IAEA Safety Standards

for protecting people and the environment

Geological Disposal of Radioactive Waste

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Safety Requirements

No. WS-R-4

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International Atomic Energy Agency

IAEA SAFETY RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

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

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, and also general safety (i.e. all these areas of safety). The publication categories in the series are **Safety Fundamentals, Safety Requirements** and **Safety Guides**.

Safety standards are coded according to their coverage: nuclear safety (NS), radiation safety (RS), transport safety (TS), waste safety (WS) and general safety (GS).

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

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 P.O. Box 100, A-1400 Vienna, Austria.

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

OTHER SAFETY RELATED PUBLICATIONS

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

Reports on safety and protection in nuclear activities are issued in other publications series, in particular the **Safety Reports Series**. Safety Reports provide practical examples and detailed methods that can be used in support of the safety standards. Other IAEA series of safety related publications are the **Provision for the Application of Safety Standards Series**, the **Radiological Assessment Reports Series** and the International Nuclear Safety Group's **INSAG Series**. The IAEA also issues reports on radiological accidents and other special publications.

Safety related publications are also issued in the **Technical Reports Series**, the **IAEA-TECDOC Series**, the **Training Course Series** and the **IAEA Services Series**, and as **Practical Radiation Safety Manuals** and **Practical Radiation Technical Manuals**. Security related publications are issued in the **IAEA Nuclear Security Series**.

GEOLOGICAL DISPOSAL OF
RADIOACTIVE WASTE

IAEA SAFETY STANDARDS SERIES No. WS-R-4

GEOLOGICAL DISPOSAL OF RADIOACTIVE WASTE

SAFETY REQUIREMENTS

JOINTLY SPONSORED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

by Mohamed ElBaradei
Director General

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.

PREFACE

Radioactive waste arises from the generation of nuclear power and the use of radioactive material in medicine, industry, agriculture, research and education. The importance of the safe management of radioactive waste for the protection of human health and the environment has long been recognized and considerable experience has been gained in this field.

This Safety Requirements publication establishes requirements relating to the disposal of radioactive waste in geological disposal facilities. It sets out the objective and criteria for the protection of human health and the environment during the operation of geological disposal facilities and after such facilities are closed, and establishes the requirements for ensuring their safety. Failure to meet any of the requirements would require an action to be taken to provide for safety.

The safety requirements are derived from the IAEA Safety Fundamentals publications on The Principles of Radioactive Waste Management (Safety Series No. 111-F (1995)) and Radiation Protection and the Safety of Radiation Sources (Safety Series No. 120 (1996)), as well as international experience in the development of geological disposal facilities.

This Safety Requirements publication does not reiterate the requirements in respect of legal and governmental infrastructure, radiation protection and emergency planning that are established in other Safety Requirements publications. It is based on the premise that, in general, arrangements will be in place to ensure that these requirements are met.

It does establish some requirements closely related to these thematic areas that are of particular importance to the safety of geological disposal facilities. Guidance on the fulfilment of these requirements will be provided in a Safety Guide. This publication supersedes the IAEA publication on Safety Principles and Technical Criteria for the Underground Disposal of High Level Radioactive Wastes (Safety Series No. 99 (1989)).

This publication is jointly sponsored with the OECD Nuclear Energy Agency (OECD/NEA). The IAEA and the OECD/NEA wish to express their appreciation to all those who assisted in the drafting and review of this publication.

IAEA SAFETY STANDARDS

SAFETY THROUGH INTERNATIONAL STANDARDS

While safety is a national responsibility, international standards and approaches to safety promote consistency, help to provide assurance that nuclear and radiation related technologies are used safely, and facilitate international technical cooperation, commerce and trade.

The standards also provide support for States in meeting their international obligations. One general international obligation is that a State must not pursue activities that cause damage in another State. More specific obligations on Contracting States are set out in international safety related conventions. The internationally agreed IAEA safety standards provide the basis for States to demonstrate that they are meeting these obligations.

THE IAEA STANDARDS

The IAEA safety standards have a status derived from the IAEA's Statute, which authorizes the Agency to establish standards of safety for nuclear and radiation related facilities and activities and to provide for their application.

The safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment.

They are issued in the IAEA Safety Standards Series, which has three categories:

Safety Fundamentals

— Presenting the objectives, concepts and principles of protection and safety and providing the basis for the safety requirements.

Safety Requirements

— Establishing the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements, which are expressed as 'shall' statements, are governed by the objectives, concepts and principles of the Safety Fundamentals. If they are not met, measures must be taken to reach or restore the required level of safety. The Safety Requirements use regulatory language to enable them to be incorporated into national laws and regulations.

Safety Guides

— Providing recommendations and guidance on how to comply with the Safety Requirements. Recommendations in the Safety Guides are expressed as 'should' statements. It is recommended to take the measures stated 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. Each Safety Requirements publication is supplemented by a number of Safety Guides, which can be used in developing national regulatory guides.

The IAEA safety standards need to be complemented by industry standards and must be implemented within appropriate national regulatory infrastructures to be fully effective. The IAEA produces a wide range of technical publications to help States in developing these national standards and infrastructures.

MAIN USERS OF THE STANDARDS

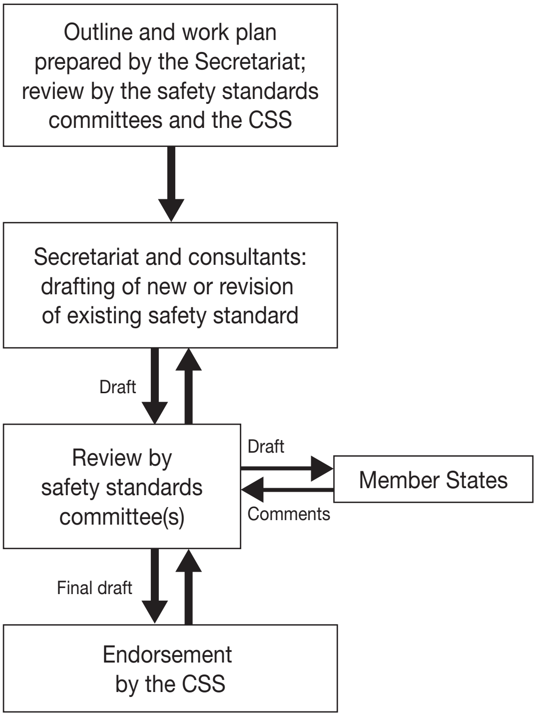
As well as by regulatory bodies and governmental departments, authorities and agencies, the standards are used by authorities and operating organizations in the nuclear industry; by organizations that design, manufacture for and apply nuclear and radiation related technologies, including operating organizations of facilities of various types; by users and others involved with radiation and radioactive material in medicine, industry, agriculture, research and education; and by engineers, scientists, technicians and other specialists. The standards are used by the IAEA itself in its safety reviews and for developing education and training courses.

DEVELOPMENT PROCESS FOR THE STANDARDS

The preparation and review of safety standards involves the IAEA Secretariat and four safety standards committees for safety in the areas of nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on Safety Standards (CSS), which oversees the entire safety standards programme. All IAEA Member States may nominate experts for the safety standards committees and may provide comments on draft standards. The membership of the CSS is appointed by the Director General and includes senior government officials having responsibility for establishing national standards.

For Safety Fundamentals and Safety Requirements, the drafts endorsed by the Commission are submitted to the IAEA Board of Governors for approval for publication. Safety Guides are published on the approval of the Director General.

Through this process the standards come to represent a consensus view of the IAEA's Member States. 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 standards. Some 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 International



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

Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization.

The safety standards are kept up to date: five years after publication they are reviewed to determine whether revision is necessary.

APPLICATION AND SCOPE OF THE STANDARDS

The IAEA Statute makes the safety standards binding on the IAEA in relation to its own operations and on States in relation to operations assisted by the IAEA. Any State wishing to enter into an agreement with the IAEA concerning any form of Agency assistance is required to comply with the requirements of the safety standards that pertain to the activities covered by the agreement.

International conventions also contain similar requirements to those in the safety standards, and make them binding on contracting parties. The Safety Fundamentals were used as the basis for the development of the Convention on Nuclear Safety and the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. The Safety

Requirements on Preparedness and Response for a Nuclear or Radiological Emergency reflect the obligations on States under the Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency.

The safety standards, incorporated into national legislation and regulations and supplemented by international conventions and detailed national requirements, establish a basis for protecting people and the environment. However, there will also be special aspects of safety that need to be assessed case by case at the national level. For example, many of the safety standards, particularly those addressing planning or design aspects of safety, are intended to apply primarily to new facilities and activities. The requirements and recommendations specified in the IAEA safety standards might not be fully met at some facilities built to earlier standards. The way in which the safety standards are to be applied to such facilities is a decision for individual States.

INTERPRETATION OF THE TEXT

The safety standards use the form 'shall' in establishing international consensus requirements, responsibilities and obligations. Many requirements are not addressed to a specific party, the implication being that the appropriate party or parties should be responsible for fulfilling them. Recommendations are expressed as 'should' statements in the main text (body text and appendices), indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures) for complying with the requirements.

Safety related terms are to be interpreted as stated in the IAEA Safety Glossary (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 within the 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 main text, is included in support of statements in the main text, or describes methods of calculation, experimental 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 standard. Material in an appendix has the same status as the main 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 published in standards that is under other authorship may be presented in annexes. Extraneous material presented in annexes is excerpted and adapted as necessary to be generally useful.

CONTENTS

1. INTRODUCTION

BACKGROUND

General

1.1. Radioactive waste arises from the generation of electricity in nuclear power plants, from nuclear fuel cycle operations and from other activities in which radioactive material is used. Radioactive waste presents a potential hazard to human health and the environment and it must be managed so as to reduce any associated risks to acceptable levels.

1.2. The principles to be applied in all radioactive waste management activities are set out in the IAEA Safety Fundamentals publication on the Principles of Radioactive Waste Management [1]. These principles formed the technical basis for the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (Joint Convention) [2]. The relevant principles and requirements for radiation protection are set out in the Safety Fundamentals publication on Radiation Protection and the Safety of Radiation Sources [3] and in the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (the Basic Safety Standards) [4]. Many of the basic principles and concepts of protection adopted in these standards and in the Joint Convention [2] are derived from the recommendations of the International Commission on Radiological Protection (ICRP) [5–7].

1.3. The term 'geological disposal' refers to the disposal of solid radioactive waste in a facility located underground in a stable geological formation (usually several hundred metres or more below the surface) so as to provide long term isolation of the radionuclides in the waste from the biosphere. Disposal means that there is no intention to retrieve the waste, although such a possibility is not ruled out. Geological disposal was conceived of as a method for disposing of the more hazardous types of radioactive waste, including heat generating waste and long lived waste. Such waste includes spent nuclear fuel (if declared as waste under the national policy), high level waste (HLW) from the reprocessing of nuclear fuel, and other radioactive waste that generates significant amounts of heat or that contains concentrations of long lived radionuclides that are unsuitable for its disposal in near surface facilities. However, the actual types of waste to be disposed of in a particular geological disposal facility will be determined by the national policy and strategy for waste disposal. The defining characteristic of the waste concerned is that it could pose a significant radiological hazard for periods of time well in excess of those for which surveillance and maintenance of the site — as would be required if it were to remain in surface or near surface disposal facilities — can be guaranteed.

The concept of geological disposal

1.4. Concentrating and containing radioactive waste and isolating it from the biosphere is the accepted strategy for its management [1]. Containment can be provided by a number of means, including containment by the waste form itself, waste packaging, backfill materials and the host geology. The depth of disposal and the characteristics of the host geological environment generally provide for isolation of the waste from the biosphere. The disposal of highly concentrated and long lived waste in a solid form in a geological disposal facility provides a high degree of containment of such waste and the necessary degree of isolation of the waste from the accessible environment. As such it is widely considered to be an appropriate method for the disposal of such waste as the final step in its management in this strategy.

1.5. Geological disposal facilities are designed to ensure both operational safety and post-closure safety. Operational safety is provided by means of engineered features and operational controls. Post-closure safety is provided by means of engineered and geological barriers; it does not depend on monitoring or institutional controls after the facility has been closed. That is, the facility is designed to be passively safe. This does not mean that monitoring could not be carried out, if the relevant authorities now or in the future decide to take such action. It is likely that institutional controls would be applied for a period after the closure of a geological disposal facility; for example, to contribute to the social acceptability of the geological disposal facility and for the purposes of nuclear safeguards.

1.6. The aims of geological disposal are:

- To contain the waste until most of the radioactivity, and especially that associated with shorter lived radionuclides, has decayed;
- To isolate the waste from the biosphere and to substantially reduce the likelihood of inadvertent human intrusion into the waste;
- To delay any significant migration of radionuclides to the biosphere until a time in the far future when much of the radioactivity will have decayed;

— To ensure that any levels of radionuclides eventually reaching the biosphere are such that possible radiological impacts in the future are acceptably low.

The aim of geological disposal is not to provide a guarantee of absolute and complete containment and isolation of the waste for all time.

Development of geological disposal facilities

1.7. The development (i.e. the siting, design and construction), operation and closure of a geological disposal facility are likely to take place over several decades. Current plans for geological disposal in several States envisage that a disposal facility is developed in a series of steps. Such a step by step approach involves: the ordered accumulation and assessment of the necessary scientific and technical data; the evaluation of possible sites; the development of disposal concepts; iterative studies for design and safety assessment with progressively improving data; technical and regulatory reviews; public consultations; and political decisions. The step by step approach, together with the consideration of a range of options for the design and operational management of a disposal facility, is expected to provide flexibility in responding to new technical information, advances in waste management and materials technologies, and in enabling social, economic and political aspects to be addressed. This approach may include options for reversing a given step in the development or even retrieving waste after its emplacement if this were to be appropriate. The developers of geological disposal facilities may define a number of steps related to their own programme needs. In this publication, however, the step by step approach refers mainly to the steps that are imposed by the regulatory and political decision making processes.

1.8. It is convenient to identify three periods associated with the development, operation and closure of a geological disposal facility: pre-operational, operational and post-closure. Various activities will take place during these periods and some may be undertaken to varying degrees throughout part or all of the lifetime of the facility:

— The *pre-operational period* includes concept definition, site investigation and confirmation, environmental impact assessments, site selection, design studies and development of those aspects of the safety case for operational and post-closure safety that are required in order to obtain the authorization to proceed with the construction of the geological disposal facility and the initial operational activities.

- The *operational period* begins when waste is first received at the facility. From this time, radiation exposures may occur as a result of waste management activities, and these are subject to control in accordance with the requirements for radiation protection and safety. In this period, monitoring and testing programmes, on the basis of which the decision to close the geological disposal facility is taken, continue, and the post-closure aspects of the safety case are further developed. During the operational period, construction activities may take place at the same time as waste emplacement in and closure of other parts of the facility. This period may include activities for waste retrieval, if considered necessary, prior to closure, activities following the completion of waste emplacement, and the final closure and sealing of the facility.
- The *post-closure period* begins at the time when all access routes from the surface are sealed. After closure, the safety of the geological disposal facility is ensured by passive means inherent in the characteristics of the site and the facility and those of the waste packages. However, institutional controls, including some monitoring, may continue in order to provide public assurance, for example.

1.9. This publication establishes requirements for protecting people and the environment from the hazards associated with waste management activities related to disposal, i.e. hazards that could arise during the operational period and following closure. Assurance of this protection will be provided by the application of legal and regulatory requirements on the planning, development and assessment activities that are carried out during the pre-operational and operational periods.

1.10. The safety of a geological disposal facility after closure depends on a combination of the site features and the quality of the facility's design, as well as that of the waste packages, and on the proper implementation of the design. This involves the deployment of competent professional staff in the planning, siting and design and in the implementation of the design. Ensuring the required level of safety and quality entails developing the geological disposal facility in an integrated manner, on the basis of sound scientific understanding, good engineering, the application of sound technical and managerial principles, and thorough and robust safety assessments, and with the application of quality assurance (QA) to all of these elements. The *geological disposal system* (the disposal facility and the geological environment in which it is sited) is developed in a series of steps in which the scientific understanding of the disposal system and of the design of the geological disposal facility is progressively advanced. At each step, safety assessment is important in evaluating the prevailing level of understanding of the disposal system and assessing the associated uncertainties.

1.11. The basis for this understanding of the disposal system and the key arguments for its safety, and an acknowledgement of the existing unresolved uncertainties and of their safety significance and approaches for their management is incorporated into a *safety case* (a collection of arguments and evidence to demonstrate the safety of a facility), which is developed together with the development of the facility. This approach provides a basis for decisions relating to the development, operation and closure of the facility and allows the identification of areas on which attention needs to be focused to further improve the understanding of those aspects influencing the safety of the geological disposal system.

OBJECTIVE

1.12. The objective of this Safety Requirements publication is to set down the protection objectives and criteria for geological disposal and to establish the requirements that must be met to ensure the safety of this disposal option, consistent with the established principles of safety for radioactive waste management.

1.13. This publication is intended for use by those involved in the management of radioactive waste and in making decisions regarding the development, operation and closure of geological disposal facilities, especially those concerned with the related regulatory aspects. A Safety Guide will provide comprehensive guidance on international best practices for meeting the requirements.

SCOPE

1.14. Geological disposal, as a concept, encompasses a range of options, including disposal in specially mined and engineered facilities, disposal in pre-existing mines and excavations, and disposal in deep boreholes. The distinctive feature of geological disposal is the depth of emplacement, usually taken to be hundreds of metres below ground level. This is in contrast to near surface disposal or disposal in rock caverns several tens of metres below ground level, which is considered to be a type of near surface disposal. This Safety Requirements publication applies specifically to the disposal of radioactive waste in solid form by emplacement in disposal facilities sited in deep geological formations. Safety requirements for near surface disposal facilities are established in Ref. [8].

1.15. Solid radioactive waste of all types could be disposed of in a geological disposal facility, subject to the appropriate conditioning of the waste and the design of the facility. In some States it is planned to dispose of solid radioactive waste of all types in geological disposal facilities. In other States, low activity, short lived solid waste is placed in near surface facilities and geological disposal is reserved for waste that does not meet the criteria established for the acceptance of waste in near surface disposal facilities. This Safety Requirements publication applies to the geological disposal of solid radioactive waste of all types, subject to the necessary controls and limitations being placed on the waste to be disposed of and on the development, operation and closure of the facilities. The focus, however, is on the disposal of spent nuclear fuel, HLW from the reprocessing of nuclear fuel, other heat generating waste and waste containing high concentrations of long lived radionuclides. The classification of radioactive waste is discussed in Ref. [9].

1.16. The prospects and associated rationale for reversing various actions during the development and operation of geological disposal facilities, including the retrieval of emplaced waste, have been discussed internationally [10, 11]. Moreover, the development of disposal facilities that incorporate design or operational provisions to facilitate reversibility, including retrievability, is under consideration in several national programmes. No relaxation of safety standards or requirements could be allowed on the grounds that waste retrieval may be possible or facilitated by a particular provision. It would have to be ensured that any such provision would not have an unacceptable adverse effect on safety or performance. This subject is not extensively dealt with further in this publication.

1.17. This publication establishes requirements to ensure the radiological safety of the geological disposal of radioactive waste during the operational period and especially in the post-closure period. The objective, to protect people and the environment from exposure to ionizing radiation, is achieved by setting requirements for the design of a geological disposal facility and for its development, operation and closure, including organizational and regulatory requirements. Meeting these requirements forms a part of the wider activities involved in selecting a site and developing a geological disposal facility, wherein broader planning, financial, economic and social issues as well as general safety and environmental impacts are considered. This publication does not address these broader issues.

1.18. Experience to date in selecting sites for geological disposal facilities has shown that acceptance of a geological disposal facility by a broad range of interested parties depends on a number of factors. The process of involving interested parties in decision making processes for geological disposal facilities is increasingly being seen to be of great importance. The detailed consideration of such processes is, however, beyond the scope of this publication.

STRUCTURE

1.19. The background to, the concepts of and the protection objectives for geological disposal are set out in Sections 1 and 2. The safety requirements for geological disposal facilities are set out in Section 3. They are set down in 23 discrete paragraphs which make use of the word *shall*. The requirements are supported by explanatory text that elaborates on them and provides some explanation of the requirements. An appendix presents explanatory material on the assurance of compliance with the safety objectives and criteria for the post-closure period. Supporting material on the concept of geological disposal and its consistency with the principles of radioactive waste management is presented in Annex I. The principles of radioactive waste management from the Safety Fundamentals [1] are reproduced in Annex II.

2. PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

PRINCIPLES OF RADIOACTIVE WASTE MANAGEMENT

2.1. The IAEA Safety Fundamentals publication on The Principles of Radioactive Waste Management [1] applied to all activities in radioactive waste management, including the geological disposal of radioactive waste. As stated in para. 201 of Ref. [1]:

> “201. The objective of radioactive waste management is to deal with radioactive waste in a manner that protects human health and the environment now and in the future without imposing undue burdens on future generations.”

This objective was elaborated in the old Safety Fundamentals [1] as nine principles (see Annex II). The consistency of the concepts of geological disposal with these principles is discussed in Annex I.

2.2. The strategy adopted at present to achieve this objective is to concentrate and contain the waste and to isolate it from the *biosphere*, for all types of radioactive waste for which this is practicable. The biosphere is that part of the environment that is normally inhabited by living organisms and in this Safety Requirements publication it is taken generally to include those elements accessible to humans or used by humans, including groundwater, surface water and marine resources. The biosphere is therefore that part of the environment that the objective, criteria and requirements set out in this publication are intended to protect.

2.3. By applying the strategy of concentrate and contain, the entry of radionuclides into the biosphere is limited and the corresponding hazards associated with the waste are considerably reduced. This means, however, that control has to be maintained over the waste when it is stored and some method of safe disposal has to be adopted. This strategy also results in a concentration of the hazard, so that if controls lapse before disposal of the waste or if the waste is inadvertently disturbed in the geological disposal facility before its radioactive content has significantly decayed, then the individual radiation doses that could be incurred as a consequence could be significant.

2.4. According to The Principles of Radioactive Waste Management, geological disposal facilities are required to be developed in such a way that human health and the environment are protected both now and in the future [1]. In this regard, the prime concern is the radiological hazard presented by radioactive waste. The ICRP has developed a system of radiological protection that applies to all *practices*, and this system has been adopted in the Basic Safety Standards [4]. The ICRP has elaborated the application of the system to the disposal of solid radioactive waste in its Publications 77 and 81 [6, 7]. This provides a starting point for the consideration here of radiological protection in relation to geological disposal facilities. Wider environmental concerns and other non-radiological concerns are discussed at the end of this section.

2.5. The protection objective and criteria set out in this section apply regardless of present-day national boundaries. Transboundary issues are dealt with in the framework of existing conventions, treaties and bilateral agreements. Particular specific obligations apply to Contracting Parties to the Joint Convention [2].

RADIOLOGICAL PROTECTION DURING THE OPERATIONAL PERIOD

2.6. The radiological protection requirements for the operational period of a geological disposal facility and the related safety criteria are the same as for any licensed nuclear facility, and are established in the Basic Safety Standards [4].

2.7. In radiological protection terms, the source is under control in a geological disposal facility during the operational period: releases can be verified, exposures can be controlled and actions can be taken if necessary. The engineering and practical means of achieving protection are well known, although their use underground in a geological disposal facility requires specific consideration. The primary goal is to ensure that radiation doses are as low as reasonably achievable. A necessary, though not in itself sufficient, condition is that all doses are kept within applicable dose limits.

2.8. The optimization of protection (that is, ensuring that radiation doses are as low as reasonably achievable) is required to be considered in the design of the geological disposal facility and in the planning of operations above and below the ground [4]. Relevant considerations include: the separation of mining and construction activities from waste emplacement activities; the use of remote handling equipment and shielded equipment for waste emplacement, when necessary; the control of the working environment, reducing the potential for accidents and their consequences; and the minimization of maintenance needs in supervised and controlled areas. Contamination is required to be controlled and avoided to the extent possible [4].

2.9. No releases, or only very minor releases, of radionuclides (such as small amounts of gaseous radionuclides) and no significant doses to members of the public may be expected during the normal operation of a geological disposal facility. Even in the event of accidents involving the breach of a waste package, releases are unlikely to have an impact outside the facility. This will need to be confirmed by means of a safety assessment (see the requirements concerning the safety case and safety assessments, para. 3.42); relevant considerations include the waste form (the packaging and the radionuclide content of the waste), the control of contamination on waste packages and equipment, and the monitoring and control of the ventilation exhaust air and the drainage water from the geological disposal facility.

2.10. For a geological disposal facility, as for any other operational nuclear facility, an operational radiation protection programme is required to be in place to ensure that the doses to workers during normal operations are controlled and that the requirements for the limitation of radiation doses are met (Ref. [4], paras 2.24–2.26; and Ref. [12]). In addition, contingency plans are required to be in place for dealing with accidents and incidents and for ensuring that any consequent radiation doses are controlled to the extent possible, with due regard for the relevant emergency reference levels [13].

2.11. The doses and risks associated with the transport of radioactive waste to the geological disposal facility are required to be managed in the same way as the doses and risks associated with the transport of other radioactive material. The safety of transporting waste to the geological disposal facility is achieved by complying with the requirements of the IAEA Regulations for the Safe Transport of Radioactive Material [14].

RADIOLOGICAL PROTECTION IN THE POST-CLOSURE PERIOD

2.12. The objective and criteria for the protection of human health and the environment in the post-closure period are presented in the following.

- **Objective.** Geological 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 a reasonable assurance is provided that doses or risks to members of the public in the long term will not exceed the dose or risk level that was used as a design constraint.
- **Criteria.** The dose limit for members of the public from all practices is an effective dose of 1 mSv in a year [4], and this or its risk equivalent is considered a criterion not to be exceeded in the future. To comply with this dose limit, a geological 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[1]. 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 farther 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.

2.13. The primary goal of geological disposal is the protection of human health and the environment in the long term, after the geological disposal facility has been closed. In this period, the migration of radionuclides to the biosphere and the consequent exposure of people may occur, owing to the slow degradation of barriers and the slow movement of radionuclides through the surrounding geosphere by natural processes. Exposures could also arise following discrete events that may alter the barriers of the disposal system, leading to the release of radionuclides.

2.14. Constrained optimization is the central approach adopted to ensure the radiological safety of a waste disposal facility [7]. In this context, the optimization of protection is a judgemental process, with social and economic factors being taken into account, and it should be conducted in a structured but essentially qualitative manner, supported by quantitative analysis (see the Appendix).

2.15. Different analytical methods may be used to assess the post-closure impacts from radioactive waste disposal and to demonstrate compliance with national regulations expressed in terms of levels of dose and/or risk. This matter is addressed further in the appendix.

ENVIRONMENTAL AND NON-RADIOLOGICAL CONCERNS

2.16. The assessment of non-radiological environmental impacts such as may occur during the operational period, e.g. related to traffic, noise, visual amenity, disturbance of natural habitats, restrictions on land use, and social and economic factors, are outside the scope of this publication. The focus here is on

[1] Risk in this context is to be understood as the probability of death or serious hereditary disease.

the protection of the environment from the radioactive material in the geological disposal facility, especially in the post-closure period.

2.17. For the current recommendations of the ICRP [5] and the requirements of the Basic Safety Standards [4], it is assumed that, subject to the appropriate definition of exposed groups, the protection of people against the radiological hazards associated with a geological disposal facility will also satisfy the principle of protecting the environment [5]. The issues of the radiation protection of the environment from ionizing radiation and the possible development of standards for this purpose are under discussion internationally [15].

2.18. Estimates of doses due to the future migration of radionuclides from a geological disposal facility are indicators for the protection of people. On the basis of the assumption mentioned in para. 2.17, dose estimates to humans that take account of a range of possible environmental transfer pathways could already be considered as indicators of environmental protection. Additional indicators and comparisons, such as estimates of the concentrations and fluxes of contaminants and their comparison with the concentrations and fluxes of naturally occurring radionuclides, may also prove valuable to indicate a level of overall long term environmental protection that is independent of assumptions about human habits [16]. Other factors to be considered may include the protection of groundwater resources and the ecological sensitivity of the environment into which contaminants may be released.

2.19. The impact of non-radioactive materials present in a geological disposal facility should be assessed according to national or other specific regulations. Factors that should be considered include the content of chemically or biologically toxic materials in the waste and in the materials of the facility, their release and migration from the geological disposal facility, the protection of groundwater resources, and the ecological sensitivity of the environment into which contaminants may be released. If non-radioactive material may have an impact upon the release and migration of radioactive contaminants from the radioactive waste, then such interactions will be considered in the safety assessment.

3. SAFETY REQUIREMENTS FOR GEOLOGICAL DISPOSAL

3.1. Safety requirements are established for ensuring that the protection objective and criteria set out in Section 2 are fulfilled. Safety is primarily the responsibility of the operator, to whom the majority of the requirements apply; however, the assurance of safety and the development of a broader confidence in safety also require a competent regulatory process within a defined legal framework. The safety requirements for planning geological disposal facilities apply to those elements that have to be in place prior to the development of a geological disposal facility, with the purpose of ensuring safety during the operational and post-closure periods.

3.2. Post-closure safety is achieved by developing a disposal system in which the various components work together to provide and to ensure the required level of protection. This approach offers flexibility to the designer of a geological disposal facility to adapt the facility's layout and engineered barriers so as to take advantage of the natural characteristics and barrier potential of the host geological formation. Assurance of operational safety is also necessary, and this may require the consideration of a number of complex issues, including the impact of operations on the potential post-closure performance of the geological disposal facility.

3.3. The safety requirements for geological disposal established here are grouped into those in respect of the planning phase and those in respect of the development, operation and closure of facilities.

SAFETY REQUIREMENTS FOR PLANNING GEOLOGICAL DISPOSAL FACILITIES

3.4. The requirements in respect of the planning of facilities are set out under three headings: the legal and organizational framework; the safety approach; and safety design principles.

LEGAL AND ORGANIZATIONAL FRAMEWORK

Requirements for government responsibility

3.5. The government is required to provide an appropriate national legal and organizational framework within which a geological disposal facility can be sited, designed, constructed, operated and closed [17]. This shall include the definition of the steps in the facility's development and licensing, the clear allocation of responsibilities, the securing of financial and other resources, and the provision of independent regulatory functions.

3.6. Such a provision is one of the principles of radioactive waste management [1] and is also stipulated under the terms of the Joint Convention [2]. Requirements for establishing a national system for radioactive waste management are set out in Ref. [17]. Geological disposal is given special consideration within this infrastructure because of the relatively long time necessary for the development of such projects.

3.7. Matters that are considered include:

- — Defining the national policy for the long term management of radioactive waste of different types;
- — Setting clearly defined legal, technical and financial responsibilities for organizations to be involved in the development of waste management facilities, including geological disposal facilities;
- — Ensuring the adequacy and security of financial provisions;
- — Defining the overall process for the development, operation and closure of waste facilities, including the legal and regulatory requirements (e.g. licence conditions) at each step, and the processes for decision making and the involvement of interested parties;
- — Ensuring that the necessary scientific and technical expertise remains available both for the operator and for the support of independent regulatory review and other national review functions;
- — Defining legal, technical and financial responsibilities for any post-closure institutional arrangements that are envisaged, including monitoring and ensuring the security of the disposed waste.

Requirements for regulatory body responsibility

3.8. The regulatory body shall establish the regulatory requirements for the development of geological disposal facilities 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 a geological disposal facility and shall carry out such activities as are necessary to ensure that the conditions are met.

3.9. General standards for the protection of human health and the environment are usually set out in a national policy or in legislation. The regulatory body develops regulatory requirements specific to geological disposal facilities on the basis of the national policy and with due regard to the objective and criteria set out in Section 2. The regulatory body provides guidance on the interpretation of the national legislation and regulatory requirements, as necessary, and guidance on what is expected of the operator. It also engages in dialogue with the operator and interested parties to ensure that the regulatory requirements are appropriate and practicable. The regulatory body will also undertake research, acquire independent assessment capabilities and participate in international cooperation as necessary to fulfil its regulatory functions.

3.10. The regulatory body will document the procedures that it uses to evaluate the safety of a geological disposal facility, the procedures that operators are expected to follow in the context of licensing and important pre-licensing decisions and licence applications, and the procedures that it applies in reviewing submissions from operators to assess compliance with regulatory requirements. Similarly, the regulatory body sets out the procedures that an operator is expected to follow in demonstrating compliance with the conditions for the development and operation of the facility, and the procedures that it applies to assess compliance with the conditions throughout all phases of the development, operation and closure of the geological disposal facility.

Requirements for operator responsibility

3.11. The operator of a geological disposal facility shall be responsible for its safety. The operator shall carry out safety assessments and develop a safety case, and shall carry out all the necessary activities for siting, design, construction, operation and closure, in compliance with the regulatory requirements and within the national legal infrastructure.

3.12. The operator is responsible for developing a practical and safe geological disposal facility and for demonstrating its safety, consistent with the requirements of the regulatory body. This task is undertaken in consideration of the characteristics and quantities of the radioactive waste to be disposed of, the site or sites available, the mining and engineering techniques available, and the national legal infrastructure and regulatory requirements. The operator is also responsible for preparing a thorough safety case, on the basis of which decisions on the development, operation and closure of the geological disposal facility will be made (see paras 3.60, 3.63 and 3.66).

3.13. The operator is responsible for conducting or commissioning the research and development necessary to ensure and to demonstrate that the planned technical operations can be practically and safely accomplished, and the research necessary to investigate, understand and support the processes on which the safety of the geological disposal facility depends. The operator is also responsible for carrying out all the necessary investigations of the site or sites and of materials and for assessing their suitability, and for providing data for safety assessments.

3.14. The operator establishes technical specifications that are justified by the safety assessment, to ensure that the geological disposal facility is developed in accordance with the safety case. This includes waste acceptance criteria (see para. 3.70) and other controls and limits to be applied during construction, operation and closure. The operator retains all the information relevant to the safety case and the supporting safety assessments of the geological disposal facility, and the inspection records that demonstrate compliance with regulatory requirements and with the operator's own specification. Such information and records will be retained at least up until the time when the information is shown to be superseded or until responsibility for the facility is passed on to another organization, such as at closure. The operator cooperates with the regulatory body and supplies all the information that the regulatory body may require for licensing purposes. The need to preserve the records for long time periods is taken into account in selecting the format and media to be used for records.

SAFETY APPROACH

Requirements concerning the importance of safety in the development process

3.15. Throughout the development of a geological disposal facility, an appropriate understanding of the relevance and implications for safety of the available options shall be developed by the operator with the ultimate goal of providing an optimized level of operational and post-closure safety.

3.16. Geological disposal facilities are developed and operated over a period of several years or decades. Key decisions, such as decisions on the siting, design, construction, operation and closure of the facility, are expected to be made as the project develops. In this process, decisions are made on the basis of the information available at the time, which may be of a quantitative or qualitative nature, and the confidence that can be placed in that information. Decisions on the development, operation and closure of the facility are constrained by external factors, such as the national policy and preferences and the availability of suitable sites and geological formations within national borders to host a geological disposal facility. Nevertheless, an adequate level of confidence in the safety of the geological disposal facility will be developed before decisions are made, meaning that the safety implications of the design or operational options to be adopted will be considered.

3.17. At each major decision point the implications for safety of the available options for the geological disposal facility are considered and taken into account. Ensuring both operational and post-closure safety is the overriding factor at each decision point. If more than one option is capable of providing the required level of safety, then other factors will also be considered. These factors could include public acceptability, cost, site ownership, and existing infrastructure and transport routes. Consideration will be given to locating the facility away from known underground mineral, geothermal and water resources so as to reduce the risk of human intrusion into the site and the potential for uses of the surrounding area that are in conflict with the facility. Safety is considered at every step in the decision making process to ensure that the geological disposal facility is optimized in the sense discussed in the appendix.

Requirements concerning passive safety

3.18. The operator shall site, design, construct, operate and close the geological disposal facility in such a way that post-closure safety is ensured by passive means and does not depend on actions being taken after the closure of the facility.

3.19. Providing for passive safety in the post-closure period entails proper closure of the geological disposal facility and bringing an end to the need for active management of the facility. The cessation of management means that the geological disposal facility, as a source of radiation hazard, is no longer under active control. Thus, it is the performance of the natural and engineered barriers that provides safety in the post-closure period.

3.20. In practice, institutional controls, including restrictions on land use, may be maintained even after the geological disposal facility has been closed. Such controls and monitoring are not necessary to ensure the safety of the facility; however, they may be regarded as additional measures for assurance. Institutional controls and monitoring are discussed further in paras 3.73–3.76.

Requirements for an adequate understanding and for confidence in safety

3.21. The operator of a geological disposal facility shall develop an adequate understanding of the features, events and processes that influence its post-closure safety over suitably long time periods, so that a sufficient level of confidence in safety is achieved.

3.22. The development of sufficient confidence in the results of the safety assessment is facilitated by identifying the features and processes that provide for safety, and also the features, events and processes that might be detrimental to safety, and demonstrating that they are sufficiently well characterized and understood. Where there is uncertainty, it is taken into consideration in the estimation of safety. The aim is to establish that there is a high level of confidence that a sufficient set of features and processes provide for safety and that they can be relied on over the required periods for containment and isolation. Other, less well quantified, features and processes may also contribute to safety, although the reasoning is based on more qualitative arguments, and constitute a safety reserve or safety margin.

3.23. The need for demonstrability requires that safety be provided for by robust features (i.e. features whose performance is of low sensitivity to disturbing events and processes), for which sufficient evidence has been presented of their feasibility and effectiveness, before construction activities commence. In this regard, the range of possible disturbing events and processes that it is reasonable to include in such considerations is subject to approval by the regulatory body. These considerations provide for the development of an understanding of whether or not such events and processes could lead to the widespread loss of safety functions.

3.24. An understanding of the performance of the disposal system and its safety features and processes evolves as more data are accumulated and scientific knowledge is developed. Early in the development of the concept, the data and the level of understanding gained should provide the confidence necessary to commit the resources for further investigations. Before the start of construction, during emplacement and at closure, the level of understanding should be sufficient to support the safety case for fulfilling the applicable regulatory requirements. In establishing these requirements, it is important to recognize that there are multiple components of uncertainty inherent in modelling complex environmental systems and that there are inevitably significant uncertainties associated with projecting the performance of a geological disposal system.

SAFETY DESIGN PRINCIPLES

3.25. Geological disposal facilities are designed to contain the radionuclides associated with the radioactive waste and to isolate them from the biosphere. The various components of the geological disposal system contribute to fulfilling these safety functions in different ways over different timescales. Requirements are established in this section to ensure that there is adequate defence in depth so that safety is not unduly dependent on the fulfilment of a single safety function. This is achieved by demonstrating that the individual safety functions are robust and that the performance of the various physical barriers and their safety functions can be relied upon, as assumed in the safety case and the supporting safety assessments. It is the responsibility of the operator to demonstrate the following design requirements to the satisfaction of the regulator.

Requirements for multiple safety functions

3.26. The natural and engineered barriers shall be selected and designed so as to ensure that post-closure safety is provided by means of multiple safety functions. That is, safety shall be provided by means of multiple barriers whose performance is achieved by diverse physical and chemical processes. The overall performance of the geological disposal system shall not be unduly dependent on a single barrier or function.

3.27. A barrier means a physical entity, such as the waste form, the packaging, the backfill or the host geological formation. A safety function may be provided by means of a physical or chemical property or process that contributes to safety, such as: impermeability to fluids; limited corrosion, dissolution, leach rate and solubility; and retention. The presence of multiple barriers and safety functions enhances both safety and confidence in safety by ensuring that the overall performance of the geological disposal system is not unduly dependent on a single barrier or safety function. The presence of multiple barriers and safety functions provides assurance that, even if a barrier or safety feature does not perform fully as expected (e.g. owing to an unexpected process or an unlikely event), a sufficient margin of safety will remain.

3.28. The barriers and their functions are complementary and work in combination. The performance of a geological disposal system is thus dependent on different barriers and safety functions, which act over different time periods. The safety case explains and justifies the functions provided by each barrier and identifies the time periods over which they are expected to perform their various safety functions and also the alternative or additional safety functions that operate if a barrier does not fully perform.

Requirements concerning containment

3.29. The engineered barriers, including the waste form and packaging, shall be so designed, and the host geological formation shall be so selected, as to provide containment of the waste during the period when the waste produces heat energy in amounts that could adversely affect the containment, and when radioactive decay has not yet significantly reduced the hazard posed by the waste.

3.30. Containment of waste implies designing for the minimal release of radionuclides. Releases of gaseous radionuclides and of small fractions of other highly mobile species from waste of some types may be inevitable. Such releases will nevertheless be demonstrated to be acceptable by the safety assessment. The containment may be provided both by the characteristics of the waste form and the packaging and by the characteristics of the other engineered barriers and the host geological formation, which, for example, prevent the access of water to the packages and protect their physical integrity. The containment of the radionuclides in the waste form and packaging over an initial period of several hundreds to thousands of years ensures that the majority of shorter lived radionuclides decay in situ. It also ensures that any migration of radionuclides occurs only after the heat produced by radioactive decay has substantially decreased and a more stable physical and chemical environment has developed.

3.31. Containment is most important for the most highly concentrated radioactive waste such as spent nuclear fuel and vitrified waste from fuel reprocessing. Attention is also given to the durability of the waste form and to emplacing the most highly concentrated waste in containers that are designed to remain intact for a long enough period of time for most of the shorter lived radionuclides to decay and for the associated heat generation to decrease substantially. Such containment may not be practicable or necessary for lower activity long lived waste. The containment capability of the waste package is demonstrated by means of a safety assessment to be appropriate for the waste type and the overall geological disposal system.

Requirements for isolation of waste

3.32. The geological disposal facility shall be sited in a geological formation and at a depth that provide isolation of the waste from the biosphere and from humans over the long term, for at least several thousand years, with account taken of both the natural evolution of the geological disposal system and events that could disturb the facility.

3.33. Isolation means retaining the waste and its associated hazard away from the biosphere in a disposal environment that provides substantial physical separation from the biosphere, making human access to the waste difficult without special technical capabilities, and that provides for a very slow mobility of most of the long lived radionuclides. Isolation is an inherent feature of geological disposal.

3.34. Location in a stable geological formation provides protection of the geological disposal facility from the effects of geomorphological processes such as erosion and glaciation. Location away from known areas of underground mineral resources is desirable to reduce the likelihood of inadvertent disturbance of the geological disposal facility and to avoid resources being made unavailable for exploitation.

3.35. Over time periods of several thousand years or more, the migration of a fraction of the longer lived and more mobile radionuclides from the waste in a geological disposal facility may be inevitable. The safety criteria to apply in assessing such possible releases are set out in Section 2. Care needs to be exercised in using the criteria beyond the time where the uncertainties become so large that these criteria may no longer serve as a reasonable basis for decision making. For such long times after closure, indicators of safety other than dose or individual risk may be appropriate, and their use should be considered.

REQUIREMENTS FOR THE DEVELOPMENT, OPERATION AND CLOSURE OF GEOLOGICAL DISPOSAL FACILITIES

3.36. This section establishes safety requirements relating to the planned steps that are necessary for safety and to assist in developing confidence in the safety of geological disposal facilities. The requirements are set out under four headings: framework for geological disposal, safety case and safety assessments, steps in the development, operation and closure of geological disposal facilities, and assurance of safety and nuclear safeguards.

FRAMEWORK FOR GEOLOGICAL DISPOSAL

Requirements for step by step development and evaluation

3.37. Geological disposal facilities shall be developed in a series of steps, each supported, as necessary, by iterative evaluations of the site, of the options for design and management, and of the performance and safety of the geological disposal system.

3.38. A step by step approach to the development of a geological disposal facility refers mainly to the steps that are imposed by the regulatory and political decision making processes (see para. 1.7). This approach ensures the quality of the technical programme and the associated decision making. For the operator, it provides a framework in which sufficient confidence in the technical feasibility and safety of the geological disposal facility can be built at each step of its development. This confidence is developed and refined by means of iterative design and safety studies as the project progresses [18]. The process provides for: the collection, analysis and interpretation of the relevant scientific and technical data; the development of designs and operational plans; and the development of the safety case for operational and post-closure safety. Access is provided for all interested parties to the safety basis for the geological disposal facility so as to facilitate the relevant decision making processes that enable the operator to proceed to the next significant step in the development and operation of the facility and finally to its closure.

3.39. The step by step approach also allows opportunities for independent technical reviews, regulatory reviews, and political and public involvement in the process. The nature of the reviews and involvement will depend on national practices. Technical reviews by or on behalf of the operator and the regulatory body may focus on: siting and design options; the adequacy of the scientific basis and analyses; and whether safety standards and requirements have been met. Alternative waste management options, the siting process and aspects of public acceptability, for example, may be considered in farther reaching reviews. Technical reviews would be undertaken prior to selecting a disposal option, prior to selecting a site, prior to construction and prior to operation. Periodic reviews will also be undertaken during the operation of the facility and before its closure.

SAFETY CASE AND SAFETY ASSESSMENTS

3.40. The development of a safety case and supporting safety assessments for review by the regulator and other interested parties are central to the development, operation and closure of a geological disposal facility. The safety case substantiates the safety, and contributes to confidence in the safety, of the geological disposal facility. The safety case is an essential input to all the important decisions concerning the facility. It includes the output of safety assessments (see below), together with additional information, including supporting evidence and reasoning on the robustness and reliability of the facility, its design, the design logic, and the quality of safety assessments and underlying assumptions. The safety case may also include more general arguments relating to the need for the disposal of radioactive waste, and information to put the results of the safety assessments into perspective. Any unresolved issues at any step in the development, operation and closure of the facility will be acknowledged in the safety case and guidance for work to resolve these issues will be provided.

3.41. Safety assessment is the process of systematically analysing the hazards associated with the facility and the ability of the site and the design of the facility to provide for the safety functions and to meet technical requirements. Safety assessment includes quantification of the overall level of performance, analysis of the associated uncertainties and comparison with the relevant design requirements and safety standards. The assessments are site specific, since geological systems, in contrast to engineered systems, cannot be standardized. As site investigations progress, safety assessments become increasingly refined, and at the end of a site investigation sufficient data will be available for a complete assessment. Safety assessments also identify any significant deficiencies in scientific understanding, data or analysis that might affect the results presented. Depending on the stage of development, safety assessments may be used to aid in focusing research, and their results may be used to assess compliance with the various safety objectives and standards.

Requirements concerning preparation of the safety case and safety assessment

3.42. A safety case and supporting safety assessment shall be prepared and updated by the operator, as necessary, at each step in the development, operation and closure of the geological disposal facility. The safety case and safety assessment shall be sufficiently detailed and comprehensive to provide the necessary technical input for informing the regulatory and other decisions necessary at each step.

3.43. A site specific safety case is prepared early in the development of a geological disposal facility to provide a basis for licensing decisions, and to guide activities in research and development, siting and design. The safety case is progressively developed and elaborated as the project proceeds, and is presented at each key step in the development of the geological disposal facility. The regulatory body may mandate an update of or revision to the safety case before given steps, or such an update or revision may be necessary to gain political or public support for taking the next step in the development and operation of the geological disposal facility. The formality and level of technical detail of the safety case depend on the stage of development of the project, the decision in hand, the audience to which it is addressed, and specific national requirements.

3.44. A safety assessment in support of the safety case is performed and updated throughout the development and operation of the geological disposal facility and as more refined site data become available. Safety assessment provides input to continuing decision making by the operator, such as decision making relating to subjects for research, development of the capability for assessment, the allocation of resources, and the development of waste acceptance criteria. Safety assessments also identify key processes relevant to safety, contribute to the development of an understanding of the performance of geological disposal facilities, and support judgements with regard to alternative management options as an element of optimizing protection and safety. Such an understanding provides the basis for the safety arguments presented in the safety case. The operator decides on the timing and level of detail of the safety assessment, in consultation with and subject to the approval of the regulatory body.

Requirements on the scope of the safety case and safety assessment

3.45. The safety case for a geological disposal facility shall describe all the safety relevant aspects of the site, the design of the facility, and the managerial and regulatory controls. The safety case and its supporting assessments shall illustrate the level of protection provided and shall provide assurance that safety requirements will be met.

3.46. The safety case for a geological disposal facility addresses both operational safety and post-closure safety. All aspects of operation relevant to radiation safety are considered, including underground development work, waste emplacement, and backfilling, sealing and closing operations. Consideration is given to both occupational exposure and public exposure resulting from normal operations, which includes operational occurrences anticipated to occur over the operating lifetime of the geological disposal facility. Accidents of a lesser frequency but with significant radiological consequences — that is, accidents that could give rise to radiation doses over the short term in excess of annual dose limits (see Section 2) — are considered with regard to both their likelihood of occurrence and the magnitude of possible radiation doses. The adequacy of the design and operational features is also evaluated.

3.47. With regard to post-closure safety, the expected range of possible developments affecting the geological disposal system and the low probability events that might affect its performance are considered in the safety case and in the supporting assessment, by:

— Presenting evidence that the geological disposal system, its possible evolutions and relevant events that might affect it are sufficiently well understood;
— Demonstrating the feasibility of implementing the design;
— Providing convincing estimates of the performance of the geological disposal system and a reasonable level of assurance that all the relevant safety requirements will be complied with and that radiation protection has been optimized;
— Identifying and presenting an analysis of the associated uncertainties.

The safety case may include the presentation of multiple lines of reasoning based, for example, on studies of natural analogues and palaeohydrogeological studies, the quality of the site, the properties of the host rock, engineering considerations and operational procedures, and institutional assurances.

3.48. Safety assessments analyse the performance of the geological disposal system under the expected and less likely evolutions and events, which can be outside the designed performance range of the geological disposal facility. A judgement of what is to be considered as the expected evolution and less likely evolution will be discussed by the regulatory body and the operator. Sensitivity analyses and uncertainty analyses will be undertaken to obtain an understanding of the performance of the geological disposal system and its components under a range of evolutions and events. The consequences of unexpected events and processes may be explored to test the robustness of the geological disposal system. In particular, the resilience of the geological disposal system is assessed. Quantitative analyses are undertaken, at least over the time period for which regulatory compliance is required, but the results from detailed models of safety assessments are likely to be more uncertain for time periods in the far future. For such timeframes, arguments may be needed to illustrate safety, on the basis, for example, of complementary safety indicators, such as concentrations and fluxes of naturally occurring radionuclides and bounding analyses.

3.49. The management systems established to provide QA in these design and operational features are addressed in the safety case.

Requirements concerning documentation of the safety case and safety assessments

3.50. The safety case and its supporting safety assessments shall be documented to a level of detail and quality sufficient to support decisions to be made at each step and to allow for their independent review.

3.51. The necessary scope and structure of the documentation setting out the safety case and its supporting safety assessments will depend on the step reached in the project for the geological disposal facility and on the national requirements. This includes consideration of the needs of different interested parties for information. Important considerations are justification, traceability and clarity.

3.52. Justification concerns explaining the basis for the choices that have been made and the arguments for and against the decisions, especially those decisions concerning the main safety arguments. Traceability refers to the ability of an independent qualified person to follow what has been done. Good traceability is essential to enable technical and regulatory review. Justification and traceability both require a well documented record of the decisions made and the assumptions made in the development and operation of a geological disposal facility, and of the models and data used in arriving at a particular set of results for the safety assessments.

3.53. Clarity refers to good structure and presentation at an appropriate level of detail so as to facilitate an understanding of the safety arguments. This requires that material be presented in the documents in such a way that interested parties can gain a good understanding of the safety arguments and their basis. Different styles and levels of documentation may be required in order to provide material that is useful to different parties.

STEPS IN THE DEVELOPMENT, OPERATION AND CLOSURE OF GEOLOGICAL DISPOSAL FACILITIES

Requirements for site characterization

3.54. The site for a geological disposal facility shall be characterized at a level of detail sufficient to support both a general understanding of the characteristics of the site, including its past evolution and its probable future natural evolution over the period of interest with regard to safety, and a specific understanding of the impact on safety of features, events and processes associated with the site and the facility.

3.55. A general understanding of the site and its associated geology is necessary in order to present a convincing scientific description of the geological disposal system on which the more conceptual descriptions that are used in the safety assessments can be based. The focus is on features, events and processes related to the site that could have an impact on safety and which are addressed in the safety case and its supporting safety assessments. In particular, this includes demonstrating sufficient geological stability, the presence of features and processes that contribute to safety, and a demonstration that other features, events and processes do not undermine the safety case.

3.56. Characterization of the geological aspects includes activities such as the investigation of: long term stability, faulting and the extent of host rock fracturing; seismicity; volcanism; confirmation of the volume of rock suitable for the construction of disposal zones; geotechnical parameters relevant to the design; groundwater flow regimes; geochemical conditions; and mineralogy. Site characterization undertaken in an iterative manner provides input to and is in turn guided by the safety case. Additionally, investigation of, for example, the natural background radiation and the radionuclide content in soil, groundwater and other media may contribute to a better understanding of the characteristics of the geological disposal site and may assist in the evaluation of radiological impacts on the environment by providing a reference for future comparisons.

Requirements for geological disposal facility design

3.57. The geological 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 geological environment, and to provide post-closure safety features that complement those afforded by the host geological environment. The facility and its engineered barriers shall be designed to ensure safety during the operational period.

3.58. The designs of geological disposal facilities may differ widely depending on the types of waste and the geological environment. In general, the aim is to make optimal use of the safety features offered by the host geological environment by designing a geological disposal facility that does not introduce unacceptable long term disturbances to the site, is itself protected by the site and performs safety functions that complement the natural barrier, and that is designed with the goal of ensuring that fissile materials remain in a subcritical configuration. The layout is designed so that waste is emplaced in the most suitable rock zones and so that key features, such as shafts and seals, are appropriately located. Materials used in the facility are resistant to degradation under the conditions in the facility (e.g. in respect of chemistry and temperature) and also selected so as not to interfere with the safety functions of any element of the geological disposal system.

3.59. A geological disposal facility is expected to perform over much longer time periods than those usually considered in engineering applications. Investigation of the ways in which analogous natural materials have behaved in geological settings in nature, or how ancient artefacts and human made constructions have behaved over time, may contribute to confidence in the assessment of long term performance. Demonstration of the feasibility of fabrication of waste containers and of the construction of engineered barriers and their features, for example in underground laboratories, is important to generate confidence that an adequate level of performance can be achieved.

Requirements for geological disposal facility construction

3.60. A geological disposal facility shall be constructed in accordance with the design as described in the approved safety case and safety assessments. It shall be constructed in such a way as to preserve the post-closure safety functions of the geological barrier that have been shown to be important by the safety case. The construction shall be carried out to ensure safety during the operational period.

3.61. Construction of a geological disposal facility is a complex technical undertaking and it will be constrained by the rock conditions and the techniques that are available for underground excavation and construction. Construction will not begin until an adequate level of characterization has been completed. Mining and construction activities will be carried out in such a way as to avoid unnecessary disturbance of the geological environment. Sufficient flexibility in the underground engineering techniques will be adopted to allow for variations in rock or groundwater conditions.

3.62. Construction of a geological disposal facility could continue after the commencement of operation of part of the facility and the emplacement of waste packages. Such overlapping construction and operational activities are planned and carried out so as to ensure both operational and post-closure safety.

Requirements for geological disposal facility operation

3.63. A geological disposal facility shall be operated in accordance with the conditions of the licence and the relevant regulatory requirements to maintain safety during the operational period, and in such a manner as to preserve the post-closure safety functions assumed in the safety case.

3.64. All operations and activities important to safety are subjected to documented limitations, controls and operating procedures, and documented emergency plans [13] will be in place. The safety case addresses and justifies both the design and operational management arrangements, which are used to ensure that the safety objectives and criteria set out in Section 2 are met. Additional, facility specific criteria may be established by the regulatory body or by the operator. The safety case also includes considerations with regard to reducing hazards to workers and to members of the public in normal and abnormal operational situations. Active control of safety will be maintained for as long as the facility remains unsealed, and this may include an extended period after the emplacement of waste and before the final closure of the facility.

3.65. Fissile material is managed and emplaced in the geological disposal facility in a configuration that will remain subcritical [19]. This may be achieved by various means, including the appropriate distribution of fissile material during the conditioning of the waste and the proper design of the waste packages. Assessments of the possible evolution of the nuclear criticality hazard after waste emplacement, including in the post-closure period, will be undertaken.

Requirements for geological disposal facility closure

3.66. A geological disposal facility shall be closed in such a way that the safety functions shown by the safety case to be important for the post-closure period are provided for. 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.

3.67. The post-closure safety of a geological disposal facility depends on a number of activities, which can include the backfilling and sealing of the geological disposal facility. Closure will be considered in the initial design of the facility, and plans for closure and seal designs will be updated as the design of the facility is developed. It is important that before construction activities commence there is sufficient evidence that the performance of the backfilling and seals is effective.

3.68. The geological disposal facility will be closed in accordance with the conditions set for closure by the regulatory body in the facility's licence, with particular consideration given to any changes in responsibility that may occur at this stage. Consistent with this, backfilling may be performed in parallel with waste emplacement operations. The placing of seals may be delayed for a period after the completion of waste emplacement, for example to allow monitoring to assess aspects relating to post-closure safety or for reasons relating to public acceptability. If seals are not to be put in place for a period of time after the completion of waste emplacement, then the implications for operational and post-closure safety will be considered in the safety case.

3.69. The operator ensures that the technical and financial resources necessary to achieve closure are in place and are protected. These arrangements, and any changes to them, are subject to the approval of the regulatory body or other government authority.

Requirements on waste acceptance

3.70. Waste packages and unpackaged waste accepted for geological disposal shall conform to criteria consistent with the safety case for aspects of the operational and post-closure safety of the geological disposal facility.

3.71. Waste acceptance requirements and criteria are developed by the operator and approved by the regulatory body. These requirements ensure the safe handling of waste packages and unpackaged waste in normal and abnormal conditions and the fulfilment of the safety functions of the waste form and waste packaging with regard to long term safety. The waste acceptance criteria specify the characteristics of the waste packages and the unpackaged waste to be disposed of, such as the radionuclide content or activity limits, the heat output and the properties of the waste form and packaging. Modelling and/or testing of waste form behaviour is undertaken to ensure the physical and chemical stability of the different waste packages and unpackaged waste under the conditions expected in the geological disposal facility, and to ensure their adequate performance in the event of accidents or abnormal conditions.

3.72. Waste intended for geological disposal is characterized to provide sufficient information to ensure compliance with waste acceptance requirements and criteria. Arrangements will be put in place to verify that the waste and waste packages received for disposal comply with these requirements and criteria and, if they do not, to confirm that corrective measures are taken by the generator of the waste or the operator of the geological disposal facility. The quality control of waste packages is mainly based on records, preconditioning testing (e.g. of containers) and control of the conditioning process. Post-conditioning testing and the need for corrective measures will be limited as far as is practicable.

Requirements concerning monitoring programmes

3.73. A programme of monitoring shall be defined and carried out prior to and during the construction and operation of a geological disposal facility. This programme shall be designed to collect and update the information needed to confirm the conditions necessary for the safety of workers and members of the public and the protection of the environment during the operation of the facility, and to confirm the absence of any conditions that could reduce the post-closure safety of the facility.

3.74. Monitoring is carried out during each step of the development and operation of the geological disposal facility. The purposes of the monitoring programme include providing baseline information for subsequent assessments, assurance of operational safety and operability of the facility, and confirmation that conditions are consistent with post-closure safety. Monitoring programmes are designed and implemented so as not to reduce the overall level of post-closure safety of the facility.

3.75. A discussion of monitoring relating to the post-closure safety of geological disposal facilities is given in Ref. [20]. Plans for monitoring with the aim of providing assurance of post-closure safety are drawn up before construction of the geological disposal facility to indicate possible monitoring strategies, but remain flexible and, if necessary, will be revised and updated during the development and operation of the facility.

Requirements concerning post-closure and institutional controls

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

3.77. Geological disposal facilities do not rely on long term post-closure institutional control as a passive safety function (see para. 3.19). Nevertheless, institutional controls may contribute to safety by preventing or reducing the likelihood of human actions that could inadvertently interfere with the waste, or degrade the safety features of the geological disposal system. Institutional controls may also contribute to increasing the societal acceptability of geological disposal.

3.78. Geological disposal facilities are not likely to be closed for several tens of years after operations have commenced. Thus, plans drawn up to identify possible controls and the period over which they would be applied remain flexible and conceptual in nature. Consideration is given to: local land use controls; site restrictions or surveillance and monitoring; local, national and international records; and the use of durable surface and/or subsurface markers. Arrangements will be made to be able to pass on information about the geological disposal facility to future generations to enable them to make any future decisions on the geological disposal facility and its safety.

Requirements in respect of nuclear safeguards

3.79. Nuclear safeguards requirements shall be considered in the design and operation of a geological disposal facility to which nuclear safeguards apply, and shall be implemented in such a way as not to compromise the safety of the geological disposal facility.

3.80. Nuclear safeguards were developed primarily to provide for accountability for nuclear material, to detect its diversion for unauthorized or unknown purposes in the short and medium term. As presently organized, nuclear safeguards depend on active surveillance and controls. During the operation of a geological disposal facility, for waste containing fissile material, safeguards surveillance aims at ensuring the continuity of knowledge concerning the fissile material and the absence of any undeclared activities at the site in relation to such material. For some radioactive waste, such as spent nuclear fuel, certain safeguards requirements have to continue even after the waste has been sealed in a geological disposal facility [21, 22].

3.81. For a closed geological disposal facility, nuclear safeguards might in practice be achieved by remote means (e.g. satellite monitoring, aerial photography, microseismic surveillance and administrative arrangements). Intrusive methods, which might compromise post-closure safety, will be avoided. Since nuclear safeguards are in some instances internationally supervised, their continuation might increase confidence in the longevity of administrative controls, which would also prevent inadvertent disturbance of the geological disposal facility. The continuation of safeguards and monitoring after closure may thus be beneficial to improving confidence in the post-closure safety. A discussion of interface issues between nuclear safeguards and radioactive waste management is included in Ref. [21].

Requirements concerning management systems

3.82. Management systems to provide for QA shall be applied to all safety related activities, systems and components throughout all the steps of the development and operation of a geological disposal facility. The level of assurance for each aspect shall be commensurate with its importance to safety.

3.83. An appropriate management system, including a QA programme, contributes to confidence that the relevant requirements and criteria for site characterization, construction, operation, closure and post-closure safety are met. The relevant activities, systems and components are identified on the basis of the results of systematic safety assessments. The level of attention assigned to each aspect is commensurate with its importance to safety. The management system will comply with IAEA standards on management systems and with other recognized codes, regulations and standards [23–25].

3.84. The management system defines the organizational structure for implementing the QA activities. It also defines the responsibilities and authorities of the various personnel and organizations involved in designing, implementing and auditing the QA activities.

3.85. Because of the nature of geological disposal facilities, the management system for a geological disposal facility — with its integrated QA programme — is designed with account taken of the fact that the host geological formation, while an important element for safety, cannot be designed or manufactured but only characterized, and that too only to a limited extent. Also, geological disposal involves several sequential steps in design, characterization and assessment, with an increasing degree of detail and accuracy. A degree of uncertainty may always remain; it may not be possible to eliminate it by the use of any QA measures. The significance of this uncertainty is assessed in the evaluation of the safety case and its supporting assessments.

3.86. The management system and the supporting QA programme for the geological disposal facility: provide for the production and retention of documentary evidence to illustrate that the necessary quality of data has been achieved; ensure that components have been supplied and used in accordance with the relevant specifications; and ensure that the waste packages and unpackaged waste comply with established requirements and criteria and have been properly emplaced in the geological disposal facility. They also ensure that all information recorded during all steps in the development and operation of the facility is collated, and that information which could be important to safety and for any reassessment of the facility in the future is preserved.

Appendix

ASSURANCE OF COMPLIANCE WITH THE SAFETY OBJECTIVE AND CRITERIA

A.1. A well designed and located geological disposal facility will provide a high level of assurance that radiological impacts in the post-closure period will be low, both in absolute terms and in comparison with the impacts expected from any other options for waste management that are available at present. A host geological formation and site will be identified that provide favourable conditions for isolation of the waste from the biosphere and the preservation of the engineered barriers (e.g. low groundwater flow and a favourable geochemical environment over the long term). The geological disposal facility will be designed with account taken of the characteristics offered by the host geological formation and site so as to optimize protection and not exceed the dose and/or risk constraints. The geological disposal facility will then be developed according to the assessed design so that the assumed safety characteristics of both the engineered and the natural barriers are realized.

A.2. The optimization of protection for a geological disposal facility is a judgemental process that is applied to the decisions made during the development of the facility's design. Most important is that sound engineering and technical solutions are adopted and sound principles of quality management are applied throughout the development, operation and closure of the geological disposal facility. Given these considerations, protection can then be considered optimized provided that:

- Due attention has been paid to the long term safety implications of various design options at each step in the development and operation of the geological disposal facility;
- There is a reasonable assurance that the assessed doses and/or risks resulting from the generally expected range of the natural evolution of the disposal system do not exceed the appropriate constraint, over time frames for which the uncertainties are not so large as to prevent meaningful interpretation of the results;
- The likelihood of events that might disturb the performance of the geological disposal facility, so as to give rise to higher doses or risks, has been reduced as far as is reasonably possible by the siting or design.

A.3. 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 farther into the future. Nevertheless, estimates of doses and risks for long time periods can be made and used as indicators for comparison with the safety criteria.

A.4. In estimating the doses to individuals who will be living in the future, it is assumed that humans will be present locally, and that they will make some use of local resources that may contain radionuclides originating from the waste in the geological disposal facility. The representation of future human behaviour in assessment models is necessarily stylized, as it is not possible to predict behaviour in the future with any certainty. The rationale and possible approaches to the modelling of the biosphere and the estimation of doses arising from waste disposal facilities have been considered in the IAEA BIOMASS Project [26].

A.5. In the event of inadvertent human intrusion into a geological disposal facility, a small number of individuals involved in activities such as drilling or mining into the facility could receive high radiation doses. The doses and risks to any individuals who take part in activities to disturb deliberately the geological disposal facility or its waste need not be taken into consideration, as such actions would be planned. In general, the likelihood of inadvertent human intrusion into the waste will be low as a consequence of the chosen depth of the geological disposal facility and the decision to site it away from known mineral resources. While the doses received from such an inadvertent intrusion could be high, the associated risk is likely to be more than outweighed by the higher level of protection afforded by geological disposal in comparison with other strategies, since the likelihood of human intrusion is low.

A.6. A geological disposal facility may be affected by a range of possible evolutions and events, with some judged to be relatively likely to occur over the period of assessment, while others are considered rather unlikely or very unlikely to occur. With a view to optimizing protection, the design process will focus on ensuring that the disposal system provides for safety (i.e. on compliance with dose and/or risk constraints), in consideration of the expected evolution of the disposal system, and with account taken of uncertainties concerning that evolution and the natural events that are likely to occur over the period of assessment.

A.7. The achievement of a level of protection such that calculated doses are less than the dose constraint is not in itself sufficient for the acceptance of a safety case for a geological disposal facility, since protection is also required to be optimized [4]. Conversely, an indication that calculated doses could, in some unlikely circumstances, exceed the dose constraint need not necessarily result in the rejection of a safety case. In very long timeframes, radioactive decay will reduce the hazard associated with the geological disposal facility; however, uncertainties could become much larger and calculated doses may exceed the dose constraint. Comparison of the doses with doses from naturally occurring radionuclides may provide a useful indication of the significance of such cases. It is recognized that radiation doses to people in the future can only be estimated and the uncertainties associated with these estimates will increase for times further into the future. Care has to be exercised in applying the criteria for periods beyond the time where the uncertainties become so large that the criteria may no longer serve as a reasonable basis for decision making (see the criterion in para. 2.12).

A.8. The evaluation of whether or not the design of a geological disposal facility will provide an optimized level of protection may require a judgement in which other factors would also 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 calculations for the safety assessment less reliable, then comparisons with dose or risk constraints have to be treated with caution. For a geological disposal facility, this is likely to be the case in considering human intrusion events and very low frequency natural events, as well as events far in the future. The robustness of the geological disposal system can be demonstrated, however, by undertaking an assessment of reference events that are typical of such very low frequency events.

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Annex I

GEOLOGICAL DISPOSAL AND THE PRINCIPLES OF RADIOACTIVE WASTE MANAGEMENT

I.1. The principles of radioactive waste management set out in the Safety Fundamentals (see Annex II) apply to geological disposal facilities. The concept of geological disposal is inherently consistent with several of these principles, and the measures that will be taken to ensure overall compatibility are presented in the requirements of this publication, as discussed here.

I.2. A well designed and implemented geological disposal facility will be able to contain radioactive waste and to isolate it so as to provide for the radiation protection of the public and the environment. This is consistent with Principles 1 and 2. The protection of human health and the environment is discussed in Section 2, which sets out objectives and criteria that define a level of protection of human health and the environment, both now and in the future, that is deemed to be acceptable by States. The criteria are applied regardless of present-day national boundaries, consistent with Principle 3, and the criteria for post-closure safety are no less stringent than those that apply now, consistent with Principle 4.

I.3. Following the closure of a geological disposal facility, the long term containment and isolation of the waste will be provided by passive means so that no further actions are required to maintain the safety of the waste and to provide for the protection of human health and the environment. Thus, undue burdens on future generations are avoided, consistent with Principle 5. The practice of geological disposal does not itself create significant additional amounts of radioactive waste, consistent with Principle 7.

I.4. The principles of radioactive waste management were taken into account in the formulation of the objectives and criteria for protection to apply in the development, operation and closure of a geological disposal facility, as set out in Section 2, and the requirements set out in Section 3. Specifically:

— The provision of an appropriate national legal framework, consistent with Principle 6;
— The interdependence between geological disposal and earlier stages of waste generation is taken into account in the application of waste acceptance criteria, consistent with Principle 8;

— Consistent with Principle 9, a comprehensive set of objectives, criteria and requirements is set out for ensuring the safety of geological disposal facilities, including requirements concerning the safety approach and safety functions, the safety case and monitoring.

Annex II

PRINCIPLES OF RADIOACTIVE WASTE MANAGEMENT[2]

Principle 1: Protection of human health

Radioactive waste shall be managed in such a way as to secure an acceptable level of protection for human health.

Principle 2: Protection of the environment

Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment.

Principle 3: Protection beyond national borders

Radioactive waste shall be managed in such a way as to assure that possible effects on human health and the environment beyond national borders will be taken into account.

Principle 4: Protection of future generations

Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.

Principle 5: Burdens on future generations

Radioactive waste shall be managed in such a way that [it] will not impose undue burdens on future generations.

Principle 6: National legal framework

Radioactive waste shall be managed within an appropriate national legal framework including clear allocation of responsibilities and provision for independent regulatory functions.

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Principle 7: Control of radioactive waste generation

Generation of radioactive waste shall be kept to the minimum practicable.

Principle 8: Radioactive waste generation and management interdependencies

Interdependencies among all steps in radioactive waste generation and management shall be appropriately taken into account.

Principle 9: Safety of facilities

The safety of facilities for radioactive waste management shall be appropriately assured during their lifetime.

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