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Borehole Disposal Facilities for Radioactive Waste

DRAFT SAFETY GUIDE

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Draft Safety Guide

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CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide provides recommendations and guidance on the development, operation, closure, institutional control and regulation of borehole disposal facilities for radioactive waste to fulfil the safety principles and requirements contained in the IAEA Safety Standards, particularly in IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [1], IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [2], IAEA Safety Standards Series No. GSR Part 5, Predisposal Management of Radioactive Waste [3], and IAEA Safety Standards Series No. SSR-5, Disposal of Radioactive Waste [4]. The radioactive waste considered in this Safety Guide comprises disused sealed radioactive sources[1] that have been declared radioactive waste, and low level waste and intermediate level waste generated during their management.

1.2. This Safety Guide supersedes IAEA Safety Standards Series No. SSG-1[2]. Since SSG-1 was published in December 2009, relevant safety requirements have been revised, and significant further research and development has been conducted on borehole disposal of disused sealed radioactive sources in preparation for its implementation by Member States. In addition, borehole disposal of disused sealed radioactive sources has been licensed in one Member State and pilot borehole disposal projects are underway. Several other Member States are actively interested in developing their own borehole disposal facilities for disused sealed radioactive sources. It is timely, therefore, to provide revised guidance that properly reflects the current safety standards and the state of knowledge regarding borehole disposal for these types of radioactive waste.

1.3. The modifications incorporated into this Safety Guide reflect recent research and development, research studies and pilot projects on borehole disposal of waste as 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 – (the Joint Convention), Ref. [6] and the supplementary guidance to the Code of Conduct on the Safety and Security of Radioactive Sources (the Code of Conduct) on the Management of Disused Sealed Radioactive Sources, Ref. [7].

[1] 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, Ref. [5].

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

OBJECTIVE

1.4. The objective of this Safety Guide is to provide recommendations and guidance on the development, operation, closure, institutional control and regulation of borehole disposal facilities for disused sealed radioactive sources that have been declared radioactive waste and small amounts of low level waste and intermediate level waste generated during the management of the disused sealed radioactive 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 No. SSG-29, Near Surface Disposal Facilities for Radioactive Waste [8][3] and IAEA Safety Standards Series No. SSG-14, Geological Disposal Facilities for Radioactive Waste [9].

SCOPE

1.6. This Safety Guide provides recommendations and guidance on borehole disposal facilities for disused sealed radioactive sources that have been declared radioactive waste, and low level waste and intermediate level waste generated during their management as described in para. 1.1. This Safety Guide does not provide recommendations and guidance on the predisposal management or disposal of other radioactive waste; in particular high level waste is not addressed[4].

1.7. There is a potential to develop safe borehole disposal facilities with various designs and different methods for conditioning waste for disposal. For example, borehole disposal facilities could include different numbers of boreholes and boreholes with different diameters. Further information on such concepts and facilities is provided in Annex I. 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. The recommendations in this Safety Guide are relevant to all borehole disposal facilities for radioactive waste as described in para. 1.1. However, in providing recommendations on borehole disposal, this Safety Guide focusses on a recommended borehole disposal concept that involves the conditioning and disposal of radioactive waste as identified in para. 1.1 using cement-based and stainless steel engineered barriers and narrow diameter boreholes – see paras 2.12 to 2.18. Furthermore, in light of experiences in various States, this Safety Guide focuses on the disposal of radioactive waste at depths that are sufficient in conjunction with other factors to

[3] Near surface disposal facilities include disposal facilities at the surface and at depths of up to a few tens of meters underground – SSG-29 [8]

[4] In IAEA Safety Standards Series No. GSG-1, Classification of Radioactive Waste [10] spent fuel that has been declared radioactive waste is included in high level waste.

make adverse effects on safety due to inadvertent human intrusion improbable (see paras 4.33 to 4.37 and Annex II)[5].

1.8. The Safety Guide assumes that all transport of radioactive material as defined in IAEA Safety Standards Series No. SSR-6 (Rev. 1), Regulations for the Safe Transport of Radioactive Material [11] is conducted in accordance with SSR-6 (Rev. 1).

1.9. This Safety Guide addresses the safety of the predisposal management of waste as described in para. 1.1 and its disposal. This Safety Guide addresses both operational safety and post-closure safety at borehole disposal facilities. This safety guide addresses the interdependencies between the predisposal management steps for the radioactive waste in question and its disposal in borehole disposal facilities.

1.10. It is recognized that radioactive waste disposal is carried out within a wider process that, for example, includes consideration of financial, economic and social issues, as well as issues of conventional safety, security, planning and aspects of environmental protection not related to protection from exposure to ionizing radiation. These 'wider' issues are not specifically addressed in this Safety Guide.

1.11. This Safety Guide is intended for those persons whose prime interest is in the regulation and implementation of the safe disposal of radioactive waste in borehole disposal facilities.

STRUCTURE

1.12. Following this Introduction, Section 2 provides an overview of borehole disposal and describes a recommended borehole disposal concept for waste as identified in para. 1.1. Section 3 provides recommendations and guidance 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 describes the process of developing a borehole disposal facility. Section 7 provides recommendations and guidance on measures to give additional assurance of safety. Section 8 addresses existing borehole disposal facilities. Two Appendices complement the main text with respect to (a) siting and site characterization for borehole disposal facilities and (b) safety assessment for borehole disposal facilities. Two Annexes address (a) other borehole disposal concepts and (b) the relationship between disposal depth and isolation of waste from people and the environment.

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[5] Radioactive waste disposal facilities comprising rock caverns, silos and tunnels at depths of up to a few tens of meters underground are near surface disposal facilities and are addressed in SSG-29 [8].

2. OVERVIEW OF BOREHOLE DISPOSAL AND ITS IMPLEMENTATION

BOREHOLE DISPOSAL OF DISUSED SEALED RADIOACTIVE SOURCES

2.1. Para. 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. The safety standards recognize three options for the disposal[6] of radioactive waste: near surface disposal, borehole disposal, and geological disposal. From a safety perspective, borehole disposal is not conceptually different from either near surface disposal or geological disposal. In all cases, 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 and, thereby, ensure an adequate level of protection for people and the environment.

2.3. 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. Isolation should be provided *inter alia* by reducing the probability of inadvertent human intrusion.

2.4. Borehole disposal facilities have to comply with the requirements and standards of safety that apply to all disposal facilities. It is a requirement that the operating organization[7] develops 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 – see SSR-5 [4]. The safety assessments have to comply with the requirements in SSR-5 [4] and in IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Facilities and Activities [13].

2.5. Borehole disposal offers flexibility concerning the possible depth of waste disposal; the range of depths that may be accessed by boreholes can reach from the surface (but see paras 4.33 to 4.36) down to and beyond the depths typically associated with geological disposal facilities – see SSR-5 [4]. The depth chosen for the disposal of radioactive waste in a particular facility should be determined by the need to reduce the probability of inadvertent human intrusion (as discussed further below in paras

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

[7] 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, self-employed persons. Operating organization is synonymous with 'operator'" [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]. The operating organization may not be the holder of the licence (e.g. the operator 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].

4.33 to 4.36) and by factors including the nature of the waste and the suitability of the host geology and the associated hydrogeological and hydrogeochemical conditions, and the possible influence of climatic and other surface related processes (e.g. erosion).

2.6. A borehole disposal facility at a specific site should include one or more boreholes. The number of boreholes and the depths of waste disposal should be determined by taking into consideration the inventory of waste to be disposed of, the probability of inadvertent human intrusion, the geology of the site, and the results of safety assessment. Each borehole should be fitted with a casing which is sealed at the bottom of the borehole to provide a dry and well-defined disposal volume. The spacing between boreholes should be optimized taking account of the practicalities of drilling and operations, the potential for interactions between boreholes, and the results of safety assessment.

2.7. The operating organization should use waste packages that are suitable for the borehole disposal facility. The size of the waste packages for disposal should be compatible with the diameter of the borehole and the length of the disused sealed radioactive sources. The waste package is the product of conditioning the waste. The waste package should include one or more waste containers. Backfill material should be used to fill any spaces in the waste package. Backfill material should also be used to fill the spaces in the boreholes outside the waste packages, and the spaces between the borehole casing and the host geology. All these components together with the surrounding rocks should provide a multi-barrier system that ensures a safe and sustainable management solution for the radioactive waste.

2.8. To the fullest extent possible, the safety of a disposal facility is required to be ensured by passive means, and the need for actions to be taken after closure of the facility is required to be minimized (Requirement 5 of SSR-5 [4]). The operating organization should design a borehole disposal facility so that safety is provided by passive means through the inherent characteristics of the components of the facility itself; the waste package, backfill materials and the host geological environment, and there should be no need for actions to be taken to ensure safety after release of the site from regulatory control[8].

2.9. Borehole disposal facilities are constructed by drilling and, therefore, have a characteristic geometry. The geometry of a borehole disposal facility is such that it 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. When planning waste disposal, consideration should be given to the volumes of waste that need to be disposed of and to the volumes of existing and planned disposal facilities and their capacities to receive safely the radioactive waste that needs to be disposed of[9].

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[8] Monitoring at a borehole disposal facility is discussed in Section 7.

[9] The volume capacity of borehole disposal facilities to receive conditioned radioactive waste is limited by the diameter and length of borehole in host rocks suitable for safe disposal – see main text; the term 'small volumes' here refers to volumes that are significantly less than the thousands to hundreds of thousands of cubic meters of

2.10. The operating organization should optimize the design a borehole disposal facility so that in combination with appropriate facility siting (see paras 6.16 to 6.23 and Appendix I) and disposal of waste at sufficient depth, it is improbable that radioactive waste disposed of in a borehole would be affected by inadvertent human intrusion or other potential causes of the waste returning to the surface.

2.11. This safety guide focusses on the disposal of disused sealed radioactive sources and describes a concept that involves one or more vertical boreholes drilled using widely available drilling technology; this concept differs from some other borehole disposal concepts (see para. 2.26 and Annex I). The concept for borehole disposal on which this safety guide focusses is described in the following subsection - more detail is provided in Refs. [14], [15] and [16] and the safety of the concept is considered in Refs. [17] and [18].

Concept for borehole disposal of disused sealed radioactive sources

2.12. A concept for the disposal of disused sealed radioactive sources in boreholes was described in Ref. [14]. The concept was designed to assist IAEA Member States that have hazardous disused sealed radioactive sources in storage, recognizing the associated security issues and the obligations under the Joint Convention, Ref. [6] and the recommendations of the Code of Conduct, Ref. [7] to implement a disposal solution. While there have been improvements to details of the design since Ref. [14] was published - see Refs [15] and [16] - the concept remains essentially the same and has become a recommended concept. It entails the emplacement of disused sealed radioactive sources that have been declared radioactive waste, and possibly some small amounts of low level waste and intermediate level waste generated during their management, in borehole disposal facility drilled and operated from the surface.

2.13. In the recommended borehole disposal concept, the borehole is assumed to be vertical and straight, and to have a minimum diameter of around 260 mm - this diameter is large enough to accommodate borehole casing, backfill and reasonably sized waste packages[10]. 260 mm is also a diameter for which drilling rigs are widely available because boreholes of this size are often used for water abstraction. In the concept, the borehole is cased to full depth using high-density polyethylene (HDPE) tubing whose purpose is to facilitate operations such as emplacement of the waste packages into the borehole. The bottom of the casing should be sealed with a cement-based plug, and the gap between the casing and the borehole wall is filled with cement-based backfill. The plug and backfill should prevent the ingress of groundwater and allows the waste emplacement operations to be

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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, such as the accident that occurred at the Goiânia in Brazil and which generated approximately 3,500 m^3 of radioactive waste Ref. [12], could be disposed of by borehole disposal.

[10] Note that the dimensions provided are for the recommended concept, but they can and should be varied to meet the safety requirements for a particular implementation.

conducted in essentially dry conditions. The cement-based material in the recommended borehole disposal concept comprises principally a sulphate-resistant Portland cement and sand with a maximum particle size of 4 mm. The operating organization should justify the choice of the materials to be used in the disposal facility, taking account of their intended purposes, safety functions and performance in the conditions of the disposal system.

2.14. In the recommended borehole disposal concept, disused sealed radioactive sources should be placed inside a 3 mm-thick stainless steel disposal capsule which should be closed by welding on a 3 mm-thick stainless steel lid. The weld should be tested for leaks. The thickness of the weld should be at least as thick as the disposal capsule walls. The sealed disposal capsule containing the radioactive sources should then be placed inside a pre-cast cement-based insert inside a 6 mm-thick stainless steel disposal container. The cement-based insert should comprise two pieces, a larger body part and a lid. The lid of the insert should be fixed to the insert body using a small amount of liquid grout, which will set and solidify. The disposal container should be closed by welding on 6 mm-thick stainless steel lid. The thickness of the weld should be at least as thick as the disposal container walls. Disposal capsules, cement-based inserts and disposal containers should be made in diameters and lengths to accommodate the sizes of the sources to be disposed of and taking account of the diameter of the borehole and casing.

2.15. 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 stainless steel described in Ref. [14] 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 to be disposed of (e.g. in terms of their potential to generate heat and to cause radiolysis of water – see Appendix II).

2.16. In the recommended borehole disposal concept, the waste packages should be emplaced into the borehole and the spaces around the waste packages in the borehole should be backfilled using cement-based backfill. The number of waste packages and the size of the spaces between them, which will be filled by backfill, should be assessed to determine the total length of disposal zone needed. The total length of disposal zone needed should be considered together with the characteristics of the host rocks to determine the number of boreholes and disposal zones needed and the locations and depths of the disposal zones.

2.17. Fig. 1 illustrates a disposal facility for disused sealed radioactive sources with two boreholes; the inset highlights the components present in the disposal zone.

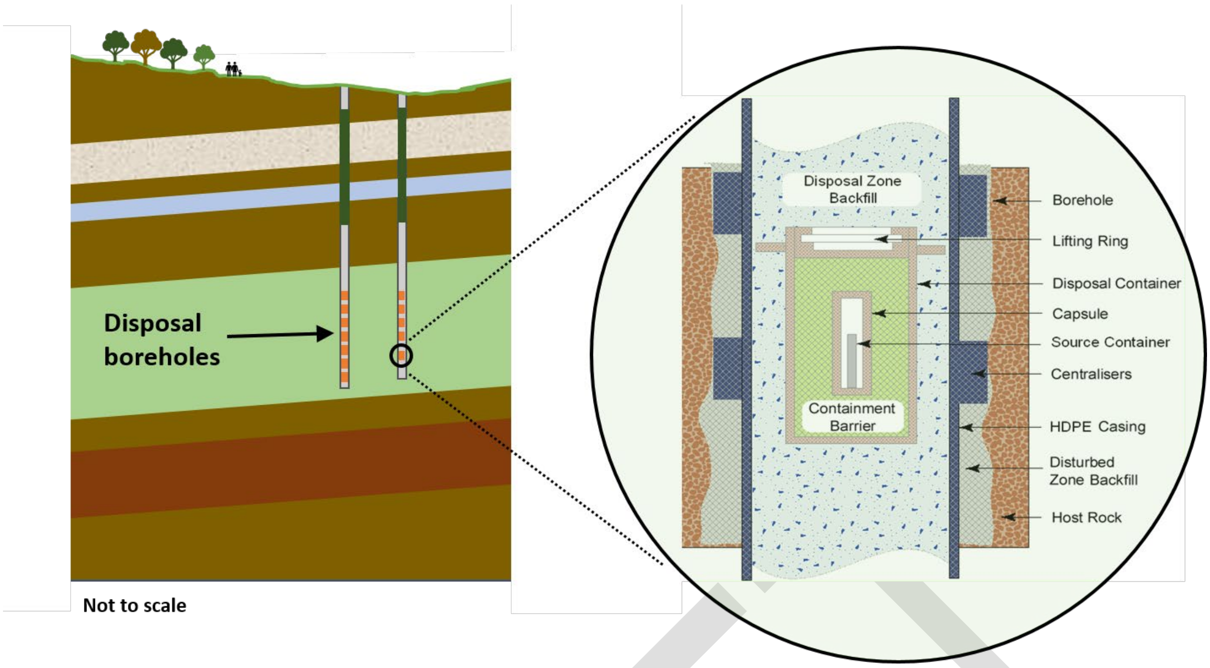

FIG. 1. Main components of a borehole disposal system for disused sealed radioactive sources – modified from Ref. [17].

2.18. When the final waste package has been emplaced and any temporary casing above the disposal zone has been removed, a steel deflection plate should be inserted into the borehole above the waste. This deflection plate should prevent a drill bit from running into the waste packages in the event that someone drilled into the borehole. The borehole above the deflection plate should be backfilled with concrete to a depth of five metres from the ground surface. The top five metres of the borehole should be filled with crushed rock and local soil so that the borehole is undetectable without specialist equipment.

Periods in borehole disposal of disused sealed radioactive sources

2.19. A step by step approach should be followed in developing a borehole disposal facility – SSR-5 [4]. It is probable that a programme for developing a borehole disposal facility (including *inter alia* site characterization and selection, safety case development, interactions with interested parties, and authorization) will take several years to a decade. It is probable that once the necessary authorization processes are completed, the operation and closure of a disposal borehole[11] would not last more than a few months or 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

[11] A small borehole disposal facility might have only one disposal borehole.

reviews also provide opportunities for independent technical review and involvement of interested parties.

2.20. The operating organization should design the step by step process of facility development so that there is flexibility for the disposal programme to be adapted in response to new scientific and technical information that becomes available. Throughout the development, 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. Guidance on how a graded approach can be taken to post-closure safety assessment for borehole disposal is provided in Ref. [18].

2.21. It is convienient to identify three periods in the development, operation, closure and institutional control of a radioactive waste disposal facility, namely the pre-operational period, the operational period and the post-closure period – SSR-5 [4]. Various activities take place during the three periods depending *inter alia* on the disposal concept. The following applies for borehole disposal:

The pre-operational period

2.22. The pre-operational period includes all of the activities before waste is received at the site. The extent of these activities should reflect the situation in the State and can include the characterization of waste in the country and 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, and regulatory review and authorization. Waste processing for storage and disposal could 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 (e.g. operational and post closure safety assessments) in accordance with the national legal and regulatory framework.

The operational period

2.23. The operational period begins after an authorization has been obtained when waste is first received at the site. During this period waste management activities could result in radiation exposures – hence these activities are required to be authorized by the regulatory body and subject to controls in accordance with the requirements for radiation protection and safety – see GSR Part 3 [2] and GSR Part 5 [3]. The operating organization should conduct predisposal management activities in accordance with the guidance and recommendations contained in IAEA Safety Standards Series Nos WS-G-6.1, Storage of Radioactive Waste [19] and SSG-45, Predisposal Management of Radioactive Waste from the Use of Radioactive Material in Medicine, Industry, Agriculture, Research and Education [20].

(a) In some cases, waste received at the site may already have been processed, meaning that following successful passage through applicable waste acceptance procedures, and any necessary period of buffer storage, waste emplacement can proceed directly;

(b) In other cases, the operating organization should process the waste so that it is ready for disposal using appropriate facilities and following appropriate procedures for the necessary predisposal management activities (e.g. dismantling of devices containing disused sealed radioactive sources, removal of the disused sealed radioactive sources, conditioning). The operating organization should design and conduct the waste processing activities so that there are no 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 [21] recognizes five categories of radioactive sources. Hot cell facilities, such as the one described in Ref. [22], typically have sufficient shielding to be used for processing all categories of disused sealed radioactive sources. Processing of Category 3 to 5 disused sealed radioactive sources can be done safely with relatively less shielding and can be performed using a facility such as the one described in Ref. [23]. Whichever facilities are used, the operating organization should provide sufficient shielding to ensure protection of workers appropriate to the nature of the waste – the operating organization should consider the possible need to provide shielding for both gamma and neutron sources. The operating organization should provide appropriate storage facilities at the site to facilitate the waste management process;

(c) The operation of a borehole disposal facility includes handling of waste packages, emplacement of waste packages in the disposal facility, emplacement of engineered barriers (e.g. borehole backfill, seals, anti-intrusion barriers) and facility closure. The operating organization should conduct disposal activities in accordance with the requirement in SSR-5 [4] and the guidance and recommendations contained in this safety guide.

2.24. 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 IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [24] and IAEA Safety Standards Series No. GSG-16, Leadership, Management and Culture for Safety in Radioactive Waste Management [25]. 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. All important safety-related information

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

concerning radioactive waste management should be retained and controlled – GSG-16 [25]. Facilities other than the borehole that were used during operations should be decommissioned in accordance with IAEA Safety Standards Series No. GSR Part 6, Decommissioning of Facilities [26].

The post-closure period

2.25. The post-closure period begins immediately after the borehole disposal facility has been closed. 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 (such as maintenance of site security and monitoring – see para. 7.15), but active controls cannot be maintained indefinitely and so, later, passive institutional controls may become more relevant. Passive institutional controls may, for example, include administrative restrictions on land use that provide additional assurance that inadvertent human intrusion would be improbable. The authorization for the disposal facility should be terminated when the necessary technical, legal and financial requirements have been fulfilled – see IAEA Safety Standards Series No. WS-G-5.1, Release of Sites from Regulatory Control on Termination of Practices [27].

OTHER BOREHOLE DISPOSAL CONCEPTS

2.26. Several other concepts have been proposed involving the use of boreholes for radioactive waste storage or disposal, and some of these have been implemented for various types of radioactive waste (Annex 1). In accordance with the objectives and scope of this safety guide, the disposal concepts described in Annex 1 for waste types other than those identified in para. 1.1 are not considered further in any detail, although the guidance provided may be of general interest. The guidance in this safety guide, and particularly that 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

3.1. The development, operation, closure and institutional control of a borehole disposal facility necessitates the assignment of responsibilities among three types of organization: the national government, the appointed regulatory body (or bodies) and the operating organization of the facility. Recommendations on the responsibilities of each of these are provided in this section.

RESPONSIBILITIES OF THE GOVERNMENT

3.2. General safety requirements for the establishment of national policies and strategies for safety and for radioactive waste management are set out in Requirement 1 of GSR Part 1 (Rev. 1) [28] and Requirement 2 of GSR Part 5 [3]. Requirement 2 of GSR Part 5 [3] states:

> **"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 national policies and strategies for radioactive waste management, the Government should ensure the following:

(a) Development and maintenance of a comprehensive national register of radioactive sources – see para 4.63 of GSR Part 1 (Rev. 1) [28];

(b) The establishment and implementation of a decision-making process for declaring disused sealed radioactive sources radioactive waste – see Ref. [7];

(c) Development and maintenance of a comprehensive national inventory of radioactive waste (including disused sealed radioactive sources declared radioactive waste);

(d) That the preferred options for radioactive waste management are identified – see para 3.5 of GSR Part 5 [3];

(e) That due consideration is given to interdependences between the various steps in waste management;

(f) That long-term storage of disused sealed radioactive sources that have not been declared radioactive waste is avoided;

(g) That a disposal programme is developed for disused sealed radioactive sources that have been declared radioactive waste which is compatible with the State's overall radioactive waste management programme[13] – see Ref. [7];

(h) That consideration is given to the need nationally for one or more disposal facilities, depending on the inventory of disused sealed radioactive sources and other radioactive waste for disposal in the State. 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;

[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.

(i) That safety is paramount amongst the factors considered when selecting appropriate types of disposal facilities for disused sealed radioactive sources that have been declared radioactive waste 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 materials, and relevant socio-economic factors;

(j) That the resources devoted to safety by the licensee, and the scope and stringency of regulations and their application, are commensurate with the magnitude of the radiation risks and their amenability to control – para. 3.24 of SF-1 [1]. The numbers of disused sealed radioactive sources in States varies from just a few sources in some small States, to well in excess of 100,000 sources in some States. The volumes of packaged radioactive waste envisaged to result from conditioning of disused sealed radioactive sources are estimated as varying from less than ten m^3 in typical small States to several hundred m^3 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.

3.4. In addition to the development of national policies and strategies, the Government is required to establish and maintain an appropriate governmental, legal and regulatory framework, including relevant laws and regulations, an effective regulatory body that is independent of the operating organization, and a regulatory process that defines the steps to be taken in the licensing and development, operation, closure and institutional control of the facility. 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."**

3.5. In accordance with Requirement 1 and para. 3.7 of SSR-5 [4], the Government should in the governmental, legal and regulatory framework:

(a) Confirm at the national level the need for disposal facilities of different types (including where appropriate borehole disposal facilities);

(b) Establish or identify organizations for the development, operation, closure and institutional control of disposal facilities (including where appropriate borehole disposal facilities);

(c) Set clearly defined legal, technical and financial responsibilities for organizations that are to be involved in the development, operation, closure and institutional control of disposal facilities (including where appropriate borehole disposal facilities);

(d) Ensure 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;

(e) Define the overall process for the development, operation, closure and institutional control of disposal facilities (including where appropriate borehole disposal facilities), including the legal and regulatory requirements at each step, and the processes for decision making and the involvement of interested parties;

(f) Define legal, technical and financial responsibilities and, if necessary, provide for any institutional arrangements that are envisaged after disposal facility closure, including monitoring and arrangements that may be required for ensuring the security of the disposed of waste;

(g) Establish a regulatory body with appropriate responsibilities for oversight of predisposal waste management facilities and disposal facilities (including where appropriate borehole disposal facilities);

(k) Ensure that the necessary scientific and technical expertise is available to both the operating organization and the regulatory body (e.g. from national institutes for health and radiation protection, geology and hydrology, and other relevant disciplines).

3.6. The government should ensure that the regulatory body is independent of the generators of the waste and operating organizations. The regulatory body should possess the expertise to provide proper oversight and objectivity in evaluating predisposal waste management and disposal activities. Individuals working within the regulatory body should be 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.

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

RESPONSIBILITIES OF THE REGULATORY BODY

3.8. Requirement 3 of GSR Part 5 and Requirement 2 of SSR-5 establish the responsibilities of the regulatory body for radioactive waste management facilities and activities. 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."**

3.9. The regulatory body should develop and implement a process for establishing regulatory requirements. The regulatory body should involve interested parties in the process for establishing regulatory requirements. Regulatory requirements should be established well in advance of any licence application. The regulatory arrangements should cover all stages in the development, operation, closure and institutional control of facilities and activities, specifying the principles, requirements and criteria that will be used to regulate the facilities and activities, and requiring the operating organization to establish arrangements for what should happen in the event of non-compliances, events and accidents. The safety objective and relevant criteria are provided in paras 3.23 to 3.26. Model regulations for borehole disposal are provided in Ref. [29].

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

3.11. The regulatory body should define and follow a step by step approach to authorization. At each step, the operating organization should as far as is possible describe in its application for authorization and safety case the totality of the disposal programme 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 potential long-term safety of the facility when it reviews applications for initial steps in the facility development process.

3.12. The regulatory body should not grant an authorization for facility construction, commissioning or operation until regulatory review and assessment of relevant applications for authorization and the safety case have been completed and the regulatory body considers that the application is complete and the safety case presents 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 its steps (i.e. construction, commissioning, operation, closure and any planned period of post-closure active institutional control).

3.13. 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. The regulatory body should specify in the authorization, 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 and potential hazard of the facilities and activities.

3.14. The regulatory body should develop and implement processes and procedures through which it sets conditions for the development, operation, closure and institutional control of each disposal facility. These processes and procedures should include regulatory review and assessment of the safety case for the facility, and authorization with appropriate conditions.

3.15. The operating organization of a borehole disposal facility should submit the safety case to the regulatory body for independent review and assessment. The regulatory body should review and assess the safety case for the 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.

3.16. General guidance on regulatory review and assessment is provided in IAEA Safety Standards Series No. GSG-13, Functions and Processes of the Regulatory Body for Safety [30]. GSG-13 indicates that 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 whether:

(a) The operating organization has the necessary competences and resources;

(b) The site is suitable;

(c) All aspects of the facility design and the limits and controls are adequate;

(d) The operating organization uses an appropriate safety management system;

(e) The safety assessments are adequate;

(f) There are any additional requirements (or conditions) that should be imposed and, if these were imposed previously, whether they have been complied with.

3.17. The regulatory body should develop a plan for managing the regulatory review and assessment process; this plan should cover staffing and resourcing, 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. Guidance for the regulatory body on interacting with interested parties is contained in IAEA Safety

Standards Series No. GSG-6, Communication and Consultation with Interested Parties by the Regulatory Body [31].

3.18. Regulatory reviews and assessments of facility safety cases should reflect the scale and potential hazard of the facilities and activities. The regulatory body should focus on issues, review comments and findings according to their importance to safety.

3.19. The regulatory body should ensure that it has an independent capability to carry out reviews and assessments of facility safety cases in order to determine whether the facility is and will be safe and what conditions of authorization should be specified and attached to the authorization. Regulatory review and assessment of the safety case and licence application may be undertaken in various ways, and may include the use of independent external experts in accordance with the guidance provided in IAEA Safety Standards Series No. GSG-12, Organization, Management and Staffing of the Regulatory Body for Safety [32].

3.20. The regulatory body should check that the operating organization exercises adequate control of the borehole disposal facility. The regulatory body should carry out activities to ensure that the conditions of authorizations are met. This should include checking that the operating organization is properly developing and complying with waste acceptance criteria and conducting appropriate regulatory inspection and enforcement activities.

3.21. 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 examine the operating organization's compliance with the authorization, safety case and operating procedures, and the safety culture of the operating organization's staff and contractors – GSG-16 [25].

3.22. The regulatory body is required to establish appropriate requirements for radiation protection.

Radiation protection in the operational period

3.23. The following key requirements apply in the operational period:

(a) Justification: Requirement 10 of GSR Part 3 [2] states: "The government or the regulatory body shall ensure that only justified practices are authorized." Radioactive waste management is part of the 'practice' giving rise to the waste, and as such does not require separate justification [3].

(b) Optimization: Requirement 11 of GSR Part 3 [2] states: "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) Dose limits: Requirement 12 of GSR Part 3 [2] states: "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) Dose and risk constraints: para. 3.120 of GSR Part 3 [2] states “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 risks of all cancers and the risks of hereditary effects.

3.24. Predisposal radioactive waste management activities may lead to planned exposures. Radioactive waste disposal may lead to planned exposures of workers and the public in the operational period and planned potential exposures of the public in the post-closure period – planned potential exposures are not certain to occur. Schedule III of GSR Part 3 [2] sets out dose limits that apply to radioactive waste management; the key criteria are:

“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

3.25. The fundamental safety objective is to protect people and the environment from harmful effects of ionizing radiation – SSR-5 [4] and this requires the operating organization 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. 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.

3.26. The following key criteria apply in the post-closure period:

(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, GSR Part 3 [2]. This and its risk equivalent are considered criteria that are not to be exceeded in the future;

(b) To comply with this dose limit, a disposal facility (considered as a single source) is so designed that the calculated dose or risk to the representative person who might be exposed in the future as a result of possible natural processes 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 – 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;

(d) If human intrusion were expected to lead to a possible annual dose of more than 20 mSv (see Table 8 of Ref. [33]) to those living around the site, then alternative options for waste disposal are to be considered;

(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 facility design;

(f) The ICRP considers that a dose rising towards 100 mSv will almost always justify protective action (para. 241 of Ref. [33]);

(g) 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 (para. 236 of Ref. [33]).

RESPONSIBILITIES OF THE OPERATING ORGANIZATION

3.27. Requirement 4 of GSR Part 5 and Requirement 3 of SSR-5 establish the responsibilities of the operator 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."**

3.28. The operating organization has prime responsibility for the safety of facilities and activities; this responsibility cannot be delegated. This responsibility 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 work, the operating organization retains the prime responsibility for safety and ensuring compliance with legal and regulatory requirements. – see paras 2.14 and 2.15 of GSR Part 1 (Rev. 1) [28].

3.29. The operating organization is responsible for preparing and maintaining a safety case, including relevant safety assessments, on which decisions on the authorization and development, operation, closure and institutional control of the disposal facility should be based. The operating organization is responsible for submitting the safety case to the regulatory body for review and assessment. 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. General guidance on the safety case and safety assessment for the predisposal management of radioactive waste is contained in IAEA Safety Standards Series No. GSG-3, The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste [34]. General guidance on the safety case and safety assessment for the disposal of radioactive waste is contained in SSG-23 [35]. More detailed information, specific to post-closure safety at borehole disposal facilities for disused sealed radioactive sources, is contained in Section 5 and in Refs [17] and [18].

3.30. The operating organization is responsible for conducting or commissioning investigations of sites as necessary to evaluate 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 integrate results from site investigations into the safety case.

3.31. The operating organization should seal site investigation boreholes before commissioning the disposal facility; sealing should be done in a timely manner and in accordance with the authorization and the safety case. Site investigation boreholes should be sealed to prevent them from acting as pathways for groundwater or gas flow and radionuclide migration. The operating organization should seal site investigation boreholes so that the permeability of the sealed boreholes is no worse than that of the surrounding intact rocks. Further guidance on site characterization is contained in Section 6 and Appendix I.

3.32. The operating organization should take full responsibility for radioactive sources and radioactive waste at the 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 information should at least include the following:

(a) The radionuclide, its half-life and activity at a specified date;

(b) The nature of radiation emitted; dose rate at contact and 1 m distance;

(c) The size of the sources to be disposed;

(d) Whether the source is known to be leaking or not.

(e) The physical and chemical form of the sources and the materials of the containers and their thickness.

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

(a) Manufacturer, serial number and the dates of manufacture, import and receipt by the operating organization;

(b) Previous owners, the name and type of device in which it was used and the use to which was put.

3.34. The operating organization should attempt to fill any gaps in the information available. The operating organization should as appropriate consult with the manufacturers and users of disused sealed radioactive sources, with the waste generators and the IAEA sealed source catalogue and other information sources.

3.35. The operating organization is responsible for processing of the radioactive sources and radioactive waste, for producing waste packages suitable for disposal, and for waste disposal. The operating organization should:

(a) Provide the facilities and equipment necessary for the 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.

3.36. 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 that have been trained in the procedures to be followed. The operating organization should ensure that interdependencies in the waste management process are taken into account (e.g. that the disposal capsules and waste packages are suitable for emplacement in the disposal facility).

3.37. The operating organization is responsible for all steps in the disposal of radioactive waste. The operating organization should not begin construction of disposal borehole(s) or any other activities that could significantly affect baseline (e.g. hydrogeological) conditions at the site (see SSG-31, [36]) until an authorization has been granted. The operator should engage with the regulatory body beginning at an early stage in the process leading to authorization and the development of a borehole disposal facility. The operating organization should ensure that all construction and disposal activities are performed in accordance with the approved safety case.

3.38. The operating organization is responsible for establishing limits, controls and conditions (e.g. technical specifications), from 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 implement and maintain appropriate security measures.

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

3.40. The operating organization is responsible for all steps necessary for the safe and sustainable decommissioning of predisposal management facilities and activities at the site. Decommissioning should be conducted in accordance with GSR Part 6 [26].

3.41. The operating organization should record and retain all information relevant to the safety of the disposal facility, including inspection records and other assessments of compliance with regulatory requirements, the operating organization's management system and the operating procedures. If responsibility for the facility is transferred between organizations, the operating organization should hand over to the newly responsible organization all information relevant to the safety of the facility. The operating organization is required to cooperate with the regulatory body and supply all the information that the regulatory body may require to fulfil its responsibilities.

4. SAFETY APPROACH

IMPORTANCE OF SAFETY IN THE DEVELOPMENT AND OPERATION OF A 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**". Demonstrating that doses and risks will be below the relevant dose and risk criteria set by the regulatory body is a necessary, but not sufficient objective. The operating organization should seek to reduce doses and risks to levels that are as far below the relevant dose and risk criteria as can be reasonably achieved, taking account of economic and social factors. Decisions on whether protection has been optimized will be judgemental because of the needs 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, costs, uncertainties, and the views of interested parties. The optimization of protection should be considered at every step 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) Providing appropriate radiation shielding;

(c) Controlling working environments;

(d) The design of predisposal waste management facilities and activities (e.g. waste processing);

(e) Designing facilities and activities so that the need for any discharges is avoided;

(f) Separating facility construction activities (e.g. drilling) from waste emplacement operations;

(g) Procedures for operating the disposal facility (e.g. waste emplacement, borehole backfilling);

(h) Using remote techniques as necessary (e.g. for waste handling and emplacement);

(i) Reducing the potential for accidents and minimizing their potential consequences;

(j) Minimizing the need for maintenance activities in radiation and contamination areas.

4.3. The operating organization should determine how to place radioactive sources and waste into disposal capsules and containers by considering the radionuclides present, the sizes of the sources, and the volumes of the waste to be disposed of. The operating organization should in general avoid mixing dissimilar sources (such as those containing short-lived radionuclides and those containing long-lived radionuclides) in disposal capsules and containers. The operating organization should consider using a software tool such as, SIMBOD, to help refine plans for the placement of sources into disposal capsules and containers; SIMBOD is described in Ref. [37].

4.4. The following are examples of aspects that the operating organization and the regulatory body should consider when optimizing the protection that will be provided in the post closure period at a borehole disposal facility or when judging whether optimization has been achieved:

(a) That due attention has been paid during the facility development process to the post-closure safety implications of possible options, including the design and siting related issues discussed in paras 6.16 to 6.23 and Appendix I - in particular:

   i) selecting a suitable site for the borehole disposal facility;

   ii) designing the facility so that it is appropriate for the volume of waste to be disposed of (e.g. by choosing the number and diameter of the boreholes to be used);

   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 keep the probability of inadvertent human intrusion low.

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

(c) 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) The siting, design, construction, operation and closure programmes have been conducted in accordance with a suitable management system to ensure the necessary level of quality in safety related aspects of the project. Guidance on the management system for radioactive waste management is contained in GSG-16 [25].

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 isolating the waste from the surface environment in a borehole disposal facility at depths greater than 100 m (see Annex II). Another safe, secure and sustainable management option for these waste types is geological disposal.

4.7. Options for the safe, secure and sustainable management of some short-lived disused sealed radioactive sources might be provided by borehole disposal at depths shallower than 100 m or by 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 at the disposal facility site until the hazard has reduced to safe levels by radioactive decay. In the case of waste disposal at depths shallower than 100 m, 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 (as was noted in para. 4.1). The operating organization should in the safety case complement the results from safety assessment with other types of argument to show that the disposal facility will provide a safe, secure and sustainable (permanent) solution for the waste.

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

(a) Where should the facility be sited?

(b) How can the facility layout be designed to take advantage of the natural characteristics and barrier potential of the host environment?

(c) How should predisposal waste management operations be performed?

(d) How many boreholes should be constructed?

(e) In what depth range should waste be disposed of?

(f) What type of borehole casing should be used?

(g) What materials should be used as engineered barriers?

(h) What institutional controls should be put in place?

4.9. In addressing and coming to decisions on such questions, the operating organization should conduct safety assessments and demonstrate that a range of available options has been considered and that the safety implications of the available options have been assessed and are understood. The operating organization should document these assessments of the available options clearly with the aim of increasing confidence in the disposal system. Complying with the safety requirements in SSR-5 [4] will ensure adequate levels of operational and post-closure safety. At all stages, the operating organization should provide reasonable assurance of safety to the regulatory body and other interested parties.

4.10. For the recommended borehole disposal concept, much of the documentation needed to satisfy the requirement to demonstrate an optimized level of protection and safety is already available, for example:

(a) A generic design including the use of stainless steel and cement-based engineered barriers – Section 2 (see also Refs [38] and [39]);

(b) Procedures for, and a demonstration of, operational safety, Refs [40] and [41];

(c) A generic safety assessment, Ref. [17] – 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. In all cases, the operating organization should follow a graded approach in addressing the safety requirements. The operating organization should expend effort to comply with the safety requirements in a way that is commensurate with the hazard and the level of risk associated with the waste – further guidance on this aspect is provided in paras 5.28 to 5.47.

PASSIVE MEANS FOR THE SAFETY OF A 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, government or future generations.

4.14. The operating organization should promote passive safety by:

(a) Siting the facility at a location that benefits from stable geological conditions, has low potential for the abstraction of water and or the extraction of minerals, oil and gas and other resources (a site that has a low probability of inadvertent human intrusion) and that has groundwaters that will be chemically unreactive to the structures, systems and components of the facility;

(b) Designing the disposal facility so that it includes solid, unreactive waste forms, chemically and physically stable waste packages, and other structures, systems and components, and that facilitates waste disposal at depths greater than 100 m;

(c) Keeping the operational period short 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'. The operating organization should provide sufficient storage capacity for waste prior to 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 (para. 4.13 of GSR Part 5 [3]). 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;

(d) Closing the facility in a way that does not require subsequent maintenance of the structures, systems and components of the facility that are designed to provide barriers to the migration of radionuclides;

(e) Implementing passive institutional controls, such as the archiving of records of the 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 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 should develop and demonstrate to the regulatory body and, as appropriate, to other interested parties, an adequate understanding of the 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 and guidance provided in GSR Part 4 (Rev. 1) [13], SSG-23 [35] and in this publication. The operating organization should develop safety assessments covering the predisposal management activities, the disposal operations and the post-closure period that are based on a systematic and as comprehensive as possible analysis of the features events and processes that could affect the disposal system and analyses of the safety functions of the structures systems and components of the 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 may behave and evolve in 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. [17]; the operating organization should consider this information when identifying features events and processes and scenarios for a borehole disposal facility at a specific site.

4.18. To demonstrate reasonable assurance of safety the operating organization should develop a safety case that includes safety assessments which show that the system's features events and processes and their possible interactions have been identified and are sufficiently well understood, and analyses of uncertainties. The operating organization should perform structured uncertainty analyses to identify the range of possible disposal system behaviours. The operating organization should consider conducting more detailed modelling and sensitivity studies for parts of the disposal system that are significant to safety. Further discussion of the analysis of uncertainties through the use of scenarios and features events and processes in safety assessment is contained in GSR Part 4 (Rev. 1)[13], GSG-3 [34], SSG-23 [35] and Refs [17] and [18].

4.19. The operating organization should acknowledge openly the uncertainties that exist at any stage in the development, operation, closure and institutional control of the 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 manner that will be safe. The existence of uncertainties is not a reason for not proceeding 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 disposal programme proceeds to reflect new data and lessons learned from the experience. The level of 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 the 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 that the relevant regulatory requirements will be satisfied.

4.21. Confidence-building should be an integral part of safety assessment and the safety case development process. The operating organization should present in safety case documents a series of arguments that is intended to build confidence in the safety of the disposal system. The operating organization should seek to build confidence in safety of the disposal system by, for example:

(a) Showing that the safety assessment is as comprehensive as possible and is based on good science and engineering practice and high-quality data;

(b) Showing that the disposal system is robust (i.e. its performance is not unduly sensitive to individual detrimental events and processes);

(c) Providing evidence regarding the appropriateness and effectiveness of controls such as waste acceptance criteria – see paras 6.58 to 6.66;

(d) Providing information to demonstrate the feasibility 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 related, for example, to defence in depth, multiple lines of reasoning, institutional control, monitoring, information from natural analogues, and 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 facility that includes multiple safety functions. A safety function is a specific purpose that must be accomplished for safety - IAEA Safety Glossary, Ref. [5]. Safety functions are usually attributed to particular structures, systems and components. A safety function could be provided by a physical or chemical quality of a structures, systems and components.

4.25. The operating organization should ensure that safety functions are provided by a combination of engineered and natural barriers. The operating organization should design the disposal system so that the number and complexity of the barriers and safety functions in in accordance with the hazards 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 and where the rate of groundwater movement and the degree of radionuclide sorption onto the rocks together ensure that the radionuclides would 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. Ref. [15] suggests the use of containers made of particular stainless steels for the disposal of different types of disused sealed radioactive sources;

(c) Solid waste forms that are insoluble and release radionuclides only slowly;

(d) Engineered barrier materials that retard radionuclide migration. For example, a cement-based backfill placed between the container and the borehole casing can create high-pH conditions that limit solubility and promote sorption and so provide containment.

4.27. The operating organization should ensure that the performance of the 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 so 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 so that they are compatible with each other and with the natural barriers. Examples of components that are probably incompatible include the following:

(a) The use of ordinary Portland cement when the surrounding groundwater or geology has high levels of sulphate; a situation which is common in some types of clay;

(b) The use of 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, Ref. [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, Ref. [5].

4.31. The operating organization is required to design the engineered barriers and select the host rock so as to provide containment of the radionuclides in the waste, especially during the initial period after disposal when the level of activity is most intense and radioactive decay can significantly reduce the hazard. The operating organization should provide sufficient containment 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. Some disused sealed radioactive sources generate significant amounts of heat as a result of radioactive decay. The operating organization should pay special attention to the need to provide sufficient containment for such wastes by selecting or designing suitable waste containers and waste packages. The operating organization should take particular account of the characteristics of, and processes associated with, high-activity disused sealed radioactive sources, including heat generation, the emission of neutrons and the radiolysis of water. The operating organization should design the waste package so that it includes suitable barriers which are compatible with other barriers in the disposal system (e.g. the borehole backfill, the host rocks) and which 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 the environment, Ref. [5]. Isolation is a requirement for safe waste disposal and is also important in providing and maintaining nuclear security over certain types of disposed waste.

4.35. When siting a borehole disposal facility, the operating organization is required to provide sufficient isolation and should give due consideration to processes and events that might lead to a loss of isolation. Such processes and events might bring disposed waste closer to the surface environment and cause people to become exposed to radiation, and include erosion, tectonic uplift, glaciation, permafrost melting and inadvertent human intrusion. In order to minimize the probability of inadvertent human intrusion, the operating organization should site borehole disposal facilities away from areas with resources, including mineral, oil, gas, geothermal energy and water resources. 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 characteristics of the waste and the requirements for isolation and nuclear security. For waste that will have significant activity at the end of the period of active institutional control[14] (e.g. long-lived disused sealed radioactive sources that have been declared waste and intermediate level waste generated during their management), the operating organization should locate the disposal zone(s) in a borehole disposal facility below 100 m (Annex II). Disposal at depths shallower than 100 m could be a safe option for short-lived disused sealed radioactive sources and low level waste that are not subject to safeguards (see paras 7.23 to 7.29), but the operating organization has to demonstrate that such facilities would provide sufficient isolation and nuclear security. In addition to providing sufficient isolation and nuclear security, the operating organization should take account of the characteristics (e.g. permeability) of the host rocks and the geochemistry of the groundwaters when deciding on the depth of the disposal zone(s) in a borehole disposal facility (see Section 6).

4.37. In designing a borehole disposal facility, the operating organization should give due consideration to further enhancing confidence in the isolation provided by the selection of the site and the design of the facility, including the choice of disposal depth, by including mechanically strong and heavy engineered anti-intrusion barriers (e.g. 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 is used to mean physical inspection of the facility to verify its integrity and the capability to protect and preserve passive barriers [5]. 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 affect the structures, systems and components of the facility. The operating organization should update the safety case for the facility if changes to conditions or human activities

[14] For example, Figure 3 of Ref. [14] shows that some sealed radioactive sources containing Cs-137 will not decay to exemption levels for more than 1,000 years and that Ra-226 sources can remain potentially dangerous for tens of thousands of years.

at or near the site have occurred that could significantly affect the structures, systems and components of the facility. The regulatory body should check periodically that any passive institutional controls implemented remain in place and are adequate.

STEP BY STEP DEVELOPMENT AND EVALUATION OF 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, operation and closure of a borehole disposal facility could take place over a shorter period than typical programmes for the development, operation and closure of near surface and geological disposal facilities. Nonetheless, the operating organization should follow a step by step approach to the development, operation, closure and institutional control of a borehole disposal facility that includes iterative evaluations (assessments) of the site and the options for the facility.

4.42. The most important steps in the development, operation, closure and institutional control of a borehole disposal facility should coincide with regulatory or governmental decision points. These decision points are typically the selection of a site, the approval of the design concept for the disposal facility, authorization of the start of construction of the disposal facility, 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 the regulatory body at the start of the development process in order that there is clarity on the direction of the disposal programme and to facilitate legitimate decision making.

4.44. Decisions on the selection of a site, the design of the facility, the 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. Organizations making decisions on whether to proceed from one step to the next should also 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 assess the safety of the 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 develop and build confidence in the safety of the disposal facility as the disposal programme progresses.

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, the development of designs and operational plans and procedures, and should cover both the operational and post-closure periods – 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 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 introduce additional iterations as appropriate to facilitate management of the disposal facility development project.

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 facility in question.

5. SAFETY CASE AND SAFETY ASSESSMENT

5.1. The safety case is the collection of scientific, technical, administrative and managerial arguments and evidence in support of the safety of a disposal 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 disposal facility. Safety assessments are an integral part of the safety case. Safety assessment involves quantification of radiation dose and radiation risks that may arise from the disposal facility for comparison with dose and risk criteria, and provides an understanding of the behaviour of the disposal facility under normal conditions and disturbing events, considering the time frames over which the radioactive waste remains hazardous (para. 1.3 of SSG-23 [35]).

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

(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 all safety related work and activities – see Section 4 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 has the prime responsibility for safety and is required to develop a safety case for the facilities and activities and to provide it to the regulatory body for approval. The operating organization should start to develop the safety case, including appropriate safety assessments, early in the development of the 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 develop and use the safety case and safety assessments to guide all steps and decisions in the development, operation, closure and institutional control of a borehole disposal facility and as a basis for communication with interested parties – SSG-23 [35]. The safety case should be regarded as a “living document”. The operating organization should update the safety case to take account of new information at each step and as required in the authorization issued by the regulatory body. Fig 2, from Ref. [42], illustrates the progressive updating of the safety case during the development, 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, operation, closure and institutional control of the borehole disposal facility, including research and development, site characterization, facility design, and optimization.

5.6. For a small borehole disposal facility, some of the periods in the step by step development approach could be significantly shorter than would be the case for near surface and geological disposal facilities. For example, at a small borehole disposal facility the operational period could be just a few months to a year long. The regulatory body should define its requirements for 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.

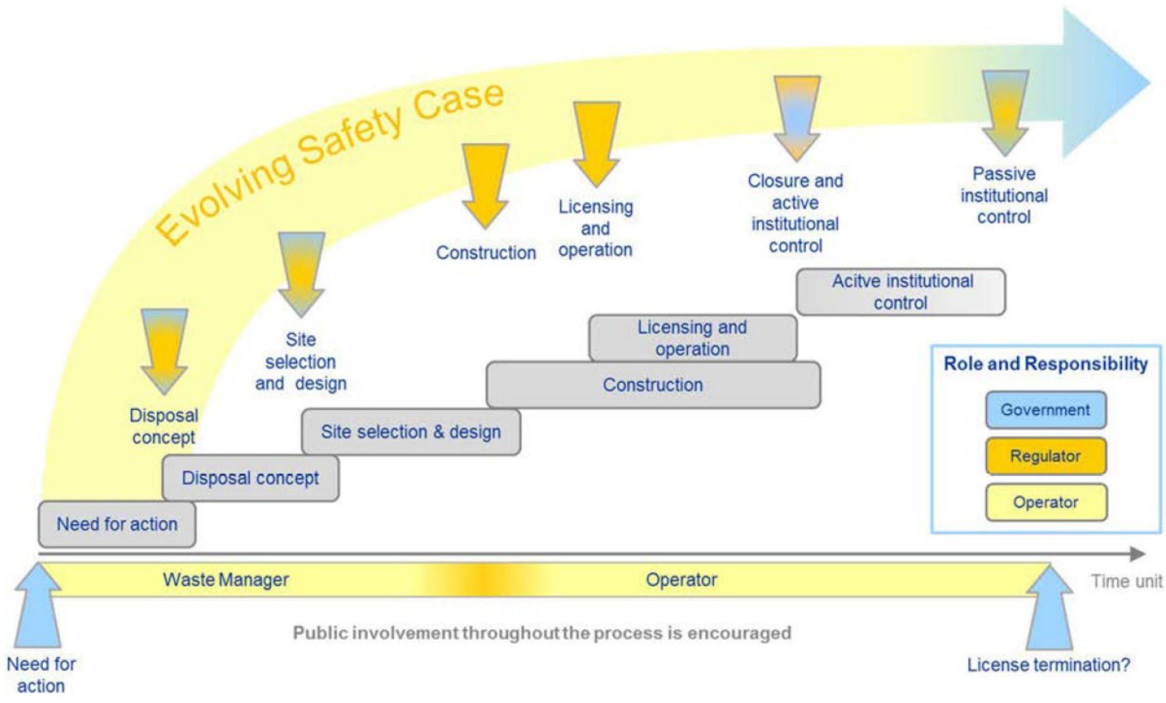

FIG. 2 The typical sequence of decisions made in the development, operation, closure and institutional control of a disposal facility for radioactive waste - Ref. [42]

5.7. When preparing the safety case, the operating organization should consider the regulatory body to be the primary audience but 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. The safety case developed to support authorization may be highly-technical and so the operating organization should also provide a description of the safety case that is readily understandable by the general public.

5.8. The operating organization should make the safety case sufficiently detailed and comprehensive so that it provides the information needed by the regulatory body for deciding whether regulatory requirements have been fulfilled or have the potential to be fulfilled and, therefore, whether the project can proceed from one step to the next. Early in the disposal programme, the safety case may have weaknesses or gaps in some areas due to incomplete knowledge; in such cases, the operating organization should acknowledge the lack of data or information in the safety case, should describe the potential significance of the uncertainties, and describe how the uncertainties will be addressed and 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, disposal 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, operation, closure and institutional control of a small borehole disposal facility ought to be significantly smaller than is typically needed 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 [14], [17], [18], [22], [23] and [37].

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”.**

Safety case

5.12. The structure and main components of the safety case are illustrated in Fig. 3 from SSG-23 [35]. The operating organization should in the safety case describe and assess all of the safety relevant aspects of the site, the facility and the activities, both during operations and following the closure of the disposal facility, and 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 the facility and its operation, closure and institutional control – GSG-16 [25]. Paras 5.15 to 5.26 address the safety case components identified in FIG. 3.

5.13. The operating organization and the regulatory body should engage in appropriate formal dialogue starting at an early stage in the programme leading to development of a borehole disposal facility – this dialogue should include discussion of regulatory requirements, guidance and expectations of the safety case and its scope and content. Detailed technical discussion may also be needed on the safety assessments and on all other aspects relating for example to the design of the facility and plans for its operation, closure and monitoring. The programme of 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.

5.14. The operating organization should establish and lead a programme of dialogue with interested parties on the disposal facility. This programme of dialogue should be appropriate to the situation in the State and local to the site. As part of this programme of dialogue, the operating organization should use information from the safety case to provide assurance that safety requirements will be met. 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 guidance on interactions with interested parties on radioactive waste management is provided in – GSG-16 [25]. Guidance on the role of the regulatory body in such dialogue is provided in GSG-6 [31].

FIG 3 Components of the safety case, Ref. [35].

5.15. The operating organization should describe in the safety case the safety case context comprising the high-level framework, or boundary conditions, applicable to the development of the safety case. The operating organization should include a description and discussion of aspects including the following:

(a) The legal and regulatory framework for the management of the waste, which may include international commitments (e.g. the Joint Convention – Ref. [6] and the Code of Conduct – Ref. [7]) and national laws, regulations, policies and strategies for radioactive waste management, and their relationships to the use of 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 facility (e.g. predisposal management of waste, site characterization, facility design, construction, commissioning, operation, closure, cessation of active institutional control, safety reassessment, safety upgrading), possibly supplemented with specific supporting objectives (e.g. relating to proposed changes to operations);

(c) The scope of the safety case at this stage (e.g. which features, events and processes are included in the safety case and which are excluded); this should be accompanied by justifications and arguments to support the inclusions and exclusions. Aspects that may influence the scope of the safety case include, the site selection process for the implementation of borehole disposal, public engagement and acceptance, environmental and social impact assessment, the operational and post-closure timeframes, and the application of the graded approach to safety case development;

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

5.16. The operating organization should document in the safety case a safety strategy which comprises the high-level integrated approach adopted to achieve safety of borehole disposal. The operating organization's safety strategy should describe the approach that will be taken to comply with the safety objective, principles, protection criteria and other regulatory requirements as defined in the safety case context, and to ensure that good science and engineering practices are adopted. The operating organization's safety strategy should describe:

(a) How the waste is to be contained and isolated from the biosphere using borehole disposal;

(b) The inclusion in the borehole disposal system of passive safety features;

(c) The robustness and the defence in depth provided by the borehole disposal system;

(d) The approach to management of uncertainties, interdependencies and the application of the graded approach.

5.17. The safety strategy should be defined at an early stage in the safety case development process.

5.18. The operating organization should document in the safety case a system description. The system description should include detailed information on:

(a) The inventory of waste and how it 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. a hot cell or other facility for conditioning of waste);

(d) The operating procedures to be used;

(e) The disposal facilities and activities (e.g. of the waste packages and borehole(s) and their configuration and construction, commissioning activities, waste emplacement operations) and the closure activities;

(f) The safety functions associated with the engineered and natural components in the disposal system and how these are expected to be fulfilled over time to provide safety.

5.19. The operating organization should include in the safety case, safety assessments as necessary to address all aspects relevant to the safety of the predisposal management facilities and activities, and to the development, operation, closure and institutional control of the borehole disposal facility. The operating organization should in the safety case for a radioactive waste disposal facility address both operational safety and post-closure safety. The operating organization should in the operational safety assessment show that, in conjunction with application of the management system, the facility will be safe during operation. The operating organization should in the post-closure safety assessment provide reasonable assurance that the facility will be safe after it is closed. In these assessments, the operating organization should consider potential impacts on humans and the environment. The operating organization should include other safety assessments in the safety case as appropriate to address, for example, transport, non-radiological hazards (e.g. non-radiological hazardous substances such as asbestos, lead), and 'conventional' health and safety hazards (e.g. hazards to workers during construction of the borehole repository).

5.20. To demonstrate the level of protection of people and the environment provided, the operating organization should in the post-closure safety assessment take account of all waste disposed of at the site (e.g. 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.

5.21. Further guidance on post-closure safety assessment for borehole disposal facilities is provided in paras 5.27 to 5.46 and in Appendix II.

5.22. The operating organization should in the safety case 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, restrictions on the mixing of radionuclides in a disposal capsule, a condition on the minimum thickness of a certain engineered barrier, the timing of a backfilling operation, prohibitions on powdered, pyrophoric and or putrescible wastes).

5.23. 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 discussion of iteration and design refinement is provided in paras 4.1 to 4.11 and para. 6.35;

5.24. 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 are and will always be uncertainties, including when considering the safety of radioactive waste disposal, and particularly when considering long time frames and disposal systems that include natural environmental systems. Some uncertainties relate to 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. When developing a borehole disposal facility there will often be alternative ways of managing uncertainties. For example, if results from a post-closure safety assessment suggest that it is uncertain that the disposal of a certain inventory of waste in a proposed borehole disposal facility would lead to potential doses and risks below the relevant dose and risk criteria, it might be possible for the operating organization to increase confidence by gathering more data, by reducing conservatism in the models, by changing the design of the facility, or through some combination of such actions. The operating organization should set out and apply an approach to the management of uncertainties and should document this in the safety case. Many uncertainties in borehole disposal of waste relate to the site and the potential pathways by which radiation exposures could occur in 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 appropriate site selection and appropriate location, depth and design of the disposal borehole(s), and or by gathering more data and or improving assessment models, and that having made these strategic management choices and taken such actions, the safety assessments give confidence that potential doses and risks will be below the relevant dose and risk criteria;

5.25. The operating organization should ensure that the 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 the supply chain, are conducted in accordance with an appropriate management system. The operating organization's 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 upon. The regulatory body should ensure that activities related to regulatory review and assessment of the safety case, including those performed by the supply chain, are conducted in accordance with an appropriate management system – see GSG-16 [25] and paras 7.38 to 7.40.

5.26. The operating organization should present in the safety case an integration of safety arguments. The safety case should synthesize of all the available evidence, arguments and analyses conducted and these must lead logically to the conclusion that the proposed activities can be safely and securely managed. The operating organization's synthesis should explain how relevant data and information have been collected, quality assured and considered, how models have been tested, and how rational and systematic procedures for safety assessment have been followed. The operating organization's synthesis should address all relevant aspects and requirements, including the importance of safety, the requirement for passive safety, the level of confidence that exists in the understanding of the disposal system, disposal system design principles (e.g. multiple safety functions, containment, isolation), the steps in the disposal facility development process (site characterization and facility design, construction, operation, closure) and assurance measures (e.g. monitoring and surveillance, institutional controls).

The operating organization's synthesis should acknowledge any limitations of the currently available evidence, arguments and analyses, 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 nevertheless be continued.

5.27. 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 development, operation, closure and institutional control of the disposal facility. For example, initial assessments of disposal concepts and feasibility will differ from later assessments for regulatory approval, commissioning, operation and closure. The operating organization should consider available information which may be of assistance in developing the safety case and safety assessments appropriate to the situation in the State and the stage that the disposal programme has reached.

Safety assessment

5.28. The operating organization is required to undertake safety assessments to evaluate the performance of the disposal system and quantify its potential radiological impacts on human health and the environment – see para. 2.5 of SSG-23 [35]. The operating organization should undertake safety assessments to develop and demonstrate an understanding of the behaviour of the disposal facility under normal conditions and following disturbing events – SSG-23 [35]. The operating organization should use safety assessment to guide site characterization studies and to guiding the design of the facility – SSR-5 [4]. The operating organization should use safety assessment throughout the development, operation, closure and institutional control of the facility to evaluate the prevailing level of understanding of the disposal system and assess uncertainties – SSR-5 [4]. The following paragraphs in this section address; post-closure safety assessment, operational safety assessment, and other assessments.

5.29. The IAEA has undertaken various studies to assess, and provide tools for assessing, the post-closure safety of borehole disposal of disused sealed radioactive sources. A series of models at different levels of complexity has been developed that can be used when applying a graded approach to assessing post-closure safety, Ref. [18]. These models include a detailed generic safety assessment – see Ref. [17] – which can be used as a basis for the development of a site-specific post-closure safety assessment that could form part of the information needed for authorization. These studies – Refs [17] and [18] – focussed initially on the disposal of Category 3 to Category 5 disused sealed radioactive sources – see RS-G-1.9 [21] –, but were later extended also to allow consideration of the safety of the disposal of Category 1 and Category 2 disused sealed radioactive sources – e.g. see Ref. [15] and Appendix II. Although Refs [17] and [18] provide much useful information, 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.

5.30. 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, Appendix II and Ref. [18]. The operating organization should consider using the tiered assessment approach presented in Ref. [18] to establish the scope, complexity and level of conservatism in post-closure safety assessment:

(a) Tier 1 assessment (least complex, extremely conservative) in which the toxicity of the radionuclide inventory for borehole disposal is assessed;

(b) Tier 2 assessment in which the activity concentrations in the radionuclide inventory for borehole disposal are compared against predefined waste acceptance criteria (e.g. as defined in Ref. [18], for example) and clearance level values as defined in GSR Part 3 [2];

(c) Tier 3 assessment in which the Borehole Disposal Concept Scoping Tool – Ref. [43] is used to perform conservative scoping calculations for borehole disposal;

(d) Tier 4 assessment (less complex, more realistic) in which a screening model is used to assess the performance of the disposal system;

(e) Tier 5 assessment (most complex, more realistic) in which the models developed for the generic safety assessment – Ref. [17] are applied to assess the post-closure performance of the disposal system.

5.31. The operating organization should use these models or similar models to assess the safety of a borehole disposal system following the graded approach by working systematically from simpler, more conservative models (e.g. Tier 1) to more complex, more realistic models (e.g. Tier 5). By following such a graded approach, the operating organization should gradually define and refine the scope of what to consider and include in the safety assessments – for example:

(a) The Tier 1 and Tier 2 assessments can be used to exclude some radionuclides from further analysis. If the models in Tier 1 and Tier 2 show that the potential radiation exposures from certain radionuclides are insignificant, even under very conservative assumptions, then there is no need to consider those radionuclides in more detailed modelling at a later stage;

(b) The use of relatively simple models can provide indications regarding the ease of making a convincing safety case for the disposal of a certain waste inventory at a particular site. Such models can also help to identify which properties of the disposal system and which uncertainties are the most important to safety, and which of these may need to be addressed and quantified in greater detail;

(c) By comparison, a lower tier assessment model is simpler than a higher tier model and, therefore, requires fewer input data and less modelling effort. The operating organization should define its data gathering and site characterization efforts so that they focus on aspects that are significant to safety.

5.32. The operating organization should define clearly and justify the assessment approach to be followed, including aspects such as the following: the use of probabilistic and or deterministic assessment methods, conservative versus realistic assumptions, the approach to the assessment of uncertainties, the assessment time frames to be considered, the assessment endpoints to be calculated e.g. potential doses, risks, radionuclide fluxes (e.g. from engineered barriers or from the geosphere to the biosphere).

5.33. The operating organization should make a systematic assessment of the uncertainties associated with the safety and the performance of the disposal system. The operating organization should use the safety assessments to identify and, where possible, quantify uncertainties. The operating organization should include in the safety assessments appropriate treatments of scenario, model, and data and parameter uncertainty. Fig. 4 shows a general structure for analysing uncertainties in this way.

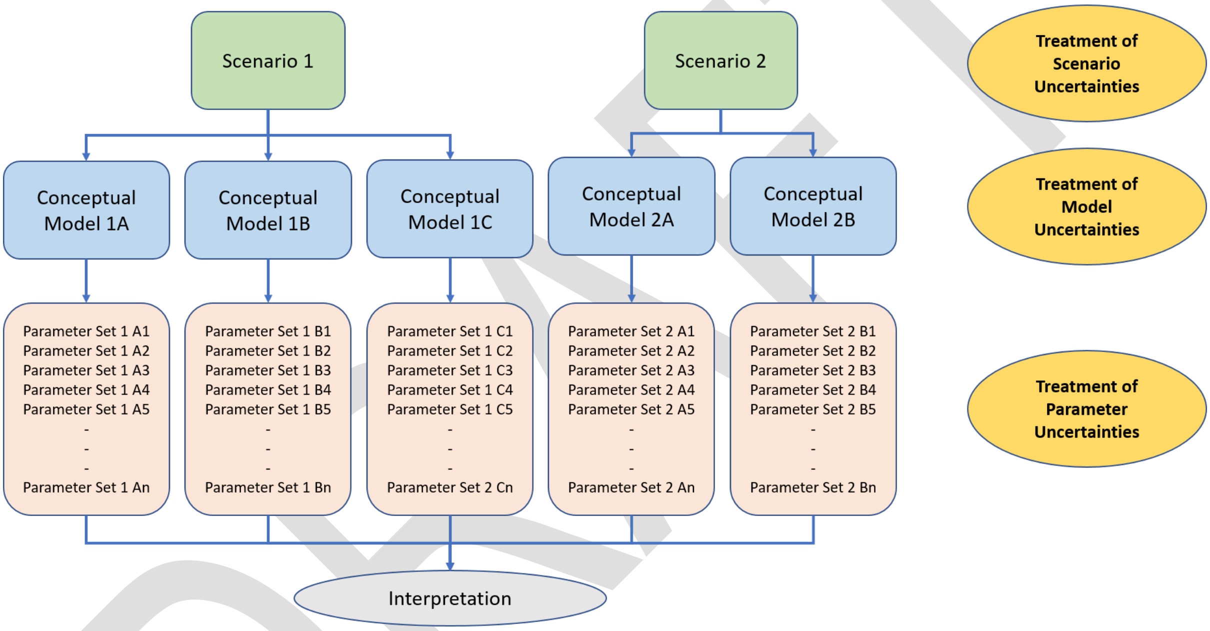

FIG. 4 Structure of uncertainty analysis, showing the treatment of scenario, model, and parameter uncertainties – modified from Ref. [44]

5.34. The treatment of uncertainty in post-closure safety assessment for disposal facilities is discussed in general in SSG-23 [35]. More specifically, experience gained during the development of the generic safety assessment for borehole disposal – Ref. [17], during development of the graded approach to post-closure safety assessment for borehole disposal – Ref. [18] and during pilot projects for the implementation of borehole disposal – Refs [45] and [46] – 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;

(b) Scenarios including initial defects in engineered barriers;

(c) Scenarios that address uncertainties in, and potential changes to, environmental conditions (e.g. climate, hydrogeology);

(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 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;

(g) Scenarios including inadvertent human intrusion.

5.35. 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 at the time of the intrusion and afterwards caused by disruption of the waste, 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.

5.36. In cases where waste has been or is to be placed in boreholes at depths shallower than 100 m, the operating organization should consider scenarios including the following:

(a) The construction of building foundations, cuttings for roads and railways, ‘cut and cover’ tunnels, and standard tunnels;

(b) Drilling.

5.37. Where waste has been or is to be placed in boreholes at depths shallower than 100 m, the operating organization should assess inadvertent human intrusion as a probable event. In such cases, the operating organization should implement effective active institutional controls during the period until the activity of the waste has decayed sufficiently so 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. The operating organization should specify the institutional controls envisaged, justify the period over which they are assumed to be effective and provide financial assurance for implementation of the institutional controls envisaged. The regulatory body should include the provision of these institutional controls as conditions of the authorization.

5.38. For borehole disposal facilities in which waste has been or is to be disposed of at depths greater than 100 m, the operating organization should consider scenarios that include drilling, but need not consider the activities in para 5.36(a). Where the depth of waste disposal is greater than 100 m, the operating organization should assess inadvertent human intrusion as an event of low probability.

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

5.40. The operating organization should use results from the assessment of plausible “what-if” scenarios to help in demonstrating that the performance of the disposal system is robust and includes defence in depth, and to help in optimization.

5.41. In assessing potential doses and risks associated with waste 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 any certainty, the operating organization should avoid undue speculation regarding future human habits. The operating organization should, however, take account of probable changes at the site, such as expected changes in land use, population and climatic conditions, and the effects of such changes on potentially exposed groups. Given that many borehole disposal facilities for disused sealed radioactive sources would be 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 that could receive exposure.

5.42. The operating organization should use uncertainty and sensitivity analyses to demonstrate robustness and defence in depth, i.e. that the safety of the disposal system does not rely unduly on any single:

(a) Feature of the design or the site;

(b) Assumption made in the safety assessment;

(c) Safety function.

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

5.44. The operating organization should build confidence in the safety of the disposal system by presenting multiple lines of reasoning. These lines of reasoning should include, but not necessarily be limited to, arguments related to robustness, defence in depth, 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. The operating organization should identify the main factors that contribute to the safety of borehole disposal (e.g. Fig. 5) 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.

5.45. The operating organization is required to assess the safety of operations at a borehole disposal facility in accordance with the requirements for the predisposal management of radioactive waste in GSR Part 5 [3] and the requirements for the disposal of radioactive waste in SSR-5 [4]. At a borehole disposal facility for the disposal of disused sealed radioactive sources, the principal predisposal waste management activities involved are processing of the disused sealed radioactive sources, including conditioning them for disposal. These activities are then followed by waste disposal in the borehole(s) – more detail is provided in Section 6. Procedures and operational safety assessments for these activities have been developed in support of concept development and as part of pilot projects on borehole disposal – see Refs [23], [40], [41] and [47]; the operating organization should consider the available information when developing assessments and procedures for use at a particular facility.

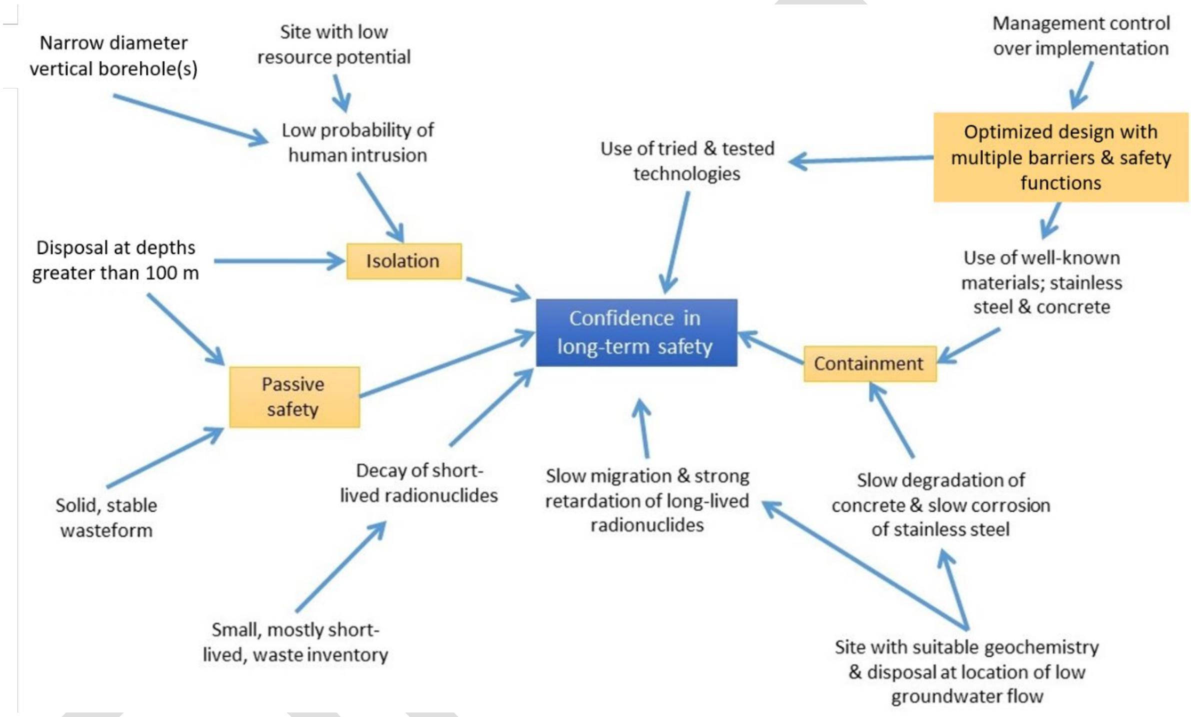

FIG. 5 Factors that contribute to confidence in the long-term safety of borehole disposal of disused sealed radioactive sources – modified from Ref. [18].

5.46. The operating organization should, in accordance with national laws and regulations, undertake further assessments as necessary to address non-radiological risks. The operating organization should, as appropriate, assess the impacts on people of non-radiological components of the waste, the impacts 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 into which contaminants could be released. For example, if disused sealed radioactive sources were 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.

5.47. With regard to the protection of non-human species, it is often the case that the system of radiation protection also provides sufficient protection for non-human species – IAEA Safety Standards Series No. GSG-8, Radiation Protection of the Public and the Environment [48]. 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 – IAEA Safety Standards Series No. GSG-10, Prospective Radiological Environmental Impact Assessment for Facilities and Activities [49]. Notwithstanding these assurances, the regulatory body should consider requesting the operating organization to undertake assessments of present day and potential future impacts of the facility on flora and fauna, in addition to assessing the environmental impacts of noise, traffic, dust and possibly other factors.

DOCUMENTATION OF THE SAFETY CASE AND SAFETY ASSESSMENT

5.48. 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."**

5.49. The operating organization should document the safety case as a hierarchy of documents; Fig. 6 illustrates a possible hierarchy of safety case documents. 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 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 addresses directly the safety requirements. Even for a small borehole disposal facility, the hierarchy of safety case documentation may be quite extensive.

5.50. The operating organization should present in the safety case documents arguments, reasoning and supporting evidence (models, parameters, data) in a convincing, traceable and transparent way. The operating organization should prepare the safety case and safety assessment documentation to facilitate understanding of the 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.

5.51. The operating organization should present the results of safety assessment in a manner that illustrates both the performance of the entire 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 that should be improved and should implement appropriate design refinement activities to increase confidence in the performance of the waste management system.

5.52. 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, increases in scientific understanding, 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).

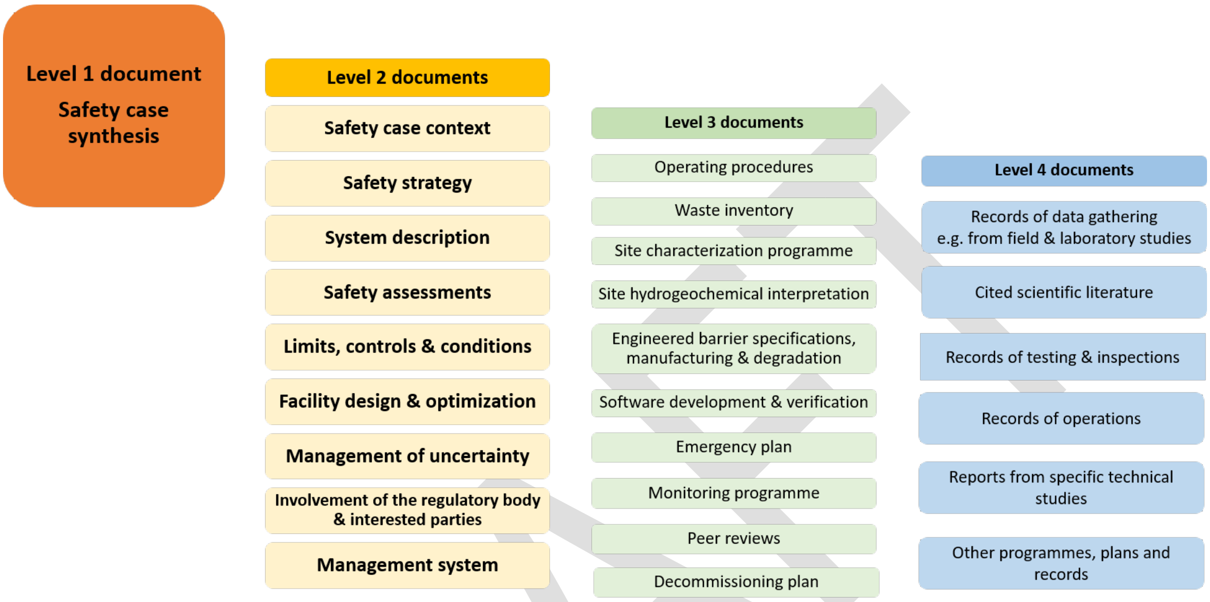

FIG. 6 Possible hierarchy of documents comprising a safety case.

5.53. Safety cases for near surface or geological disposal facility are typically developed gradually over a period of several years or more throughout the step by step facility development process. In contrast, the potentially short period between construction and closure at a small 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 of construction.

5.54. 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 all safety case documentation should be consistent in terms of the main conclusions and messages presented.

5.55. The operating organization should include in the safety case documentation a ‘Level 1’ synthesis, or executive summary, 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 and officials within government and members of the public. Such a ‘high-level’ document should convey the main messages from the safety case (e.g. that the disposal facility is safe and will be safely managed during operations and will remain safe in the long-term).

5.56. The operating organization should support the Level 1 synthesis by developing more detailed, 'Level 2', documents as necessary and appropriate to the facility and the decision-making step in question. The Level 2 documents supporting the synthesis should address the main components of the safety case, as illustrated in Fig. 3.

5.57. The operating organization should provide yet more detailed, 'Level 3', documents as appropriate that record various studies, work and peer reviews conducted during safety case and facility development, operation, closure and institutional control, such as reports on the waste inventory, from engineered barrier studies, from hydrological and geochemical interpretation work, reports on software development and verification, plans for monitoring, plans relating to emergencies and for decommissioning and, where relevant, studies on options for remedial actions at existing facilities.

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

5.59. The regulatory body should provide guidance on the expectations of the safety case documentation, including as appropriate the scope, contents and level of detail of the documents, and on arrangements for the provision of information.

5.60. When documenting the safety case, the operating organization should ensure that:

(a) The documents provide a complete record of (i) the decisions and assumptions made in the development, operation, closure and institutional control of the disposal facility and (ii) the models and data used in the safety assessments;

(b) Information is presented in a traceable way so that that independent suitably qualified and experienced personnel could go back to the original sources of information supporting the various elements of the safety case and understand how these elements have been used in the safety case and could, if necessary, reproduce the safety assessments;

(c) The reasoning for decisions taken (e.g. regarding the siting, design and operation of the facility) is recorded and is logical and clear. The operating organization should document reasons for and against alternative options, and should explain why one option was chosen over another.

5.61. 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. over 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.

5.62. In accordance with the graded approach, the length and the depth 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 that, on the basis of verified data and information, assessed potential doses and risks are orders of magnitude below the relevant dose and risk criteria, this should increase confidence and allow the safety case to be simplified. How simple the safety case can be may depend on various factors (e.g. national and local circumstances, regulatory requirements, the audiences for the safety case), and be a matter of judgement that should benefit from dialogue between the operating organization, the regulatory body and other interested parties.

6. APPROACH TO THE DEVELOPMENT OF A BOREHOLE DISPOSAL FACILITY

6.1. The operating organization should establish and implement a management system (see paras 7.38 to 7.40).

6.2. Before operations commences, the operating organization should determine the needs for human resources in terms of numbers, responsibilities and expertise, and proceed to recruit and train sufficient suitably qualified and experienced personnel to perform the operations. The operating organization's training programme should cover all activities that are significant for safety and should provide the knowledge and practical experience necessary for conducting the activities safely. The operating organization and the training programme should foster the development of a safety culture – GSG-16 [25]. The training should provide staff with a high degree of awareness of the design features of the borehole disposal facility that are significant for safety. 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; radiological protection, handling of radioactive sources and waste, waste conditioning (including cement and concrete technologies, and welding), waste transport, borehole construction, casing and backfilling, borehole sealing, safety assessment and safety case development.

PREDISPOSAL MANAGEMENT OF RADIOACTIVE WASTE FOR BOREHOLE DISPOSAL

6.3. The operating organization should conduct predisposal management activities in accordance with the guidance and recommendations contained in GSR Part 5 [3] WS-G-6.1 [19] and SSG-45 [20]. This section provides further specific guidance on the predisposal management of radioactive waste, as identified in para. 1.1, intended for disposal in narrow diameter boreholes as described in paras 2.12 to 2.18.

6.4. Requirement 6 of GSR Part 5 [3] states:

> **"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".**

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

6.6. In cases where disused sealed radioactive sources ultimately intended for disposal are located at many locations across a State (e.g. at user's sites), the Government should ensure that:

(a) Short-term storage of a disused source always occurs in safe and secure conditions, with proper authorization and periodic inspections – Ref. [7];

(b) Short-term storage occurs in a manner that does not preclude future management options – Ref. [7];

(c) The regulatory body sets an appropriate time limit for short-term storage of a disused source, contingent upon availability of other management options – Ref. [7];

(d) Consideration is given to centralized storage - see WS-G-6.1 [19] and SSG-45 [20][15].

6.7. 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. In cases where it is not appropriate to process the waste for disposal at a centralized facility, 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.

6.8. The operating organization is required to implement a radiological 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 to 28. Guidance on occupational protection is provided in IAEA Safety Standards Series No. GSG-7, Occupational Radiation Protection [50]. The radiological 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 radiological protection programme – GSG-16 [25].

6.9. The operating organization should determine the need for personnel in terms of numbers, responsibilities and expertise, and proceed to recruit and train suitably qualified and experienced persons to perform the operations. The operating organization's training programme should cover all activities that are significant for safety and should provide the knowledge and practical experience necessary for conducting the activities safely. The operating organization and the training programme

[15] Para 5.3 of WS-G-6.1 states: "The storage of waste in centralized facilities rather than in a multitude of on-site facilities should be considered, since there will be opportunities to adopt more stringent safety standards and at the same time to realize economies of scale." Para. 4.80 of SSG-45 states: "In instances where the operator has neither adequate storage facilities nor facilities or expertise for the conditioning of spent and disused sealed sources by encapsulation, arrangements should be made to transfer the sources to another licensed operator with proper and adequate facilities (e.g. a centralized conditioning or storage facility). A centralized facility should be established for the safe long term storage of disused sealed radioactive sources containing ^{226}Ra, ^{241}Am and other long lived radionuclides."

should foster the development of a safety culture – GSG-16 [25]. The training should provide staff with a high degree of awareness of the design features of the facilities and activities that are significant for safety. The training programme should be updated in the light of experience and staff should be retrained as necessary.

6.10. In accordance with the management system, the operating organization should establish a set of written procedures to ensure that facilities are operated and activities are conducted safely in compliance with the conditions of authorization and consistent with the safety case – GSG-16 [25]. In addition to operating procedures for normal operations, the operating organization should establish written procedures for the detection of unexpected events and accidents and for the mitigation of their consequences. Procedures for the protection of workers during the use of the Mobile Hot Cell described in Ref. [22] for the conditioning and disposal of disused sealed radioactive sources in a borehole disposal facility are described in Refs [40] and [41] and in Ref. [22]. Operating procedures ensuring the protection of workers during the use of the Mobile Tool Kit Facility described in Ref. [23] are summarised in Ref. [47].

6.11. Waste and waste packages resulting from waste conditioning should be transported to the disposal site for disposal in accordance with the requirements in SSR-6 (Rev.1) [11].

6.12. Long-term storage requires ongoing regulatory control and associated resources, which cannot be ensured indefinitely – Ref. [7]. Where disposal facilities are available, disused sources should be processed and disposed of rather than stored in a long-term storage facility.

6.13. 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 in such devices include depleted uranium, tungsten and lead. Disused sealed radioactive sources are also often stored in transport containers (e.g. “lead bombs”). Experience has shown that disused sealed radioactive sources can become difficult or impossible to remove from device shields (e.g. due to corrosion) if they are kept or stored for too long under inappropriate conditions. Working 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 stainless steel capsules.

(a) Where 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 – see Ref. [51]. IAEA Standard Source Conditioning Capsules containing the sources should be stored inside storage containers that provide appropriate shielding to protect workers. For some Category 2 sources and all Category 3, 4 and 5 sources – see RS-G-1.9 [21] – , shielding with 100 mm of lead should be sufficient. For Category 1 and some Category 2 sources, it will be necessary to provide greater amounts of shielding;

(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 and placed and sealed inside a disposal container comprising a stainless steel outer with a cement-based insert as described in paras 2.14 and 2.15. Other containers and packaging may be appropriate, but in all cases the operating organization should justify in the safety case the use and performance of alternative barriers and materials.

6.14. 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 to be disposed of. Such waste might include small volumes[16] of contaminated materials (e.g. that might be generated during 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.

6.15. The operating organization is required to decommission predisposal waste management facilities in accordance with the requirements of GSR Part 6 [26]. 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 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. 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 timeframe for decommissioning; and financing for the completion of decommissioning.

SITE CHARACTERIZATION FOR A BOREHOLE DISPOSAL FACILITY

6.16. 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**

[16] At a small borehole disposal facility, the total volume of this waste should be less than ~1 m^3; small enough that it could be disposed of in the borehole within just a few disposal containers. This option to dispose in a borehole disposal facility of waste generated during the management of the disused sealed radioactive sources to be disposed of provides flexibility to a State having only a small inventory of disused sealed radioactive sources, to dispose of all of its waste in a single disposal campaign and, thereby, avoid leaving the State with a potential legacy comprising a small amount of waste with no disposal route.

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".

6.17. The operating organization should document and implement a programme of site characterization work to gain sufficient understanding of the geomorphology, geology, hydrogeology, hydrology, geochemistry, climate, weather and ecology at and around the site. The operating organization should document and implement a programme of work to gain sufficient understanding of land use and human populations and behaviour at and around the site and how this affects 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 and implement these site characterization programmes in parallel with (to run at the same time as) the programme for the development of the safety case and the conduct of safety assessments (see Section 5).

6.18. The operating organization should use the results from the site characterization programmes to inform the development of the safety case and the safety assessments. The operating organization should use results from 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 other site-specific data and information for additional 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.

6.19. The operating organization should apply a graded approach when establishing site characterization programmes to support the development, 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 small borehole disposal facility of the type considered in the generic safety assessment, Ref. [17] is a relatively small-scale facility when compared to typical near surface or geological disposal facilities and is expected to provide a safe disposal solution under a wide range of site conditions. Ref. [18] 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 Appendix I).

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

(a) The geology and geological evolution of the area. This 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 and 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 should involve various studies to map and quantify the geomorphology and to investigate the potential for past, present-day and potential future erosive processes and land movements (e.g. landslips, faults, earthquakes, volcanism);

(c) The hydrogeological conditions of the disposal system and their evolution. This should involve various studies to establish 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 (i.e. the interface between the unsaturated zone and the saturated zone), the piezometric surface, and results from tests to determine hydraulic parameters (e.g. hydraulic head gradient, permeability, porosity, saturation);

(d) The hydrological conditions of surface water bodies in the area and their evolution. This 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 events and flooding);

(e) The geochemistry of the disposal system and its evolution. This should involve various studies to identify the mineralogy and quantify geochemistry of the rocks and waters in the disposal system. Particular attention should be focused on determining the chemical composition of groundwaters and their oxidation and reduction (redox) potentials and speciation as these parameters can strongly affect the mobility of radionuclides;

(f) The meteorological conditions at present and its evolution, including the possible effects of future climate states on landform development and site conditions (see e.g. Ref. [52]);

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

(h) Human populations and behaviours at and around the site. This should involve the studies to collect data on the size, locations and density of human populations and on human activities including land uses (e.g. agriculture) and on human behaviours (e.g. food consumption rates and sources of drinking water) that would be needed for dose assessments for past, present and potential future conditions.

6.21. The operating organization should use information gathered from these programmes and studies to develop a credible scientific description of the natural system at the site, and demonstrate understanding of the safety-significant features events and processes and 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 in evaluating the performance of a disposal facility at the site.

6.22. The operating organization should use site characterization information to help demonstrate a sufficient understanding of the potential effects of natural events and processes on the isolation of waste and containment of radionuclides provided by the borehole disposal facility. The operating organization should include in this demonstration assessments of the probability of occurrence and potential effects on the borehole disposal system of disruptive events and processes. The operating organization should use this understanding together with the site characterization data as part of the basis for the safety case and safety assessments[17]. The operating organization should use this understanding to select and establish the location and design of the borehole disposal facility including, in particular, the depths of the disposal borehole(s) and the depths of the disposal zone(s).

6.23. The operating organization should conduct site characterization work in accordance with an appropriate management system (see paras 7.38 to 7.40 and GSG-16 [25]). The management system should include a process and procedures for dealing with spatially distributed information and time-series data from site characterization and to support the establishment of a baseline for monitoring. The operating organization should use the management system to control the work of suppliers undertaking site characterization activities – see GSG-16 [25].

DESIGN OF A BOREHOLE DISPOSAL FACILITY

6.24. 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."**

6.25. 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 waste). A reference design for a borehole disposal facility for such waste has been described and assessed on a generic basis in Ref. [17]. Site-specific designs for this type of borehole disposal facility for disused sealed radioactive sources have been developed and assessed for implementation in some States – see Refs [45] and [46].

[17] In addition to describing the present-day characteristics of a site, the operator 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.

6.26. 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, results from site characterization, results from safety assessment, and arguments in the safety case for the facility. The operating organization should develop and refine the design for the disposal facility in parallel with (at the same time as) the programme for the development of the safety case and the conduct of safety assessments (see Section 5). The operating organization should use results from the design work to inform the development of the safety case and the safety assessments.

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

(a) The inventory of waste (waste types, quantities, physical and chemical properties, radionuclides present) to be disposed of;

(b) The number of boreholes, borehole dimensions (e.g. diameter and depth) and the suitability of geological conditions at the site (e.g. geological stability, groundwater flow, and the chemical compatibility of the rocks and groundwaters with the engineered barriers);

(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.

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. In developing the design of a borehole disposal facility, the operating organization should consider using the IAEA Source Inventory Management for Borehole Disposal (SIMBOD) software – Ref. [37] to determine the total inventory of radionuclides, the distribution of Category 1 to Category 5 disused sealed radioactive sources within the total inventory, how many waste packages would be required, the length of disposal zone(s) within the borehole(s) that would be required, and the number of boreholes that would be required for the waste.

Disposal boreholes

6.29. 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. The operating organization should select the depth of the disposal zone(s) to reduce the probability of inadvertent human intrusion and to ensure that the disposal zone(s) is (are) located in suitable rocks (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 the disposal zone(s), 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 will depend 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. The operating organization should consider various options for the design of the disposal facility and should document the justification for the selected design. For example, it could be possible to dispose safely and securely of a certain inventory of waste in either one borehole with a long disposal zone or in two or more boreholes with shorter disposal zones; the operating organization should give reasons for such design choices as part of the demonstration of optimization. The operating organization should assess whether different waste types should be placed in different locations in the disposal facility. The operating organization should assess the interactions that could occur between neighbouring boreholes and should justify the chosen locations for disposal boreholes.

Engineered components

6.30. The operating organization should design a system of engineered barriers that is consistent with plans for predisposal management of the waste, with the design of the disposal borehole(s), and that will contribute to the containment of the radionuclides in the waste.

6.31. The engineered barriers should include a waste package that facilitates waste handling and emplacement operations and that is compatible with geochemical conditions in the host rock and the materials of the other engineered barriers. The engineered barriers should be designed to provide containment of heat generating waste throughout the period while the waste is producing heat energy in amounts that could adversely affect the performance of the disposal system – SSR 5 [4]. The operating organization should consider using more than one containment barrier (e.g. by placing the sources inside a disposal capsule within a disposal container). The operating organization should use appropriate material(s) to fill the spaces that would otherwise exist (e.g. between the disposal capsule and container, between and around disposal containers in the borehole, and 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 development process for the facility because this will affect both the predisposal management of the waste and the disposal operations. The operating organization should address factors such as the amount of shielding provided by the waste package (as this may affect the need to handle the waste package 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 (this will influence operational feasibility and safety). The operating organization should 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.

6.32. The operating organization should design engineered barriers that will be used to seal boreholes and close the borehole disposal facility. Borehole seals could, for example, comprise clay or cement-based plugs tens of metres long placed in the borehole above the disposal zone. Such seals or plugs could also be placed at the bottom of the disposal zone).

6.33. The operating organization should consider the need for borehole casing to ensure borehole stability during the operational period, and whether some or all of the casing should be removed after waste disposal. The operating organization should consider the type of backfill material to use at depth and near the surface. The operating organization should consider the inclusion of engineered features to reduce the probability of inadvertent human intrusion (e.g. a deflector plate).

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

Design refinement

6.35. The operating organization should in the safety case and safety assessments examine alternative design options to:

(a) Assess whether the designs have the potential to fulfil the relevant dose and risk criteria;

(b) Evaluate the performance of the disposal system and its components;

(c) Inform decisions on the design and optimization.

6.36. The operating organization should consider a range of factors (including safety, security and socio-economic factors) in coming to 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 required level of engineered containment and for how operations should be carried out, and these aspects could have cost and man-power implications.

CONSTRUCTION OF A BOREHOLE DISPOSAL FACILITY

6.37. 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.”

6.38. The operating organization is required to construct the disposal facility in accordance with the disposal facility design presented and assessed in the safety case and approved by the regulatory body, and in accordance with a valid authorization. As part of the safety case, the operating organization should develop a written construction method and associated technical specifications and procedures.

6.39. To support a decision on authorization, 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 would be capable of delivering the proposed design (e.g. in terms of borehole dimensions, borehole straightness, ability to provide suitably dry conditions for waste emplacement, methods for emplacement and removal of casing, 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, unexpected failure of a borehole wall.

6.40. The operating organization should document and implement a programme of testing and inspection work to confirm and demonstrate that construction of the facility is in accordance with the design, the construction method, and associated technical specifications and procedures, and that any features revealed during construction are consistent with the safety case.

6.41. The operating organization should ensure that borehole construction is carried out by suitably qualified and experienced personnel following the construction method, technical specifications and associated procedures – Ref. GSG-16 [25]. 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 activities to be performed. The construction method, technical specifications and procedures should be based on safe and successful prior practice and should be updated as further experience is gained.

6.42. The operating organization should ensure that the construction method is sufficiently flexible for dealing with spatially variable rock conditions. The operating organization should monitor rock conditions during drilling 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 means either for remediating marginally unsuitable boreholes or sealing such boreholes without emplacing any 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).

6.43. The operating organization should specify in the construction method 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 and isolate the aquifer from the waste and avoid the creation of pathways between different strata.

6.44. 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 other relatively transmissive geological strata. The operating organization should aim to ensure that the permeability of the backfilled borehole and any disturbed rock around it are no worse than that of the surrounding intact rocks.

6.45. The operating organization should specify in the construction method means for installing any borehole casing to be used and, as appropriate, for the removal of borehole casing.

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

6.47. The operating organization should make and retain records of borehole construction to provide a complete description of the history of construction, including when, how and by whom the borehole(s) was (were) constructed and its (their) depth(s) and diameter(s), the geological formations encountered, the rate of drilling, whether water was encountered and any occurrences of unexpected events and accidents and non-compliances with construction procedures.

COMMISSIONING OF A BOREHOLE DISPOSAL FACILITY

6.48. Before a borehole disposal facility can start to operate, the operating organization should perform appropriate commissioning activities. Before waste emplacement, 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 in place the engineered barriers. The operating organization should during commissioning and after the emplacement of each waste package 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 done by lowering and then retrieving a non-radioactive, ‘dummy’ waste package down the borehole. The operating organization should include an appropriate programme of commissioning tests to verify that the backfill materials as prepared on site have appropriate characteristics (e.g. water content, density, grain size, rheology, setting time).

6.49. 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."**

6.50. The operating organization is required to operate the disposal facility in accordance with a valid authorization and the safety case approved by the regulatory body; the operating organization's management system should be compatible with the authorization and safety case and should include written operating procedures.

6.51. At a borehole disposal facility, the operational period should commence after appropriate commissioning activities. Disposal operations include waste receipt and checking that the waste is consistent with the waste acceptance criteria, waste emplacement (including the emplacement of backfill between waste packages), and backfilling and sealing the borehole. Predisposal management operations (including temporary storage of waste and waste conditioning) may be performed immediately before waste emplacement (e.g. using a mobile hot cell such as the one described in Ref. [22] or the Mobile Tool Kit Facility described in Ref. [23]). Decommissioning and closure are addressed in paras 6.79 to 6.83.

6.52. The operating organization should describe in the safety case how the 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 and accidents).

6.53. The regulatory body should review and assess the safety case and inspect the operations to satisfy itself that:

(a) The operating organization is applying its management system to ensure safe operation of the disposal facility;

(b) The operations do not compromise safety functions on which the post-closure safety of the facility depends;

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

Radiological protection programme

6.54. The operating organization is required to implement a radiological protection programme throughout the operation of a borehole disposal facility – see GSR Part 3 [2] - see in particular Requirements 19 to 28. The radiological protection programme is an essential part of the safety case and, as such, is subject to regulatory approval. Guidance on occupational protection that should be applied at disposal facilities is provided in GSG-7 [50]. The operating organization should use suitably qualified and experienced personnel to implement the radiological protection programme – GSG-16 [25].

Operating procedures

6.55. In accordance with the management system, the operating organization should prepare a set of written procedures to ensure that the facility is operated safely and in compliance with the conditions of the authorization and the safety case – GSG-16 [25]. The operating procedures should be derived from the technical specifications for the operations which, in turn, should be consistent with the operational safety assessment. In addition to operating procedures for normal operations, the operating organization should establish written procedures for the detection of unexpected events and accidents (e.g. receipt of waste that does not conform to the waste acceptance criteria, jamming of waste packages in boreholes) and for the mitigation of consequences. The operating procedures should specify when reports should be made to the regulatory body. The operating organization should train personnel in the use of the procedures.

6.56. The operating organization should verify that work is done according to the 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; the operating organization should demonstrate this through appropriate programmes of inspection, auditing and record-keeping.

6.57. The operating organization should apply formal change control procedures to proposals for changes or modifications to operating procedures or equipment and should ensure that the implications of such changes or modifications for safety are assessed, understood and taken account of.

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 is required to operate a borehole disposal facility in accordance with the limits, controls and conditions specified in the authorization. Waste acceptance criteria are required as a key component of the 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 amounts 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 that the waste package have to fulfil. The operating organization should subject proposals or requests (e.g. from waste generators) for changes to the waste packages to a change control process that includes a safety review by the operating organization and, as appropriate, regulatory scrutiny.

6.61. When designing a waste package for borehole disposal, the operating organization should consider all of the activities to be performed during the predisposal management and disposal of the waste, and should take account of the conditions that could occur throughout the predisposal management and disposal operations and after waste disposal. As an illustration, limits included in the waste acceptance criteria on the activity of gamma emitters that may be put in a waste package will probably be determined by consideration of predisposal management or operational safety (related to issues such as waste package surface dose rates). The corresponding limits for the activity of alpha emitters that can be put in a waste package, will probably be determined by consideration of issues related to post-closure safety.

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 waste forms;

(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) Specifications regarding any waste types that may be accepted in unpackaged form;

(d) Limits on the weight and size of waste packages;

(e) Limits on the levels of surface contamination on a waste package;

(f) Specifications for waste disposal containers (e.g. acceptable materials, manufacturing and welding methods, testing protocols);

(g) Specifications for backfill materials (e.g. acceptable materials, backfilling methods, testing protocols);

(h) A limit on the heat (thermal) output of a waste package;

(i) Limits to prevent the release of gases from waste packages;

(j) 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;

(k) Limits on the radionuclide content of each waste package, of each borehole and of the entire disposal facility;

(l) Controls on the mixing of different types of disused sealed radioactive sources and or radionuclides within disposal packages;

(m) Controls on the location (e.g. depth, spacing) of the emplacement of certain waste packages within disposal boreholes;

(n) Limits on the fissile nuclide content of each waste package, of each borehole and of the entire disposal facility.

6.63. Experience from considering the reference borehole disposal system assessed in Ref. [17] for the case of a single disposal borehole, includes the following:

(a) The protection of workers during disposal operations could depend on the type of shielding that is available, and this may in practice limit the activity of strong gamma emitters and neutron sources that can be accepted for processing and disposal;

(b) Post-closure safety could limit the activity of long-lived radionuclides that may 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. This need to limit waste package heat generation may mean that the largest sources that can be accepted have activities of heat generating radionuclides no more than tens of GBq – see Refs [15] and [53].

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. The operating organization is required to keep records of all pre-disposal waste management activities and of waste accepted for disposal in accordance with the management system (see paras 7.38 to 7.40).

6.65. The operating organization should, as far as possible, collate and retain records that provide a detailed description of each disused sealed radioactive sources (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. The operating organization should make appropriate estimates to fill gaps in inventory information, e.g. due to the facts that disused sealed radioactive sources sometimes fall out of regulatory control and are later found as orphan sources, and because disused sealed radioactive sources are often collected from many different users and locations, and may have been stored for considerable periods by persons or organizations other than those that originally used the sources. The operating organization should make use of the national register of radioactive sources – see RS-G-1.9 [21] – to fill gaps in inventory information.

6.66. The regulatory body should ensure that arrangements and procedures are put in place to define and control the actions to be taken by the generator of the waste and by the operating organization of the disposal facility to deal with any waste packages that do not conform with the waste acceptance criteria. The operating organization should inform the regulatory body in a timely manner of waste packages that do not conform with the waste acceptance criteria. Depending on the severity of any non-conformance, the actions to be taken may include remediation of the waste package, repackaging of the waste, and investigation and refinement of the waste package production process.

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) and 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. Pilot studies for the disposal concept described in paras 2.12 to 2.18 have found it more effective, in terms of avoiding the formation of unwanted voids in the disposal zone, to emplace each waste package into a measured amount of wet cement-based backfill that has already been placed in the borehole; this approach necessitates use of a backfill with appropriate rheology and setting time, and operating at a rate that allows for the waste packages to sink into the wet backfill grout and then for the backfill to set before the emplacement of the next waste package. The operating organization should conduct appropriate tests under realistic conditions to demonstrate that the materials and processes to be used to manufacture the backfill provide a mixture with the required properties (e.g. rheology and setting times).

6.68. At a larger scale, the operation of a borehole disposal facility can be performed following 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 (e.g. weeks to a few months). Operating on a campaign basis allows individual disposal boreholes to be constructed, receive waste and be sealed as a discrete project, and, thus, reduces the chances of the borehole remaining open for a long time and degrading or being mismanaged between individual waste emplacement operations. Continuous operation could be appropriate in the case of larger capacity boreholes where operating on a campaign basis would require 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 as necessary borehole casing, a borehole drainage system and a secure cover over the borehole in periods between waste emplacement, backfilling and sealing operations. The operating organization should provide in the safety case a justification for the proposed approach to operating the disposal facility.

6.69. In borehole disposal facilities where different types of waste are to be disposed of, it is sometimes suggested that waste packages containing high-activity or long-lived waste should be placed 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 limit the consequences of inadvertent human intrusion. However, considerable site characterization data and detailed safety assessment modelling might 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, greater assurance regarding the location and management of individual waste packages, and result in a greater total dose to the workforce. In general, therefore, the operating organization should aim for a simple and robust disposal strategy in which any waste package can safely be disposed of 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 disposal strategies should be considered. In all cases, the operating organization should provide in the safety case a justification for the proposed waste disposal strategy.

Backfilling 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 done 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 and gas flow and radionuclide migration. The operating organization should backfill boreholes so that the permeability of the backfilled boreholes is no worse than that of 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 disposal boreholes

6.71. After backfilling of a disposal borehole as described in para. 6.70, the operating organization should seal the disposal borehole; sealing should be done in a timely manner 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 remove any borehole casing from the section(s) of the borehole where the seal(s) is(are) to be placed so that the sealing materials can form a hydraulically tight seal against the surrounding rocks. Disposal boreholes should be sealed to prevent them from acting as pathways for groundwater and gas flow and radionuclide migration. The operating organization should seal boreholes so that the permeability of the sealed boreholes is no worse than that of the surrounding intact rocks.

6.72. The operating organization should specify the technique to be used for borehole sealing taking account of the size of the borehole, whether the borehole is cased or not, and the geology. In the case of narrow-diameter boreholes, standard borehole sealing techniques will probably be appropriate.

6.73. The operating organization should specify how the very top of the borehole is to be closed. Unless there are good reasons not to do so, the operating organization should fill the top two metres of the borehole with native soil so that the precise position of the borehole cannot be determined without specialist equipment.

Inspection and review

6.74. Safe operation should be achieved through the application of recognized technical and managerial principles – GSG-16 [25]. 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 for review.

6.75. The regulatory body should conduct independent audits, inspections and reviews of any or all of the disposal operations to satisfy itself that appropriate management controls are being applied and appropriate technical work is being undertaken. The operating organization should when necessary 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 (para. 5.64 of GSG-16 [25]):

(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 radionuclide(s) 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 and instruments used to describe and characterize the waste.

6.77. Records should also be created and retained to describe the history of radioactive waste management facilities, such as data obtained during facility design, construction, commissioning, operation and closure. These records include the following, as appropriate (para. 5.66 of GSG-16 [25]):

(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 made 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, taking account of the graded approach. Further information on records and their maintenance and preservation is provided in GSG-16 [25].

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 any surface facilities at a borehole disposal facility have been decommissioned (see para. 6.15) and all boreholes used for waste emplacement have been backfilled and sealed, the operating organization should close the disposal facility. The operating organization should close the facility in accordance with the plan for facility closure included in the safety case that has been approved by the regulatory body.

6.81. To gain regulatory approval for 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. 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 the site to a new organization after closure should be legal 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

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 – Ref. [5]. The safety of a disposal facility is required to be provided by passive means to the fullest extent possible and must not depend on monitoring – SSR-5 [4]; monitoring should be for the assurance of safety.

7.3. Guidance on monitoring of near surface and geological disposal facilities (and disposal facilities for waste from mining and mineral processing) is provided in SSG-31 [36]. Monitoring programmes at borehole disposal facilities developed, as recommended, with disposal zones at depths greater than 100 m should have many characteristics that are similar to those for monitoring programmes at geological disposal facilities.

7.4. The operating organization should document and implement a programme of monitoring. The operating organization should document the justification for the monitoring programme, including its objectives and scope.

7.5. The objectives of the operating organization’s monitoring programme should:

(a) Be in accordance with applicable laws and regulatory requirements;

(b) Be appropriate to the periods in facility development, 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 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.

7.6. The scope of the operating organization’s monitoring programme should reflect the graded approach and be commensurate with the hazard and the level of risk associated with the waste. The operating organization should justify which parameters are to be monitored, how and where this is to be done, at what frequency and for which duration. 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, water levels, flows and compositions, 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 small borehole disposal facility, particularly one for waste containing short-lived radionuclides that are expected to decay substantially while in the waste containers, the extent of the monitoring programme could be quite limited, both in its spatial extent and duration.

7.7. The monitoring programme should form part of the safety case. Monitoring should commence before a disposal facility becomes operational, SSR-5 [4] e.g. during site characterization. As part of site characterization, the monitoring programme should establish a baseline of environmental conditions (e.g. groundwater levels) against which subsequent measurements and changes (such as might occur due to drilling) can be compared and assessed. As the disposal programme moves from one period to the next, the operating organization should update the objectives of the monitoring programme and the monitoring activities.

7.8. It is a requirement that monitoring programmes shall be designed and implemented so as not to reduce the overall level of safety of the facility after closure SSR-5 [4]. The operating organization should seal monitoring and other boreholes at or near the site that could reduce the safety of the facility before commissioning the disposal facility; sealing should be done in a timely manner and in accordance with the authorization and the safety case. Monitoring (and other) boreholes at or near the site that could reduce the safety of the facility should be sealed to prevent them from acting as pathways for groundwater and gas flow and radionuclide migration. The operating organization should seal monitoring (and other) boreholes at or near the site that could reduce the safety of the facility so that the permeability of the sealed boreholes is no worse than that of the surrounding intact rocks.

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

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

7.11. The operating organization should include in the monitoring programme an approach for responding to unexpected monitoring results. Unexpected monitoring results do not necessarily imply that remedial actions or protective measures are necessary – SSG-31 [36]. The response may vary from no action at all to increased sampling frequency for identifying or confirming spatial and temporal trends, through to changes in design or procedures, all the way to significant remedial action or even 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 risks associated with the remedial action – SSG-31 [36].

7.12. 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

7.13. 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."**

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

7.15. Active institutional controls include:

(a) Operating the site and the facility in accordance with the authorization;

(b) Maintaining signs, fences and guards at the authorized site, for example, to prevent unauthorized access and unintended radiation exposures;

(c) Providing nuclear security;

(d) Undertaking monitoring and surveillance activities;

(e) Performing any remedial work that may become necessary.

7.16. Passive institutional controls include:

(a) Archiving of records of the disposal facility;

(b) Controls on land ownership;

(c) Restrictions on land use.

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

7.18. The duration of the active institutional control period should be established through 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 based on the safety case. The operating organization should use the safety case to take account of the specific characteristics of the site and the hazard posed by the waste now and in the future (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 disposal facility closure or it could occur at a later date. The plan for the timing of the change from active to passive institutional control should be reviewed periodically during the active institutional control period and should be approved by the regulatory body.

7.19. The safety of borehole disposal facilities in which waste has been disposed of at depths greater than 100 m should not depend on active institutional controls and, depending on the safety case, quite short periods of post-closure active institutional control could 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.

7.20. Depending on national laws and regulations, the institutional control period assumed for the purpose of safety assessment calculations could be as long as a few hundred years (e.g. 100 to 300 years). This is not to say that institutional control would necessarily be needed at a site, or that if needed and implemented it would necessarily be effective for as long as this, or indeed that it would necessarily cease after this period. Rather, a few hundred years is the maximum period an operating organization should claim in the safety case. Greater resources will be needed to maintain active institutional controls for longer periods.

7.21. 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, the disposal facility might be transferred to the regulatory body, or to the Government, or the site might be completely released from control by any institution or organization. Before the site is transferred or released, the operating organization should archive appropriate information related to the disposal facility. The arrangements for archiving of records should be designed to maintain knowledge of the facility's location and characteristics within societal institutions. Information that should be archived for a borehole disposal facility should include 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 6.16 to 6.23 and Appendix I);

(c) Details of the design of the facility, including descriptions of the borehole(s) and the associated engineered structures systems and components (e.g. borehole backfill, casing and seals) (see paras 6.24 to 6.27) and descriptions of the waste packages and the waste, including the origins of the waste, the radionuclides present and their amounts, and the cement-based insert and disposal capsules used, and the depths of 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 actions taken to rectify them (see paras 6.37 to 6.47);

(e) The facility safety case including a description of the arrangements for the post-closure period and the monitoring programme and monitoring results (paras 7.1 to 7.12);

(f) Authorizations (permits and licenses) issued by the regulatory body.

7.22. The operating organization should make arrangements for the information to be retained for as long as possible, and in doing so should consider making use of national archives.

ACCOUNTING FOR, AND CONTROL OF, NUCLEAR MATERIAL

7.23. 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."**

7.24. Systems for 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 terms. The Government should facilitate the effective implementation of for accounting for and control of nuclear material in a manner that does not compromise safety.

7.25. The borehole disposal facilities that are within the scope of this safety guide should only receive 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 for accounting and control of nuclear material. Some disused sealed radioactive sources contain fissile nuclides but do not fall within the system for accounting and control of nuclear material because the content of fissile radionuclides is low. Some disused sealed radioactive sources are contained in depleted uranium shields and this is usually present in sufficient quantities that safeguards apply.

7.26. Where nuclear material accountancy and control requirements need to be applied, they should be considered at an early stage in the design of a disposal facility.

7.27. Where IAEA nuclear safeguards requirements apply, they will apply for all three periods of development, operation, closure and institutional control of a borehole disposal facility (see para. 2.21). During the pre-operational period and during operation of a borehole disposal facility for waste that includes nuclear material, surveillance for the purposes of IAEA safeguards is aimed at ensuring the continuity of knowledge concerning the material and the absence of any undeclared activities at the site in relation to such material. As presently organized, IAEA systems for accounting and control of nuclear material, or safeguards, rely on active surveillance and controls.

7.28. Where nuclear material accountancy and control measures are required for a closed borehole disposal facility, then intrusive methods have to be avoided and safeguards should be applied by remote means (e.g. satellite monitoring, aerial photography, micro-seismic surveillance and administrative arrangements).

7.29. Physical protection measures may also have to be taken for nuclear material and nuclear facilities, and are addressed in IAEA Nuclear Security Series No. 13, Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities [54].

MANAGING INTERFACES BETWEEN SAFETY AND SECURITY

7.30. 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."**

7.31. The government should adopt a graded approach to safety and security in the management of disused sealed radioactive sources – Ref. [7]. Organizations with responsibilities for safety and security of radioactive sources should promote appropriate safety culture and nuclear security culture – see Refs [7], [24] and IAEA Nuclear Security Series No. 7, Nuclear Security Culture [55].

7.32. 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 located, designed, constructed, operated, and decommissioned or closed, as appropriate, in conformance with regulatory requirements for safety and security – Ref. [7].

7.33. The regulatory body should specify safety and nuclear security requirements for long-term storage and disposal of disused sources – Ref. [7]. 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 – para. 2.40 of GSR Part 1 (Rev. 1) [28].

7.34. Nuclear security recommendations on radioactive material and associated facilities, are provided in IAEA Nuclear Security Series No. 14 [56]. Guidance on the security of radioactive sources is provided in IAEA Nuclear Security Series No. 11-G (Rev. 1) [57]. 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 – Ref. [57]. 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 the completion of 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 – Ref. [57].

7.35. Borehole disposal of disused sealed radioactive sources in accordance with the recommendation provided in this Safety Guide should result in radioactive waste being permanently disposed of at depths greater than 100 m beneath the surface; a result that provides for both safety and nuclear security. Where the waste in a borehole disposal facility is disposed of at a depth of more than 100 m, a site security presence will be required for as long as the borehole remains open. On sealing of the boreholes and closure of the facility and site, the competent authority may consider removal of security measures in relation to the disposal site in accordance with a risk informed graded approach.

7.36. In general, waste that constitutes a significant nuclear security risk may need special security consideration and further regulatory authorization. For example, a single source containing a large amount of Cs-137 could still be quite small and would constitute a security risk if taken for malicious purposes. If such waste were disposed of near surface, the proximity of the waste to the surface could make it necessary for nuclear security measures to be continued to prevent human intrusion and unauthorized removal of the waste. The nuclear security measures would need to remain in place until the waste no longer constituted a potential nuclear security risk or hazard and would be a form of active institutional control. To fulfil the requirement for safety to be provided by passive means, safety cannot rely on the indefinite maintenance of active institutional controls.

7.37. Where a borehole disposal facility is to be located at an existing nuclear site, the prevailing nuclear security measures should consider the new activities in the site security plan.

MANAGEMENT SYSTEMS

7.38. Requirement 25 of SSR-5 [4] states:

> **"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."**

7.39. General requirements for the management system are established in GSR Part 2 [24] and recommendations on how to fulfil the requirements during the predisposal management and disposal of radioactive waste are provided in IAEA Safety Standards Series No. GSG-16 [25]. 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 – GSG-16 [25]. 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 culture for safety. The Appendix to GSG-16 [25] provides a list of elements of the management system for organizations involved in the management of radioactive waste or its regulatory oversight. The management system 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, its role and situation, and be applied according to the graded approach.

7.40. The regulatory body should review the operating organization's management system and audit its application to activities related to the predisposal management and disposal of radioactive waste. In the case of the borehole disposal system described in Section 2, key areas include:

(a) The adequacy of the collection and interpretation of site characterization data, and their use 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

7.41. Requirements for preparedness and response for a nuclear or radiological emergency are provided in GSR Part 7 [58]. GSR Part 7 [58] applies the graded approach by placing the various types of nuclear facility into categories: nuclear powers stations fall in Category I, research reactors into Category II and some hospitals using powerful sealed radioactive sources are in Category III.

7.42. A borehole disposal facility for disused sealed radioactive sources and low volumes of low level waste and intermediate level waste generated during their management would fall in Category III.

7.43. Para. 4.16 of GSR Part 7 [58] 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".

7.44. Para. 4.17 of GSR Part 7 [58] 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".

7.45. Para. 6.19 of GSR Part 7 [58] 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".

7.46. Para. 6.17 of GSR Part 7 [58] 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".

7.47. 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 [58].

8. EXISTING DISPOSAL FACILITIES

EXISTING 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 this Safety Requirements publication are not met, measures shall be put in place to upgrade the safety of the facility, economic and social factors being taken into account."**

8.2. 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. It is probable that a project to develop a borehole facility would take several years to a decade, and this period may be followed by a period of active institutional control possibly lasting several decades to a few centuries. The operating organization should assess the safety of the facility several times or more during the period of authorization to satisfy the requirement for periodic safety assessment.

8.3. The operating organization should assess the safety of any potentially significant modifications to a borehole facility, such as the addition of an additional disposal borehole to the facility. 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 licencing of a borehole facility and any modification.

8.4. The government should ensure that arrangements are established and implemented for the safety of borehole facilities for which there is no longer an operating organization to be reassessed periodically.

8.5. Standards, procedures and practices change over time and therefore some existing borehole facilities are not consistent with the safety requirements. For examples, see Ref. [59] and Section B.2.1 of Ref. [60]. Specifically, once active institutional control has ceased, exposures at some existing borehole facilities could lead to doses at levels above those at which remedial action should be considered. Inadvertent intrusion at some facilities could lead to annual doses exceeding 20 mSv, or even 100 mSv – a generic reference level above which remedial action to upgrade safety should be considered almost always justifiable (see para 3.26).

8.6. The purposes of reassessing the safety of an existing facility should be:

(a) First, 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 of GSR Part 3 [2] and SSR-5 [4];

(b) Second, if satisfactory protection is not provided, to inform a judgement 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. Any remedial action should be both justified and optimized – see GSR Part 3 [2] and the discussion in Ref. IAEA Safety Standards Series No. GSG-15, Remediation Strategy and Process for Areas Affected by Past Activities or Events [61]. Put succinctly, any remedial action should do more good than harm.

8.8. In the context of borehole facilities, this means that the body responsible for taking such decisions should identify, assess and compare options for remedial actions. When remedial actions have been identified, they should be assessed and compared in order to provide input to a decision on the preferred action (i.e. the remedial action that would do most good).

8.9. Input into decision making should be obtained by comparing the various options on the basis of their radiological and non-radiological impacts on people and the environment and a wide range of socio-economic factors. Feasibility studies and demonstrations may support the decision-making process. Because of the wide range of issues that need to be considered, interested parties (e.g. the local community) should be involved in identifying, assessing and making comparisons of potential remedial actions.

APPENDIX I. SITING AND SITE CHARACTERIZATION FOR BOREHOLE DISPOSAL FACILITIES

Siting of borehole disposal facilities

I.1. The Government is responsible for defining the overall process for the development, operation, closure and institutional control of borehole disposal facilities, including siting – Requirement 1 of SSR-5 [4]. In accordance with applicable laws and regulatory requirements, the Government should ensure that interested parties are involved at appropriate stages in decision-making for radioactive waste management facilities and activities, including borehole disposal facilities – para. 3.7 of SSR-5 [4]. The operating organization is required to carry out all the necessary activities for site selection and evaluation – Requirement 3 of SSR-5 [4]. In addition to reviewing the safety case, the regulatory body should consider whether a site is suitable as part of its review and assessment processes – GSG-13 [30].

I.2. When selecting a site for a disposal facility, the recommended approach is to select a site at which a safe facility can be developed rather than, for example, trying to identify a conceptual 'best' or 'safest' site.

I.3. Safety (i.e. protection of humans and the environment from undue radiation risks – Safety Glossary [5]) 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 disposal facility at several candidate sites, the operating organization should consider a range of other factors when selecting between the possible sites.

Safety related factors

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

(a) The geomorphology and geomorphological evolution of the site and the surrounding area, and processes and events that might affect facility operations. The site should be geomorphologically stable; this is generally consistent with there being an absence of features such as mountainous terrane with steep gradients or areas with active subsidence. Processes and events that might affect facility operations also include landslip and flooding and necessitate consideration of climate and extreme weather;

(b) The geology and geological evolution of the site and the surrounding area. The site should be geologically stable. Geological stability should be evaluated based on evidence of relevant events and processes (e.g. recent or historic tectonic events and processes, faulting and seismicity, soil liquefaction, volcanism). Geological stability is generally consistent with there being an absence of e.g. capable faults, diapirs, salt domes and volcanoes. The geology of the site should include strata or horizons with characteristics that are suitable to be used as disposal zones and which have sufficient thicknesses to accommodate the waste and separate the disposed waste from any overlying or underlying zones with greater permeability;

(c) The hydrological and hydrogeological conditions at the site and in the surrounding area and their evolution. Information with which to evaluate hydrological and hydrogeological conditions should include but not necessarily be limited to rock permeability, 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 other rock types with high permeability (e.g. karst). The generic safety assessment – Ref. [17] 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 (for more information see 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;

(d) The geochemistry of the site and the surrounding area and its evolution. Information with which to evaluate geochemical conditions should include but not necessarily be limited to rock types and mineralogy, rock and groundwater compositions and ages. Characteristics that tend to be favourable for siting a borehole disposal facility include the presence of old groundwaters, which would tend to indicate low groundwater flows in the past, and groundwaters whose geochemistry is and would be generally unreactive towards the rocks present and to the materials of the engineered barrier system. It should not necessarily be assumed, however, that it would not be possible to develop a safe disposal facility at sites with other characteristics, such as the presence of saline groundwaters; this should be tested through safety assessment;

(e) Geological setting. 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. The operating organization should site borehole disposal facilities away from areas where such events and processes might occur (e.g. sites with resources including minerals, oil, gas, geothermal and water resources) in order to reduce the probability of inadvertent human intrusion.

I.5. The recommended concept for disposal of disused sealed radioactive sources in narrow boreholes has been assessed as being potentially safe to implement in a wide range of geological and climatic conditions – see Ref. [17]; the expectation is therefore that, 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 should allow safety to be demonstrated more simply and with fewer resources than would otherwise be the case, and should be more convincing and acceptable to interested parties.

Other factors

I.7. The operating organization should give due consideration to other (e.g. scientific, technical and socio-economic) factors including; nuclear security, the views of interested parties, protection of humans and the environment from non-radiological risks (including the possible contamination of groundwater resources), the availability of information, costs, land ownership, infrastructure needs (e.g. site accessibility and the 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 would provide an existing nuclear security 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 process are clear, logical and justified.

I.9. IAEA guidance on the siting of near surface disposal facilities (Appendix I of Ref. SSG-29 [8]) suggests the adoption of 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 socio-economic suitability or unsuitability (screening) criteria to yield a shortlist of potential siting areas. Once potential siting areas have been located, the operating organization should conduct more detailed investigations to identify potentially suitable disposal sites within the potential siting areas. The operating organization should as part of the siting process consider whether there are existing sites within the potential siting areas such as nuclear facilities, including radioactive waste storage facilities and disposal facilities, and government-owned land that might be suitable for a borehole disposal facility.

I.10. Government may decide simply to nominate a site for development of a disposal facility, but there have been several instances where such approaches to the siting of disposal facilities have failed to gain societal acceptance and this approach is not recommended. Some programmes for the siting and development of radioactive waste disposal facilities have, therefore, adopted approaches involving partnerships with local communities. Partnership approaches involve collaborative working relationships between communities and the operating organization. The key feature of the partnership approach is the empowerment of local communities in decisions that affect their future. Such partnership approaches may include seeking volunteer communities. A volunteer community is one that has expressed interest in participating in a process to determine the suitability of a site for a radioactive waste management 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 the range of safety-related and other factors – for examples see paras I.4 to I.7 above. The relative ease of being able to develop a convincing safety case may also be a factor in choosing between alternative sites. The operating organization should adhere to the pre-defined siting process and should involve interested parties in the assessment of sites. The operating organization should ensure that the process is clear and logical, and documented in a traceable manner. The operating organization should ensure that the process followed includes appropriate arrangements for declaring any conflicts of interest. The operating organization should document in a transparent way the reasoning for the process followed, 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 disposal facility is to gain 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 should include investigating the geomorphology, geology, hydrogeology, hydrology, geochemistry, climate, weather and ecology and land use and human behaviour at and around the site and how land use and human behaviour affects the environment. The operating organization's site characterization programme should include characterization of the biosphere at and around the site and particularly in areas into which groundwater contaminated with radionuclides from the facility could discharge. The operating organization's site characterization programme should collect 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 such information to assist in identifying critical groups and potentially exposed groups for use in assessing 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 information needed from the programme will depend on how complex the site is and on the margin of safety indicated by the safety assessments. A large margin of safety may be indicated for various reasons, such as the following; a waste inventory that includes a small amount of long-lived radionuclides, the absence of groundwater at the site, 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 the disposal facility will fulfil the relevant dose and risk criteria despite uncertainties introduced by a less extensive site characterization programme.

I.14. The recommended borehole disposal concept for disused sealed radioactive sources has been designed to provide a high level of isolation and it has been shown to be a safe disposal solution for suitably small inventories of disused sealed radioactive sources under a wide range of site conditions – Ref. [17]. 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 and the risks associated with borehole disposal of such waste should be very low. Under these circumstances, the needs for site characterization should be less extensive than for a near surface disposal facility or a geological disposal facility for a large waste inventory.

I.15. For 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, this data can nevertheless be useful, for example, in helping to demonstrate a general understanding of the site and for developing multiple lines of reasoning in the safety case.

I.16. The generic safety assessment Ref. [17] identifies the parameters that are expected to have the greatest impact on safety of the recommended 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. Such insights are particularly valuable for defining the site characterization programme and for using the understanding derived from the site characterization programme to inform site-specific design.

I.17. The identification of key parameters – the ones most important to safety – and, from that, an ability to focus the site characterization programme was a key motivation for the development of the tiered modelling approach presented in Ref. [18]. Ref. [18] describes an approach which involves the gathering of site-specific information according to the needs of safety assessment models developed at different levels of complexity. Five models are described, with the simplest model requiring the least information and the most complex model requiring the most. Table A.1 indicates the list of site-specific information needed by the different models.

TABLE A.1. SUMMARY OF SITE-SPECIFIC PARAMETERS NEEDED FOR THE TIER 1 TO TIER 5 MODELS IN REF. [18].

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[(b)]: • outer diameter • vertical length • wall thickness • weld thickness Containment barrier[(b)]: • vertical length • gap thickness	Hydrogeology: • Percolation rate[(a)] • Degree of saturation[(a)] • Total porosity[(a)] • 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[(a)] Degree of saturation[(a)] Total porosity[(a)] Grain density Hydraulic conductivity Hydraulic gradient Water-filled porosity Failure times for disposal capsule	Diffusion coefficients Sorption coefficients Percolation rate[(a)] Degree of saturation[(a)] Total porosity[(a)] Grain density Hydraulic conductivity Hydraulic gradient Water-filled porosity A 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 House occupancy rate Irrigation rates Crop yields
5	Radionuclide inventory Diffusion coefficients Sorption coefficients Percolation rate[(a)] Degree of saturation[(a)] Total porosity[(a)] Grain density Hydraulic conductivity Hydraulic gradient Water-filled porosity Failure/degradation times for near-field components	Diffusion coefficients Sorption coefficients Percolation rate[(a)] Degree of saturation[(a)] Total porosity[(a)] Grain density Hydraulic conductivity Hydraulic gradient Water-filled porosity A 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) Only required if the disposal zone is in the unsaturated zone.
(b) Expected to be broadly similar for different systems.

Desk-based studies

I.18. The operating organization's site characterization programme for the development of a 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 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 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 gather long-term regional meteorological records and demonstrate an understanding of the range of conditions that have occurred 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 and 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 could discharge. The operating organization should use this information to identify potential pathways by which radionuclides from the disposal facility could 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), and on human behaviours (e.g. food consumption rates and sources of drinking water) that would be needed for dose assessments for present and potential future conditions. The operating organization should use information on the nature of the current day 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 critical groups and potentially exposed groups for use in safety assessment.

Surface-based studies

I.22. The operating organization should undertake surveys, fieldwork and surface-based investigations to increase knowledge and information on the site and its surroundings. The operating organization should undertake safety assessments to interpret and integrate available knowledge and information on the disposal system and to focus further site characterization activities 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. studies of landforms, evidence of erosion and past land movements such as landslips, faults and earthquakes, lakes, rivers, sediment burden, 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 those that may be present at disposal depths, and 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, scaled 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 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 subsurface geology without drilling. The operating organization should consider undertaking electrical resistivity surveys to complement results from seismic surveys and further understand the geology and hydrology 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 at least as far as 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 borehole(s) and the potential locations of disposal borehole(s) and depths of disposal zones.

Borehole-based 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 a drilling approach that minimizes disturbance to the disposal system that is to be characterized (e.g. the approach should avoid the possibility groundwater becoming contaminated by the drilling activities and or include methods for correcting for possible contamination).

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 it is proposed to dispose of waste and confirm the absence of features such as high-pressure zones that could negatively and significantly affect the performance of the disposal facility. If this is not feasible, perhaps because the base of the host formation is very deep, then the operating organization should provide a justification for the chosen depth of the base of the site characterization boreholes (which should, for example, be at least some tens of meters below the base of the deepest disposal zone). Where it is proposed to dispose of waste 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 boreholes so that rock core is extracted for study. Where it is not practical to recover 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 fragments) are collected and make 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. 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 drillers to record water strikes, water yields, drilling speeds, fractures and any unexpected events such as the loss of compression air (possibly indicating the presence of joints or fissures), changes in penetration rate (possibly indicating changes in lithology or structure), sharp changes in the colour of rock samples (possibly indicating lithological changes or weathering), and sharp changes in the size of drill chips (possibly indicating the presence of fractures). The operating organization should use the information gathered (e.g. on the geological sequence and the depth of the water table) to calibrate the geophysical surveys – see para. I.25.

I.32. The operating organization should use geophysical wireline logging techniques to monitor the shape and diameter of the 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.

I33. 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 the pilot project on borehole disposal of disused sealed radioactive sources in Ghana is provided in Table A.2.

TABLE A.2. DOWN-HOLE LOGGING PROBES AND RELATED PARAMETERS - Ref. [62].

Type of Probe	Related Parameter(s)
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
Focussed electric logging probe	Focussed 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 (medium-high flow regimes) Fluid temperature and conductivity Natural gamma radioactivity
Heat-pulse flowmeter probe	Vertical fluid flow (low flow regimes)

I34. Where the site investigation 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 inflows and outflows at different horizons (these should be made 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, e.g. in the upper parts of the borehole.

I35. Where the site investigation 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 waters, including as possible their redox potentials (Eh), acidity (pH), alkalinities and contents of solutes, colloids and particulates. The operating organization should consider measuring the electrical conductivities of the waters to provide further information on the ionic content and salinity of the waters. The operating organization should use best practice when collecting, transporting and analysing samples (e.g. including 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 the following anions; chloride, sulphate, carbonate, bicarbonate and nitrate. Where possible, the operating organization should use information on the chloride and sulphate contents of the groundwaters 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 Eh *in situ*, particularly in the disposal zone(s) by using appropriate probes and packers (inflatable plugs) 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 Eh *in situ*, the operating organization should estimate the *in situ* Eh by using Eh measurements on water samples abstracted from the borehole and making corrections 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. At sites where the disposal zone(s) is(are) to be situated in saturated, low permeability rocks (e.g. plastic clay), the rate of water ingress into site investigation boreholes may be very low or even undetectable, and this may make the measurement of hydrogeological properties and the collection of water samples difficult. In such cases, the operating organization should attempt to extract water samples from extracted core. The operating organization may need to estimate the groundwater flow rates based on the limit of detectability of water ingress to the borehole. The operating organization should determine the permeability of the host rock and relevant diffusion coefficients using extracted core samples. The operating organization should measure the thickness of the host rock layer and establish the distances between the disposal zone(s) and more permeable rocks.

I.38. At sites in some arid regions, groundwater may only be found at depth and disposal zone(s) can be situated in an unsaturated environment. Locating the disposal zones(s) in unsaturated rocks may be advantageous for post-closure safety because, in the absence of groundwater, interactions between the radionuclides in the waste and groundwaters in the saturated zone are much delayed, allowing time for radionuclides to decay and reducing potential doses and risks from groundwater pathways – Ref. [17]. At sites where the disposal zone(s) is(are) to be situated in unsaturated rocks, the operating organization should provide reasonable assurance that the host rocks to the disposal zone(s) will remain unsaturated over the assessment timescale by:

(a) Gathering information and evidence on the amount and rate of percolation of water through the unsaturated zone, on present-day and past groundwater levels, and on the characteristics of the groundwaters in the underlying rocks, including details of groundwater chemistry, origin, age, flows and pressures;

(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(s), taking account of present and past 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 groundwaters often have oxidizing properties and may contain high concentrations of solutes, characteristics that can greatly accelerate corrosion of steel waste containers.

APPENDIX II. SAFETY ASSESSMENT FOR BOREHOLE DISPOSAL FACILITIES

II.1. Guidance on the development of the safety case and safety assessments relevant to all types of radioactive waste disposal facilities is contained in SSG-23 [35]; that information is not repeated here – the purpose of this Appendix is to address safety assessment issues that are specifically related to borehole disposal facilities.

II.2. While the information in this Appendix is applicable to borehole disposal facilities developed in accordance with the concept for the disposal of disused sealed radioactive sources that have been declared waste and other radioactive waste as described in para. 1.1 in narrow diameter boreholes as described Section 2, some of the more general aspects of the guidance (e.g. relating to scenario development) should be of interest to those involved with other borehole disposal concepts.

Generic safety assessment for borehole disposal of Category 3 to 5 disused sealed radioactive sources and further studies

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, at the concept development stage and in support of site screening and selection, a generic safety assessment can be used to help identify waste inventories that are potentially suitable or unsuitable for disposal following a particular disposal concept, to determine the need for engineered barriers and other aspects of disposal facility design, and to identify potentially suitable and unsuitable sites. When a potentially suitable site has been selected for further investigation, the operating organization should consider using generic safety assessment:

(a) To help in identifying key data and parameters that will need to be gathered and evaluated in order to develop a site-specific assessment;

(b) To help in determining the extent of site characterization required;

(c) As a basis for site-specific assessment.

Generic safety assessment for borehole disposal of Category 3 to 5 disused sealed radioactive sources

II.4. A generic safety assessment for the disposal of disused sealed radioactive sources in narrow diameter boreholes was developed over a period of several years and is presented in Ref. [17]. The generic safety assessment presented in Ref. [17], considered the 31 most relevant radionuclides found in disused sealed radioactive sources and assumed that they were 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 were undertaken for waste disposal in unsaturated conditions and for waste disposal in saturated conditions. The rocks were assumed to be capable of representation as either porous rocks or fractured rocks. A range of groundwater flow rates was considered in the saturated zone and a range of safety assessment calculations was undertaken assuming low, medium or high flow rates. Various groundwater geochemical conditions (e.g. Eh, pH, chloride and sulphate content) were considered 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. [17], included a thorough features events and processes analysis and this was used in scenario development. The following scenarios were identified and defined:

(a) 'The Design Scenario'. In this scenario it was assumed that the disposal facility was constructed, operated and closed as designed and that it evolved during the post-closure period as expected;

(b) 'The Defect Scenario'. In this scenario it was assumed that not all of the components of the near field performed as envisaged in the Design Scenario due either to 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 were considered. These resulted in the earlier release of radionuclides from the near field;

(c) 'The Unexpected Geological Characteristics Scenario'. In this scenario it was assumed that the actual performance of the geosphere was worse than the expected performance (e.g. the geosphere was subjected to an unexpected seismic event resulting in the reactivation of high permeability fractures and modification of associated sorption properties);

(d) 'The Changing Environmental Conditions Scenario'. In this scenario it was assumed that the disposal system was 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 was assumed that drilling of a water abstraction borehole adjacent to the disposal borehole could result in the earlier exposure of humans to radionuclides (e.g. due to the use of contaminated water from the abstraction borehole).

II.6. In the generic safety assessment – Ref. [17], it was argued that the potential consequences of the Unexpected Geological Characteristics Scenario and the Changing Environmental Conditions Scenario were bounded by the range of geosphere and biosphere characteristics that had been assessed and the parameter sensitivity analyses undertaken for the Design Scenario.

II.7. In the generic safety assessment – Ref. [17], the Borehole Disturbance Scenario was eliminated (screened out) from more detailed consideration because of the depth of the disposal zone for the reference design (>30 m), 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 factors indicted that the probability of inadvertent human intrusion directly affecting the disposal borehole was extremely low.

II.8. The generic safety assessment presented in Ref. [17] showed that with a suitable combination of 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 Category 3 to 5 disused sealed radioactive sources containing either long-lived or short-lived radionuclides.

II.9. In the case of the borehole disposal system described in Ref. [14], 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; 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 of Ref. [17]) providing reasonable confidence in the containment of the short-lived nuclides within the near field.

II.10. The generic safety assessment presented in Ref. [17] suggests that under non-fault conditions (e.g. without any defects in the sealed disposal capsules or containers) even radionuclides with half-lives as long as Ra-226 (half-life = 1,600 years) can be disposed 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. As noted above (see Sections 4 and 5), 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 Category 1 & Category 2 disused sealed radioactive sources

II.11. Several further generic studies have been performed to assess the safety of the borehole disposal of disused sealed radioactive sources. These studies have particular relevance to the disposal of Category 1 and Category 2 disused sealed radioactive sources, and include:

(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 – Ref. [43]. The Borehole Disposal Concept Scoping Tool – Ref. [43] – allows the containment provided by the disposal capsule and container in the post-closure period and the chemical and physical degradation of the backfill to be evaluated. The Borehole Disposal Concept Scoping

Tool – Ref. [43] – 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 has been extended to allow consideration of Category 1 and Category 2 disused sealed radioactive sources;

(b) The generic safety assessment – Ref. [17] did not explicitly consider radiolysis, criticality or thermal effects because the effects of these processes are insignificant for typical Category 3 to 5 disused sealed radioactive sources to be disposed of. However, for the disposal of Category 1 and Category 2 disused sealed radioactive sources, the operating organization should assess the potential effects of radiolysis, criticality and thermal processes. Ref. [15] addressed the potential impacts of the disposal of Category 1 and Category 2 disused sealed radioactive sources on the post-closure safety of the borehole disposal concept. The study described in Ref. [15] was based on conservative assumptions and calculations, and indicated that, whilst there are no criticality issues, the disposal of some Category 1 and Category 2 disused sealed radioactive sources might result in higher temperatures and high radiation fields that could significantly reduce the expected lifetime of the waste disposal packages. Consequently, less-conservative calculations were conducted to develop an improved understanding of the thermal and radiation conditions in the borehole for representative Category 1 and Category 2, and Category 3 to 5 disused sealed radioactive sources, respectively – Ref. [63]. The work described in Refs [15] and [63] was supported by calculations using the CHEMSIMUL and Microshield codes and led to the development of various specifications for the disposal capsules and containers so that they could be used to contain Category 1 and Category 2 disused sealed radioactive sources;

(c) A review was made of the rates of general and localized corrosion of stainless steel in cementitious environments – Ref. [39]. This review also considered the potential effects of gamma radiation and galvanic corrosion between carbon and stainless steels in concrete. The focus of the review was on 304 and 316 austenitic stainless steel. The work led to recommendations for the use of super austenitic or super duplex stainless steel or a Pd-containing titanium alloy for the disposal capsules and containers for heat-generating and gamma-emitting Category 1 and Category 2 disused sealed radioactive sources;

(d) The work described in Refs [15] and [63] highlighted a need for integration of the mobile hot cell described in Ref. [22] into the conditioning and disposal operations for Category 1 and Category 2 disused sealed radioactive sources. The integration work undertaken is described in Refs [64] and [65].

REFERENCES

[1] EUROPEAN ATOMIC ENERGY COMMUNITY, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, INTERNATIONAL MARITIME ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1, IAEA, Vienna (2006).

[2] EUROPEAN COMMISSION, FOOD AND AGRICULTUREORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3, IAEA, Vienna (2014).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Predisposal Management of Radioactive Waste, IAEA Safety Standards Series No. GSR Part 5, IAEA, Vienna (2009).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Disposal of Radioactive Waste, IAEA Safety Standards Series No. SSR-5, IAEA, Vienna (2011).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safety Glossary Terminology Used in Nuclear Safety and Radiation Protection 2018 Edition, IAEA, Vienna (2019).

[6] Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, INFCIRC/546, IAEA, Vienna (1997).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Code of Conduct on the Safety and Security of Radioactive Sources: Guidance on the Management of Disused Radioactive Sources, IAEA/CODEOC/MGT-DRS/2018, Vienna (2018).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Disposal of Radioactive Waste, Near Surface Disposal Facilities for Radioactive Waste, IAEA Safety Standards Series No. SSG-29, Vienna (2014).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Disposal of Radioactive Waste, Geological Disposal Facilities for Radioactive Waste, IAEA Safety Standards Series No. SSG-14, Vienna (2011).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Classification of Radioactive Waste, IAEA Safety Standards Series No. GSG-1, Vienna (2009).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Material 2018 Edition, IAEA Safety Standards Series No. SSR-6 (Rev. 1), IAEA, Vienna (2018).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Goiânia, IAEA, STI/PUB/815, Vienna (1988).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment for Facilities and Activities, IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Vienna (2016).

[14] INTERNATIONAL ATOMIC ENERGY AGENCY, BOSS: Borehole Disposal of Disused Sealed Sources: A Technical Manual, TECDOC-1644, IAEA, Vienna (2011).

[15] LITTLE, R.H., BOND, A.E., EMERY, P., METCALFE, R., AND THATCHER, K.E., Extension of the IAEA's GSA for the Borehole Disposal Concept to include High Activity Sources, Report No. QRS-1668A-1, Quintessa, Henley (2016).

[16] COCHRAN, J.R., BENNETT, D.G., DEGNAN, P., GROUT, C., LIEBENBERG, G., LITTLE, R., RAMSEY, J., VAN BLERK, J. AND VAN MARCKE, P., International Implementation of IAEA's Borehole Disposal Concept for Sealed Radioactive Sources, Paper 18545, WM2018 Conference, March 18 - 22, 2018, Phoenix, Arizona, USA.

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Generic Post-Closure Safety Assessment for Disposal of DSRS in Narrow Diameter Boreholes, TECDOC-1824, IAEA, Vienna (2017).

[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Application of the Graded Approach to Post-Closure Safety Assessment for the Disposal of Disused Sealed Radioactive Sources in Boreholes, TECDOC-1928, IAEA, Vienna (2020).

[19] INTERNATIONAL ATOMIC ENERGY AGENCY, Storage of Radioactive Waste, IAEA Safety Standards Series No. WS-G-6.1, IAEA, Vienna (2006).

[20] INTERNATIONAL ATOMIC ENERGY AGENCY, Predisposal Management of Radioactive Waste from the Use of Radioactive Material in Medicine, Industry, Agriculture, Research and Education, IAEA Safety Standards Series No. SSG-45, IAEA, Vienna (2019).

[21] INTERNATIONAL ATOMIC ENERGY AGENCY, Categorization of Radioactive Sources, IAEA Safety Standards Series No. RS-G-1.9, IAEA, Vienna (2005).

[22] LIEBENBERG, G.R. AND AL-MUGHRABI, M. The Development of a Mobile Hot Cell Facility for the Conditioning of Spent High Activity Radioactive Sources. Waste Management '08 Conference, Phoenix, (2008).

[23] INTERNATIONAL ATOMIC ENERGY AGENCY, Procedures for the Recovering, Conditioning, Containerization and Disposal of Low Activity Disused Sealed Radioactive

Sources in a Borehole Disposal Facility using the Mobile Tool Kit Facility, Version 4.0, IAEA, Vienna, (June 2020).

[24] INTERNATIONAL ATOMIC ENERGY AGENCY, Leadership and Management for Safety, IAEA Safety Standards Series No. GSR Part 2, IAEA, Vienna (2016).

[25] INTERNATIONAL ATOMIC ENERGY AGENCY, Leadership, Management and Culture for Safety in Radioactive Waste Management IAEA Safety Standards Series No. GSG-16, IAEA, Vienna (in preparation).

[26] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Facilities, IAEA Safety Standards Series No. GSR Part 6, IAEA, Vienna (2014).

[27] INTERNATIONAL ATOMIC ENERGY AGENCY, Release of Sites from Regulatory Control on Termination of Practices, IAEA Safety Standards Series No. WS-G-5.1, IAEA, Vienna (2006).

[28] INTERNATIONAL ATOMIC ENERGY AGENCY, Governmental, Legal and Regulatory Framework for Safety, IAEA Safety Standards Series No. GSR Part 1 (Rev. 1), IAEA, Vienna (2016).

[29] INTERNATIONAL ATOMIC ENERGY AGENCY, Model Regulations for Borehole Disposal Facilities for Radioactive Waste, TECDOC-1827, IAEA, Vienna (2017).

[30] INTERNATIONAL ATOMIC ENERGY AGENCY, Functions and Processes of the Regulatory Body for Safety, IAEA Safety Standards Series No. GSG-13, IAEA, Vienna (2018).

[31] INTERNATIONAL ATOMIC ENERGY AGENCY, Communication and Consultation with Interested Parties by the Regulatory Body, IAEA Safety Standards Series No. GSG-6, IAEA Vienna (2017).

[32] INTERNATIONAL ATOMIC ENERGY AGENCY, Organization, Management and Staffing of the Regulatory Body for Safety, IAEA Safety Standards Series No. GSG-12, IAEA, Vienna (2018).

[33] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, The 2007 Recommendations of the International Commission on Radiological Protection, Publication 103, Elsevier, Amsterdam (2007).

[34] INTERNATIONAL ATOMIC ENERGY AGENCY, The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste, IAEA Safety Standards Series No. GSG-3, IAEA, Vienna (2013).

[35] INTERNATIONAL ATOMIC ENERGY AGENCY, The Safety Case and Safety Assessment for the Disposal of Radioactive Waste, IAEA Safety Standards Series No. SSG-23, IAEA, Vienna (2012).

[36] INTERNATIONAL ATOMIC ENERGY AGENCY, Monitoring and Surveillance of Radioactive Waste Disposal Facilities, IAEA Safety Standards Series No. SSG-31, IAEA, Vienna (2014).

[37] INTERNATIONAL ATOMIC ENERGY AGENCY, Source Inventory Management for Borehole Disposal (SIMBOD) User Guide, IAEA, Vienna (2013).

[38] NECSA, Design for the Borehole Disposal Concept, Report No. GEA-1623, NECSA, Pretoria (2003).

[39] KING, F., Update of BDC GSA Corrosion Analysis including Category 1 & 2 Sources, Report No. ICC-2016-02, Integrity Corrosion Consulting Ltd., Nanaimo (2016).

[40] NECSA, Procedures for the Conditioning and Disposal of Disused Sealed Radioactive Sources in a Borehole Disposal Facility Using the Mobile Hot Cell, Report No. NLM-PRO-117, NECSA, Pretoria (2015).

[41] NECSA, Radiological Operational Safety Assessment for the Conditioning and Borehole Disposal of DSRS, Report No. NLM-SAR-14/003 (Rev. 2), NECSA, Pretoria (2015).

[42] INTERNATIONAL ATOMIC ENERGY AGENCY, Contents and Sample Arguments of a Safety Case for Near Surface Disposal of Radioactive Waste, TECDOC-1814, IAEA, Vienna (2017).

[43] ROBINSON, P.C., WATSON, C.E., and LITTLE, R.H., The Borehole Disposal Concept Scoping Tool v2.0, QRS-3038B-2 Version 1.0, Quintessa, Henley-on-Thames (2016).

[44] KOZAK, M.W., Decision Analysis for Low level Radioactive Waste Disposal Safety Assessments, Radioactive Waste Management and Environmental Restoration, 18 (1994) 209-223.

[45] NUKLEAR MALAYSIA, Safety Case Synthesis Report for the Borehole Disposal Project, Report No. NUKLEARMALAYSIA/L/2018/116(S), NMA, Bangi (2018).

[46] GHANA ATOMIC ENERGY COMMISSION, Safety Case Report Required for the Implementation of the Borehole Disposal System in Ghana, Draft 1.2, GAEC, Accra, (2018).

[47] NUKLEAR MALAYSIA, Operational Safety Assessment in Support of the Development of Safety Case, Report No. NUKLEARMALAYSIA/L/2018/117(S), NMA, Bangi, (2018).

[48] INTERNATIONAL ATOMIC ENERGY AGENCY AND UNITED NATIONS ENVIRONMENT PROGRAMME, Radiation Protection of the Public and the Environment, General Safety Guide GSG-8, IAEA, Vienna (2018).

[49] INTERNATIONAL ATOMIC ENERGY AGENCY AND UNITED NATIONS ENVIRONMENT PROGRAMME, Prospective Radiological Environmental Impact Assessment for Facilities and Activities, IAEA Safety Standards Series No. GSG-10, IAEA, Vienna (2018).

[50] INTERNATIONAL ATOMIC ENERGY AGENCY AND INTERNATIONAL LABOUR OFFICE, Occupational Radiation Protection, IAEA Safety Standards Series No. GSG-7, IAEA, Vienna (2018).

[51] I-MECH Kft, Project Quality Assurance and Collaboration Plan for Manufacturing of Source Conditioning Capsules and Disposal Containers to be Used by the International Atomic Energy Agency (IAEA), Version #4, I-MECH Kft., Kertalja (2017).

[52] LINDBORG, T., THORNE, M., ANDERSSON, E., BECKER, J., BRANDEFELT, J., CABIANCA, T., GUNIA, M., IKONEN, A.T.K., JOHANSSON, E., KANGASNIEMI, V., KAUTSKY, U., KIRCHNER, G., KLOS, R., KOWE, R., KONTULA, A., KUPIAINEN, P., LAHDENPERÄ, A.-M., LORD, N.S., LUNT, D.J., NÄSLUND, J.-O., NORDÉN, M., NORRIS, S., PÉREZ-SÁNCHEZ, D., PROVERBIO, A., RIEKKI, K., RÜBEL, A., SWEECK, L., WALKE, R., XU, S., SMITH, G., and PRÖHL, G., Climate Change and Landscape Development in Post-Closure Safety Assessment of Solid Radioactive Waste Disposal: Results of an Initiative of the IAEA, Journal of Environmental Radioactivity 183 (2018) 41–53.

[53] NECSA, Waste Acceptance Criteria for the Borehole Disposal Concept, Report No. GEA-1714, NECSA, Pretoria (2006).

[54] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5), IAEA Nuclear Security Series No. 13, IAEA, Vienna (2011).

[55] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Security Culture, IAEA Nuclear Security Series No. 7, IAEA, Vienna (2008).

[56] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Security Recommendations on Radioactive Material and Associated Facilities, IAEA Nuclear Security Series No. 14, Vienna (2011).

[57] INTERNATIONAL ATOMIC ENERGY AGENCY, Security of Radioactive Material in Use and Storage and of Associated Facilities, IAEA Nuclear Security Series No. 11-G (Rev. 1), Vienna (2019).

[58] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL CIVIL AVIATION ORGANIZATION, INTERNATIONAL LABOUR ORGANIZATION, INTERNATIONAL MARITIME ORGANIZATION,INTERPOL, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, PREPARATORY COMMISSION FOR THE

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[59] INTERNATIONAL ATOMIC ENERGY AGENCY, Upgrading of Near Surface Repositories for Radioactive Waste, IAEA Technical Report Series No. 433, IAEA, Vienna (2005).

[60] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Considerations in the Disposal of Disused Sealed Radioactive Sources in Borehole Facilities, TECDOC-1368, IAEA, Vienna (2003).

[61] INTERNATIONAL ATOMIC ENERGY AGENCY, Remediation Strategy and Process for Areas Affected by Past Activities or Events, IAEA Safety Standards Series No. GSG-15, IAEA, Vienna (in preparation).

[62] GHANA ATOMIC ENERGY COMMISSION, Site Description Report for Implementation of the Borehole Disposal System, Draft 1.4, GAEC, Accra, (2018).

[63] THATCHER, K.E., PENFOLD, J.S.S., and METCALF, R., Further Calculations to Support the IAEA's Borehole Disposal Concept, QRS-1668C-1 Version 2.0, Quintessa, Henley-on Thames (2017).

[64] NECSA, Close-out Report on the MHC and BDC Integration, Report No. NLM-REP-15/216, NECSA, Pretoria, [IAEA order 201306400-VAO] (year).

[65] NECSA, Procedural HAZOP Report on Mobile Hot Cell Borehole Disposal Container Welding, Report No. SLD-HAZ2014-REP-0008. NECSA, Pretoria (year).

ANNEX I. OTHER BOREHOLE DISPOSAL CONCEPTS

I.1. This annex provides several examples of borehole disposal concepts other than that described in Section 2 which have been proposed or implemented for radioactive waste storage or disposal for various types of radioactive waste. These examples are included in this Annex to distinguish them from the recommended disposal concept for disposal of disused sealed radioactive sources. Their inclusion in this annex does not imply that they necessarily 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 – Ref. [I.1]. In the Russian Federation, for example, there is experience of 'RADON wells' dating back to the 1960s, Ref. [I.1]. These boreholes were originally designed for disposal of disused sealed radioactive sources but have now been re-designated 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, Ref. [I.3]; these facilities are also designated as storage facilities. Shallow boreholes have also been used for radioactive waste disposal at Mount Walton East, a very arid location in Western Australia. Here, the 'Intractable Waste Disposal Facility' (IWDF) includes a pair of 2 m-diameter boreholes in which drummed low level waste and intermediate level waste is stacked in layers that lie between 5.8 m and 28 m below the surface. The boreholes were operational in 1992 and 1994; more recent disposals at the IWDF have been in near surface trenches, Ref. [I.4].

I.3. In the USA, at least two 'Greater Confinement Disposal' facilities have used 3 m-diameter boreholes or shafts drilled with a large augur. At the Savannah River Plant, the Greater Confinement Test Facility consists of a square array of eighty, 6 m-deep shafts that have been used for disposal of US Class B wastes, Ref. [I.5]. A second type of Greater Confinement Disposal facility was used at the Nevada Test Site (NTS) in the 1980s to dispose of 'Greater-Than-Class-C' (GTCC) low level waste, which included disused sealed radioactive sources and some transuranic elements; here, the depth of disposal was at least 21 m and was specified to be more than 120 m above the water table, Ref. [I.6].

I.4. The Greater Confinement Disposal concept was re-evaluated in 2007 for another disposal of GTCC low level waste, again at the NTS, Ref. [I.7]. The estimated total volume of the waste was 2,500 cubic meters, with an approximate activity of 7.8 million TBq. In this case, the waste was to be disposed of at least 30 m deep because according to US regulations, Ref. [I.8], a shallower depth would require it to be classified as a near surface disposal. A maximum depth of 300 m was envisaged, and 930 boreholes would have been needed, spread over an area of 44 hectares (implying a borehole spacing of around 22 m). This proposal was eventually rejected in favour of an approach that utilized both commercial disposal facilities and the Waste Isolation Pilot Plant (WIPP) – a geological disposal facility in New Mexico, Ref. [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][18], or greater, e.g. Ref. [I.11]. The diameters of the disposal boreholes or drifts in these concepts vary in the approximate range from 0.5 to 2 m. Very deep borehole disposal of radioactive waste (i.e. disposal in boreholes deeper than a few hundred metres) was suggested in the 1970's, e.g. Ref. [I.12] and the idea has been studied intermittently since that time. Various different concepts have been described, 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 do not involve rock melting and rely for safety principally on the great depth and high degree of isolation provided by boreholes of up to 5 km deep, e.g. Ref. [I.14], and concepts that envisage the combined disposal of heat generating radioactive waste and the production of 'geothermal' energy by pumping water through very deep boreholes bored parallel to, but between, boreholes containing radioactive waste, Ref. [I.15].

I.6. The various very deep borehole disposal concepts have been reviewed at different stages by national radioactive waste disposal programmes in the UK, Ref. [I.16], in Sweden, Ref. [I.17], in Germany, Ref. [I.18] and in the US, Ref. [I.19]. Ref. [I.19] noted various remaining uncertainties (e.g. relating to rock heterogeneity and the ability to characterize the rocks at such great depths) and concluded 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.

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

REFERENCES TO ANNEX I

[I.1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Considerations in the Disposal of Disused Sealed Radioactive Sources in Borehole Facilities, TECDOC-1368, IAEA, Vienna (2003).

[I.2] SOBOLEV, I.A., OJOVAN, M.I. AND KARLINA, O.K., Management of Spent Sealed Radioactive Sources at Regional Facilities, 'Radon' in Russia", 8th International Conference on Radioactive Waste Management and Environmental Remediation, Bruges, (2001).

[I.3] PROZOROV, L., TKATCHENKO, A., TITKOV, V. AND KORNEVA, S., Prospects of Large Diameter Well Construction at 'Radon' Sites", Waste Management '01 Conference, Tucson, (2001).

[I.4] GOVERNMENT OF WESTERN AUSTRALIA, DEPARTMENT OF FINANCE, BUILDING MANAGEMENT AND WORKS, Intractable Waste Disposal Facility, Mount Walton East, Information Handbook, 2017.

[I.5] COOK, J.R., TOWLER, O.A., PETERSON, D.L., JOHNSON, G.M. AND HELTON, B.D, Greater Confinement Disposal Program at the Savannah River Plant, Waste Management '84, Conference, Tucson, (1984).

[I.6] COCHRAN, J.R., CROWE, B.M., COLARUSSO, A., Results of the Performance Assessment for the Classified Transuranic Wastes Disposed at the Nevada Test Site, Waste Management '01 Conference, Tucson, (2001).

[I.7] TONKAY, D.W., JAMES L. JOYCE, J.L. AND JOHN R. COCHRAN, J.R. A Fresh Look at Greater Confinement Boreholes for Greater-than-Class C Low level Radioactive Waste Disposal, Waste Management '07 Conference, Tucson, (2007).

[I.8] UNITED STATES NUCLEAR REGULATORY COMMISSION, Code of Federal Regulations 10 CFR 61.2, 2017.

[I.9] US DEPARTMENT OF ENERGY, Alternatives for the Disposal of Greater-than-Class C Low Level Radioactive Waste and Greater-Than-Class C-Like Waste, Report to Congress, November 2017.

[I.10] POSIVA OY AND SVENSK KÄRNBRÄNSLEHANTERING AB, KBS-3H System Design Phase 2011−2016: Final Report, Posiva SKB Report 06, SKB ID 1538999, Posiva ID RDOC-104827, Helsinki and Stockholm (2017).

[I.11] FINSTERLE, S., MULLER, R.A., GRIMSICH, J., APPS, J. AND BALTZER, R. Post-Closure Safety Calculations for the Disposal of Spent Nuclear Fuel in a Generic Horizontal Drillhole Repository, Energies 13, 2599, (2020).

[I.12] BATTELLE PACIFIC NORTH-WEST LABS., High level Radioactive Waste Management Alternatives. In: Schneider, K.J. and Platt, A.M. (eds), Battelle Pacific North-West Labs., Report No. BNWL-1900, BPNL, Richland, (1974).

[I.13] GIBB, F.G.F., A New Scheme for the Very Deep Geological Disposal of High level Radioactive Waste. Journal of the Geological Society of London, Vol. 157, pp. 27–36, (2000).

[I.14] BRADY, P.V., FREEZE, G.A., KUHLMAN, K.L., HARDIN, E.L., SASSANI, D.C. AND MACKINNON, R.J., Deep Borehole Disposal of Nuclear Waste: US Perspective, in: APTED, M. and AHN, J. (eds) 2017, Geological Repository Systems for Safe Disposal of Spent Nuclear Fuels and Radioactive Waste, 2nd Edition. Pages 89-112.

[I.15] PUSCH, R. WESTON, R. AND KASBOHM, J., Deep Boreholes for Storage of Spent Reactor Fuel and Use of the Heated Rock for Production of Electric Energy or Hot Fluid for Heating Purposes, Journal of Earth Sciences and Geotechnical Engineering, Vol.10, No. 1, pp. 127-153 (2020).

[I.16] UNITED KINGDOM NIREX LIMITED, A Review of the Deep Borehole Disposal Concept for Radioactive Waste, Nirex Report No. N/108, Harwell (2004).

[I.17] SVENSK KÄRNBRÄNSLEHANTERING AB, PASS – Project on Alternative Systems Study. Performance Assessment of Bentonite Clay Barrier in Three Repository Concepts: VDH, KBS-3 and VLH, Pusch, R. and Börgesson, L., SKB Report No. TR-92-40, SKB, Stockholm, (1992).

[I.18] BRACKE, G., CHARLIER, F., LIEBSCHER, A., SCHILLING, F. AND RÖCKEL, T., Does Deep Borehole Disposal of HLRW has a Chance in Germany? Decommissioning and Waste Management, Vol. 62, Issue 1 (2017).

[I.19] U.S. NUCLEAR WASTE TECHNICAL REVIEW BOARD. A Report to the U.S. Congress and the Secretary of Energy: Technical Evaluation of the U.S. Department of Energy Deep Borehole Disposal Research and Development Program, NWTRB, Arlington, 2016.

ANNEX II. ISOLATION AND DISPOSAL DEPTH

II.1. The Safety Guide that this publication replaces (SSG-1) relied on a 1987 reference, Ref. [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 is limited to drilling and significant excavation activities, such as tunnelling, quarrying and mining) Ref. [II.1]. In the 30 years since Ref. [II.1] was published, significant developments have been made in the construction of high-rise buildings and other infrastructure and 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 for high-rise buildings, expressways and railways cluster in the approximate range from 30 m to 50 m deep and extend to depths of approximately 80 m. Ref. [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, and 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 SFR repository in Sweden accepts low level waste and short-lived intermediate level waste for disposal at depths between approximately 60 m and 120 m Ref. [II.3].

II.3. For several reasons, including locating 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 located disposal zones deeper than 100 m. In Malaysia the proposed disposal zone lies between depths of approximately 115 m and 175 m, Ref. [II.4], in Ghana the proposed depth of the disposal zone lies between approximately 135 m and 150 m, Ref. [II.5]).

II.4. Experiences in several Member States (for examples, see Ref. [II.6] and Section B.2.1 of Ref. [II.7]) have been that some existing shallow borehole disposal facilities have had later to be reclassified as storage facilities from which the waste should be retrieved, or where safety should otherwise be upgraded (see also Section 8).

II.5. In light of these developments, practices and experiences, and given that it easy and inexpensive (in comparison with the total cost of a waste disposal programme) to drill narrow diameter boreholes, this publication recommends borehole disposal at depths below 100 m to increase confidence in the safety of disposal and in the maintenance of nuclear security over the disposed waste.

REFERENCES TO ANNEX II

[II.1] OECD NUCLEAR ENERGY AGENCY, Shallow Land Disposal of Radioactive Waste: Reference Levels for the Acceptance of Long-lived Radionuclides, Report by an NEA Expert Group, OECD, Paris (1987).

[II.2] SAKAMOTO, Y., SENOO, M., SUGIMOTO, M., OHISHI, K., OKISHIO, M. AND SHIMIZU, Survey of the Depth Distribution of Underground Structures for Consideration of Intrusion into TRU Waste Repository, Atomic Energy Society of Japan, Volume 38, No. 6, pp. 442-447, (1996).

[II.3] SKB, Safety Analysis for SFR Long-term Safety. Main Report for the Safety Assessment SR-PSU. Report No. SKB TR-14-01 Revised Edition - Updated 2017-04, SKB, Stockholm (2017).

[II.4] NUKLEAR MALAYSIA, Safety Case Synthesis Report for the Borehole Disposal Project, Report No. NUKLEARMALAYSIA/L/2018/116(S), NMA, Bangi (2018).

[II.5] GHANA ATOMIC ENERGY COMMISSION, Safety Case Report Required for the Implementation of the Borehole Disposal System in Ghana, Draft 1.2, GAEC, Accra, (2018).

[II.6] INTERNATIONAL ATOMIC ENERGY AGENCY, Upgrading of Near Surface Repositories for Radioactive Waste, IAEA Technical Report Series No. 433, IAEA, Vienna (2005).

[II.7] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Considerations in the Disposal of Disused Sealed Radioactive Sources in Borehole Facilities, TECDOC-1368, IAEA, Vienna (2003).

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