

IAEA Safety Standards

for protecting people and the environment

Borehole Disposal Facilities for Radioactive Waste

Specific Safety Guide

No. SSG-1



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

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

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<http://www-ns.iaea.org/standards/>

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

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BOREHOLE DISPOSAL FACILITIES FOR RADIOACTIVE WASTE

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

IAEA SAFETY STANDARDS SERIES No. SSG-1

BOREHOLE DISPOSAL FACILITIES FOR RADIOACTIVE WASTE

SPECIFIC SAFETY GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2009

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Sales and Promotion, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
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fax: +43 1 2600 29302
tel.: +43 1 2600 22417
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FOREWORD

The IAEA's Statute authorizes the Agency to establish safety standards to protect health and minimize danger to life and property — standards which the IAEA must use in its own operations, and which a State can apply by means of its regulatory provisions for nuclear and radiation safety. A comprehensive body of safety standards under regular review, together with the IAEA's assistance in their application, has become a key element in a global safety regime.

In the mid-1990s, a major overhaul of the IAEA's safety standards programme was initiated, with a revised oversight committee structure and a systematic approach to updating the entire corpus of standards. The new standards that have resulted are of a high calibre and reflect best practices in Member States. With the assistance of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its safety standards.

Safety standards are only effective, however, if they are properly applied in practice. The IAEA's safety services — which range in scope from engineering safety, operational safety, and radiation, transport and waste safety to regulatory matters and safety culture in organizations — assist Member States in applying the standards and appraise their effectiveness. These safety services enable valuable insights to be shared and I continue to urge all Member States to make use of them.

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

The IAEA takes seriously the enduring challenge for users and regulators everywhere: that of ensuring a high level of safety in the use of nuclear materials and radiation sources around the world. Their continuing utilization for the benefit of humankind must be managed in a safe manner, and the IAEA safety standards are designed to facilitate the achievement of that goal.

THE IAEA SAFETY STANDARDS

BACKGROUND

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

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

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

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

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

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

THE IAEA SAFETY STANDARDS

The status of the IAEA safety standards derives from the IAEA's Statute, which authorizes the IAEA to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection

of health and minimization of danger to life and property, and to provide for their application.

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

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

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

Safety Fundamentals

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

Safety Requirements

An integrated and consistent set of Safety Requirements establishes the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objective and principles of the Safety Fundamentals. If the requirements are not met, measures must be taken to reach or restore the required level of safety. The format and style of the requirements facilitate their use for the establishment, in a harmonized manner, of a national regulatory framework. The safety requirements use 'shall' statements together with statements of

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

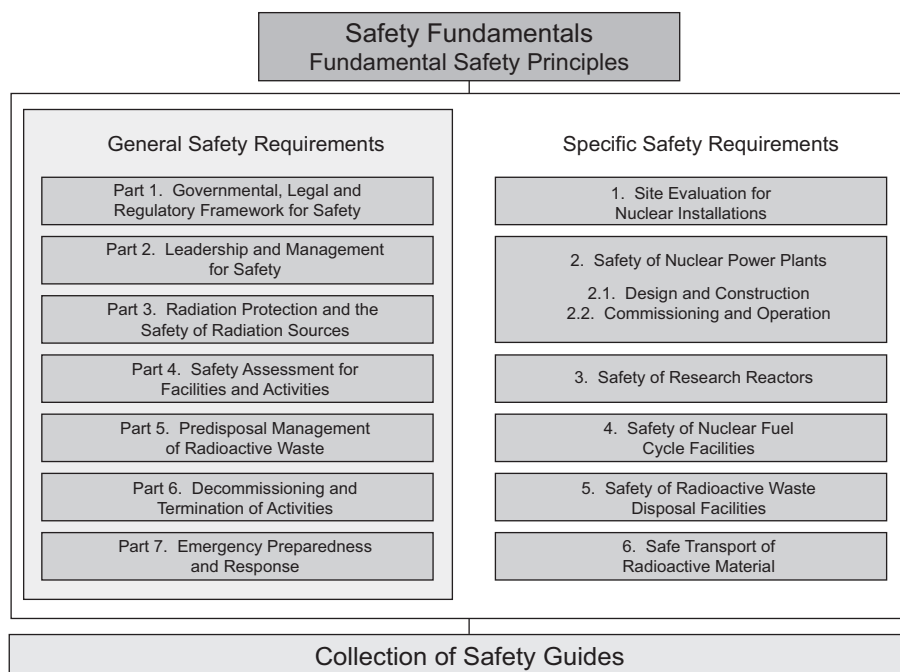


FIG. 1. The long term structure of the IAEA Safety Standards Series.

associated conditions to be met. Many requirements are not addressed to a specific party, the implication being that the appropriate parties are responsible for fulfilling them.

Safety Guides

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures). The Safety Guides present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as ‘should’ statements.

APPLICATION OF THE IAEA SAFETY STANDARDS

The principal users of safety standards in IAEA Member States are regulatory bodies and other relevant national authorities. The IAEA safety

standards are also used by co-sponsoring organizations and by many organizations that design, construct and operate nuclear facilities, as well as organizations involved in the use of radiation and radioactive sources.

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

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

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

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

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

DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

The preparation and review of the safety standards involves the IAEA Secretariat and four safety standards committees, for nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on

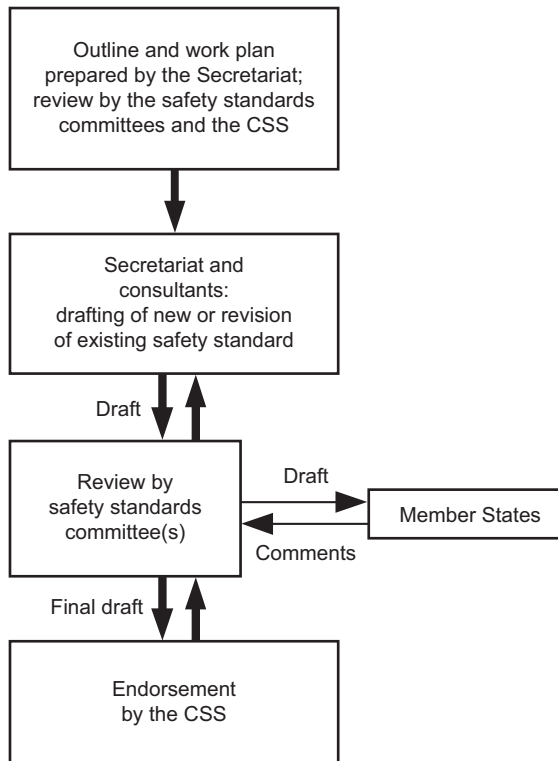


FIG. 2. The process for developing a new safety standard or revising an existing standard.

Safety Standards (CSS) which oversees the IAEA safety standards programme (see Fig. 2).

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

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

INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

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

INTERPRETATION OF THE TEXT

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

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

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

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

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1. INTRODUCTION

BACKGROUND

1.1. The use of radioactive material in nuclear research and in industrial, medical and other applications has led to the generation of small but significant volumes of radioactive waste. Some of this waste (e.g. disused radioactive sources from industrial and medical uses) is intensely radioactive. Consequently, many States now have various types of radioactive waste, all of which need to be managed and disposed of robustly and safely. The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [1] places an obligation on Contracting Parties to control and manage such radioactive waste safely.

1.2. When the activity in waste is relatively low and half-lives are less than about 30 a, near surface disposal will often be suitable. Some waste, however, is too radioactive and too long lived for near surface disposal. Such waste requires higher levels of containment and isolation than can be provided by near surface facilities, implying the need for disposal at greater depths. In States where there is a significant nuclear industry, possibilities for deep disposal may exist or, more often, may be planned. Such States are relatively few in number, however. More often, States have radioactive waste, but lack the possibility of safe disposal for such waste types, or even the prospect of such. For example, radioactive sources used in industry and medicine may be high energy photon emitters that require heavily shielded containers for their safe use, transport and storage. At the end of their useful lifetime, it is possible in some cases to return these sources to their manufacturer for recycling. In many cases though, this is not possible and even though they may be ‘spent’ sources (i.e. no longer radioactive enough for their intended use), they still present a significant hazard. This is evident from a number of incidents and accidents, including fatalities, that have arisen from their misuse [2].

1.3. Where the radionuclides in the waste have relatively short half-lives (e.g. ^{60}Co , half-life 5.3 a) and an activity of less than a few tens of MBq, it may be reasonable to assume that they can safely be placed in a facility, such as a near surface disposal facility, for the ten to twenty half-lives necessary to allow the radioactivity to decay to safe levels. For longer lived and higher activity sources and other waste, however, storage is merely an interim solution that is acceptable only as long as the search continues for a long term solution. One

potential long term solution for such waste is deep disposal in an engineered, cavern type repository.

1.4. An alternative solution is disposal in specially engineered and purpose drilled boreholes (loosely referred to as ‘borehole disposal’ [3]), which offers the prospect of economic disposal on a small scale while, at the same time, meeting all the safety requirements. The comparative ease of borehole construction and site characterization may make this method of disposal particularly suitable for States, or regional groupings of States, that have limited amounts of waste. Disposal in borehole disposal facilities is seen as having particular value for the disposal of disused sealed radioactive sources. As a general rule, however, disused sealed radioactive sources containing materials that may pose hazards to inadvertent intruders or that may be used in radioactive dispersal devices should not be placed in near surface disposal facilities.

1.5. Borehole type facilities have been used in the past in a number of States for the storage and disposal of radioactive waste; all of them are located on existing waste repository sites [3]. In the Russian Federation, for example, there has been more than 40 years of experience with borehole disposal facilities of up to 15 m in depth [4] and new facilities are being planned there [5]. Also, the Greater Confinement Test facility in Nevada, United States of America, has already been used to dispose of waste in boreholes 10 m deep by 3 m in diameter [6]. Examples such as these are considered in this Safety Guide with a view to identifying good practices. There are, however, some cases of questionable practice: concerns have been expressed, for example, over the degree of isolation provided by certain existing borehole disposal facilities in terms of their siting and depth, the reliability and efficiency of the isolation barriers and the adequacy of the associated safety assessments. These concerns highlight the need for guidance on the evaluation of the safety of existing facilities so that decisions can be taken on the necessity for remedial measures.

OBJECTIVE

1.6. The objective of this Safety Guide is to provide guidance on the design, construction, operation and closure of borehole disposal facilities for the disposal of radioactive waste in accordance with the relevant safety requirements [7–9]. The guidance can also be used as a basis for reassessing the safety of existing facilities. Compliance with the safety requirements should provide protection for people and the environment from exposure to ionizing radiation. The safety objectives and associated criteria for borehole disposal

are no less stringent than for geological disposal or near surface disposal. However, because of the relatively small quantities (in terms of both volume and activity) of waste, considerably less effort would be required to meet these objectives and the associated criteria — and to demonstrate that they will be or have been met — than would be the case for the larger scale practices.

1.7. As a practice, the disposal of radioactive waste in borehole disposal facilities falls between the two well-established options of disposal in near surface facilities and disposal in geological facilities. This Safety Guide, therefore, complements both the Safety Guide on near surface disposal [10] and the Safety Guide on geological disposal [11].

1.8. The Safety Guide is intended to support a practical and systematic approach to decision making for borehole disposal such as would be required within the framework of a management system providing for the necessary level of quality (see Appendix VI).

SCOPE

1.9. Existing or proposed borehole disposal facilities exhibit a wide range of diameters and depths, including shafts and small diameter boreholes sunk to various depths. While the present Safety Guide is relevant for all these possibilities, its main focus is on boreholes having a diameter of no more than a few hundred millimetres and a depth beyond a few tens of metres and up to a few hundred metres (i.e. the depth range between near surface disposal and geological disposal).

1.10. While borehole disposal facilities may also be suitable for other types of waste, this Safety Guide concentrates on disused sealed sources and small volumes of low and intermediate level wastes. Throughout this Safety Guide, the term ‘disused sealed sources’ refers to sealed sources that, for whatever reason, have fallen out of use and have been categorized as waste. The typical radionuclides to be found in disused sealed sources are listed in Table 1. It is envisaged that the type of radionuclides and/or waste for which borehole disposal is most likely to be suitable would need to be:

- (a) Too long lived for decay storage (e.g. a half-life greater than a few years);
- (b) Too long lived and/or too radioactive to be placed in a simple near surface facility;
- (c) Small volume waste for which no other disposal facility is available.

TABLE 1. TYPICAL RADIONUCLIDES PRESENT IN DISUSED SEALED SOURCES

Radionuclide	Half-life	Maximum expected activity (MBq)	Application
<100 d			
Au-198	2.7 d	1.5E3	Manual brachytherapy
Y-90	2.7 d	5E2	Manual brachytherapy
I-131	8.0 d	1.5E3	Manual brachytherapy
P-32	14.3 d	2E2	Vascular brachytherapy
Pd-103	17.0 d	1.5E3	Manual brachytherapy
Sr-89	50.5 d	1.5E2	Vascular brachytherapy
I-125	60.0 d	1E4	Bone dosimetry
Ir-192	74.0 d	5E6	Industrial radiography
100 d to ≤30 a			
Po-210	138.0 d		Static electricity eliminators
Gd-153	242.0 d		Bone dosimetry
Co-57	271.7 d	5E5	Markers
Ru-106	1.0 a	5E4	Manual brachytherapy
Cf-252	2.6 a	5E3	Calibration facilities
Pm-147	2.6 a	5E5	Sources as standards in instruments
Co-60	5.3 a	5E4	Sterilization and food preservation
Kr-85	10.8 a		Thickness gauges
H-3	12.3 a	5E6	Tritium targets
Sr-90	29.0 a	5E4	Thickness gauges
Cs-137	30.1 a	5E5	Sterilization and food preservation

TABLE 1. TYPICAL RADIONUCLIDES PRESENT IN DISUSED SEALED SOURCES (cont.)

Radionuclide	Half-life	Maximum expected activity (MBq)	Application
	>30 a		
Pu-238	87.7 a	3.7E3	Static electricity eliminators
Ni-63	100 a	5E2	Electron capture detectors
Am-241/Be	433 a	8E5	Well logging, fire detection
Ra-226	1600 a	3.7E3	Manual brachytherapy
C-14	5700 a		
Cl-36	3E5 a	4.00	Sources as standards in instruments
I-129	1.6E7 a	4.00	Sources as standards in instruments

1.11. Consideration is given to operational safety, the security of the waste and the achievement of post-closure safety. It is recognized that, while radiological safety is of paramount importance, it is only part of a broader context that includes planning, financial, economic and social issues, and non-radiological safety. These other issues are not specifically covered in this Safety Guide.

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

STRUCTURE

1.13. In this Safety Guide, the background to, concept of, and protection and safety objectives for, borehole disposal are set out in Sections 1–3. Recommendations on how to apply the relevant safety requirements to borehole disposal are provided in Sections 4 and 5. Section 6 describes the application of the safety strategy to existing borehole disposal facilities.

2. BOREHOLE DISPOSAL AND THE SAFETY OF RADIOACTIVE WASTE MANAGEMENT

BOREHOLE DISPOSAL CONCEPT

2.1. The borehole disposal concept (shown schematically in Fig. 1) entails the emplacement of disused sealed radioactive sources and small volumes of low and intermediate level wastes in an engineered facility bored or drilled and operated directly from the surface. In this Safety Guide, borehole disposal is envisaged mainly as a small scale activity that can be carried out without a large programme of scientific and site investigation.

2.2. In this Safety Guide, a depth of 30 m is used to differentiate between near surface disposal and disposal at intermediate and greater depths. This depth is widely accepted as the lower level of the ‘normal residential intrusion zone’ (i.e. a depth beyond which human intrusion is limited to drilling and significant excavation activities, such as tunnelling, quarrying and mining) [12]. In applying this distinction, the key parameter is not the maximum depth of the borehole but, rather, the minimum depth at which waste is located within the

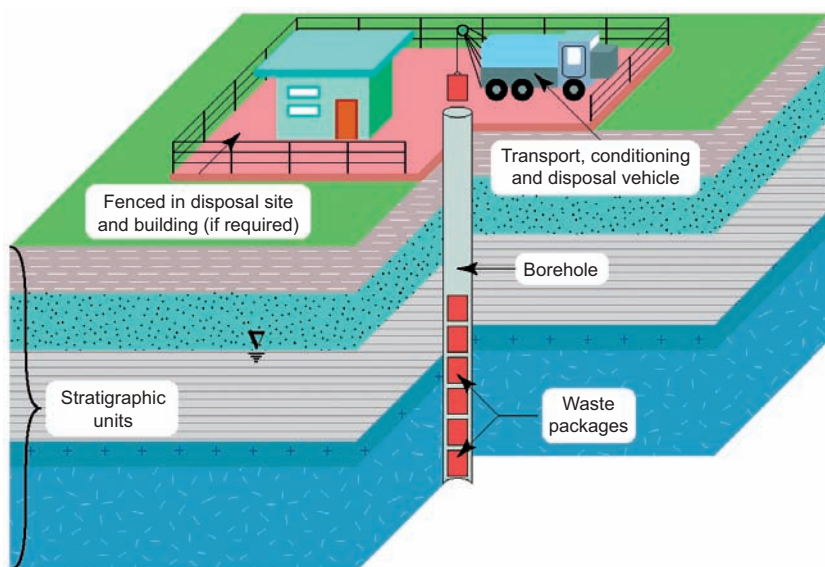


FIG. 1. Schematic layout of a borehole disposal facility.

borehole. So, even if a borehole is several hundred metres deep, if the column of waste within it extends to less than 30 m below the surface, the borehole will be considered to be a near surface disposal facility. If all the waste is located at a depth that exceeds 30 m below the surface, it will be referred to as an intermediate depth disposal facility.

2.3. From a safety perspective, borehole disposal is not conceptually different from either near surface disposal or geological disposal of radioactive waste. Indeed, because the range of depths accessed by borehole disposal approaches the depths normally associated with both near surface disposal and geological disposal, consideration is given to elements of both. As for near surface disposal and geological disposal, a combination of natural barriers and engineered barriers contribute to safety for borehole disposal. In combination, these barriers are designed to contain radioactive material until it has decayed to insignificant levels, and to provide sufficient isolation and containment to ensure an adequate level of protection for people and the environment.

APPLYING THE SAFETY PRINCIPLES IN RADIOACTIVE WASTE MANAGEMENT

2.4. The safety principles applicable to all facilities and activities, including waste disposal activities, are established in the Fundamental Safety Principles [13]. Because borehole disposal facilities are used to dispose of waste at a range of depths, from depths associated with near surface disposal to depths approaching those associated with geological disposal, and because of the nature of the waste intended for disposal, guidance needs to be provided on how the safety requirements for both geological disposal [8] and near surface disposal [9] can be met for these facilities.

2.5. The graded application of the safety requirements for near surface disposal and geological disposal to borehole disposal will ensure an adequate level of safety. In all cases, reasonable assurance of safety should be demonstrated to the regulatory body and to other stakeholders. However, the level of effort required to comply with these safety requirements for a facility with a relatively small inventory of radionuclides will generally be significantly less than for large scale repositories in terms of safety assessment, site characterization and facility construction, operation and closure. The use of generic safety assessment, which could assist in the assessment of particular sites, to facilitate safety assessment for borehole disposal facilities is discussed in paras 5.7–5.9.

3. BOREHOLE DISPOSAL AND THE PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

RADIATION PROTECTION DURING THE OPERATIONAL PERIOD

3.1. The objective for radiation protection during the operational period of a borehole disposal facility and the related safety criteria are the same as for any licensed nuclear facility and are as required by the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (BSS) [7] (see Box 1). In radiation protection terms, the source is under control, releases can be verified, exposures can be controlled and actions can be taken if needed. Optimization of radiation protection is the primary goal (application of principle 5 of Ref. [13]). See also under the heading ‘Objective’ in Box 2.

3.2. Only very minor releases of radionuclides (such as small amounts of gaseous radionuclides) may be expected during pre-disposal activities and during the operation of a borehole disposal facility. The design should be such that, even in the event of an accident involving the breach of a waste package, releases are not likely to have any impact outside the facility. Relevant considerations should include the packaging, the waste form, the radionuclide content of the waste and control of contamination on packages and equipment.

3.3. A radiological protection programme should be in place during the operational period. This should ensure that doses to workers are controlled and that the requirements for dose limitation are met [14, 15]. In addition, contingency measures should be in place to deal with accidents and incidents so that any associated radiation hazards are controlled to the extent possible. This is described more fully in paras 5.39–5.59, which deal with the operation of the disposal facility.

3.4. Doses and risks associated with the transport of radioactive waste to the borehole disposal facility should be managed in the same way as those associated with the transport of other radioactive material. Of particular importance in this respect are external dose rates and contamination of waste packages (or any overpack used during transport). Transport safety is achieved by complying with the requirements of the Regulations for the Safe Transport of Radioactive Material [16].

Box 1: Radiation protection in the operational period

Requirement [7]

The radiation doses and risks to workers and members of the public exposed as a result of operations at the borehole disposal facility are required to be kept as low as reasonably achievable, economic and social factors being taken into account, and the exposures of individuals are required to be kept within applicable dose limits.

Criteria

Radiation dose limits and constraints for workers and for members of the public are set out in Schedule II of the Basic Safety Standards [7]. This publication in particular specifies that:

- (a) “The occupational exposure of any worker shall be so controlled that the following limits be not exceeded:
 - an effective dose of 20 mSv per year averaged over five consecutive years;
 - an effective dose of 50 mSv in any single year” (Sche-II, para. II-5, Ref. [7]).
- (b) “The estimated average doses to the relevant critical groups of members of the public that are attributable to practices shall not exceed the following limit:
 - an effective dose of 1 mSv in a year” (Sche-II, para. II-8, Ref. [7]).

Members of the public could receive exposures from a number of practices and sources. To comply with the above limit, a “facility [such as a borehole disposal facility] (considered as a single source) is designed [and operated] so that the estimated average dose or average risk to members of the public who may be exposed in the future as a result of activities involving the disposal facility does not exceed a dose constraint of not more than 0.3 mSv in a year or a risk constraint of the order of 10^{-5} per year^a” [8] (according to the models and assumptions recommended by the International Commission on Radiological Protection (ICRP)).

^a Risk in this context is to be understood as the probability of death or serious hereditary disease.

Box 2: Radiation protection in the post-closure period [7, 8, 18]

Objective

“[Borehole] disposal facilities are to be sited, designed, constructed, operated and closed so that protection in the post-closure period is optimized, social and economic factors being taken into account, and an assurance is provided that doses or risks to members of the public in the long term will not exceed the applicable dose or risk that was used as a design constraint”[8].

Criteria

“The dose limit for members of the public from all practices is an effective dose of 1 mSv in a year [7], and this or its risk equivalent is considered a criterion not to be exceeded in the future. To comply with this limit, a [borehole] disposal facility (considered as a single source) is designed so that the estimated average dose or average risk to members of the public who may be exposed in the future as a result of activities involving the disposal facility does not exceed a dose constraint of not more than 0.3 mSv in a year or a risk constraint of the order of 10^{-5} per year^a”[8].

In relation to the effects of human intrusion in the post-closure period, ICRP-81 [18] recommends that, if human intrusion is expected to lead to an annual dose of less than about 10 mSv per year to those living around the site, efforts to reduce the probability of human intrusion or to limit its consequences are not likely to be justifiable. If human intrusion is expected to lead to an annual dose of more than about 100 mSv per year to those living around the site, then it is almost always justifiable to make reasonable efforts at the stage of development of the facility to reduce the probability of human intrusion or to limit its consequences. Similar considerations apply where the thresholds for deterministic human health effects in relevant organs are exceeded. This recommendation of ICRP-81 [18] is not accepted by all regulatory bodies, however.

“It is recognized that radiation doses to individuals in the future can only be estimated and that the uncertainties associated with these estimates will increase for times further into the future. Care needs to be exercised in using the criteria beyond the time where the uncertainties become so large that the criteria may no longer serve as a reasonable basis for decision making”[8].

^a Risk in this context is understood as the probability of death or serious hereditary disease.

RADIATION PROTECTION FOR THE POST-CLOSURE PERIOD

3.5. The primary goal of borehole disposal is to dispose of radioactive waste in a manner that protects human health and the environment in the long term, after the borehole disposal facility has been closed. In accordance with the BSS [7], this is achieved by means of design features that result in optimizing doses due to any migration of radionuclides from the facility while also complying with the dose constraints (see Box 2). It is recognized, however, that radiation doses and risks to individuals living in the distant future can only be estimated and the reliability of these estimates will decrease as the time period extending into the future increases (see paras III.2–III.11 of Appendix III). In this context, the optimization of protection is a judgemental process in which social and economic factors need to be taken into account, and it needs to be conducted in a structured but essentially qualitative way, supported by quantitative analysis. Optimization of protection in the post-closure period is explained further in para. 4.38.

3.6. A well-designed and well-located borehole disposal facility should provide reasonable assurance that radiological impacts in the post-closure period will be low both in absolute terms and in comparison with any other waste management options that are currently available at reasonable cost. A site should be identified that provides favourable conditions for containment and isolation of the waste from the biosphere and for preservation of the engineered barriers (e.g. with low groundwater flow and a benign geochemical environment). The borehole disposal facility should be designed to take account of the characteristics offered by the site, to optimize protection and to keep doses within the dose and/or risk constraints. The borehole disposal facility should then be constructed, operated and closed according to the assessed design so that the assumed safety characteristics of both the engineered and the natural barriers are realized.

3.7. In estimating the doses to individuals living in the future, it is assumed that humans will make use of local resources that may contain radionuclides that originate from the waste. The representation of future human behaviour in assessment models must necessarily be stylized, as it is not possible to predict future human behaviour with any certainty. The rationale and the possible approaches to the modelling of the biosphere and the estimation of doses arising as a result of the disposal of solid waste have been considered within the IAEA BIOMASS Project [17] (see Appendix III). In summary, Ref. [17] presents a methodology for the logical and defensible construction of ‘assessment biospheres’ (i.e. mathematical representations of biospheres used

in the total system performance assessment for radioactive waste disposal). Reference [17] also presents a series of example reference biospheres: stylized assessment biospheres that, in addition to illustrating the methodology, are intended to be useful assessment tools in their own right.

3.8. Evaluating whether or not the design will provide an optimized level of protection may require a judgement in which other factors will be considered. These factors may include, for example, the quality of the design and of the assessment and the presence of significant qualitative or quantitative uncertainties in the calculation of long term exposures. In general, when irreducible uncertainties make the results of safety assessment calculations less reliable, then comparison with dose or risk constraints should be treated with caution. For a borehole disposal facility, such circumstances are likely to apply when considering:

- (a) Design evolution (see definition in Appendix III) at very distant times in the future;
- (b) Very low frequency natural events;
- (c) Human intrusion events.

3.9. With respect to para. 3.8(a), it is recognized that there is an irreducible uncertainty associated with dose calculations for individuals living far into the future and this uncertainty will increase as the assessment time frame¹ increases. Sometimes, the assessment time frame is specified by the regulatory body; more often it defaults to a time longer than that required to reach peak dose. In the case of geological disposal, assessment time frames of a million years are not uncommon. However, where the wastes to be disposed of in a borehole disposal facility are fairly short lived (i.e. a few tens of years), the assessment time frame could also be relatively short (up to some hundreds of years), thereby diminishing the uncertainty associated with the calculations.

3.10. Very low frequency natural events could degrade the borehole disposal facility barriers, leading to the release of radionuclides to the environment and the exposure of humans to radiation. In circumstances where there is a significant uncertainty associated with the occurrence of an event or process and the consequent exposures, the level of safety is best demonstrated by separate consideration of the probability of occurrence and the potential

¹ The assessment time frame is the time period used in the calculations for the post-closure performance assessment.

magnitude of exposures. In these situations, the treatment of exposures far into the future is considered conceptually similar to potential exposure situations and can be treated in a similar manner [18, 19]. Again, as far as boreholes are concerned, the relatively short half-life of typical waste envisaged for disposal and the consequently shorter assessment time frame will tend to diminish the significance of very low frequency natural events.

3.11. In the event of inadvertent human intrusion into a borehole disposal facility, a few individuals who take part in activities such as drilling or excavating into the facility could receive high doses. The doses and risks to these individuals should be estimated but, according to the latest ICRP recommendations [18], they need not be a deciding factor in assessing the safety and acceptability of the facility. The doses and consequences of such intrusion should be estimated in order to evaluate and determine the appropriate measures (administrative and physical) necessary to prevent intrusion or to mitigate its consequences. Once it is determined that the disposal system includes appropriate deterrents to intrusion commensurate with the safety requirements and the potential consequences of such intrusion, the dose estimates for an intruder need not be used further. The borehole disposal system has a number of inherent features that reduce the likelihood and the consequences of intrusion. These include:

- (a) The low probability of occurrence;
- (b) The fact that the individuals would be few in number;
- (c) The possibility for such individuals to receive appropriate decontamination and medical treatment;
- (d) The fact that such hazards may be comparable with other occupational risks;
- (e) The possibility that, while doses received due to inadvertent intrusion could be high, the associated risk may be outweighed by the higher level of long term protection afforded by borehole disposal, in comparison with other strategies.

It should be noted, however, that these particular ICRP recommendations are not accepted by all regulatory bodies. Where these recommendations are not accepted, the consequences for the intruders of human intrusion will also need to be addressed.

3.12. A more significant consequence of intrusion is the possibility that it could disrupt the engineered barriers and cause long term harmful consequences for people living in the vicinity of the borehole. In this case, protection is best

achieved by means of efforts to reduce the probability of such events. One option is to assess the consequences of human intrusion, for which one or two stylized human intrusion scenarios should be evaluated using the criteria described in Box 1 [18]. Other approaches to assessing the consequences of human intrusion may also be acceptable.

3.13. The small ‘footprint’ of a borehole disposal facility will help to reduce the probability of human intrusion and this can be reduced still further by increasing the depth and length of the disposal zone. Siting of the facility away from known mineral and water resources will also decrease the likelihood of human intrusion. Over shorter timescales, actions such as preserving records, placing restrictions on land use, placing warning signs and maintaining passive institutional control should also help to reduce the incidence of such events.

ENVIRONMENTAL AND NON-RADIOLOGICAL CONCERNS

3.14. In this section, the protection of the environment from the radioactive material in the borehole disposal facility, especially over the long term, is considered. An important additional consideration is the potential impact of non-radioactive substances in the borehole disposal facility. Other, more conventional, environmental impacts, for example, traffic, noise, visual amenity, disturbance of natural habitats and restrictions on land use, together with social and economic factors, may well be subject to regulatory approval, but these fall outside the scope of this Safety Guide.

3.15. In the past, it has been assumed that, subject to appropriate definition of exposed groups, the protection of humans against the radiological hazards associated with a borehole disposal facility would also satisfy the need to protect the environment [19]. The need to consider the protection of the environment against ionizing radiation and possible protection standards is currently under discussion internationally (see, for example, Ref. [20]) and developments are to be expected in this area. It is likely, nonetheless, that in most circumstances the protection of humans will also protect the environment. However, the expectation is that, in future, methodologies for the assessment of doses to other species will allow this to be demonstrated explicitly [21].

3.16. Consequently, while recognizing that estimates of future human doses/risks due to future releases from a borehole disposal facility may serve as indicators of environmental protection, additional indicators that do not rely

on assumptions about human habits may also prove valuable. These indicators could include, for example, comparisons of repository derived radionuclide concentrations in environmental media with natural radionuclide concentrations and comparisons of radionuclide fluxes from a repository with fluxes from naturally radioactive mineralization [22].

3.17. The impact of non-radioactive materials present in a borehole disposal facility should also be assessed. Factors that should be considered may include the content of chemically or biologically toxic materials in the waste or in the engineered barrier materials, the protection of groundwater resources and the ecological sensitivity of the environment into which contaminants may be released. For example, if disused sealed sources were to be disposed of together with their lead shielding, safety assessments would need to examine the potential migration of the lead.

4. SAFETY IN THE PLANNING OF NEW BOREHOLE DISPOSAL FACILITIES

GENERAL

4.1. This section provides guidance on how, for a new borehole disposal facility, the predisposal activities may be organized to deliver the required operational and post-closure safety (i.e. how the protection requirements and associated criteria specified and discussed in Section 3 may be satisfied).

4.2. The guidance is set out under four main headings: (i) legal and organizational framework, (ii) safety approach, (iii) safety design principles and (iv) security.

LEGAL AND ORGANIZATIONAL FRAMEWORK

4.3. The discussion of the legal and organizational framework is subdivided into the responsibilities of government, regulatory bodies ('the regulatory body'), facility developers and operators or would-be operators ('the operator') and waste generators. The overall aim is that the safety and security of potential radioactive waste should be provided for at all stages of waste

management from creation through to disposal. Particular attention should be given to the issues of the appropriate legal and regulatory framework and the allocation of adequate financial resources. Funds will be required for disposal and for regulatory review and assessment. Consideration should be given as to when and how financial and legal responsibilities for the waste might pass from one body to another.

Government responsibilities

4.4. General requirements for establishing a national system for radioactive waste management are set out in Ref. [23]. In addition to the development of the necessary technical and operational capability, ensuring the safe management of radioactive waste requires relevant laws and regulations, a regulatory body that is independent of the operator, and a regulatory process that defines the steps to be taken in the licensing and development of the facility. Legislation should require a demonstration of safety and should require that the demonstration be independently reviewed by the regulatory body. Such provision is a principle of the Safety Fundamentals [13], is also required under the terms of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [1] and is a requirement for government responsibility for geological disposal established in Ref. [8].

4.5. The effort required under the legal and regulatory arrangements for controlling radioactive waste disposal in boreholes should reflect the potential hazard represented by the waste. Where small scale disposal of disused sealed radioactive sources is envisaged, the extent and complexity of the legal and regulatory arrangements should be commensurate. Matters that should be considered in the formulation of a national policy for radioactive waste management include the following:

- (a) The early establishment of a comprehensive national inventory of radioactive waste will help to ensure that the resources and the facilities envisaged to deal with the waste will be adequate so that, for instance, late design changes are not introduced to cope with initially unforeseen waste. In general, it is the amount (i.e. volume, activity) and nature (e.g. half-life and physicochemical properties) of the inventory that should largely determine the resources needed for its disposal.
- (b) The definition of the overall process for the development of borehole disposal facilities should clearly specify the legal (e.g. licensing) requirements at each step (see para. 5.1).

- (c) The means of making the necessary scientific and technical expertise available to both the operator and the regulatory body should be considered. For instance, the government may require the national institutes for geology and hydrology to maintain or develop competence in this field so that they can give support to the regulatory body.
- (d) The interdependences between the various steps in the waste management process should be considered so that, overall, the safety and the effectiveness of radioactive waste management are balanced.

4.6. The national policy and regulations should include the establishment of an operator with appropriate duties and responsibilities. This may, for instance, be a government department that then designates or subcontracts an expert body (or bodies) to design, build and operate the required facilities.

Responsibilities of the regulatory body

4.7. The regulatory body should advise the government on the necessity for, and the effectiveness of, the national policy for radioactive waste management and should provide assistance in its updating and improvement.

4.8. As with any other practice for radioactive waste disposal, the regulatory body should establish regulatory arrangements for borehole disposal facilities (see, for example, the requirements for regulatory body responsibility for geological disposal established in Ref. [8]). The regulatory arrangements should be established after consultation with all interested parties and they should be settled well in advance of any licence application. The arrangements should cover all stages of the development process for the facility, specifying the principles, requirements and criteria that will be used to regulate the practice and stating what should happen in the event of non-compliance. The arrangements should also cover more general issues such as:

- (a) Clearance levels for waste with very low levels of radioactivity and the arrangements for regulating the release of such material [24];
- (b) Regulatory approval of storage of radioactive waste prior to disposal;
- (c) Licensing of borehole disposal at an existing radioactive waste disposal facility.

4.9. The regulatory body should also provide guidance on the implementation of the regulations, on the procedures that the operator is expected to follow in terms of licence applications and safety case submissions, on the timescales likely to be required for consideration of the licence application, and on the

likely duration of any period of institutional control. While the regulatory arrangements should be comprehensive, they should also be commensurate with the scale and potential hazard of the facilities under regulatory control.

4.10. A licence for construction and operation of the facility will be issued only when, following regulatory review and assessment of the licence application, there is reasonable assurance that the safety requirements will be met and it is clear that funds are, or will be, available to finance the programme through all its stages (i.e. construction, operation, closure and any planned post-closure institutional control period). As explained in para. 5.1, a step by step approach to licensing and implementation should clarify the decision making process and highlight the key issues that will influence the various decisions. The licence application at each step should describe, as far as is known, the entire disposal programme so that early steps in the disposal programme can be seen to be compatible with later steps.

4.11. It is good practice for the licence to have sufficient flexibility to accommodate, through a change control process, unforeseen changes (e.g. in design) made as a result of improved knowledge. The conditions under which the operator can make changes without needing to apply to the regulatory body for permission should be specified in the licence. The burden imposed by the change control process should be commensurate with the size of the potential hazard.

4.12. Independent regulatory review and evaluation of the safety case (see paras 5.12 and 5.13) may vary considerably depending on the existing national regulatory practice, the potential hazard of the waste and the stage reached in the development process of the facility. The regulatory body should ensure that it has the independent capability to carry out the review and evaluation of the safety case that is needed to determine whether the facility will be safe and what conditions of authorization should be specified in the licence. This may be undertaken in various ways, such as by consultation with independent experts, by collaboration with other States that are using similar processes and by the use of generic safety assessment.

4.13. When it is envisaged that a disposal facility will remain in operation for some years, with new boreholes being added from time to time, safety should be reassessed periodically. Alternatively, the licence could approve the site but require that each new tranche of boreholes be licensed separately. This would allow the regulatory body formally to reassess safety as operation of the site yields new data and as safety standards are developed. Either way,

requirements for the reassessment of safety should be made clear early in the development process for the facility.

4.14. The regulatory body should ensure that the operator exercises adequate control at all stages in the development of the borehole disposal facility. A regulatory inspection plan should be developed for activities important to safety, such as construction, operation and closure. The regulatory inspections will help to ensure compliance with the licence and the operational procedures (e.g. acceptability of waste packages and their satisfactory emplacement). Appendix I provides an example of a regulatory inspection plan for a borehole disposal facility. When non-compliances are discovered, the actions required by the regulatory body should reflect the safety significance of the non-compliance. Very serious cases should result in activities at the site being restricted or curtailed. Minor breaches may simply require remedial action.

4.15. In some States, it is normal for borehole or surface disposal facilities that have been closed to be periodically reassessed for safety in the light of monitoring results and such good practice should be adopted.

Operator responsibilities

4.16. The requirements for operator responsibility for geological disposal established in Ref. [8] place an obligation on the operator to develop a disposal facility that is both practicable and safe and to demonstrate its safety in compliance with regulatory requirements. In some cases, this may include collection of the waste at the waste generators' premises and its transport to the disposal site. In meeting this obligation, the operator should take into consideration the characteristics and quantities of disused sealed sources that are radioactive and other radioactive waste to be disposed of, the transport infrastructure, the sites available, the drilling and engineering techniques available, research needs and the national legal framework and regulatory requirements. Where the operator employs contractors to perform the work, the operator is responsible for ensuring that they also comply with the regulatory requirements.

4.17. The operator is charged in particular with the responsibility for preparing and submitting to the regulatory body a safety case (see paras 5.2–5.13) on which decisions about the development of the disposal facility can be based. Borehole construction should not proceed until a licence has been granted.

4.18. The operator should be responsible for conducting or commissioning the research and development needed to support the feasibility and safety of the facility design. This should include site investigations. The operator also has the responsibility for carrying out or commissioning all the investigations of sites and materials necessary to assess their suitability and to provide data for safety assessments. In the case of borehole disposal facilities, it is envisaged that the designs will rely almost entirely on tried and tested materials and working practices. This will largely confine research to desk studies and will shift the emphasis of the work towards demonstrations of the operability of the design and the suitability of the site.

4.19. The operator should establish and set limits, controls and conditions (e.g. technical specifications) derived from the safety assessments to ensure that the disposal facility is developed and operated in accordance with both the safety case and the licence conditions. This will require the recruitment and training of suitably qualified staff, the exercise of due control over the receipt, transport and emplacement of waste (e.g. waste acceptance criteria, see para. 5.60), and the implementation of appropriate security measures. Any changes to the design or operation of the facility that may have a potential impact on safety should be subject to a change control process (see para. 4.11).

4.20. The operator should retain all the information relevant to the safety case, the supporting safety assessments for the disposal facility and the inspection records that show compliance with regulatory requirements and the operator's own specification, at least up until the information is superseded or responsibility for the disposal facility is passed to some other appointed agency (e.g. at closure). When this responsibility is transferred, the operator should hand over all the information that is relevant to the safety of the facility. The operator should also cooperate with the regulatory body and supply all the information that the regulatory body may require to fulfil its responsibilities. The operator should report to the regulatory body on a regular basis and should report on non-compliances as they occur.

4.21. The operator should take full responsibility for the waste upon receipt. The operator should also have the responsibility for verifying that the waste is fully and correctly described in the accompanying documentation. The description may include the dose rate at the surface of the package and at 1 m distance, as well as details of removable surface contamination, volume, mass and physical status, and chemical and radionuclide composition of the waste.