of predisposal management facilities and activities and to safety in the development, commissioning, operation, closure and institutional control of the borehole disposal facility. The operating organization should assess both operational safety and post-closure safety. In the operational safety assessment the operating organization should show that, in conjunction with the application of the management system, the facility will be safe during operation. In the post-closure safety assessment, the operating organization should provide reasonable assurance that the facility will be safe after it is closed. The operating organization should include other safety assessments in the safety case as appropriate in order to address, for example, transport, non-radiological hazards (e.g. substances such as asbestos and lead) and conventional health and safety hazards (e.g. hazards to workers during construction of the borehole disposal facility).

5.20. The operating organization should ensure that iteration and design refinement occur throughout the safety case development process and that they are properly documented in the safety case. Iteration and design refinement involve multiple interactions between data gathering activities (e.g. research and development, site characterization), safety assessment and disposal facility design. As new data and knowledge are acquired relating to the site and the performance of the disposal system for a given inventory and facility design, the design of the facility should be refined as necessary, and the safety assessment and the data gathering programme should be updated. Many cycles of iteration and design refinement may be necessary to achieve the desired result. Further recommendations on iteration and design refinement are provided in paras 4.40–4.48 and in paras 6.36 and 6.37, respectively.

5.21. The operating organization should ensure that the management of uncertainties occurs throughout the safety case development process and that it is properly documented in the safety case. There will always be uncertainties when considering the safety of radioactive waste disposal, particularly when the time frames are long and the disposal systems include natural environmental systems. Some uncertainties stem from a lack of knowledge and can potentially be reduced by gathering more data. Other uncertainties cannot be reduced because, for example, they relate to intrinsic randomness or to aspects that are inherently unknowable, such as future human behaviour. During the development of a borehole disposal facility, there will often be various options for managing uncertainties. For example, if the results of a post-closure safety assessment suggest that it is uncertain whether the disposal of a certain inventory of waste in a proposed borehole disposal facility will lead to potential doses and risks below the relevant dose and risk criteria, the operating organization might be able to increase confidence by gathering more data, by reducing conservatism in the models or by changing the design of the facility, or through some combination of these actions. The operating organization should establish and apply an approach to the management of uncertainties and should document this in the safety case. Many uncertainties in the borehole disposal of the waste described in para. 1.1 relate to the site and to the potential pathways by which radiation exposures could occur in the future. The operating organization should show in the safety case that the key uncertainties have been identified, quantified where possible, and managed, for example by selecting an appropriate site and borehole location, depth and design, by gathering more data or by improving the assessment models. As a result, the safety assessments should give confidence that potential doses and risks will be below the relevant dose and risk criteria.

5.22. In the safety case, the operating organization should propose limits, controls and conditions on how the facilities and activities will be developed, operated, closed and controlled. The regulatory body should review and approve the limits, controls and conditions proposed by the operating organization. The regulatory body should, as appropriate, include the approved limits, controls and conditions as authorization conditions, together with any further conditions that the regulatory body considers necessary. The limits, controls and conditions may relate to radiological and/or non-radiological parameters (e.g. the amount of activity that may be placed in a waste package; the mixing of radionuclides in a disposal capsule; the minimum thickness of an engineered barrier; the timing of a backfilling operation; prohibition of powdered, pyrophoric and putrescible waste).

5.23. The operating organization should present in the safety case a synthesis of the available evidence, arguments and analyses, which should logically demonstrate that the proposed facilities and activities can be safely and securely managed. This synthesis should include an explanation of how the data and information have been collected and assessed, how their quality has been assured, how models have been tested and how rational and systematic procedures for safety assessment have been followed. The synthesis should address the importance of safety, the need for passive safety, the existing level of confidence in the understanding of the disposal system, the disposal system design principles (e.g. multiple safety functions, containment, isolation), the steps in the disposal facility development process (e.g. site characterization, facility design, construction, operation, closure) and assurance measures (e.g. monitoring and surveillance, institutional controls). The operating organization should acknowledge any limitations of the evidence, arguments and analyses included in the synthesis and should highlight the principal grounds on which a judgement has been made that the planning and development of the waste management and disposal system should be continued despite the limitations.

5.24. The operating organization should ensure that an appropriate management system is applied throughout the safety case development process and that its application is properly documented in the safety case. The operating organization should ensure that all safety case development activities, including those performed by suppliers[19], are conducted in accordance with the management system. Application of the management system should ensure that independent peer reviews of the safety case for waste management facilities and activities are conducted and that peer review findings are appropriately considered and acted on. The regulatory body should ensure that all activities related to regulatory review and assessment of the safety case, including those performed by suppliers, are conducted in accordance with an appropriate management system (see GSG-16 [26] and paras 7.36–7.38 of this Safety Guide).

Scope of the safety assessment

5.25. The operating organization is required to undertake safety assessments in accordance with the relevant requirements in GSR Part 4 (Rev. 1) [13], GSR Part 5 [3] and SSR-5 [4]; recommendations on safety assessments are provided in GSG-3 [34] and SSG-23 [35], and further relevant information is provided in Refs [19, 20, 36]. The operating organization should undertake safety assessments throughout the development, commissioning, operation, closure and institutional control of the borehole disposal facility to demonstrate the safety of workers and the public during (a) predisposal management; (b) disposal operations (under both normal operating conditions and for scenarios involving events, including accidents, such as loss of electrical power or other services, fire, collapse of borehole walls, dropped waste package and waste package jammed in borehole during disposal); and (c) the post-closure period under normal conditions and following waste disturbance events.

5.26. In these assessments, the operating organization should consider potential effects on people and the environment. To demonstrate the level of protection of people and the environment, the operating organization should, in the post-closure safety assessment, take account of all waste disposed of at the site (i.e. all waste in disposal boreholes and waste in any other disposal facilities at and neighbouring the site). For example, where it is proposed to create a borehole disposal facility at or next to the site of an existing near surface disposal facility, the operating organization(s) should assess the impact of the borehole disposal facility on the safety of the near surface facility and vice versa. Information on generic post-closure safety assessment for borehole disposal facilities is provided in Appendix II.

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[19] The supply chain, described as ‘suppliers’, typically includes designers, vendors, manufacturers and constructors, employers, contractors, subcontractors, and consigners and carriers who supply safety related items. The supply chain can also include other parts of the organization and parent organizations.

5.27. The operating organization should use safety assessment to guide site characterization studies and facility design (see Requirements 15 and 16 of SSR-5 [4]). The operating organization should use safety assessment throughout the development, commissioning, operation, closure and institutional control of the facility to evaluate the prevailing level of understanding of the disposal system and assess uncertainties (see Requirement 6 of SSR-5 [4]).

5.28. The IAEA has undertaken various studies to assess the post-closure safety of borehole disposal facilities for disused sealed radioactive sources and provides tools for their assessment. A series of models at different levels of complexity has been developed for use when applying a graded approach to assessing post-closure safety [20]. These models include a detailed generic safety assessment [19] that can be used as a basis for the development of a site specific post-closure safety assessment to form part of the information needed for authorization. The studies undertaken focused initially on the disposal of disused sealed radioactive sources in Categories 3–5 (see RS-G-1.9 [23]), but were later extended to cover the disposal of disused sealed radioactive sources in Categories 1 and 2 (e.g. Ref. [17] and Appendix II to this Safety Guide). Although Refs [19, 20] can assist in performing safety assessment, the operating organization is still required to develop a safety case for the disposal facility that is specific to the site and the waste inventory to be disposed of.

5.29. In accordance with para. 3.15 of SF-1 [1], the operating organization has to assess safety in a manner that is consistent with a graded approach so that the effort expended, and the controls applied, are commensurate with the hazard and the level of risk associated with the waste. A tiered assessment approach is presented in Ref. [20] and can be used, as appropriate, to establish the scope, complexity and level of conservatism in post-closure safety assessment.

5.30. The operating organization should define clearly and justify the assessment approach to be followed, including aspects such as the use of probabilistic and/or deterministic assessment methods, the use of conservative or realistic assumptions, the assessment of uncertainties, the assessment time frames to be considered, the assessment endpoints to be calculated (e.g. potential doses, risks, radionuclide fluxes from engineered barriers or from the geosphere to the biosphere). Additional information on these topics can be found in Appendix II, in Refs [19, 20] and in SSG-23 [35].

5.31. The operating organization should make a systematic assessment of the uncertainties associated with the safety and performance of the borehole disposal system. The operating organization should use the safety assessments to identify

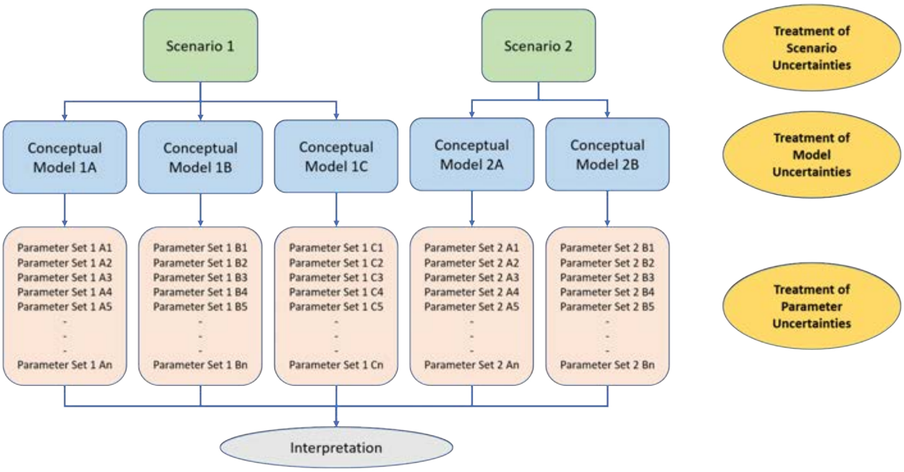

FIG. 4. Structure of uncertainty analysis showing the treatment of scenario, model and parameter uncertainties (reproduced from Ref. [39] with permission).

and, where possible, quantify uncertainties. The operating organization should include in the safety assessments appropriate treatments of scenario, model, data and parameter uncertainties. Figure 4 shows a general structure for analysing uncertainties in this way.

5.32. Recommendations on the treatment of uncertainty in post-closure safety assessment for disposal facilities are provided in paras 5.54–5.69 of SSG-23 [35]. Experience gained during the development of the generic safety assessment for borehole disposal [19], during development of the graded approach to post-closure safety assessment for borehole disposal [20] and during pilot projects for the implementation of borehole disposal has shown that the operating organization should consider a range of scenarios and potential radionuclide transport and exposure pathways, as appropriate to the facility and site, including the following:

(a) Scenarios representing the expected evolution of the disposal system, including the disposal facility as designed and as constructed (in Ref. [19] and in Appendix II to this Safety Guide, these are termed ‘design scenarios’);
(b) Scenarios including initial defects in engineered barriers (in Ref. [19] and in Appendix II to this Safety Guide, these are termed ‘defect scenarios’);
(c) Scenarios that address uncertainties in, and possible changes to, environmental conditions (e.g. climate, hydrogeology, seismic activity);

(d) Scenarios including radionuclide transport along a disposal borehole or in any zone of damaged rock adjacent to a disposal borehole;
(e) Scenarios including radionuclide transport in groundwater to a water abstraction well and/or to other groundwater discharge points (e.g. a river);
(f) Scenarios including radionuclide transport in groundwater and potential exposures via pathways that include irrigation of crops, watering of livestock and drinking water;
(g) Scenarios including inadvertent human intrusion (in Ref. [19] and in Appendix II to this Safety Guide, these are termed 'borehole disturbance scenarios').

5.33. In considering human intrusion, the operating organization should focus on inadvertent human intrusion and on the potential effects on the protection of people (including intruders and members of the public) and of the environment. This includes effects at the time of the intrusion and afterwards caused by disruption of the waste and of the engineered and natural barriers in the disposal system. In general, the probability of inadvertent human intrusion decreases with depth because fewer human activities disturb systems at greater depths.

5.34. Where waste is placed in boreholes at depths shallower than the recommended minimum depth, the operating organization should consider human intrusion scenarios including the following:

(a) The construction of building foundations, cuttings for roads and railways, 'cut and cover' tunnels and standard tunnels;
(b) Drilling (e.g. for natural resources, for research).

5.35. Where waste is placed in boreholes at depths shallower than the recommended minimum depth, the operating organization should assess inadvertent human intrusion as a probable event so that the assessment results can be used to inform judgements on the suitability of the disposal depth and the disposal option. Where waste is placed in boreholes at depths shallower than the recommended minimum depth, the operating organization should implement effective active institutional controls during the period until the activity of the waste has decayed sufficiently that it is no longer of concern; for waste containing long lived radionuclides or large initial amounts of radionuclides such as ^{137}Cs, the period of active institutional control should extend into the post-closure period as needed.[20] The operating

[20] Although ^{137}Cs (with a half-life of ~30 years) is sometimes regarded as a short lived radionuclide, some high activity ^{137}Cs sealed sources contain so much activity initially that, even after 10 half-lives (~300 years), they remain significantly hazardous.

organization should specify the institutional controls envisaged, justify the period over which they are assumed to be effective and provide financial assurance for their implementation. The regulatory body should include the provision of these institutional controls as conditions of the authorization.

5.36. For borehole disposal facilities in which waste has been or is to be disposed of at depths greater than the recommended minimum depth, in the safety assessment the operating organization should consider human intrusion scenarios that include drilling but need not consider the activities in para. 5.34(a). Where the depth of waste disposal is greater than the recommended minimum depth, the operating organization should assess inadvertent human intrusion as an improbable event.

5.37. In assessing the risks associated with each scenario, the operating organization should take account of scenario probability.

5.38. The operating organization should use the results of the assessment of improbable but plausible scenarios to help in demonstrating that the performance of the disposal system is robust and to help in optimization of the disposal system.

5.39. In assessing potential doses and risks associated with borehole disposal, the operating organization should assume that humans will be present at the site and that they will make use of local resources that could contain radionuclides originating from the waste. As it is not possible to predict future human behaviour with certainty, the operating organization should avoid undue speculation. The operating organization should, however, take account of possible changes at the site (e.g. in land use, population or climatic conditions) and the effects of such changes on potentially exposed groups. Given that many borehole disposal facilities for disused sealed radioactive sources are small facilities (as compared with near surface and geological disposal facilities) and have small footprints, the operating organization should take account of the agricultural capacity or productivity of the site, as this may limit the size of potentially exposed groups.

5.40. The operating organization should use uncertainty and sensitivity analyses to demonstrate robustness, in particular to demonstrate that the safety of the borehole disposal system does not rely unduly on any of the following:

(a) A single feature of the design or the site;
(b) A single assumption made in the safety assessment;
(c) A single safety function.

5.41. The operating organization should show that if one barrier were to fail prematurely or otherwise not perform as intended, or if one safety function were not fulfilled, safety would still be ensured.

5.42. The operating organization should build confidence in the safety of the borehole disposal system by presenting multiple lines of reasoning. These lines of reasoning should include, but not necessarily be limited to, arguments related to robustness, institutional control, monitoring, the use of good science and engineering, information from research and development work, safety assessment and peer review. The operating organization should highlight conservatisms in the safety assessments and should use uncertainty and sensitivity analyses to further support the development of multiple lines of reasoning that the disposal facility will be safe. Figure 5 illustrates factors that contribute to confidence in the long term safety of borehole disposal. The operating organization should identify the main factors in the safety assessment and explain how these factors combine to provide confidence in safety. The operating organization should show that peer review comments have been addressed in a logical and scientifically reasonable manner.

5.43. The operating organization is required to assess the safety of operations at a borehole disposal facility in accordance with the requirements for the predisposal

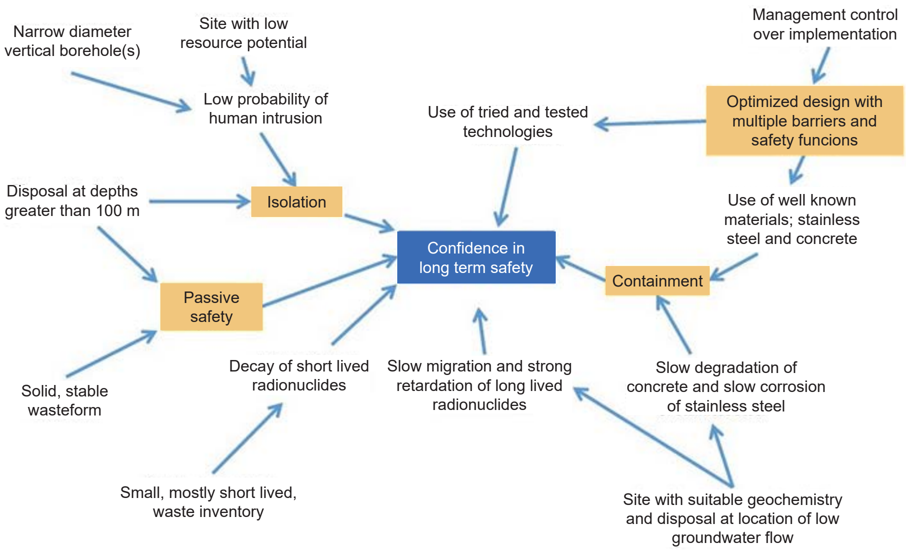

FIG. 5. Factors that contribute to confidence in the long term safety of the borehole disposal of disused sealed radioactive sources.

management of radioactive waste established in GSR Part 5 [3] and the requirements for the disposal of radioactive waste established in SSR-5 [4]. At a borehole disposal facility for disused sealed radioactive sources, the principal predisposal waste management activities performed involve the processing of disused sealed radioactive sources, including their conditioning for disposal. These activities should then followed by disposal of the sources in the borehole(s); Section 6 covers all of these activities in more detail. The operating organization should consider the available information when developing assessments and procedures for use at a particular facility.

5.44. The operating organization should, in accordance with national laws and regulations, undertake further assessments as necessary to address non-radiological risks such as the impact on people of non-radiological components of the waste, the impact on the environment of facility operations and the safety of workers during operations (e.g. lifting operations). The operating organization should, as appropriate, consider factors including the content of chemically or biologically toxic materials in the waste and in the engineered materials, the protection of groundwater resources and the ecological sensitivity of the environment to which contaminants might be released. For example, if disused sealed radioactive sources are to be disposed of together with their lead shielding, the operating organization should undertake assessments to evaluate the potential exposure of humans and other species to lead migrating from the facility.

5.45. With regard to the protection of non-human species, the present system of radiation protection generally provides appropriate protection of ecosystems in the human environment against harmful effects of radiation exposure (see para. 3.28 of SF-1 [1]). Furthermore, even though the natural environment is complex and radiation is only one of several types of impact, the optimization of protection provides a means for integration across the different impacts (see para. 1.34 of GSR Part 3 [2]). Nevertheless, the operating organization should, as appropriate, undertake environmental impact assessments (e.g. of present and potential future impacts on flora and fauna, of the environmental impacts of noise, traffic, dust and other relevant factors) in accordance with national and international requirements and guidance. The regulatory body should review the environmental impact assessments.

DOCUMENTATION OF THE SAFETY CASE AND SAFETY ASSESSMENT

5.46. Requirement 14 of SSR-5 [4] states:

> "**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.**"

5.47. The operating organization should document the safety case as a hierarchy of documents; Fig. 6 illustrates a sample hierarchy. At the lowest, most detailed level are documents containing the data and information gathered through research and development work, site characterization studies, experiments, literature reviews and other studies covering a wide spectrum of scientific, engineering and other disciplines, as well as records of activities undertaken during the development programme. The operating organization should use these data and information to prepare various scientific, engineering and other reports that support the safety assessments. The operating organization should use the reports and safety assessments as a basis for preparing the higher level safety case documentation that directly addresses the safety requirements. Even for a borehole disposal facility for a small volume of the waste described in para. 1.1, the hierarchy of safety case documentation may be quite extensive.

FIG. 6. Sample hierarchy of documents that constitute a safety case.

5.48. The operating organization should include in the safety case documents that present arguments, reasoning and supporting evidence (e.g. models, parameters, data) in a convincing, traceable and transparent way. The operating organization should prepare the safety case and safety assessment documentation in such a way as to facilitate understanding of the borehole disposal system and its behaviour and performance; of the models, data and assumptions used in safety assessment; and of the basis for and veracity of the arguments that show that the facility is or will be safe (see SSG-23 [35]).

5.49. The operating organization should present the results of the safety assessment in a manner that illustrates both the performance of the entire borehole disposal system and the performance of individual structures, systems and components of the waste management system. The operating organization should identify and document any weaknesses in the design to be improved and should implement appropriate design refinement activities to increase confidence in the performance of the waste management system.

5.50. The operating organization should update the safety case periodically, for example to take account of the conduct of iterative cycles of design and safety assessment work, developments in scientific understanding or changes to the disposal system (e.g. receipt of new waste types, addition of further disposal boreholes) and in accordance with regulatory requirements (e.g. for periodic safety reviews).

5.51. Safety cases for near surface or geological disposal facilities are typically developed gradually over a period of many years throughout the step by step facility development process. In contrast, the potentially short period between the construction and closure of a borehole disposal facility means that the operating organization should make the safety case documentation as complete and as detailed as reasonably possible at the time of applying for authorization for construction.

5.52. The operating organization should develop the safety case documentation, taking account of the audiences for the documents, including the regulatory body and other interested parties. The operating organization should consider preparing safety case documents with various levels of technical detail and in different styles for different audiences and purposes, but they should all be consistent in terms of the main conclusions and messages presented.

5.53. The operating organization should include in the safety case documentation a Level 1 synthesis (see Fig. 6) that provides an overview of the safety case using relatively simple and, as far as possible, non-technical language intended to be understandable by non-specialists, who may include elected representatives, government officials and members of the public. The synthesis should convey the main messages from the safety case (e.g. that the disposal facility is safe, will be safely managed during operations and will remain safe in the long term).

5.54. The operating organization should support the Level 1 synthesis by developing more detailed Level 2 documents as necessary and appropriate to the borehole disposal facility and the decision making step. The Level 2 documents supporting the synthesis should address the main components of the safety case, as illustrated in Fig. 6.

5.55. The operating organization should provide yet more detailed documents, as appropriate, at Level 3, including studies, reports and peer reviews conducted during preparation of the safety case and during facility development, commissioning, operation, closure and institutional control, such as reports on the waste inventory, engineered barrier studies, hydrological and geochemical interpretation work, reports on software development and verification, plans for monitoring, emergency plans, decommissioning plans and, where relevant, studies on options for remedial actions at existing facilities. The operating organization should provide transparent and traceable referencing, such as by using a consistent report referencing system and, where data are referenced, by providing the precise page number(s) for the source of the data.

5.56. The operating organization should develop and compile Level 4 documents as necessary, including detailed records of laboratory and field studies, tests, inspections and operations, and the scientific literature cited in the safety case. These documents should collectively provide the basis for the parameter values used and assumptions made in the safety assessments.

5.57. The regulatory body should provide guidance on its expectations for the safety case documentation, including the scope, content and level of detail of the documents, and on arrangements for the provision of information.

5.58. When documenting the safety case, the operating organization should ensure the following:

(a) That the documents provide a complete record of the decisions and assumptions made in the development, commissioning, operation, closure and institutional control of the borehole disposal facility and a complete record of the models and data used in the safety assessments.

(b) That information is presented in a traceable way so that independent, suitably qualified and experienced personnel could go back to the original sources of information supporting the various elements of the safety case, understand how these elements have been used in the safety case and, if necessary, reproduce the safety assessments.
(c) That the reasoning for decisions taken (e.g. on the siting, design or operation of the facility) is recorded in a logical and clear way. The operating organization should document the arguments for and against the alternative options and should explain why one option was chosen over another.

5.59. The operating organization should include in the safety case documentation evidence of the use of the management system, including processes and procedures for quality assurance and quality control (e.g. of data gathering, safety assessment modelling and document production). The operating organization should include in the safety case documentation evidence of and results from internal and external independent peer reviews of the safety case and responses to peer review comments.

5.60. In accordance with the graded approach, the volume and level of detail of the safety case documentation should be commensurate with the hazard and the level of risk associated with the waste. Where it can be shown, on the basis of verified data and information, that assessed potential doses and risks are orders of magnitude below the relevant dose and risk criteria, confidence in the safety of the borehole disposal facility should increase, allowing the safety case to be simplified. The extent to which the safety case can be simplified will be a matter of judgement that depends on various factors (e.g. national and local circumstances, regulatory requirements, the audiences for the safety case); such judgements may be facilitated by dialogue among the operating organization, the regulatory body and other interested parties.

6. APPROACH TO THE DEVELOPMENT OF A BOREHOLE DISPOSAL FACILITY

6.1. In accordance with Requirement 25 of SSR-5 [4], the operating organization is required to establish and implement a management system (see paras 7.36–7.38). Before operations commence, the operating organization should determine the human resource needs in terms of numbers, responsibilities and expertise and should ensure, through recruitment and training, that there are sufficient suitably qualified and experienced personnel to perform the predisposal management and disposal operations. The operating organization's training programme should cover all activities that are significant to safety and should provide the knowledge and practical experience necessary for conducting the activities safely. The operating organization, through its training programme, should foster the development of a safety culture (see Section 6 of GSG-16 [26]). The training programme should provide staff with a high level of awareness of the design features of the facilities and activities that are significant to safety and should be aimed at preventing incidents, (including accidents), and protecting people and the environment. The training programme should be updated in the light of experience and staff should be retrained as necessary. The operating organization should have access to technical expertise in various disciplines including radiation protection, handling of radioactive sources and waste, waste conditioning (including cement and concrete technologies and welding), waste transport, borehole construction, casing, backfilling and sealing, safety assessment and safety case development.

PREDISPOSAL MANAGEMENT OF RADIOACTIVE WASTE FOR BOREHOLE DISPOSAL

6.2. The predisposal management of the radioactive waste identified in para. 1.1 for disposal in narrow diameter boreholes may be conducted at the site of the borehole disposal facility or at another site and it may be undertaken by the organization operating the disposal facility or by another operating organization. The appropriate operating organization is required to conduct predisposal management activities in accordance with the requirements established in GSR Part 5 [3]. Further recommendations on the predisposal management of the types of waste described in para. 1.1 are provided in WS-G-6.1 [21] and SSG-45 [22].

6.3. Requirement 6 of GSR Part 5 [3] states that "**Interdependences among all steps in the predisposal management of radioactive waste, as well as the impact of the anticipated disposal option, shall be appropriately taken into account.**"

6.4. The operating organization should identify, plan and undertake predisposal management activities for borehole disposal as appropriate. The operating organization should consider the locations of the waste relative to disposal facility site, the types of source and waste to be managed, the need for waste characterization, and the infrastructure available and needed for processing, transport and storage prior to disposal.

6.5. In cases where disused sealed radioactive sources intended for disposal are located at many locations across a State (e.g. at user sites), the government should ensure the following:

(a) That the short term storage of the sources always occurs in safe and secure conditions, with proper authorization and periodic inspections (see Ref. [8]);
(b) That the short term storage of the sources occurs in a manner that does not preclude future management options (see Ref. [8]);
(c) That the regulatory body sets an appropriate time limit for short term storage of the sources, contingent on availability of other management options (see Ref. [8]);
(d) That consideration is given to centralized storage (see para. 5.3 of WS-G-6.1 [21] and para. 4.80 of SSG-45 [22]).

6.6. In cases where the waste is located in a centralized storage facility, the operating organization should consider undertaking waste characterization and waste processing at the centralized facility. If this is not feasible, the operating organization should undertake waste characterization and processing to produce waste packages for disposal at the disposal site using appropriate fixed facilities or mobile facilities.

6.7. The operating organization is required to implement a radiation protection programme throughout the management of radioactive sources and during the predisposal management of radioactive waste (see GSR Part 3 [2], in particular Requirements 19–28). Recommendations on occupational protection are provided in IAEA Safety Standards Series No. GSG-7, Occupational Radiation Protection [40]. The radiation protection programme is an essential part of the safety case and, as such, is subject to regulatory approval. The operating organization should use suitably qualified and experienced personnel to implement the radiation protection programme.

6.8. In accordance with the management system (see GSG-16 [26]), the operating organization should prepare a set of written procedures to ensure that predisposal management facilities are operated and activities are conducted safely, in compliance with the conditions of authorization and consistent with the safety case. In addition to written procedures for normal operations, the operating organization should establish written procedures for the detection and prevention of unexpected events and accidents and for the mitigation of their consequences. The operating organization should train personnel in the use of the procedures. Procedures for the protection of workers using a mobile hot cell to condition disused sealed radioactive sources for a borehole disposal facility are described in Ref. [24].

6.9. The transport to the disposal site of waste and waste packages resulting from waste conditioning is required to be undertaken in accordance with the requirements established in SSR-6 (Rev. 1) [12].

6.10. The long term storage of disused sealed radioactive sources requires ongoing regulatory control and associated resources, which cannot be ensured indefinitely. Where disposal facilities are available, disused sources should be processed and disposed of rather than stored in a long term storage facility (see Ref. [8]).

6.11. Prior to appropriate processing, disused sealed radioactive sources are often kept or stored in the shielding that formed part of the device that utilized the source. Common shielding materials include depleted uranium, tungsten and lead. Experience has shown that disused sealed radioactive sources can become difficult or impossible to remove from device shields (e.g. owing to corrosion) if they are kept or stored for too long under inappropriate conditions. In accordance with an authorization from the regulatory body, the operating organization should remove radioactive sources from the devices in which they were housed and place them in appropriate stainless steel capsules as follows:

(a) If it is necessary to store the disused sealed radioactive sources temporarily before they can be conditioned for disposal, the operating organization should consider using IAEA standard source conditioning capsules. The capsules containing the sources should be stored inside containers that provide appropriate shielding to protect workers.
(b) To condition disused sealed radioactive sources for borehole disposal, the operating organization should transfer the sources into disposal capsules, which should be sealed by welding, then placed and sealed inside a waste disposal container made of stainless steel with a cement based insert, as described in paras 2.15 and 2.16. Other containers and packaging may be used, but in all cases the operating organization should justify their use and demonstrate their performance in the safety case.

6.12. The operating organization should keep records of all waste management activities and waste, including records of any waste other than disused sealed radioactive sources, generated during the management of the sources (see paras 6.76–6.78). Such waste might include small volumes of contaminated materials (e.g. waste generated during the management of a leaking source), depleted uranium and other waste. The operating organization should assess in the safety case whether this waste can be disposed of safely in the borehole disposal facility.

6.13. The operating organization is required to decommission predisposal waste management facilities in accordance with GSR Part 6 [27]. The operating organization is required to prepare a decommissioning plan and to maintain it throughout the lifetime of the facilities. For each facility, the operating organization is required to prepare and submit to the regulatory body an initial decommissioning plan together with the application for authorization to operate the facility. This initial decommissioning plan is required in order to identify decommissioning options, to demonstrate the feasibility of decommissioning, to ensure that sufficient financial resources will be available for decommissioning, and to identify and estimate the types and quantities of waste that will be generated during decommissioning. The decommissioning plan is required to be updated by the operating organization and reviewed by the regulatory body periodically or when specific circumstances warrant. In accordance with Requirement 11 of GSR Part 6 [27], prior to the conduct of decommissioning, the operating organization is required to prepare and submit a final decommissioning plan to the regulatory body for approval. The final decommissioning plan is required to cover the decommissioning strategy; the schedule, type and sequence of decommissioning actions; the waste management strategy; the proposed site end state and how the operating organization will demonstrate that the end state has been achieved; the time frame for decommissioning; and financing for the completion of decommissioning.

SITE CHARACTERIZATION FOR A BOREHOLE DISPOSAL FACILITY

6.14. Requirement 15 of SSR-5 [4] states:

> "**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.**"

6.15. The operating organization should develop, document and implement a site characterization programme to gain sufficient understanding of the geomorphology, geology, hydrogeology, hydrology, geochemistry, climate, weather and ecology at and around the borehole disposal site. The operating organization should also develop, document and implement a site characterization programme to gain sufficient understanding of land use and human populations and behaviour at and around the site and how these affect the environment. The operating organization should document the scientific basis and reasoning for the contents of these site characterization programmes. The operating organization should develop the site characterization programmes in conjunction with the programme for the development of the safety case and the conduct of safety assessments (see Section 5) and should implement them simultaneously.

6.16. The operating organization should use the results of the site characterization programmes to inform the development of the safety case and the safety assessments. The operating organization should also use the results of the safety assessments and the safety case development work to refine and focus the contents of the site characterization programmes on issues of importance to safety. Although the collection of site specific data should focus on issues of importance to safety, the operating organization should also collect site specific data and information for confidence building purposes; while these data might not be absolutely necessary for demonstrating safety, they can nevertheless be useful, for example in helping to support multiple lines of reasoning in the safety case.

6.17. The operating organization should apply a graded approach when establishing site characterization programmes to support the development, commissioning, operation, closure and institutional control of a borehole disposal facility so that the effort expended is commensurate with the hazard and the level of risk associated with the waste. A borehole disposal facility of the type considered in the generic safety assessment [19] is a relatively small scale facility when compared with typical near surface or geological disposal facilities and is expected to provide a safe disposal solution under a wide range of site conditions. Reference [20] describes a graded approach to post-closure safety assessment for a borehole disposal facility and discusses how safety assessment models at different levels of complexity might be used to guide site characterization (see also Appendix I).

6.18. Site characterization activities for a borehole disposal facility should include, but not necessarily be limited to, the investigation of the following (see also Appendix I):

(a) The geology and geological evolution of the area. This investigation should involve various surface based and underground activities such as geophysical and borehole drilling investigations and the collection of rock samples for examination and characterization. Investigatory drilling may help to establish drill penetration rates, determine the presence of resources and establish the geology at depth, including the presence of faults or other geological features that may influence the performance of the borehole disposal facility.

(b) The geomorphology and geomorphological evolution of the area. This investigation should involve various studies to map and quantify the geomorphology and to investigate past, present and potential future erosive processes and land movements (e.g. landslips, faults, earthquakes, volcanism).

(c) The hydrogeology and hydrogeological evolution of the area. This investigation should involve various studies to establish the groundwater conditions at the site, including the presence of perched water, the properties of the partially saturated or unsaturated zone, the depth to the water table, the piezometric surface and results from tests to determine hydraulic parameters (e.g. hydraulic head gradient, permeability, porosity, saturation).

(d) The hydrology and hydrological evolution of surface water bodies in the area. This investigation should involve various studies to identify and establish the behaviour of surface water bodies in response to local meteorological conditions (e.g. precipitation), including studies of hydrological responses to adverse conditions (e.g. extreme rainfall, flooding).

(e) The geochemistry and geological evolution of the disposal system. This investigation should involve various studies to identify the mineralogy and understand the geochemistry of the rocks and water in the disposal system. Particular attention should be focused on determining the chemical composition, redox potential and speciation of groundwater, as these parameters can strongly affect the mobility of radionuclides.

(f) The meteorological conditions at present and their evolution, including the possible effects of future climate states on landform development and site conditions (e.g. Ref. [41]).

(g) The ecology at and around the site. This investigation should include studies to collect data on fauna and flora.

(h) Human populations and behaviours at and around the site. This investigation should involve studies to collect data on the size, locations and density of human populations; on human activities, including land uses (e.g. agriculture); and on human behaviours (e.g. where people obtain food and water from and consumption rates) that are needed for dose assessments in past, present and potential future conditions.

6.19. The operating organization should use the information gathered from the programmes and studies described in paras 6.15 and 6.18 to develop a credible scientific description of the natural system at the site and to demonstrate understanding of the safety significant features, events and processes, as well as their spatial and temporal extent and variability (in the past, at present and potentially in the future). The operating organization should use this information in determining the suitability of the site for a borehole disposal facility and/or in evaluating the performance of an existing disposal facility at the site.

6.20. The operating organization should demonstrate sufficient understanding of the potential effects of natural events and processes on the isolation and containment provided by the borehole disposal facility using the site characterization information and assessments of the probability and potential consequences of disruptive events and processes. In addition to describing the present-day characteristics of a site, the operating organization should collate and interpret information on the past and potential future evolution of the site. Such information should be used to support the identification of scenarios for the site and for evaluating the relevance of features, events and processes that could affect the performance of the disposal facility. The timescale for consideration of past site evolution should be at least comparable to the future timescale of interest in safety assessments. The operating organization should use this understanding as a basis for selecting the location and design of a borehole disposal facility, in particular, the depth(s) of the disposal borehole(s) and of the disposal zone(s).

6.21. The operating organization should conduct site characterization work in accordance with an appropriate management system (see paras 7.36–7.38 and GSG-16 [26]). The management system should include a process and procedures for handling spatially distributed information and time series data from site characterization and for establishing a baseline for monitoring. The operating organization should ensure that site characterization activities undertaken by suppliers are also in accordance with the management system.

DESIGN OF A BOREHOLE DISPOSAL FACILITY

6.22. Requirement 16 of SSR-5 [4] states:

> “**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."

6.23. The designs of borehole disposal facilities for radioactive waste may differ widely from one another, depending on the types of waste to be disposed of and the host geological formation and/or surface environment. The waste could, for example, comprise disused sealed radioactive sources that have been encapsulated in concrete within steel drums — a previously recommended but now obsolete practice.

6.24. Borehole disposal, particularly using narrow diameter boreholes, is appropriate for the disposal of relatively small volumes of waste (e.g. disused sealed radioactive sources that have been declared as waste). A reference design for a borehole disposal facility for such waste is described and assessed on a generic basis in Ref. [19]. Site specific designs for this type of facility have been developed and assessed for implementation in some States.

6.25. The operating organization should undertake a programme of work to develop and refine the design of a borehole disposal facility that takes due account of the inventory of waste to be disposed of, the results of site characterization, the results of safety assessment and arguments in the safety case for the facility. The operating organization should develop and refine the design of the disposal facility in parallel, and simultaneously, with the programme for the development of the safety case and the conduct of safety assessments (see Section 5). The operating organization should use the results of the design work to inform the development of the safety case and the conduct of safety assessments.

6.26. The operating organization should consider the following aspects in developing the design of a borehole disposal facility:

(a) The inventory of waste, including the types, quantities and physical and chemical properties of the waste to be disposed of and the radionuclides present;
(b) The geological conditions at the site (e.g. geological stability, groundwater flow, chemical compatibility of the rocks and groundwater with the engineered barriers) and how these affect considerations such as the number of boreholes, borehole dimensions, and number and depth of disposal zones;
(c) The engineered barrier system;
(d) Plans for operation of the borehole disposal facility, including waste emplacement and backfilling;

(e) Plans for sealing of boreholes and closure of the borehole disposal facility;
(f) Plans for the post-closure period.

6.27. The operating organization should consider various options for the design of the borehole disposal facility and should document the justification for the selected design. For example, there might be the option to dispose of a certain inventory of waste either in one borehole with a long disposal zone or in two or more boreholes with shorter disposal zones; the operating organization should give reasons for the option that it selects as part of the demonstration of optimization. In selecting a design, the operating organization should assess whether different waste types should be placed in different locations at the disposal facility. The operating organization should also assess the interactions that could occur between neighbouring boreholes to justify the chosen locations for disposal boreholes.

Waste inventory

6.28. The operating organization should identify and quantify the inventory of waste to be disposed of in the facility at an early stage in the development process. The operating organization should determine the number of boreholes and the borehole dimensions, taking account of the volume of waste to be disposed of, the drilling technology proposed to be used and the need for the borehole diameter to be consistent with the dimensions of the waste packages. In developing the design of a borehole disposal facility, the operating organization should consider using appropriate software to determine the total inventory of radionuclides within the waste, how many waste packages are needed, the length of the disposal zone(s) needed within the borehole(s) and the number of boreholes needed for the waste.

Geology and borehole design

6.29. In accordance with para. 4.30 of SSR-5 [4], optimal use is required to be made of the safety features offered by the host environment. This is done by designing a disposal facility that does not cause an unacceptable long term disturbance of the site, is itself protected by the site and performs safety functions that complement the natural barriers.

6.30. The operating organization should select the depth of each disposal zone to reduce the probability of inadvertent human intrusion and to ensure that disposal zones are located in suitable rocks (i.e. those having appropriate mechanical, hydrogeological and hydrogeochemical properties). The operating organization should reduce the risk from inadvertent human intrusion by keeping the footprint of the facility small and by disposing of the waste at sufficient depth. In selecting the depth of disposal zones, the operating organization should consider the time it would take for radionuclides released from the disposed waste to migrate to the biosphere. In deciding on the number of disposal boreholes, the operating organization should consider the total length of disposal zone needed, which depends on the number and lengths of the waste packages and their spacing and the geometry (e.g. thicknesses) of suitable strata within the host rock at depth.

Engineered components

6.31. The operating organization should ensure that the design of the system of engineered components is consistent with plans for predisposal management of the waste and with the design of the disposal borehole(s), and that the design will contribute to the containment of the radionuclides in the waste. The operating organization should take account of the results of relevant geological surveys and of research and development work when designing engineered components for use at a particular site.

6.32. The engineered barriers should include a waste package that facilitates waste handling and emplacement operations and that is compatible with the geochemical conditions in the host rock and the materials of the other engineered barriers. The operating organization should consider using more than one containment barrier (e.g. by placing the sources inside a disposal capsule within a waste container). The operating organization should use appropriate material(s) to backfill any spaces between barriers (e.g. between the disposal capsule and container, between and around waste containers in the borehole, between the borehole casing and the surrounding rocks; see Fig. 1). The operating organization should decide on the design of the waste package relatively early in the facility development process because this will affect both the predisposal management of the waste and the disposal operations. These design elements can include, for example, the amount of shielding provided by the waste package (which may affect whether the waste package needs to be handled remotely); the dimensions and weight of the waste package (which will affect lifting, handling and emplacement operations); the corrosion and radiation resistance of the materials to be used (further information is provided in Appendix II); and the method of waste package emplacement in the borehole (which will influence operational feasibility and safety). The operating organization should also assess and consider the long term performance of the waste package in the disposal borehole, as this may play an important part in the post-closure safety of the disposal system.

6.33. The operating organization should design engineered barriers to seal boreholes and close the borehole disposal facility. Borehole seals could, for example, comprise clay or cement based plugs placed in the borehole above the disposal zone. Such seals or plugs could also be placed at the bottom of the disposal zone.

6.34. The operating organization should consider the need for borehole casing to ensure borehole stability during the operational period and to facilitate waste emplacement and should further consider whether some of the casing should be removed after waste disposal. In making this decision, the operating organization should bear in mind that casing left in place above the disposal zone might degrade and act as a pathway for radionuclide transport towards the surface; on the other hand, it should consider the practicalities, difficulties and implications of casing removal (e.g. the creation of voids). The operating organization should consider the type of backfill material to use at depth and near the surface. The operating organization should also consider the inclusion of engineered features to reduce the probability of inadvertent human intrusion (e.g. a deflection plate).

6.35. In accordance with Requirement 7 of SSR-5 [4], the operating organization is required to use a multiple safety function approach so that the performance of the disposal system does not depend unduly on a single barrier or a single safety function. The operating organization should specify the safety function(s) of each of the components in the borehole disposal system and should justify the selection of materials for the engineered barriers and features by providing evidence to support a reasonable expectation that each component will fulfil its function(s). The operating organization should document analyses of features, events and processes that could cause the components to degrade or stop fulfilling their safety functions.

Design refinement

6.36. In the safety case and safety assessments, the operating organization should examine the various design options for the following purposes:

(a) To assess whether a design has the potential to fulfil the relevant dose and risk criteria (if it does not, the design can be eliminated from further consideration);
(b) To evaluate the performance of the disposal system and its components;
(c) To inform decisions on the design and on optimization.

6.37. The operating organization should consider a range of factors (including safety, security and socioeconomic factors) in making decisions on the design of a borehole disposal facility. For example, the expected performance of the natural barriers in containing radionuclides in a borehole disposal system could have implications for the level of engineered containment needed or for how operations should be conducted, which could, in turn, have implications for costs and human resources.

CONSTRUCTION OF A BOREHOLE DISPOSAL FACILITY

6.38. Requirement 17 of SSR-5 [4] states:

> "**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. As part of the safety case, the operating organization should develop a written construction method and associated technical specifications and procedures.

6.40. The operating organization should ensure that borehole construction is carried out by suitably qualified and experienced personnel, following the construction method and associated technical specifications and procedures (see paras 5.75–5.86 and 5.172–5.177 of GSG-16 [26]) and in accordance with a valid authorization. The regulatory body should undertake inspections during construction of the facility to verify that the operating organization has a sufficient number of suitably qualified and experienced personnel available for the construction activities to be performed. The construction method and associated technical specifications and procedures should be based on safe and successful prior practice and should be updated as further experience is gained.

6.41. To support a decision on authorization for construction, the regulatory body should review the safety case prepared by the operating organization, including the safety assessments for both the operational and post-closure periods and the construction method and associated technical specifications and procedures. The regulatory body should consider, inter alia, whether the proposed method of construction is capable of delivering the proposed design (e.g. in terms of borehole dimensions, borehole straightness, ability to provide suitable conditions for waste emplacement, methods for emplacement and removal of casing and methods for backfilling and sealing of boreholes) without having a significant detrimental effect on the host environment. The regulatory body should consider whether the safety case adequately describes and justifies the actions to be taken in the event of abnormal events during construction, such as the loss of a drill bit, excessive water ingress or the unexpected failure of a borehole wall.

6.42. The operating organization should document and implement a programme of testing and inspection work to confirm and demonstrate that the construction of the borehole disposal facility is in accordance with the design, the construction method and associated technical specifications and procedures, and that any unexpected features (e.g. strata, faults, fracture zones) revealed during construction are consistent with the safety case.

6.43. The operating organization should ensure that the construction method is sufficiently flexible to deal with spatially variable rock conditions. The operating organization should monitor rock conditions during drilling (e.g. by collecting rock samples, by using borehole logging methods) and should take appropriate timely actions to counteract unfavourable conditions (e.g. fracture zones) or unexpected events (e.g. failure of the borehole wall). The operating organization should specify in the construction method the means of either remediating marginally unsuitable boreholes or sealing such boreholes without emplacing waste. The regulatory body should consider whether the safety case adequately describes and justifies measures for sealing ‘failed’ boreholes (i.e. boreholes where waste emplacement proves to be impracticable).

6.44. The operating organization should specify in the construction method the means of avoiding unnecessary disturbance to the geology, particularly where boreholes pass through different hydrogeological regimes. The operating organization should not locate a waste disposal zone in an aquifer. Where it is necessary to drill through an aquifer to reach a waste disposal zone, the operating organization should case the borehole throughout the interval where it passes through the aquifer and provide sufficient isolation of the waste from the aquifer to avoid radionuclide transfer to the aquifer. In determining what is sufficient isolation, the operating organization should consider the properties of the rocks and the potential for any radionuclides that may be released from the waste and waste containers to migrate to the aquifer.

6.45. The operating organization should take measures to prevent the borehole and any disturbed rock zone around it from providing pathways through which radionuclides could be transported in gas or groundwater towards the surface or towards other relatively transmissive geological strata. The operating organization should aim to ensure that the backfilled borehole and any disturbed rock around it are no more permeable than the surrounding intact rocks by using appropriate backfill materials and backfilling methods.

6.46. The operating organization should specify in the construction method the means of installing any borehole casing to be used and, as appropriate, the means of removing such casing. The operating organization should ensure that the casing is strong enough to withstand expected vertical and horizontal loads and shear forces. The operating organization should justify the construction method by documenting the reasons for design decisions, such as decisions to use certain types of casing material, to install casing at certain depths, to leave casing in place or to remove casing from certain depth intervals.

6.47. The operating organization should construct and operate only one disposal borehole at a time at the facility site. The construction of any new boreholes at the site of an existing borehole disposal facility should be conducted only after the previous disposal boreholes have been sealed and should be carefully planned by the operating organization and authorized by the regulatory body.

6.48. The operating organization should create and retain records of borehole construction in order to provide a complete description of the history of construction, including when, how and by whom a borehole was constructed, its depth and diameter, the geological formations encountered, the rate of drilling, whether water was encountered and any occurrences of unexpected events, accidents or non-compliance with the construction method.

COMMISSIONING OF A BOREHOLE DISPOSAL FACILITY

6.49. The operating organization should describe in the safety case how the facilities and activities are to be commissioned and operated. Before a borehole disposal facility can start to operate, the operating organization should perform appropriate commissioning activities, including, where appropriate, for predisposal management facilities. Before beginning waste emplacement in the borehole disposal facility, the operating organization should test and confirm that the operations can be undertaken successfully and as planned, in compliance with the conditions specified in the authorization and the safety case. The operating organization should pay particular attention to testing the processes for emplacing waste packages in the borehole and for putting the engineered barriers in place. During commissioning and after the emplacement of each waste package, the operating organization should check that the borehole does not contain any obstructions that might prevent the successful emplacement of the next waste package. In pilot studies, this has been achieved by lowering a non-radioactive, dummy waste package down the borehole and then retrieving it. The operating organization should develop an appropriate programme of commissioning tests to verify that the backfill materials prepared on site have appropriate characteristics (e.g. water content, density, grain size, rheology, setting time). The regulatory body should undertake appropriate inspections of the commissioning activities.

OPERATION OF A BOREHOLE DISPOSAL FACILITY

6.50. Requirement 18 of SSR-5 [4] states:

> "**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.**"

6.51. At a borehole disposal facility, the operational period should commence after appropriate commissioning activities. All operations should be performed in accordance with written operating procedures. Predisposal management operations (including temporary storage of waste and waste conditioning) can be performed immediately before waste emplacement using, for example, a mobile hot cell (see Ref. [24]) or a mobile tool kit facility. Disposal operations include receiving waste, checking that the waste meets the waste acceptance criteria, emplacing the waste and the backfill between waste packages, and backfilling and sealing the borehole.

6.52. The operating organization should describe in the safety case how the borehole disposal facility is to be commissioned and operated. The operating organization should describe in the safety case how doses to workers are to be controlled under normal circumstances and what arrangements will be in place to protect workers and members of the public in abnormal situations (e.g. events, accidents).

6.53. During the operational period, the regulatory body should review and assess the safety case and perform inspections to verify the following:

(a) That the operating organization is applying its management system to ensure the safe operation of the borehole disposal facility;
(b) That the operations do not compromise any safety functions on which the post-closure safety of the borehole disposal facility depends;

(c) That only waste that complies with the waste acceptance criteria is accepted for disposal in the borehole disposal facility (see paras 6.58–6.66).

Radiation protection programme

6.54. In accordance with GSR Part 3 [2], in particular Requirements 19–28, the operating organization is required to implement a radiation protection programme throughout the operation of a borehole disposal facility. The radiation protection programme is an essential part of the safety case and, as such, is subject to regulatory approval. Recommendations on occupational protection that should be applied at disposal facilities are provided in GSG-7 [40]. The operating organization should use suitably qualified and experienced personnel to implement the radiation protection programme.

Operating procedures

6.55. In accordance with the management system, the operating organization should prepare a set of written procedures to ensure that the borehole disposal facility is operated safely and in compliance with the conditions of the authorization and the safety case (see GSG-16 [26]). These operating procedures should be derived from the technical specifications for operations, which should, in turn, be consistent with the operational safety assessment. In addition to written procedures for normal operations, the operating organization should establish written procedures for the detection and prevention of unexpected events and accidents (e.g. receipt of waste that does not meet the waste acceptance criteria, collapse of borehole walls, jamming of waste packages in boreholes) and for the mitigation of their consequences. The operating procedures should specify when reports should be made to the regulatory body, in accordance with the authorization. The operating organization should train personnel in the use of the operating procedures.

6.56. The operating organization should verify that work is conducted according to the operating procedures, that the work achieves the design aims for the operations and that the work and operations are adequately covered by the safety assessment and the safety case; this verification should be performed through appropriate programmes of inspection, auditing and record keeping.

6.57. The operating organization should apply formal change control procedures to proposals for changes to operating procedures or equipment and should ensure that the safety implications are assessed, understood and taken into account when making a decision on the proposed changes. The operating organization should notify the regulatory body of changes that are potentially significant to safety and should obtain agreement from the regulatory body for such changes prior to implementing them.

Waste acceptance

6.58. Requirement 20 of SSR-5 [4] states:

> "**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.**"

6.59. The operating organization should operate the borehole disposal facility in accordance with the limits, controls and conditions specified in the authorization, which are established from, and specified in, the safety case approved by the regulatory body and the operating procedures. Waste acceptance criteria are a key component of these limits, controls and conditions. The operating organization should develop waste acceptance criteria to ensure that waste packages accepted for disposal in a borehole facility are consistent with the safety case. The waste acceptance criteria should be approved by the regulatory body. The operating organization should use the waste acceptance criteria to control the types, volumes and characteristics of waste that are disposed of in the disposal facility.

6.60. The safety of a borehole disposal facility depends in part on the waste packages. The operating organization should, therefore, develop specifications for the waste packages. The operating organization should subject proposals or requests (e.g. from waste generators) for changes to the waste package specifications to a change control process that includes a safety review by the operating organization and, as appropriate, regulatory scrutiny.

6.61. When developing the waste package specifications, the operating organization should take account of all the activities to be performed during the predisposal management and disposal of the waste and all the conditions that might occur throughout the predisposal management and disposal operations and after waste disposal, focusing on the safety relevant aspects. As an illustration, limits included in the waste acceptance criteria on the activity of gamma emitters in a waste package will probably be based predominantly on predisposal management and operational safety considerations (e.g. waste package surface dose rates). The corresponding limits for the activity of alpha emitters in a waste package will probably be based predominantly on post-closure safety considerations.

6.62. The operating organization should develop and use the waste acceptance criteria to provide confidence that the waste forms and waste packages will fulfil the safety functions attributed to them in the safety case. The operating organization should consider establishing waste acceptance criteria such as the following:

(a) A limitation to accept for disposal only solid disused sealed radioactive sources and low and intermediate level secondary radioactive waste generated during the management of the disused sealed radioactive sources;
(b) A limitation to accept for disposal only waste forms with stable chemical and physical properties (e.g. no powders; no putrescible, reactive or explosive materials or waste);
(c) Limits on the weight and size of waste packages;
(d) Limits on the levels of surface contamination on a waste package;
(e) Specifications for capsules and waste containers (e.g. materials, manufacturing and welding methods, testing protocols);
(f) Specifications for backfill materials (e.g. materials, backfilling methods, testing protocols);
(g) Limits on the heat output of a waste package;
(h) Limits on the disposal of waste that might generate gas;
(i) Limits on the total activity of each waste package, of the waste in each borehole and of the waste that can be disposed of in the entire disposal facility;
(j) Limits on the radionuclide content of each waste package, of each borehole and of the entire disposal facility;
(k) Controls on the mixing of different types of disused sealed radioactive sources and/or radionuclides within waste packages;
(l) Limits on the fissile nuclide content of each waste package, of each borehole and of the entire disposal facility.

6.63. A generic assessment of the reference borehole disposal concept [19] for the case of a single disposal borehole indicated the following:

(a) The protection of workers during disposal operations depends on the type of shielding available, which might in practice limit the activity of strong gamma emitters and neutron sources that can be accepted for processing and disposal.
(b) Post-closure safety considerations might limit the activity of long lived radionuclides that can be disposed of in the borehole disposal facility.
(c) To avoid excessive temperature rises in the disposal borehole, heat generation should be kept below a few tens of watts per waste package, which might

mean that the largest sources that can be accepted have activities of heat generating radionuclides of no more than several tens of GBq (see Ref. [16]).

6.64. The operating organization should ensure that waste intended for disposal is characterized sufficiently and shown to comply with the waste acceptance criteria before the waste is accepted for disposal. In accordance with para. 3.11 of GSR Part 5 [3], the operating organization is required to keep records of all predisposal waste management activities and of waste accepted for disposal, in accordance with the management system (see also paras 7.36–7.38).

6.65. The operating organization should, as far as possible, create and retain records that provide a detailed description of each disused sealed radioactive source (including its physical, chemical and radiological characteristics) and of the total inventory of disused sealed radioactive sources and other waste accepted for disposal and disposed of. There are sometimes gaps in inventory information, for example because a disused sealed radioactive source has fallen out of regulatory control and later been found as an orphan source or because disused sealed radioactive sources have been collected from many different users and locations and stored for considerable periods by persons or organizations other than those that originally used the sources. The operating organization should make appropriate estimates to fill such gaps in inventory information, including by making use of the national register of radioactive sources (see RS-G-1.9 [23]).

6.66. The regulatory body should ensure that there are arrangements and procedures in place to define and control the actions taken by waste generators and by the operating organizations of borehole disposal facilities to deal with any waste packages that do not conform to waste acceptance criteria. The operating organization should provide information to the regulatory body on waste acceptance and non-conformances in accordance with the national legal and regulatory framework and the authorization for the facility.

Waste emplacement

6.67. The operating organization should emplace waste packages in the disposal borehole(s) in accordance with the authorization and the safety case. The operating organization should ensure that waste packages are emplaced centrally in the borehole(s). For this reason, the designs considered in the pilot studies for the reference borehole disposal concept described in paras 2.12–2.19 have employed waste packages that include small tabs, called ‘centralizers’, which are made of the same material as the waste packages. The operating organization should use appropriate backfilling materials to ensure that the waste packages are emplaced with appropriate spacing to provide for the management of heat and interactions between waste packages. The operating organization should emplace the waste and backfill (see para. 6.70) in such a way that they are strong enough to withstand expected vertical and horizontal loads and shear forces.[21]

6.68. On a larger scale, the operation of a borehole disposal facility can be performed using a continuous or a campaign approach. In the case of continuous operation, waste packages are emplaced in the borehole disposal facility as they are generated, and the operating organization may, therefore, need to keep the borehole open and exercise control over the borehole for several years. Campaign operation involves the accumulation of waste in storage facilities until there is sufficient waste to be disposed of within a short period (i.e. a few weeks to a few months). Operating on a campaign basis allows an individual disposal borehole to be constructed, receive waste and be sealed as a discrete project, and thus reduces the chances of the borehole degrading or being mismanaged if it remains open for a long time between individual waste emplacement operations. Continuous operation might be appropriate in the case of larger capacity boreholes, where operating on a campaign basis would necessitate more extensive waste storage facilities. In either case, the operating organization should prevent rainwater, surface water and groundwater from entering the borehole while it is open. This can be achieved by providing borehole casing, a borehole drainage system and a secure cover over the borehole as necessary in periods between waste emplacement, backfilling and sealing operations. The operating organization should provide a justification for the proposed approach to operating the disposal facility in the safety case.

6.69. The operating organization should consider whether to establish a waste emplacement strategy, such as one relating to the location of waste packages containing high activity or long lived waste in the bottom part of the disposal zone and waste packages containing low activity short lived radionuclides at the top of the disposal zone. In theory this could improve post-closure safety and

[21] In the pilot studies for the reference borehole disposal concept described in paras 2.12–2.19, it has been found to be more effective, in terms of avoiding the formation of unwanted voids in the disposal zone, to emplace each waste package in a measured amount of wet cement based backfill grout (cement slurry) that has already been placed in the borehole. To follow this approach, a backfill with appropriate rheology and setting time is needed so that the waste package can sink into the cement slurry and the backfill can then set before the emplacement of the next waste package. The operating organization should conduct appropriate tests under realistic conditions in order to demonstrate that the materials and processes to be used to manufacture the backfill produce a mixture with the desired properties (e.g. appropriate rheology and setting time).

limit the consequences of inadvertent human intrusion. However, considerable site characterization data and detailed safety assessment modelling would be needed to justify such emplacement strategies and they might also be difficult to implement in practice, as they might necessitate longer storage times, more complicated storage arrangements and greater assurance regarding the location and management of individual waste packages and might result in a greater total dose to workers. In general, the operating organization should aim for a simple and robust waste emplacement strategy in which any waste package can be disposed of safely at any location in the disposal facility. In cases where this is not possible, for example where there are large numbers of high activity sources to be disposed of, more complex waste emplacement strategies should be considered. The operating organization should provide in the safety case a justification for the proposed waste emplacement strategy.

Backfilling of disposal boreholes

6.70. After completing waste emplacement in a disposal borehole, the operating organization should backfill the space in the borehole above the disposal zone up to the point at which a borehole seal will be placed; backfilling should be performed in a timely manner and in accordance with the authorization and the safety case. Disposal boreholes should be backfilled to prevent them from acting as pathways for groundwater or gas flow and for radionuclide migration. The operating organization should backfill boreholes in such a way that they are no more permeable than the surrounding intact rocks. Materials that could potentially be suitable as backfills include mixtures of cement and sand, bentonite and mixtures of bentonite and sand. The operating organization should implement measures, such as backfilling in stages, to reduce the possibility of leaving voids in the backfill.

Sealing of disposal boreholes

6.71. After backfilling a disposal borehole, the operating organization should seal the borehole; sealing should be done in a timely manner and in accordance with the authorization and the safety case. The operating organization should document the approach to, and design for, borehole sealing in the safety case. The operating organization should ensure that the sealing materials form a hydraulically tight seal. Disposal boreholes should be sealed to prevent them from acting as pathways for groundwater or gas flow and for radionuclide migration. The operating organization should seal boreholes in such a way that they are no more permeable than the surrounding intact rocks.

6.72. The operating organization should select the technique to be used for borehole sealing, taking account of the size of the borehole, whether the borehole is cased and the geology of the site. In the case of narrow diameter boreholes, standard borehole sealing techniques will probably be appropriate.

6.73. The top few metres of the borehole above the backfill should be filled with soil so that the borehole is undetectable without special equipment [15]. Various backfill materials and depth intervals may be used, but in all cases the operating organization should justify the choice of material and the design of the disposal facility components, taking account of their intended purposes, safety functions and performance in the conditions of the disposal system. For example, depending on site specific conditions, the operating organization could consider using clay based backfills and/or soil to fill the top of the borehole above the rock zone.

Inspection and review

6.74. The regulatory body should require the operating organization to conduct periodic reviews covering issues such as quality assurance audits, operating conditions, environmental sampling and analysis, occupational health and safety, and maintenance of records. The operating organization should submit the results of these reviews to the regulatory body.

6.75. The regulatory body should conduct independent audits, inspections and reviews of disposal operations to satisfy itself that appropriate management controls are being applied and appropriate technical work is being undertaken. The operating organization should, upon request, apply appropriate corrective actions in a timely manner.

Records

6.76. Traceable records should be created that describe and characterize the radioactive waste and the waste management activities undertaken. The records should include various types of information including the following, as appropriate (see para. 5.64 of GSG-16 [26]):

(a) The origin of the waste and the processes by which it was generated;
(b) The physical and chemical forms and properties of the waste (e.g. of the materials used in waste conditioning and their radionuclide retention properties);
(c) The activity concentration and total activity of radionuclides in the waste;

(d) The mass, activity concentration and total activity of fissile nuclides in the waste;
(e) The type of waste package;
(f) The radiation level at the surface of the waste package;
(g) The level of surface contamination on the waste package;
(h) The mass and weight of the waste or waste package;
(i) The date(s) of waste processing;
(j) The methods, equipment and procedures used to describe and characterize the waste and to confirm compliance with established waste acceptance criteria.

6.77. Records describing the history of radioactive waste management facilities, such as data obtained during facility design, construction, commissioning, operation and closure, should also be created and retained. These records include the following, as appropriate (see para. 5.66 of GSG-16 [26]):

(a) Authorizations (e.g. licences, permits, amendments);
(b) Commissioning records;
(c) The safety case and safety assessments;
(d) An environmental impact assessment;
(e) Peer review reports;
(f) Technical specifications and amendments;
(g) Design options, concepts, documents, calculations and drawings;
(h) Records of the facility actually constructed ('as-built' records);
(i) Approved design changes;
(j) Procurement records for structures, systems and components;
(k) Operating procedures;
(l) Records of the implementation, review, updating and maintenance of emergency preparedness and response arrangements, including records of training, exercises, response to actual emergencies, lessons identified and corrective actions implemented;
(m) Waste emplacement plans;
(n) Records generated during facility operation, including records of emplaced waste packages;
(o) Records of assessments, inspections and verifications of processes and activities;
(p) Records of any non-conformances and corrective actions;
(q) Records of the training, experience and qualification of personnel;
(r) Monitoring data;
(s) Records of any incidents, including accidents, that have occurred;

(t) Records of interactions between the operating organization and the regulatory body (e.g. meetings, inspections).

6.78. The range of information and the level of detail to be recorded should be specified in the management system, applying a graded approach. Further recommendations on records and their maintenance and preservation are provided in paras 5.64–5.74 of GSG-16 [26].

CLOSURE OF A BOREHOLE DISPOSAL FACILITY

6.79. Requirement 19 of SSR-5 [4] states:

> "**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.**"

6.80. When the surface facilities at a borehole disposal facility have been decommissioned (see para. 6.13) and all boreholes used for waste emplacement have been backfilled and sealed, the facility should be closed. The operating organization should close the facility in accordance with the plan for facility closure included in the safety case approved by the regulatory body.

6.81. To gain regulatory approval for borehole disposal facility closure, the operating organization should develop and provide the regulatory body with an updated safety case that is based on current data (including records of the facility as built and operated) and that provides reasonable assurance that post-closure safety will be achieved.

6.82. The closure plan should demonstrate that the closure activities will not impair the post-closure performance of the facility. For example, closure activities should not lead to the top(s) of the disposal borehole(s) being exposed or damage any anti-intrusion barriers that are included in the design. The closure plan should also describe any arrangements for the post-closure institutional control period. The operating organization should undertake the closure activities and demonstrate to the regulatory body that they have been satisfactorily completed.

6.83. Any arrangements for the transfer of responsibility for the site to another organization after closure should be undertaken in accordance with regulatory requirements and clearly documented. When the closure operations have been satisfactorily completed, the period of post-closure institutional control can begin. Depending on the regulatory framework and the conditions of the authorization, the transition to the period of post-closure institutional control may require separate regulatory approval.

7. ASSURANCE OF SAFETY FOR A BOREHOLE DISPOSAL FACILITY

MONITORING PROGRAMMES AT A BOREHOLE DISPOSAL FACILITY

7.1. Requirement 21 of SSR-5 [4] states:

> "**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.**"

7.2. Monitoring is the continuous or periodic measurement of radiological or other parameters or determination of the status of a structure, system or component [5]. In accordance with Requirement 5 of SSR-5 [4], the safety of a disposal facility is required to be provided by passive means to the fullest extent possible, and its dependence on future actions such as surveillance has to be minimized. Monitoring of the borehole disposal facility should therefore be for the purpose of assuring safety.

7.3. The operating organization should consider the level of hazard posed by the waste and apply a graded approach accordingly when designing the monitoring programme for a borehole disposal facility. The operating organization should document the justification for the monitoring programme, and the programme itself, including its objectives and scope.

7.4. The monitoring programme should have the following objectives:

(a) Be in accordance with applicable laws and regulatory requirements;
(b) Be appropriate to the periods of facility development, commissioning, operation, closure and institutional control;
(c) Include the collection and updating of information to help evaluate the behaviour of the disposal facility and its structures, systems and components, and the impact of the waste disposal system on the public and the environment;
(d) Contribute to building confidence in the safety of the facility and to developing the safety case by providing measurements that can be used to demonstrate compliance and test assumptions;
(e) Provide information that can be used to reassure interested parties, including the public, of the safety of the facility.

7.5. The operating organization should describe and justify which parameters are to be monitored, and how, where, how often and for how long monitoring is to be performed. The operating organization should, as appropriate, include in the monitoring programme the measurement of radiological, environmental and engineering parameters, for example background levels of radioactivity; the level, flow and compositions of the water; and rock stresses. When deciding what to measure, the operating organization should note that the concentrations of radionuclides that migrate from waste in the disposal facility and reach locations (e.g. groundwater discharge points in the biosphere) where they could affect receptors (e.g. people) in the future are likely be so low that it would not be possible for them to be measured. For a borehole disposal facility, particularly one for waste containing short lived radionuclides that are expected to decay substantially while in the waste containers, the monitoring programme may be quite limited, both in its spatial extent and duration.

7.6. In accordance with Requirement 21 of SSR-5 [4], monitoring is required to commence before a borehole disposal facility becomes operational. During site characterization, the operating organization should use the monitoring programme to establish a baseline of environmental conditions (e.g. groundwater levels) against which subsequent measurements and changes (e.g. owing to drilling) can be compared and assessed (see paras 6.3–6.6 of SSG-31 [37]). As the borehole disposal programme moves from one stage to the next, the operating organization should update the objectives of the monitoring programme and, consequently, the monitoring activities.

7.7. In accordance with para. 5.4 of SSR-5 [4], monitoring programmes are required be designed and implemented so as not to reduce the overall level of safety of the facility after closure. Before commissioning a borehole disposal facility, the operating organization should seal any monitoring or other boreholes at or near the site that might reduce the safety of the facility, for example by acting as pathways for groundwater or gas flow and for radionuclide migration. Sealing should be done in a timely manner, in accordance with the authorization and the safety case, and in such a way that the sealed boreholes are no more permeable than the surrounding intact rocks.

7.8. The operating organization should clearly document and communicate to interested parties the objectives, scope and results of the monitoring programme and take appropriate account of the results and of the views of interested parties.

7.9. The operating organization should use the results of monitoring to update and build confidence in the safety case for the borehole disposal facility and to aid decision making on future steps. The operating organization should use the results of monitoring to gain and improve understanding of potential radionuclide transfer pathways and potential discharge locations. The operating organization should, where possible, use the results of the monitoring programme to assist in the development and calibration of the geosphere and biosphere models used in safety assessment.

7.10. The operating organization should establish an approach for responding to unexpected monitoring results. Unexpected monitoring results do not necessarily imply that remedial actions or protective measures are necessary (see paras 8.11–8.15 of SSG-31 [37]). The response may vary from no action to increased sampling frequency for identifying or confirming spatial and temporal trends to changes in design or procedures to significant remedial action or even to retrieval of emplaced waste. The operating organization should place emphasis on identifying trends in monitoring results rather than assigning too much significance to individual measurements. Actions such as retrieval of waste should be undertaken only after very careful study and justification, including consideration of the risks associated with remedial action (see para. 8.15 of SSG-31 [37]).

7.11. The regulatory body should provide guidance on the establishment of a suitable monitoring programme in accordance with the national regulatory framework and should regularly review the operating organization's monitoring arrangements and results. The regulatory body should consider conducting independent monitoring.

THE PERIOD AFTER CLOSURE AND INSTITUTIONAL CONTROLS

7.12. Requirement 22 of SSR-5 [4] states:

> "**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.**"

7.13. The operating organization is responsible for implementing and maintaining active institutional control of the borehole disposal site and facility throughout the period of its authorization. This responsibility includes planning for the period after the facility's closure. Institutional controls are generally classified into active and passive controls.

7.14. Active institutional controls include the following:

(a) Operation of the site and the facility in accordance with the authorization;
(b) Maintenance of signs, fences and guards at the authorized site, for example, to prevent unauthorized access and unintended radiation exposures;
(c) Provision of nuclear security;
(d) Monitoring and surveillance activities;
(e) Remedial work that might become necessary.

7.15. Passive institutional controls include the following:

(a) Archiving of records of the disposal facility;
(b) Controls on land ownership;
(c) Restrictions on land use.

7.16. The period of active institutional control should be followed by a period in which passive institutional controls provide assurance of safety. The operating organization should specify in the plan for closure and institutional control which active and passive controls are to be implemented and for how long active institutional control will be maintained.

7.17. The duration of the active institutional control period should be established in the authorization process and approved by the regulatory body. The operating organization should provide a justification for the proposed duration of the period of active institutional control on the basis of the safety case. The operating organization should use the safety case to assess the specific characteristics of the site and the present and future hazards posed by the waste (e.g. as a function of radioactive decay, environmental change and the probability of inadvertent human intrusion). The timing of the change from active institutional control to passive institutional control could coincide with the completion of the borehole disposal facility closure, or it could occur at a later date. The planned timing of the change to passive institutional control should be reviewed periodically during the active institutional control period and should be approved by the regulatory body.

7.18. The safety of borehole disposal facilities in which waste has been disposed of at depths greater than the recommended minimum depth should not depend on active institutional controls and, depending on the safety case, quite short periods of post-closure active institutional control might be justifiable. In such cases it might be possible to convert the disposal site to other uses in just a few years, possibly with some ongoing passive institutional controls (e.g. on land ownership). Borehole disposal facilities in which waste has been disposed of at depths shallower than the recommended minimum depth should contain waste having predominantly short lived radionuclides, as determined by the safety case; the safety of such facilities should therefore also not depend on long periods of post-closure active institutional control.

7.19. Depending on national laws and regulations, the institutional control period assumed for the purpose of safety assessment calculations for a borehole disposal facility might be as long as a few hundred (e.g. 100–300) years. Institutional control would not necessarily be needed or effective for so long, nor would it necessarily cease after this period; rather, a few hundred years is the maximum period an operating organization should claim in the safety case. More resources will be needed the longer active institutional controls are maintained.

7.20. The operating organization should propose and, as far as possible, initiate appropriate passive institutional controls for the period after the authorization is terminated. At the end of the period of active institutional control by the operating organization, responsibility for the borehole disposal facility might be transferred to the regulatory body or to the government, or the site might be completely released from control. Before the site is transferred or released, the operating organization should archive all relevant information on the borehole disposal facility. The archiving of records should be done in such a way as to maintain knowledge of the facility's location and characteristics within multiple institutions. Information that should be archived for a borehole disposal facility includes the following:

(a) The location of the disposal facility;
(b) Information on the geology, geochemistry and hydrology of the disposal facility site, including data derived from site characterization (see paras 6.14–6.21 and Appendix I);
(c) Details of the design of the facility, including the locations and descriptions of the borehole(s) and the associated engineered structures, systems and components (e.g. borehole backfill, casing, seals) (see paras 6.22–6.26) and descriptions of the waste and waste packages, including the origins of the waste, the radionuclides present, the waste containers used and the depths of waste disposal;
(d) Descriptions of the construction and operation of the facility, including dates and details such as measured water inflows to boreholes, and any non-conformances and the actions taken to rectify them (see paras 6.38–6.48);
(e) Records of any incidents, including accidents, that have occurred;
(f) The safety case and safety assessments, including a description of the arrangements for the post-closure period and the monitoring programme and monitoring results (paras 7.1–7.11);
(g) Authorizations (i.e. permits and licences) issued by the regulatory body.

7.21. The operating organization should make arrangements for the information to be retained for as long as possible and should consider making use of national archives for this purpose. If responsibility for the site has been transferred to another entity (e.g. the regulatory body, the government), the operating organization should, if possible, provide assistance to that entity as requested.

ACCOUNTING FOR AND CONTROL OF NUCLEAR MATERIAL

7.22. Requirement 23 of SSR-5 [4] states:

> "**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**".

7.23. Systems of accounting for and control of nuclear material have been developed to provide for the accountability of nuclear material so as to detect, in a timely manner, its diversion to unauthorized or unknown purposes in the short and medium term. The government should facilitate the effective implementation of nuclear material accounting and control in a manner that does not compromise safety.

7.24. The borehole disposal facilities that are within the scope of this Safety Guide should only receive radioactive waste of the types specified in para. 1.1. Most of this waste does not comprise or include nuclear material and so does not fall within the system of accounting for and control of nuclear material. Some disused sealed radioactive sources contain fissile nuclides but do not fall within the system of accounting for and control of nuclear material because the fissile nuclide content is low. Where applicable, the system of accounting for and control of nuclear material should be considered at an early stage in the design of a borehole disposal facility.

7.25. The shielding of some disused sealed radioactive sources contains sufficient depleted uranium that IAEA safeguards apply. IAEA safeguards, where applicable, apply throughout the development, commissioning, operation, closure and institutional control of a borehole disposal facility. During the pre-operational period and during operation of a borehole disposal facility for waste that includes fissile material, surveillance for the purposes of IAEA safeguards is aimed at ensuring the continuity of knowledge concerning the fissile material and the absence of any undeclared activities at the site in relation to such material. As organized at present, IAEA safeguards activities depend on active surveillance and controls (see paras 5.16 and 5.17 of SSR-5 [4]).

7.26. Where the system of accounting for and control of nuclear material applies to a closed borehole disposal facility, intrusive methods have to be avoided. Where IAEA safeguards apply to a closed borehole disposal facility, safeguards control measures should be applied by remote means (e.g. satellite monitoring, aerial photography, micro-seismic surveillance, administrative arrangements).

7.27. It may also be necessary to implement physical protection measures for nuclear material and nuclear facilities; such measures 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) [42].

7.28. Requirement 24 of SSR-5 [4] states:

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

7.29. As indicated in Ref. [8], the government should adopt a graded approach to safety and security in the management of disused sealed radioactive sources. Organizations with responsibilities for the safety and security of radioactive sources should promote appropriate safety culture and nuclear security culture (see Ref. [8], GSR Part 2 [25] and IAEA Nuclear Security Series No. 7, Nuclear Security Culture [43]).

7.30. The government should ensure that long term storage facilities and disposal facilities for disused sealed radioactive sources are subject to safety and security assessment prior to authorization by the regulatory body and are sited, designed, constructed, operated, and decommissioned or closed, as appropriate, in conformance with regulatory requirements for safety and security [8].

7.31. The regulatory body should specify safety and nuclear security requirements for the long term storage and disposal of disused sources [8]. In accordance with para. 2.40 of GSR Part 1 (Rev. 1) [28], the operating organization is required to design and implement safety measures and nuclear security measures in an integrated manner so that nuclear security measures do not compromise safety and safety measures do not compromise nuclear security.

7.32. In accordance with IAEA Nuclear Security Series No. 11-G (Rev. 1), Security of Radioactive Material in Use and Storage and of Associated Facilities [44], the operating organization should design and implement a nuclear security system to protect radioactive material through the implementation of security measures to address deterrence, the three security functions of detection, delay and response, and security management. The extent of nuclear security measures should reflect the potential for damage to the facility and the assessed risk of unauthorized removal of radioactive material or radioactive waste. The security system should include an integrated set of nuclear security measures intended to prevent a malicious act during site operations, closure and any period of post-closure active institutional control. Cooperation is encouraged, through arrangements and appropriate liaison with relevant competent authorities, to facilitate assistance in the event of malicious acts. Nuclear security measures should be based on a risk informed graded approach so that similar security is provided for material capable of resulting in similar potential radiological consequences arising from use in a malicious act (see IAEA Nuclear Security Series No. 11-G [44]). Further recommendations are provided in IAEA Nuclear Security Series No. 14, Nuclear Security Recommendations on Radioactive Material and Associated Facilities [45].

7.33. Borehole disposal, in accordance with the recommendations provided in this Safety Guide, should result in the permanent disposal of the radioactive waste described in para. 1.1 at depths greater than the recommended minimum depth beneath the surface, thus providing for both safety and nuclear security. Where the waste in a borehole disposal facility is disposed of at a depth greater than the recommended minimum depth, security measures are needed at the disposal site for as long as any borehole remains open there. On sealing of the borehole(s) and closure of the facility and site, the competent authority may consider removal of security measures in accordance with a risk informed graded approach.

7.34. Waste that constitutes a significant nuclear security risk may need special security considerations and further regulatory authorization. For example, a small disused sealed radioactive source may still contain a large amount of ^{137}Cs and would therefore constitute a nuclear security risk if taken for malicious purposes. If such waste is disposed of near the surface, nuclear security measures may need to be continued after closure of the disposal facility in order to prevent human intrusion and unauthorized removal of the waste. Such measures should remain in place until the waste no longer constitutes a potential nuclear security risk or hazard and should form part of active institutional control. To fulfil the requirement for safety to be provided by passive means (see Requirement 5 of SSR-5 [4]), however, safety cannot rely on the indefinite maintenance of active institutional controls.

7.35. Where a borehole disposal facility is to be located at an existing nuclear site, the new activities should be taken into consideration in the site's nuclear security plan.

MANAGEMENT SYSTEMS

7.36. Requirement 25 of SSR-5 [4] states (footnote omitted):

> "**Management systems 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.”

7.37. General requirements for the management system are established in GSR Part 2 [25], and recommendations on how to fulfil the requirements during the predisposal management and disposal of radioactive waste are provided in GSG-16 [26]. The regulatory body and the operating organization should develop, implement, monitor and seek to continuously improve management systems appropriate to the scope of their facilities and activities. The management systems should be aimed at ensuring the protection of people and the environment, should allocate clear responsibilities for safety, should address leadership for safety, should ensure that safety is integrated into the management system, and should address the culture for safety. The appendix to GSG-16 [26] provides a list of elements of the management system for organizations involved in the management of radioactive waste or its regulatory oversight. The elements included in an organization’s management system and the level of detail contained in the processes and procedures should reflect the nature of the organization concerned, as well as its role and situation, and should be applied in accordance with a graded approach.

7.38. The regulatory body should review the operating organization’s management system and audit its application to predisposal management and borehole disposal activities. In the case of the reference borehole disposal concept described in Section 2, the key areas of such a review and audit include the following:

(a) The adequacy of the collection and interpretation of site characterization data, and of the use of the data in safety assessment models;
(b) The training of staff who will undertake predisposal management and disposal operations;
(c) The capability of any contractor(s) employed (e.g. for borehole construction);
(d) The proper management of waste emplacement and of events and incidents.

PREPAREDNESS AND RESPONSE FOR A NUCLEAR OR RADIOLOGICAL EMERGENCY

7.39. IAEA Safety Standards Series No. GSR Part 7, Preparedness and Response for a Nuclear or Radiological Emergency [46], applies a graded approach by placing the various types of facility into emergency preparedness categories: for example, nuclear power plants are in category I, research reactors are in category II and some hospitals using powerful sealed radioactive sources are in category III.

A borehole disposal facility for disused sealed radioactive sources and small volumes of low and intermediate level secondary waste generated during their management would fall into category III.

7.40. Paragraph 4.16 of GSR Part 7 [46] states:

> "The operating organization shall establish and maintain arrangements for on-site preparedness and response for a nuclear or radiological emergency for facilities or activities under its responsibility, in accordance with the applicable requirements".

7.41. Paragraph 4.17 of GSR Part 7 [46] states:

> "The operating organization shall demonstrate that, and shall provide the regulatory body with an assurance that, emergency arrangements are in place for an effective response on the site to a nuclear or radiological emergency in relation to a facility or an activity under its responsibility."

7.42. Paragraph 6.19 of GSR Part 7 [46] states:

> "The operating organization of a facility or for an activity in category I, II, III or IV shall prepare an emergency plan. This emergency plan shall be coordinated with those of all other bodies that have responsibilities in a nuclear or radiological emergency, including public authorities, and shall be submitted to the regulatory body for approval."

7.43. Para. 6.17 of GSR Part 7 [46] states:

> "Emergency plans shall specify how responsibilities for managing operations in an emergency response are to be discharged on the site, off the site and across national borders, as appropriate."

7.44. Where a borehole disposal facility is to be located on an existing nuclear site, the emergency plan for that site should be modified to take account of the new facility (see para. 4.26 of GSR Part 7 [46]).

8. EXISTING BOREHOLE DISPOSAL FACILITIES

8.1. Requirement 26 of SSR-5 [4] states:

> "**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 [SSR-5] are not met, measures shall be put in place to upgrade the safety of the facility, economic and social factors being taken into account.**"

8.2. The regulatory body should require the operating organization of a borehole facility to reassess the safety of the facility periodically throughout the period of authorization, taking account of new information relevant to the site and facility, including monitoring results. A borehole disposal facility is likely to take several years to a decade to develop, and this period may be followed by a period of active institutional control lasting several decades to a few centuries. In accordance with Requirement 26 of SSR-5 [4], the operating organization is required to assess the safety of the facility several times during this period.

8.3. The operating organization should assess the safety of potentially significant modifications to a borehole disposal facility, such as the addition of another disposal borehole. Potentially significant modifications to a borehole disposal facility might also include a proposal to accept a type of waste not previously considered in the safety case. The regulatory body should make clear at an early stage the requirements for periodic safety assessment and for assessment of modifications to facilities, and the approach to the authorization of a borehole disposal facility and any modification to the facility.

8.4. The government should ensure that arrangements are established and implemented for the periodic assessment of the safety of borehole disposal facilities for which there is no longer an operating organization.

8.5. As standards, procedures and practices change over time, existing borehole disposal facilities might not continue to fulfil the safety requirements (e.g. Ref. [47] and section B.2.1 of Ref. [48]). Specifically, once active institutional control has ceased, exposures at some existing borehole facilities might lead to doses at levels above those at which remedial action should be considered. Inadvertent intrusion at some facilities might lead to annual doses exceeding 20 mSv, or even up to

100 mSv — a generic reference level above which remedial action to upgrade safety should be considered almost always justifiable (see also para. 3.28).

8.6. The safety of an existing borehole disposal facility should be reassessed for the following purposes:

(a) To assess whether the facility provides satisfactory protection from radiation for future generations and the environment, in accordance with the Fundamental Safety Principles [1] and the requirements established in GSR Part 3 [2] and SSR-5 [4];
(b) Where satisfactory protection is not provided, to assist in decision making on whether it is justified to take remedial action to upgrade the safety of the facility, for example by adding further physical and/or administrative protection or by retrieving the waste.

8.7. In accordance with para. 2.9 of GSR Part 3 [2], any remedial action is required to be both justified and optimized and is expected to yield sufficient benefits to outweigh the detriments associated with taking the remedial action. In the context of borehole facilities, this means that the body responsible for taking decisions on remedial actions should identify the various options and then assess and compare the options in order to provide input to a decision on the preferred action. The options should be compared on the basis of their radiological and non-radiological impacts on people and the environment and on the basis of a wide range of socioeconomic factors. Feasibility studies and demonstrations may support the decision making process. Interested parties (e.g. the local community) should be involved in identifying, assessing and making comparisons of potential remedial actions. Further recommendations on the justification and optimization of remedial actions are provided in IAEA Safety Standards Series No. GSG-15, Remediation Strategy and Process for Areas Affected by Past Activities or Events [49].

Appendix I

SITING AND SITE CHARACTERIZATION FOR BOREHOLE DISPOSAL FACILITIES

SITING OF BOREHOLE DISPOSAL FACILITIES

I.1. In accordance with Requirement 1 of SSR-5 [4], the government is responsible for defining the overall process for the development, operation and closure of disposal facilities, including siting, and for ensuring that interested parties are involved at appropriate stages in the decision making. The operating organization is required to carry out all the necessary activities for site selection and evaluation [4]. In addition to reviewing the safety case, the regulatory body should assess the suitability of the site from the point of view of safety as part of its review and assessment processes (see para. 3.170 of GSG-13 [30]).

I.2. When selecting a site for a borehole disposal facility, the operating organization should select a site at which a safe facility can be developed rather than trying to identify a conceptually ‘best’ or ‘safest’ site.

I.3. Safety should be the primary consideration in siting a borehole disposal facility. If a reasonable assurance of safety can be provided for the development of a borehole disposal facility at several candidate sites, the operating organization should consider a range of other factors when choosing from among the sites (see para. I.7).

Safety related factors

I.4. When selecting a site for a borehole disposal facility, the operating organization should provide a reasonable assurance of safety, giving due consideration to the following aspects:

(a) The geology and geological evolution of the site and the surrounding area. The site should be geologically stable. Some events and processes might bring disposed waste closer to the surface environment, result in a loss of isolation and cause people to be exposed to radiation. Such events and processes include erosion, tectonic uplift, glaciation and permafrost melting. Geological stability should be evaluated on the basis of evidence of relevant events and processes (e.g. recent or historic tectonic events and processes, faulting and seismicity, in situ stress, soil liquefaction, volcanism). Geological stability is generally consistent with an absence of features such as capable faults, diapirs, salt domes and volcanoes, and an absence of large in situ stress differentials. The geology of the site should include strata or horizons with characteristics that are suitable to be used as disposal zones and that have sufficient thicknesses to accommodate the waste and separate the disposed waste from any overlying or underlying zones with greater permeability.

(b) The geomorphology and geomorphological evolution of the site and the surrounding area, and the events and processes that might affect facility operations. The site should be geomorphologically stable; this is generally consistent with an absence of features such as mountainous terrain with steep gradients or areas with active subsidence or landslip.

(c) The hydrology and hydrogeological evolution. Information with which to evaluate hydrological and hydrogeological conditions should include, but not necessarily be limited to, rock permeability and porosity, groundwater flow rates and directions, hydraulic conductivity, hydraulic heads and gradients, and the presence of groundwater wells. Characteristics that tend to be favourable for siting a borehole disposal facility include rocks with low permeability, low hydraulic head gradients and low rates of groundwater flow at depth; these characteristics are generally consistent with low topography and the absence of aquifers and rocks with high permeability (e.g. karst). Events and processes that might affect borehole disposal facility operations include flooding, thus necessitating consideration of the climate and extreme weather conditions in the area of the facility. The generic safety assessment contained in Ref. [19] suggests that it is possible to develop safe borehole facilities for the disposal of disused sealed radioactive sources in either hydrologically unsaturated or saturated conditions, but it is recommended to avoid disposing of waste in a zone through which the level of the water table varies over time (see also para. I.39). The operating organization should ensure through appropriate facility design that disposed waste will be sufficiently isolated from any aquifers containing potable water that are present at the site (see para. 6.44).

(d) The geochemistry and geochemical evolution. The information used to evaluate geochemical conditions should include, but not necessarily be limited to, rock types and mineralogy, and rock and groundwater compositions and ages. Characteristics that tend to be favourable for siting a borehole disposal facility include the presence of old groundwater, which tends to indicate low groundwater flows in the past, and groundwater whose geochemistry is and will remain generally unreactive to the rocks present and to the materials of the engineered barrier system. It should not be assumed, however, that a safe disposal facility cannot be developed at sites with other characteristics, such as the presence of saline groundwater; the suitability of these sites should be ascertained through safety assessment.

(e) Inadvertent human intrusion. The operating organization should site borehole disposal facilities away from areas with mineral, oil, gas, geothermal, water or other resources in order to reduce the probability of inadvertent human intrusion.

I.5. The reference borehole disposal concept described in Section 2 has been assessed as potentially safe to implement in a wide range of geological and climatic conditions (see Ref. [19]). Therefore, depending on the size of the waste inventory to be disposed of, it should be possible to fulfil the safety requirements at many sites.

I.6. Although very few of the factors identified above represent absolute exclusion criteria for the siting of a borehole disposal facility, the selection of a site that combines favourable characteristics and avoids unfavourable ones allows safety to be demonstrated more easily and economically than would otherwise be the case, making the site more easily acceptable to interested parties.

Other factors

I.7. The operating organization should give due consideration to other (e.g. scientific, technical, socioeconomic) factors, including nuclear security; the views of interested parties; the protection of humans and the environment from non-radiological risks (including the possible contamination of groundwater resources); the availability of information; cost; land ownership; infrastructure needs (e.g. site accessibility, provision of services such as water and electricity); transport, legal and planning considerations; and the proximity of the site to population centres, national parks, nature reserves, sites of special scientific interest, hazardous facilities, cultural and religious sites, disputed boundaries and national borders. Siting a borehole disposal facility on the site of an existing nuclear facility provides an existing nuclear security and, as appropriate, safeguards infrastructure.

Process for site selection

I.8. Working in accordance with applicable laws and regulations and relevant policies and strategies, the operating organization should develop, communicate and lead a well planned and systematic site selection process that involves interested parties in making decisions at appropriate stages. The operating organization should ensure that the steps in the site selection process are clear, logical and justified and are documented in a traceable manner.

I.9. Appendix I to SSG-29 [9] on the siting of near surface disposal facilities describes a process in which, starting with a large area (possibly the whole country), potential locations for a disposal facility are progressively narrowed down using a list of predefined technical and socioeconomic suitability or unsuitability (screening) criteria to yield a shortlist of potential siting areas. The same process may be applied to the siting of a borehole disposal facility. Once potential siting areas have been located, the operating organization should conduct more detailed investigations to identify whether they are suitable for borehole disposal. The operating organization should consider whether the potential siting areas include any existing sites of nuclear facilities (including radioactive waste storage facilities and disposal facilities) or government owned land that might be suitable for a borehole disposal facility.

I.10. The government may decide simply to nominate a site for the development of a disposal facility; this is not recommended, however, owing to several cases where this approach has failed to gain societal acceptance. Some programmes for the siting and development of radioactive waste disposal facilities have involved collaboration with the government and partnerships with local communities and the operating organization. The key benefit of such a partnership approach is the empowerment of local communities in decisions that affect their future. The partnership approach may involve seeking volunteer communities that have expressed an interest in participating in the process to determine the suitability of a site for a radioactive waste disposal facility. Such an expression of interest may be conveyed by appropriate representatives of the community (e.g. from a local governing body) and may be made in response to an invitation by the operating organization or by the government, or may be an unsolicited offer. A volunteer community should have either a formal or informal right to withdraw from the process and may receive an appropriate community benefits package.

I.11. Having established a shortlist of potentially suitable sites, the operating organization should assess each site against safety related and other factors (see paras I.4–I.7). The relative ease of developing a convincing safety case may also be a factor in choosing between alternative sites. The operating organization should adhere to the predefined siting process and should involve interested parties in the assessment of sites. The operating organization should ensure that the process that is followed includes appropriate arrangements for declaring conflicts of interest. The operating organization should document in a transparent way the reasoning for the factors considered, for the ranking of sites against the factors and for the recommendation regarding which site is to be selected.

SITE CHARACTERIZATION FOR BOREHOLE DISPOSAL FACILITIES

I.12. The objective of site characterization for a borehole disposal facility is to support a general understanding of both the characteristics of the site and how the site will evolve over time (see Requirement 15 of SSR-5 [4]). The operating organization's site characterization programme for a borehole disposal facility should include investigating the geomorphology, geology, hydrogeology, hydrology, geochemistry, climate, weather and ecology as well as how land use and human behaviour affect the environment. The programme should include characterization of the biosphere at and around the site, particularly in areas into which groundwater contaminated with radionuclides from the facility could discharge. The programme should also include the collection of information covering land use, habits of the local population (especially data on the consumption of food) and sources of drinking water; the operating organization should use this information to assist in identifying critical groups and potentially exposed groups for the assessment of potential doses and risks.

Graded approach to site characterization

I.13. In general terms, the extent of the site characterization programme (including the number of site investigation boreholes) and the amount of site characterization information needed will depend on the complexity of the site and the necessary margin of safety indicated in the safety assessments. A large margin of safety may result for various reasons, such as a waste inventory that includes a small amount of long lived radionuclides, the absence of groundwater at the site or very arid conditions on the surface. Where there is a large margin of safety, it may be possible for the operating organization to provide reasonable assurance that the borehole disposal facility will fulfil the relevant dose and risk criteria despite uncertainties introduced by a less extensive site characterization programme.

I.14. The reference borehole disposal concept described in Section 2 was designed to provide a high level of isolation and has been demonstrated as a safe disposal solution for suitably small inventories of disused sealed radioactive sources under a wide range of site conditions [19]. In many States, the inventory of disused sealed radioactive sources to be disposed of is small and includes a high proportion of short lived radionuclides; the risks associated with the borehole disposal of such waste are considered very low. Under these circumstances, site characterization for a borehole disposal facility should be less extensive than for a near surface disposal facility or a geological disposal facility for a large waste inventory.

I.15. In the case of a borehole disposal facility for a small inventory of disused sealed radioactive sources containing mostly short lived radionuclides, the operating organization should focus the collection of site specific data on parameters that are relevant to the assessment models used. Other site specific data and information may be collected for confidence building purposes; although such data might not be necessary for demonstrating the safety of the borehole disposal facility, they can nevertheless be useful, for example in demonstrating understanding of the site and in developing multiple lines of reasoning in the safety case.

I.16. The generic safety assessment described in Ref. [19] identifies the parameters that are expected to have the greatest impact on the safety of the reference borehole disposal concept for disused sealed radioactive sources. These lie in the fields of hydrogeology and geochemistry, which together determine the rate of corrosion of the stainless steel disposal capsules and containers and the rate of radionuclide migration through the geosphere. This knowledge is particularly valuable for defining the site characterization programme and for using the understanding derived from the programme to inform site specific design.

I.17. The identification of key parameters (i.e. the ones most important to safety), which allows for the focusing of the site characterization programme, was a key motivation for the development of the tiered modelling approach presented in Ref. [20]. Five models are described, with the simplest model (tier 1) needing the least information and the most complex model (tier 5) needing the most. Table 1 of this Safety Guide indicates the list of site specific information needed by the different models.

Desk based site characterization studies

I.18. The operating organization's site characterization programme for the development of a borehole disposal facility should generally begin with desk based studies. The operating organization should aim to make the maximum possible use of existing information on the disciplines within the scope of site characterization (see para. I.12). The operating organization should consult relevant national and other libraries, surveys, records and institutes (e.g. for geology, hydrology, hydrogeology and meteorology) and local experts to gather

TABLE 1. SUMMARY OF SITE SPECIFIC PARAMETERS NEEDED FOR THE TIER 1 TO TIER 5 MODELS (BASED ON REF. [20])

Tier	Near field	Geosphere	Biosphere
1	Radionuclide inventory	-	-
2	Radionuclide inventory Borehole disposal zone: • Inner diameter • Vertical length	-	-
3	Radionuclide inventory Disposal capsule and container[a]: • Outer diameter • Vertical length • Wall thickness • Weld thickness Containment barrier[a]: • Vertical length • Gap thickness	Hydrogeology: • Percolation rate[b] • Degree of saturation[b] • Total porosity[b] • Hydraulic conductivity • Hydraulic gradient • Water-filled porosity Geochemistry: • pH • Eh • Chloride concentration • Sulphate concentration • Total inorganic carbon concentration	-
4	Radionuclide inventory Diffusion coefficients Sorption coefficients Percolation rate[b] Degree of saturation[b] Total porosity[b] Grain density Hydraulic conductivity Hydraulic gradient Water-filled porosity Failure times for disposal capsule	Diffusion coefficients Sorption coefficients Percolation rate[b] Degree of saturation[b] Total porosity[b] Grain density Hydraulic conductivity Hydraulic gradient Water-filled porosity Fraction of water demand supplied by contaminated water	Concentration factors House dimensions House ventilation rate Soil total porosity Soil degree of saturation Percolation rate Ingestion rates Inhalation rates Occupancy rate Irrigation rates Crop yields

TABLE 1. SUMMARY OF SITE SPECIFIC PARAMETERS NEEDED FOR THE TIER 1 TO TIER 5 MODELS (BASED ON REF. [20]) (cont.)

Tier	Near field	Geosphere	Biosphere
5	Radionuclide inventory Diffusion coefficients Sorption coefficients Percolation rate[b] Degree of saturation[b] Total porosity[b] Grain density Hydraulic conductivity Hydraulic gradient Water-filled porosity Failure/degradation times for near field components	Diffusion coefficients Sorption coefficients Percolation rate[b] Degree of saturation[b] Total porosity[b] Grain density Hydraulic conductivity Hydraulic gradient Water-filled porosity Fraction of water demand supplied by contaminated water	Concentration factors Garden dimensions House dimensions House ventilation rate Soil total porosity Soil degree of saturation Percolation rate Inhalable dust concentration Erosion rate Ingestion rates Inhalation rates Occupancy rates Irrigation rates Crop yields

Notes:

[a] Expected to be broadly similar for different systems.

[b] Required only if the disposal zone is in the unsaturated zone.

\- No data required.

detailed knowledge and information relating to the site. Where it is proposed to create a borehole disposal facility at the site of an existing nuclear (or other) facility, the operating organization of the borehole disposal facility should request and make use of the information held by the operating organization of the existing facility, including any safety case, safety assessment or similar analysis that exists.

I.19. The operating organization should consult the long term (i.e. covering several years) meteorological records for the region, demonstrate an understanding of the range of meteorological conditions that have occurred during that time and assess the range of conditions that are expected to occur in the future. The operating organization should assess the susceptibility of a site to severe weather events (e.g. storms, flooding). The operating organization should use meteorological data to estimate evapotranspiration rates and recharge at the site.

I.20. The operating organization should gather information to characterize the geology, hydrology, hydrogeology and geochemistry of the site and the surrounding area, particularly to identify and characterize the source(s) of local groundwater (both deep and shallow) and areas where groundwater from the vicinity of the facility might discharge. The operating organization should use this information to identify potential pathways by which radionuclides from the disposal facility might lead to radiological exposures.

I.21. The operating organization should collect information on the size, locations and density of human populations; on human activities, including land uses (e.g. agriculture); on human behaviours (e.g. food consumption rates); and on sources of drinking water needed for dose assessments for present and potential future conditions. The operating organization should use information on the nature of the current biosphere to set the context for the models used in safety assessment. The operating organization should use information on human populations and habits to identify representative persons and potentially exposed groups for consideration in the safety assessment.

Surface based site characterization studies

I.22. The operating organization should undertake surveys, fieldwork and surface based investigations as part of the site characterization programme in order to increase knowledge and information on the site and its surroundings. The operating organization should undertake safety assessments to interpret the available knowledge and information on the disposal system and to ensure that further site characterization activities are focused on issues that are relevant to the safety of waste disposal.

I.23. The operating organization should conduct surface based studies to gather information on the geomorphology and hydrology of the site and its surrounding area (e.g. landforms, erosion, land movements, landslips, faults, earthquakes, lakes, rivers, sedimentation, coastlines), including the effects of past climate states on landform development.

I.24. The operating organization should conduct surface based geological studies to gather information on the rock types present (particularly at disposal depths) and to understand their mineralogy, spatial distribution, variability and structure, including the presence of faults, fractures and fabrics.

I.25. The operating organization should conduct surface based geophysical studies to gather information on the geology, geological structure and hydrogeology at depth. Unless data of sufficient quality and relevance are already available, the operating organization should undertake seismic refraction surveys appropriate to the size of the site and proposed depth of the disposal facility and with survey lines suitably arranged (e.g. to form a square or rectangular array surrounding the disposal site). The operating organization should use appropriate computer based techniques to interpret the data that have been gathered and should attempt to understand the spatial distribution of weathered and intact bedrock and the position of faults and other geological structures. Even for complex sites, where multiple interpretations may be possible, a seismic survey will usually be the most effective way of understanding the subsurface geology without drilling. The operating organization should consider undertaking electrical resistivity surveys to complement the results of the seismic surveys and further understand the geology and hydrogeology of the site.

I.26. The operating organization should record and document the data gathered during the desk based and surface based studies, following the relevant procedures in the management system. The operating organization should interpret the data in the form of preliminary conceptual models of the site that extend from the surface down to at least the bottom of the deepest disposal zone. The operating organization should document any significant inconsistencies between the conceptual models and the data (e.g. aspects where the models do not explain the observations well), should recognize these as uncertainties and should plan and undertake further studies as necessary to reduce the uncertainties.

I.27. The operating organization should use the data, models and the understanding gained from the desk based and surface based site characterization studies to help decide on the locations of site characterization boreholes and the potential locations of disposal boreholes and depths of disposal zones.

Borehole based site characterization studies

I.28. The operating organization should conduct a programme of carefully planned borehole based site characterization studies in accordance with defined procedures. Unless suitable boreholes already exist at the site, the operating organization should drill one or more site characterization boreholes. The number and locations of site characterization boreholes should be in accordance with the needs of the safety case for information and the graded approach. The operating organization should use an approach to drilling and a drilling method that minimizes disturbance to the disposal system that is to be characterized, avoids the possibility of groundwater becoming contaminated by the drilling activities and includes means of correcting any contamination that does occur.

I.29. It is recommended that site characterization boreholes have a diameter of 100 mm or less. Where possible, the operating organization should drill site characterization boreholes down to the base of the formation in which waste disposal is proposed and should confirm the absence of features such as high pressure zones that could negatively and significantly affect the performance of the borehole disposal facility. If drilling to such a depth is not feasible, perhaps because the base of the host formation is very deep, then the base of the site characterization borehole should be at least a few tens of metres below the base of the deepest disposal zone, and the operating organization should provide a justification for the depth chosen. Where waste disposal is proposed in the hydrologically unsaturated zone, the operating organization should drill site characterization boreholes down to at least the depth of the water table.

I.30. Where possible, the operating organization should design and drill site characterization and other (e.g. disposal) boreholes in such a way that rock core can be extracted for study. Where it is not practical to extract rock core, the operating organization should collect and study rock fragments from the drilling. The operating organization should use best practice to identify the locations and depths from which rock samples (including rock core and rock fragments) are collected and should keep careful, detailed records. The operating organization should use the rock core and/or rock fragments to establish the geological sequence and the mineralogy of the rocks. The rock samples should be kept and preserved for more detailed examination (e.g. for use in assessing the radionuclide retardation properties of the rocks).

I.31. The operating organization should, in the drilling procedures, instruct workers drilling boreholes to record water strikes, water yields, drilling speeds, fractures and any unexpected events such as the loss of compression air (indicating the possible presence of joints or fissures), changes in penetration rate (indicating possible changes in lithology or structure), sharp changes in the colour of rock samples (indicating possible lithological changes or weathering) and sharp changes in the size of drill chips (indicating the possible presence of fractures). The operating organization should use the relevant information recorded (e.g. on the geological sequence and the depth of the water table) to calibrate the geophysical surveys described in para. I.25.

I.32. The operating organization should use geophysical wireline logging techniques to monitor the shape and diameter of the site characterization boreholes, to detect fractures and breakouts, and to investigate the acoustic and electrical properties of the rocks (which should be used to help interpret seismic and electrical geophysical surveys) and their natural gamma radioactivity.

I.33. The operating organization should consider undertaking further borehole based studies to support the safety case as appropriate. A list of probes and related parameters used during a pilot project on the borehole disposal of disused sealed radioactive sources is provided in Table 2.

I.34. Where the site characterization boreholes contain groundwater, the operating organization should conduct hydrogeological investigations including, as appropriate, measurements of water pressure, hydraulic heads and gradients, and measurements of the rates of water inflow and outflow at different horizons (using pump tests, flow recovery tests and cross-hole tests, as appropriate) with the placement of packers, and the results should be used to establish the hydrogeological properties of the rocks. If hydrogeological tests are conducted in open boreholes (without packers), the values measured will tend to be strongly influenced by zones with high flow rates, for example in the upper parts of the borehole.

TABLE 2. DOWN-HOLE LOGGING PROBES AND RELATED PARAMETERS

Type of probe	Related parameters
Optical borehole imaging probe	Optical borehole image Borehole inclination Natural gamma radioactivity
Acoustic borehole imaging probe	Acoustic borehole image Borehole inclination Natural gamma radioactivity
Dual induction conductivity probe	Medium and long spacing induction conductivity Natural gamma radioactivity
Focused electric logging probe	Focused resistivity Natural gamma radioactivity
Three-arm calliper probe	Borehole diameter
Full-wave sonic probe	Acoustic travel time and speed
Flowmeter gamma temperature conductivity probe	Vertical fluid flow (for medium to high flow regimes) Fluid temperature and conductivity Natural gamma radioactivity
Heat pulse flowmeter probe	Vertical fluid flow (for low flow regimes)

I.35. Where the site characterization boreholes contain groundwater, the operating organization should conduct geochemical investigations, including the collection of water samples and the determination of the chemical composition of the water, such as (if possible) its redox potential (Eh), acidity and alkalinity (pH), and the content of solutes, colloids and particulates. The operating organization should consider measuring the electrical conductivity of the water to provide further information on ionic content and salinity. The operating organization should use best practices when collecting, transporting and analysing samples (e.g. the use of sealed containers with as little air space as possible) to avoid artefacts (e.g. oxidation) and contamination.

I.36. The operating organization should attempt to determine the concentrations in groundwater of chloride, sulphate, carbonate, bicarbonate and nitrate anions. Where possible, the operating organization should use information on the chloride and sulphate content of the groundwater to inform decisions on the materials of the engineered barrier system (chloride may affect the rate of waste container corrosion; sulphate may cause undesirable reactions in some cement based materials). Where possible, the operating organization should measure redox potential in situ, particularly in the disposal zone(s), by using appropriate probes and packers in the borehole to separate the depth interval being measured from other parts of the borehole. In cases where it is not possible to measure redox potential in situ, the operating organization should estimate it by taking redox potential measurements of water samples abstracted from the borehole and making corrections to allow for changes in chemical speciation, by using data collected in situ from adjacent depth intervals and by using information on the mineralogy of the rocks.

I.37. For a site characterization borehole whose disposal zone is situated in saturated, low permeability rocks (e.g. plastic clay), the rate of water ingress may be very low or even undetectable, making the measurement of hydrogeological properties and the collection of water samples difficult. In such cases, the operating organization should attempt to take water samples from the extracted rock core to determine the permeability of the host rock and relevant diffusion coefficients. The operating organization may need to estimate the groundwater flow rates on the basis of the limit of detectability of water ingress into the borehole. The operating organization should measure the thickness of the host rock layer and establish the distances between the disposal zone and more permeable rocks.

I.38. For a site characterization borehole located in an arid region, groundwater may only be found at depth, and the disposal zone may be situated in an unsaturated environment. Locating the disposal zones in unsaturated rocks may be advantageous for post-closure safety because, in the absence of groundwater, interactions between the radionuclides in the waste and groundwater in the saturated zone are greatly delayed, thus allowing time for the radionuclides to decay and reducing the potential doses and risks from groundwater pathways [19]. For a site characterization borehole whose disposal zone is situated in unsaturated rocks, the operating organization should provide reasonable assurance that the host rocks will remain unsaturated throughout the assessment period by taking the following measures:

(a) Gathering information and evidence on the amount and rate of percolation of water through the unsaturated zone, on the basis of past and present groundwater levels and the characteristics of the groundwater in the underlying rocks, including details of groundwater chemistry, origin, age, flow and pressure;
(b) Making an assessment of possible future movements of the water table and the probability of temporary saturation of the rock of the disposal zone, taking account of past and present hydrogeological conditions, possible future climatic conditions, and rates of erosion.

I.39. The operating organization should not situate disposal zones in rocks that might become saturated periodically (e.g. seasonally or every few years) because such ephemeral groundwater often has oxidizing properties and may contain high concentrations of solutes; such characteristics can greatly accelerate the corrosion of steel waste containers.

Appendix II

GENERIC POST-CLOSURE SAFETY ASSESSMENT FOR BOREHOLE DISPOSAL FACILITIES

II.1. The purpose of this appendix is to address safety assessment issues that are specifically related to borehole disposal facilities. Recommendations on the development of the safety case and safety assessments for radioactive waste disposal facilities in general are provided in SSG-23 [35] and are not repeated here.

II.2. While the information in this appendix relates specifically to borehole disposal facilities developed in accordance with the reference borehole disposal concept described in Section 2, some of the more general aspects of the guidance (e.g. relating to scenario development) may be applicable to facilities developed in accordance with other borehole disposal concepts.

GENERIC SAFETY ASSESSMENT FOR BOREHOLE DISPOSAL

II.3. In the context of this Safety Guide, a generic safety assessment is a preliminary safety assessment for a disposal concept that is not based on a specific site. If a site has not been selected, the operating organization should consider undertaking a generic safety assessment to assist planning in the early stages of a disposal programme. For example, a generic safety assessment can be undertaken at the concept development stage in support of site screening and selection to help identify waste inventories that are potentially suitable (or unsuitable) for a particular disposal concept, to determine the need for engineered barriers and other design aspects, and to identify potentially suitable (or unsuitable) sites. When a potentially suitable site has been selected for further investigation, the operating organization should consider using the outcome of the generic safety assessment for the following purposes:

(a) To help identify the key data and parameters that will need to be gathered and evaluated in order to develop a site specific assessment;
(b) To help determine the extent of site characterization needed;
(c) To serve as a basis for site specific assessment.

Generic safety assessment for borehole disposal of disused sealed radioactive sources in Categories 3–5

II.4. The generic post-closure safety assessment for the disposal of disused sealed radioactive sources in narrow diameter boreholes presented in Ref. [19] was developed over a period of several years; it considers the 31 most relevant radionuclides found in disused sealed radioactive sources and assumes that they have been disposed of in a borehole with stainless steel and cement based barriers, as described in Section 2, under a range of different geosphere conditions. Separate safety assessment calculations are performed for waste disposal in unsaturated conditions and for waste disposal in saturated conditions. The rocks are assumed to be capable of representation as either porous rocks or fractured rocks. A range of groundwater flow rates is considered in the saturated zone, and a range of safety assessment calculations are performed, assuming low, medium and high flow rates. Various groundwater geochemical conditions (e.g. redox potential, pH, chloride and sulphate content) are analysed to investigate the influence of geochemistry on the performance of the engineered components in the system.

II.5. The generic safety assessment presented in Ref. [19] includes a thorough analysis of the features, events and processes used in scenario development. The following scenarios are identified and defined:

(a) The design scenario. In this scenario it is assumed that the disposal facility has been constructed, operated and closed as designed and that it has evolved as expected during the post-closure period.
(b) The defect scenario. In this scenario it is assumed that not all of the components of the near field have performed as envisaged in the design scenario owing to either defective manufacturing of waste packages (e.g. welding defects) or defective implementation of the borehole disposal concept (e.g. improper emplacement of backfill). Several variants of the defect scenario are considered, all of which result in an earlier release of radionuclides from the near field.
(c) The unexpected geological characteristics scenario. In this scenario it is assumed that the actual performance of the geosphere is worse than the expected performance (e.g. the geosphere has been subjected to an unexpected seismic event, resulting in the reactivation of high permeability fractures and/or modification of associated sorption properties).
(d) The changing environmental conditions scenario. In this scenario it is assumed that the disposal system has been affected by climate change, resulting in modifications to certain geosphere characteristics (e.g. groundwater

recharge rates) and biosphere characteristics (e.g. water demand, surface erosion rates).

(e) The borehole disturbance scenario. In this scenario it is assumed that the drilling of a water abstraction borehole adjacent to the disposal borehole has resulted in an earlier exposure of humans to radionuclides (e.g. owing to the use of contaminated water from the abstraction borehole).

II.6. In the generic post-closure safety assessment [19], it is argued that the potential consequences of the unexpected geological characteristics scenario and the changing environmental conditions scenario are bounded by the range of geosphere and biosphere characteristics that have been assessed and by the parameter sensitivity analyses undertaken for the design scenario.

II.7. In the generic post-closure safety assessment [19], the borehole disturbance scenario is eliminated (screened out) from more detailed consideration because of the depth of the disposal zone, because of the small footprint of the disposal borehole and because of the facility's location in an area with no natural resources that might lead to extensive surface excavation or underground mining. All of these assumptions indicate that the probability of inadvertent human intrusion directly affecting the disposal borehole is extremely low.

II.8. The generic post-closure safety assessment [19] shows that, with a suitable inventory, disposal facility design, and geological and hydrogeochemical environment, the borehole disposal concept can provide a safe long term management solution for the disposal of disused sealed radioactive sources in Categories 3–5 (see RS-G-1.9 [23]) containing either long lived or short lived radionuclides.

II.9. In the borehole disposal system described in Ref. [15], all but the long lived radionuclides are expected to decay to negligible levels of activity in the disposal zone. Although it is not possible to provide a demonstration of such containment over hundreds to thousands of years, the extremely low corrosion rates measured for the stainless steel from which the disposal capsules and containers are made imply such containment times.[22] Furthermore, the mechanisms that might cause the corrosion rate to increase are well understood and are considered to be of low probability (see appendix IX to Ref. [19]), providing reasonable confidence in the containment of the short lived nuclides within the near field.

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[22] The quality of container welds is also important in this context because the welds may undergo preferential corrosion (see Ref. [19]).

II.10. The generic post-closure safety assessment presented in Ref. [19] suggests that under non-fault conditions (e.g. without defects in the sealed disposal capsules or containers), even radionuclides with half-lives as long as ^{226}Ra (half-life = 1600 years) can be disposed of safely in almost unlimited quantities. For long lived radionuclides such as ^{239}Pu, ^{241}Am and ^{237}Np, the disposal capsules and containers will delay their release into the geosphere surrounding the disposal zone but will not prevent it altogether; for these radionuclides, the performance of the borehole disposal system also depends on containment in the geosphere (which results from a combination of factors, including slow radionuclide diffusion, a long groundwater travel time, radioactive decay and radionuclide sorption). Depending on the site and the design of the disposal facility, it may be necessary to limit the inventory of long lived radionuclides that can be disposed of.

II.11. As noted in Sections 4 and 5 of this Safety Guide, the operating organization is required to undertake a site specific safety assessment and to establish and apply appropriate waste acceptance criteria.

Further generic studies for borehole disposal of disused sealed radioactive sources in Categories 1 and 2

II.12. Several further generic studies have been performed to assess the safety of the borehole disposal of disused sealed radioactive sources, in particular those in Categories 1 and 2, including the following:

(a) The stainless steel corrosion models and backfill degradation models developed as part of the generic safety assessment were incorporated into a borehole disposal concept scoping tool. The tool makes it possible to evaluate the containment provided by the disposal capsule and container in the post-closure period and the chemical and physical degradation of the backfill. The tool also allows radionuclide transport and subsequent exposure of humans via the drinking water pathway to be evaluated using a conservative model that takes no account of the retardation of radionuclides during transport. The borehole disposal concept scoping tool was originally developed for disused sealed radioactive sources in Categories 3–5 but has been extended to allow consideration of sources in Categories 1 and 2.
(b) The generic post-closure safety assessment presented in Ref. [19] does not explicitly consider radiolysis, criticality or thermal processes because the effects of these processes are insignificant for the disposal of typical disused sealed radioactive sources in Categories 3–5. However, for the disposal of sources in Categories 1 and 2, the operating organization should

assess the potential effects of radiolysis, criticality and thermal processes. Reference [17] addresses the potential impacts of the disposal of disused sealed radioactive sources in Categories 1 and 2 on the post-closure safety of the borehole disposal concept. The study described in Ref. [17] is based on conservative assumptions and calculations; it is indicated in the study that, while there are no criticality issues, the disposal of some disused sealed radioactive sources in Categories 1 and 2 might result in high temperatures and high radiation fields that significantly reduce the expected lifetime of the waste disposal packages. Consequently, less conservative calculations have been performed to improve understanding of the thermal and radiation conditions in the borehole for representative disused sealed radioactive sources in Categories 1 and 2 and in Categories 3–5. The work described in Ref. [17] was supported by calculations using the CHEMSIMUL [50] and MicroShield [51] software and led to the development of various specifications for the disposal capsules and containers so that they could be used to contain disused sealed radioactive sources in Categories 1 and 2.

(c) The rates of general and localized corrosion of stainless steel in cementitious environments have been analysed (e.g. Ref. [20]). This analysis also considered the potential effects of gamma radiation and galvanic corrosion between carbon and stainless steels in concrete, focusing on grades 304 and 316 austenitic stainless steel. This led to suggestions that, depending on the performance of the natural barriers at the site, super austenitic or super duplex stainless steel or a palladium-containing titanium alloy may be used for the disposal capsules and containers for heat-generating and gamma-emitting disused sealed radioactive sources in Categories 1 and 2.

(d) The work described in Ref. [17] highlights the need to integrate the mobile hot cell described in Ref. [24] into conditioning and disposal operations for disused sealed radioactive sources in Categories 1 and 2.

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Annex I

OTHER BOREHOLE DISPOSAL CONCEPTS

I–1. This annex provides several examples of borehole disposal concepts other than the reference concept described in Section 2 of this Safety Guide, which have been proposed or implemented for radioactive waste storage or disposal for various types of radioactive waste. These examples are included in the annex for information; their inclusion does not imply that they meet the relevant safety requirements.

I–2. Shallow boreholes have been used in the past in a number of States for the storage and disposal of radioactive waste [I–1]. In the Russian Federation, for example, experience of using shallow ground boreholes dates back to the 1960s [I–2]. These boreholes were originally designed for the disposal of disused sealed radioactive sources, but they have now been redesignated as storage facilities. More recent designs can accommodate drummed waste and have depths of almost 40 m, although the uppermost waste packages are just a few metres below the surface [I–3]; these facilities are also designated as storage facilities. Shallow boreholes have also been used for radioactive waste disposal at the Intractable Waste Disposal Facility in Mount Walton East, a very arid location in Western Australia. The facility includes two 2 m diameter boreholes in which drummed low level and intermediate level waste is stacked in layers 5.8–28 m below the surface. The boreholes were operational for two disposal campaigns in 1992 and 1994; more recent disposals at the Intractable Waste Disposal Facility have been in near surface trenches [I–4].

I–3. In the United States of America, at least two ‘greater confinement disposal’ facilities have used 3 m diameter boreholes or shafts drilled with a large auger. At the Savannah River Site, the greater confinement disposal test facility consists of a square array of 80 shafts, each 6 m deep, that have been used for the disposal of US Class B waste [I–5]. A second type of greater confinement disposal facility was used at the Nevada Test Site in the 1980s to dispose of radioactive waste from defence activities (similar to commercial ‘greater-than-class C’ low level waste), which included disused sealed radioactive sources and some transuranic elements. The depth of disposal at this facility was at least 21 m and was specified to be more than 120 m above the water table [I–6].

I–4. The greater confinement disposal concept was re-evaluated in 2007 for the disposal of greater-than-class C low level waste, again at the Nevada

Test Site [I–7]. The estimated total volume of the waste was 2500 m^3, and its approximate activity was 7.8 million TBq. In this case, the waste was to be disposed of at a depth of at least 30 m because, according to US regulations [I–8], a shallower depth would require the disposal to be classified as near surface. A maximum depth of 300 m was envisaged, and 930 boreholes would have been needed, spread over an area of 44 hectares (implying a spacing of around 22 m between boreholes). This proposal was eventually rejected in favour of an approach that utilized both commercial disposal facilities and the Waste Isolation Pilot Plant — a geological disposal facility in New Mexico [I–9].

I–5. Various studies have been made of concepts for the disposal of high level waste, including spent fuel, in boreholes or bored drifts at depths associated with geological disposal (e.g. Ref. [I–10][1]) or even deeper (e.g. Ref. [I–11]). The diameters of the disposal boreholes or drifts in these concepts vary within the approximate range of 0.5–2 m. Very deep borehole disposal of radioactive waste (i.e. disposal in boreholes deeper than a few hundred metres) was suggested in the 1970s (e.g. Ref. [I–12]) and the idea has been studied intermittently since that time. Various concepts have been proposed, including concepts that involve using the heat produced by the radioactive waste to melt the surrounding rock and, thereby, form a barrier to radionuclide migration (e.g. Ref. [I–13]); concepts that involve boreholes up to 5 km deep that do not involve rock melting, whose safety relies principally on the great depth and high degree of isolation provided by the boreholes (e.g. Ref. [I–14]); and concepts that envisage combining the disposal of heat-generating radioactive waste with the production of geothermal energy by pumping water through very deep boreholes that run between the boreholes containing radioactive waste [I–15].

I–6. The various very deep borehole disposal concepts have been reviewed at different times for national radioactive waste disposal programmes in the United Kingdom [I–16], Sweden [I–17], Germany [I–18] and the United States of America [I–19]. With regard to the United States of America, Ref. [I–19] notes various remaining uncertainties (e.g. relating to rock heterogeneity and the ability to characterize the rocks at such great depths) and concludes that very deep borehole disposal offers few clear advantages over conventional geological disposal, including in terms of safety or the speed at which disposal could be implemented.

[1] The disposal concept described in Ref. [I–10] is considered to be a form of geological disposal.

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Annex II

DISPOSAL DEPTH

II–1. The previous version of this Safety Guide[1] relied on a 1987 report [II–1] for recommending a minimum depth at which waste should be disposed of in a borehole disposal facility. This minimum depth was 30 m and was at that time regarded as a depth beyond which human intrusion would be limited to drilling and significant excavation activities, such as tunnelling, quarrying and mining. Since Ref. [II–1] was published, significant developments have been made in the construction of high-rise buildings and other infrastructure, and other types of excavations deeper than 30 m have become common. For example, Ref. [II–2] presents data on the depths of underground structures in Japan; the data on drilling and excavation activities for high-rise buildings, expressways and railways cluster in the approximate range of 30–50 m deep and extend to depths of approximately 80 m. Reference [II–2] also shows that the depths of underground structures in Japan increased significantly over the period from 1910 to 1980.

II–2. In practice, there are many operating near surface disposal facilities for low level waste at depths of up to several tens of metres, some of which also accept short lived intermediate level waste. Several disposal facilities are in operation for the disposal of low level waste and short lived intermediate level waste in vaults and silos at depths of up to approximately 120 m. For example, the Final Repository for Short-lived Radioactive Waste in Sweden accepts low level waste and short lived intermediate level waste for disposal at depths of approximately 60–120 m [II–3].

II–3. For several reasons — including the need to locate the waste below local topography and below the zone of weathered rocks near the surface, which is often tens of metres thick in tropical environments — the two pilot projects on borehole disposal of disused sealed radioactive sources in Malaysia and Ghana have disposal zones located deeper than 100 m. In Malaysia the proposed disposal zone lies at depths of 115–175 m, whereas in Ghana the proposed depth of the disposal zone lies at a depth of between 135 m and 150 m.

II–4. Experiences in several Member States (e.g. Ref. [II–4] and section B.2.1 of Ref. [II–5]) have shown that some existing shallow borehole disposal facilities

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