IAEA Safety Standards

for protecting people and the environment

Monitoring and Surveillance of Radioactive Waste Disposal Facilities

Specific Safety Guide

No. SSG-31

IAEA

International Atomic Energy Agency

IAEA SAFETY STANDARDS AND RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

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

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

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

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

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

RELATED PUBLICATIONS

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

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

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

MONITORING AND SURVEILLANCE OF RADIOACTIVE WASTE DISPOSAL FACILITIES

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

IAEA SAFETY STANDARDS SERIES No. SSG-31

MONITORING AND SURVEILLANCE OF RADIOACTIVE WASTE DISPOSAL FACILITIES

SPECIFIC SAFETY GUIDE

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FOREWORD

by Yukiya Amano
Director General

The IAEA's Statute authorizes the Agency to "establish or adopt… standards of safety for protection of health and minimization of danger to life and property" — standards that the IAEA must use in its own operations, and which States can apply by means of their regulatory provisions for nuclear and radiation safety. The IAEA does this in consultation with the competent organs of the United Nations and with the specialized agencies concerned. A comprehensive set of high quality standards under regular review is a key element of a stable and sustainable global safety regime, as is the IAEA's assistance in their application.

The IAEA commenced its safety standards programme in 1958. The emphasis placed on quality, fitness for purpose and continuous improvement has led to the widespread use of the IAEA standards throughout the world. The Safety Standards Series now includes unified Fundamental Safety Principles, which represent an international consensus on what must constitute a high level of protection and safety. With the strong support of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its standards.

Standards are only effective if they are properly applied in practice. The IAEA's safety services encompass design, siting and engineering safety, operational safety, radiation safety, safe transport of radioactive material and safe management of radioactive waste, as well as governmental organization, regulatory matters and safety culture in organizations. These safety services assist Member States in the application of the standards and enable valuable experience and insights to be shared.

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

Safety is not an end in itself but a prerequisite for the purpose of the protection of people in all States and of the environment — now and in the future. The risks associated with ionizing radiation must be assessed and controlled without unduly limiting the contribution of nuclear energy to equitable and sustainable development. Governments, regulatory bodies and operators everywhere must ensure that nuclear material and radiation sources are used beneficially, safely and ethically. The IAEA safety standards are designed to facilitate this, and I encourage all Member States to make use of them.

THE IAEA SAFETY STANDARDS

BACKGROUND

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

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

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

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

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

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

THE IAEA SAFETY STANDARDS

The status of the IAEA safety standards derives from the IAEA's Statute, which authorizes the IAEA to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property, and to provide for their application.

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

Safety measures and security measures[1] have in common the aim of protecting human life and health and the environment. Safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

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

Safety Fundamentals

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

Safety Requirements

An integrated and consistent set of Safety Requirements establishes the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objective and principles of the Safety Fundamentals. If the requirements are not met, measures must be taken to reach or restore the required level of safety. The format and style of the requirements facilitate their use for the establishment, in a harmonized manner, of a national regulatory framework. Requirements, including numbered 'overarching' requirements, are expressed as 'shall' statements. Many requirements are not addressed to a specific party, the implication being that the appropriate parties are responsible for fulfilling them.

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

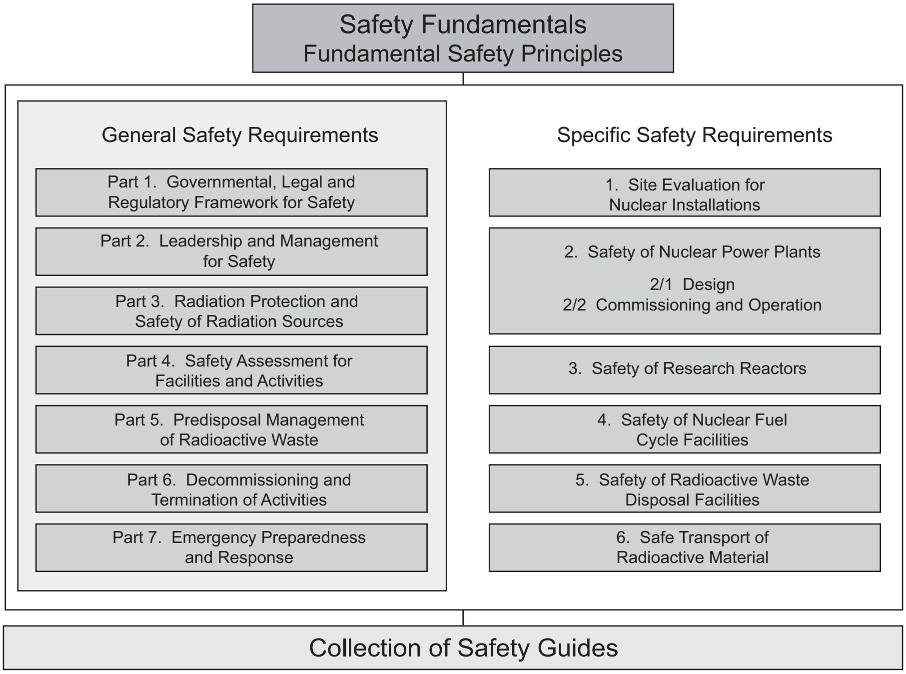

FIG. 1. The long term structure of the IAEA Safety Standards Series.

Safety Guides

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

APPLICATION OF THE IAEA SAFETY STANDARDS

The principal users of safety standards in IAEA Member States are regulatory bodies and other relevant national authorities. The IAEA safety standards are also used by co-sponsoring organizations and by many organizations that design, construct and operate nuclear facilities, as well as organizations involved in the use of radiation and radioactive sources.

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

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

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

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

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

DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

The preparation and review of the safety standards involves the IAEA Secretariat and four safety standards committees, for nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on Safety Standards (CSS) which oversees the IAEA safety standards programme (see Fig. 2).

All IAEA Member States may nominate experts for the safety standards committees and may provide comments on draft standards. The membership of the Commission on Safety Standards is appointed by the Director General and

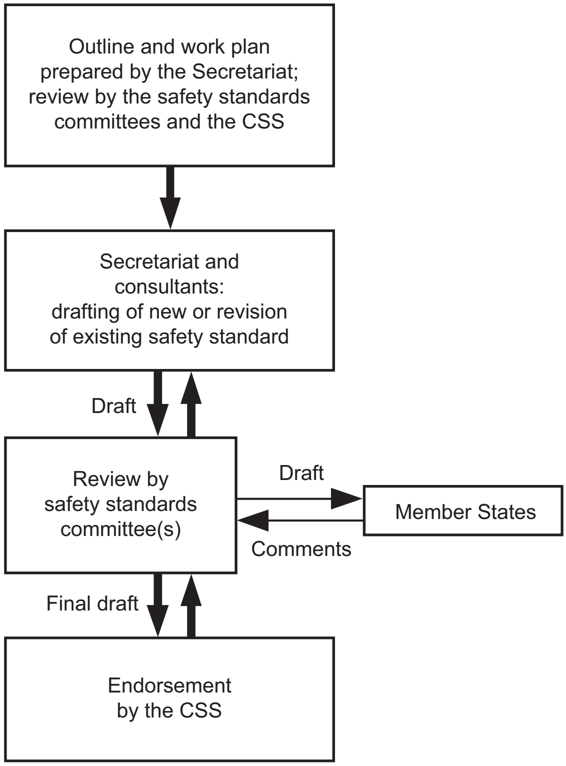

FIG. 2. The process for developing a new safety standard or revising an existing standard.

includes senior governmental officials having responsibility for establishing national standards.

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

INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

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

INTERPRETATION OF THE TEXT

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

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

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

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

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. Radioactive waste arises from the generation of electricity in nuclear power plants, from nuclear fuel cycle operations and from other activities in the nuclear fuel cycle, such as the mining and processing of uranium and thorium ores. Radioactive waste also arises from a wide range of activities in industry, medicine, agriculture, education, and research and development. It also arises from activities and processes in which radioactive material of natural origin becomes concentrated in waste material and safety needs to be considered in its management.

1.2. A monitoring and surveillance programme is a key element in verifying that a licensed radioactive waste disposal facility meets its specified performance and safety requirements. The safety principles to be applied in all radioactive waste management activities are established in the Fundamental Safety Principles [1]. The Safety Requirements publication on Disposal of Radioactive Waste [2] sets out disposal options corresponding to the recognized classes of radioactive waste as specified in Ref. [3].

1.3. The IAEA has developed Safety Guides on geological disposal facilities and on near surface disposal facilities [4, 5], and a Safety Guide on the management of radioactive residues from mining, mineral processing, and other activities relating to naturally occurring radioactive material (NORM) is in preparation. The present Safety Guide provides support for these safety standards in the area of monitoring and surveillance of radioactive waste disposal facilities.

1.4. Monitoring and surveillance programmes are important elements in providing assurance that a disposal facility for radioactive waste performs at the required level of safety during the operational and post-closure phases. The type of waste and the corresponding disposal facility will influence the monitoring approach taken. In the case of a near surface disposal facility, for waste containing relatively short lived radionuclides, it is possible to apply direct controls to determine whether the safety goals are being met. In the case of geological disposal of waste with long lived radionuclides, direct controls after closure are not feasible. The goals for safety and protection in this case can only be derived by predictions that are based on the available data and existing knowledge.

1.5. Differing kinds of monitoring activities are necessary in each period in the lifetime of a radioactive waste disposal facility. This Safety Guide covers monitoring and surveillance in the pre-operational, operational, closure and post-closure periods for specific landfill disposal facilities, near surface disposal facilities, geological disposal facilities and disposal facilities for waste from thorium and uranium mining. The pre-operational, operational and post-closure periods set out in Ref. [2] can be further described as follows:

— The pre-operational period includes concept definition, site evaluation (selection, verification and confirmation), safety assessment and design studies. In the case of waste from mining, the pre-operational period corresponds to preparation for environmental remediation of mining facilities, tailings management facilities, piles of waste rock and clean-up waste of the contaminated sites (remediation of mining waste can be looked upon as disposal of the mining waste). The pre-remediation activities include environmental impact assessment[1] of the sites surrounding the mine, selection and design of the remedial actions and implementation of an environmental monitoring programme that comprises monitoring of the impact of the remedial actions at the site and monitoring for any change in the environmental baseline conditions outside the remediation site. The pre-operational period also includes the development of programmes and procedures required in support of the application for a licence for construction and initial operation of a disposal facility. The monitoring and testing programmes that are needed to establish baseline conditions should be put in place during this period.
— 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 protection and safety. Safety assessments and the safety case for the period of operation are updated as necessary to reflect actual experience and increasing knowledge, gained both on the site and at other facilities, in the State and in other States. In the operational period, construction activities may take place at the same time as waste emplacement in and closure or decommissioning 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

[1] The term ‘environmental impact assessment’ is used here in a broad sense. In some States, the term denotes a specified process covering all potential impacts of the project, with a view to soliciting acceptance of a project from all relevant authorities, and which often involves participation of the public.

emplacement and final closure, including backfilling and sealing of the facility. Records of the waste inventory should be kept throughout the operational period.

— Many reasons could lead to a decision to close a disposal facility. For example, the capacity of the disposal facility may have been reached; other solutions for disposal may have been found; or a political decision may have been made to close the facility. Irrespective of the rationale behind the decision, except in the case of remediation, a decision to close a disposal facility is also a decision to initiate a period of active institutional control, for a near surface disposal facility, or, for other disposal facilities, the post-closure period. Such a decision is specific to disposal facilities and is of high importance for near surface disposal facilities. Initiation of a period of active institutional control will lead to decisions on further activities following the completion of waste emplacement, namely closure and sealing of the disposal facility. At this time, the duration of this period of active institutional period should be determined in accordance with a 'de minimis' approach to the risks incurred by a potential human intruder.
— The post-closure period begins at the time when all the engineered containment and isolation features have been put in place, operational buildings and supporting services have been decommissioned, and the facility is in its final configuration. After its closure, the safety of the disposal facility is provided for by means of passive features inherent in the characteristics of the site and the facility and characteristics of the waste packages. A monitoring and surveillance programme is put in place aimed at confirming that the disposal system is performing as expected. Monitoring may also be carried out to enhance confidence in, and therefore acceptance of, the disposal process. For near surface disposal facilities in particular, institutional controls are put in place to prevent intrusion into the facility. Depending on national legislation, the licence to operate a disposal facility may be terminated after the period of active institutional control when all the necessary technical, legal and financial requirements have been fulfilled.

1.6. The IAEA's General Safety Requirements publication Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [6] and the IAEA Safety Guide on Environmental and Source Monitoring for Purposes of Radiation Protection [7] provide a framework for all generic aspects of monitoring. In particular, Ref. [6] establishes the basic requirements for monitoring of public exposure, while Ref. [7] covers pre-operational monitoring, operational monitoring and post-closure monitoring. It also acknowledges the need for monitoring a variety of non-radioactive variables. The present Safety

Guide provides recommendations on meeting the requirements in Ref. [6] and complements the guidance provided in Ref. [7], with particular regard to the role of monitoring in the context of the development of a disposal facility. On matters pertaining to source and environmental monitoring, the present Safety Guide refers to Ref. [7].

1.7. Reference [6] establishes requirements on the regulatory control and monitoring of public exposure and risks to the environment, as well as requirements on the safe management of radioactive waste.

1.8. Four IAEA publications address monitoring and surveillance of disposal facilities: Safety Reports Series No. 27 on Monitoring and Surveillance of Residues from the Mining and Milling of Uranium and Thorium [8]; Safety Reports Series No. 35 on Surveillance and Monitoring of Near Surface Disposal Facilities for Radioactive Waste [9]; Safety Reports Series No. 64 on Programmes and Systems for Source and Environmental Radiation Monitoring [10]; and IAEA-TECDOC-1208 on Monitoring of Geological Repositories for High Level Radioactive Waste [11]. The scope of the present Safety Guide is broader than that of these informational publications, which have served as a resource for development of this Safety Guide.

OBJECTIVE

1.9. The objective of this Safety Guide is to provide guidance for the monitoring and surveillance of radioactive waste disposal facilities throughout their entire lifetime. It addresses the different aims that monitoring and surveillance have at the various periods of the lifetime of a disposal facility, from initiation of work on a candidate site, to the period after closure of the disposal facility.

SCOPE

1.10. This Safety Guide considers monitoring and surveillance for three types of disposal facility:

- — Near surface disposal facilities;
- — Geological disposal facilities;
- — Facilities for the disposal of waste from mining and mineral processing.

These three types of disposal facility cover all disposal options as identified in Ref. [2]. Specific landfill disposal facilities are not specifically mentioned as they involve the same considerations as near surface disposal facilities. Borehole disposal facilities also are not specifically addressed in this Safety Guide. However, borehole disposal involves many considerations similar to near surface disposal or geological disposal of radioactive waste. A possible surveillance and monitoring programme suitable for a small scale borehole disposal facility is described in Ref. [12].

1.11. The disposal of intermediate level waste in facilities, as described in Ref. [2], has to provide for long term, passive safety through a combination of natural and engineered barriers. The overall approach to monitoring in this case is similar to the monitoring system used for deep geological disposal. The similarities between the monitoring system for intermediate level waste (ILW) disposal and that for deep geological disposal are due to the fact that the waste is located at a considerable depth, and the monitoring system will reflect the combined long term effect of engineered barriers and the host rock formation.

1.12. As explained in Ref. [3], the term 'near surface disposal' generally refers to disposal at or within a few tens of metres from the surface of the ground. The term 'geological disposal' generally refers to disposal in deep, stable geological formations, usually several hundred metres or more below the surface. Disposal facilities for mining waste cover a spectrum of designs, from above ground mounds of waste to geological disposal of tailings slimes (a dispersion of fine tailings in water), which are sometimes used as backfill in old mines. The type of disposal required depends on the characteristics of the waste and the potential risk that the waste may pose to the environment [3]. The suitability of waste for disposal in a particular disposal facility is required to be demonstrated by the safety case and supporting safety assessment for the facility [2]. A dedicated monitoring and surveillance programme is part of this demonstration.

1.13. This Safety Guide emphasizes the integration of monitoring and surveillance activities necessary for development of and compliance with the safety case. The safety case includes information related to siting, construction, operation, closure and the period after closure that is necessary for supporting decisions on managing the disposal programme, as well as information that is of particular interest to interested parties such as local parties and the wider public [2, 13]. Technical details on monitoring and surveillance methodologies are beyond the scope of this Safety Guide; however, Refs [8–11] contain such information, and Annexes I and II provide examples of monitoring programmes for geological disposal programmes and for near surface disposal programmes.

1.14. Nuclear security aspects of the monitoring and surveillance of disposal facilities are outside the scope of this publication. Guidance on addressing nuclear security aspects can be found in publications of the IAEA Nuclear Security Series (see Refs [14, 15] and supporting guidance). The term 'surveillance' in this Safety Guide is used strictly with the meaning expressed in para. 2.7; therefore, this term is not to be understood as including surveillance for security purposes. Nevertheless, while designing surveillance programmes for security purposes, it may be taken into account that surveillance of disposal facilities for safety measures also can provide information relevant for security issues.

1.15. This Safety Guide focuses on monitoring for the purpose of confirming the performance of the disposal system and for radiation protection of the public and protection of the environment.

1.16. This Safety Guide does not specifically address monitoring that will be required for the following purposes:

— Occupational radiation protection (e.g. by means of dosimetry). This topic is covered in Ref. [16].
— Waste characterization or waste tracking.
— State systems of accounting for and control of nuclear material, or IAEA nuclear safeguards, for facilities that will contain significant quantities of nuclear material.
— Socioeconomic conditions (such as demographic changes, presence of industries, trade of goods, changes in social order).

This Safety Guide also does not provide recommendations on monitoring for non-radiological contaminants that may be of concern. However, the operator of the disposal facility should consider such contaminants when designing the monitoring programme.

STRUCTURE

1.17. Section 2 provides an overview of monitoring and surveillance for radioactive waste disposal facilities, and describes the overall objectives for a monitoring and surveillance programme. Section 3 addresses the roles and responsibilities of the regulatory body and the operator with regard to monitoring and surveillance. Section 4 addresses the design of a monitoring programme and includes some consideration of strategic issues for monitoring. Section 5 provides guidance on monitoring for different types of disposal facility (geological disposal facilities, near surface disposal facilities and facilities for waste from mining and mineral processing). Section 6 addresses the monitoring that is necessary at different stages in the development of a disposal facility. Section 7 provides specific guidance for surveillance activities. Finally, Section 8 is concerned with the use of information from monitoring and surveillance with regard to aspects of compliance with regulations and the development and improvement of the safety case, and Section 9 describes briefly issues relating to the management system for a disposal facility. Annex I provides an example of monitoring and surveillance information collected for a geological disposal programme. Annex II describes a monitoring and surveillance programme for a near surface disposal facility, specifically the radioactive waste treatment and disposal facility at Püspökszilágy operated by the Hungarian national radioactive waste management company (PURAM).

2. OVERVIEW OF MONITORING AND SURVEILLANCE

2.1. Monitoring has been defined in various IAEA publications in different ways [6–11]. In the context of this Safety Guide, the term ‘monitoring’ refers to continuous or periodic observations and measurements to help evaluate the behaviour of the components of a waste disposal system and the impact of the waste disposal system on the public and the environment. Most specifically, it covers the measurement of radiological, environmental and engineering parameters.

2.2. The need to address public concern and expectations may also be considered in defining the monitoring programme.

2.3. As stated in para. 5.4 of Ref. [2], “Monitoring programmes have to be designed and implemented so as not to reduce the overall level of safety of the facility after closure”.

2.4. The monitoring programme should be designed in accordance with a graded approach. This means that the extent of the monitoring programme should be commensurate with the level of risk associated with the disposal facility.

2.5. The duration and frequency of monitoring should be in accordance with the timescale of natural variations in the processes and in the parameters being measured, as determined by regulatory requirements, and with changes in processes and parameters associated with construction and operation of the disposal facility.

2.6. The safety case is usually supported by data from a number of sources, including site specific measurements, regional data and generic information. Generally, site specific data are preferred. Where these are absent, relevant monitoring data may be available from other sources.

2.7. In the context of this Safety Guide, the term ‘surveillance’ refers to the physical inspection of a waste disposal facility in order to verify the integrity of the safety barriers.

2.8. Surveillance is employed periodically to verify through inspection that structures, systems and components continue to function as described in the safety case. In this respect the function of surveillance is to facilitate the detection of changes in the engineering structures and systems of the disposal facility that might affect the performance of the disposal system.

2.9. “A programme for the surveillance of the facility should be established and implemented as necessary and feasible. It should consist of planned activities carried out to verify that the facility is operating within the design limits and conditions and to detect any deterioration of structures, systems and components that could result in unsafe conditions” [17].

2.10. In some States there is no distinction between the concepts of monitoring and of surveillance for disposal facilities.

GENERAL OBJECTIVES FOR THE MONITORING AND SURVEILLANCE OF DISPOSAL FACILITIES

2.11. Monitoring is needed to evaluate any changes either in the actual performance of the facility or in processes or parameters that might influence the performance of the facility. Requirement 21 of Ref. [4] states:

> “A programme of monitoring shall be carried out prior to, and during, the construction and operation of a disposal facility and after its closure, if this is part of the safety case. This programme shall be designed to collect and update information necessary for the purposes of protection and safety. Information shall be obtained to confirm the conditions necessary for the safety of workers and members of the public and protection of the environment during the period of operation of the facility. Monitoring shall also be carried out to confirm the absence of any conditions that could affect the safety of the facility after closure.”

2.12. In addition, Requirement 10 of Ref. [4] states:

> "An appropriate level of surveillance and control shall be applied to protect and preserve the passive safety features, to the extent that this is necessary, so that they can fulfil the functions that they are assigned in the safety case for safety after closure."

2.13. The monitoring and surveillance of disposal facilities for radioactive waste has five broad objectives:

(i) To demonstrate compliance with regulatory requirements and with the licence conditions.
(ii) To verify that the disposal system is performing as expected, as set out in the safety case. This means that the components of the disposal system are carrying out their functions as identified in the safety assessment.
(iii) To verify that the key assumptions made and models used to assess safety are consistent with actual conditions.
(iv) To establish a database of information on the disposal facility, the site and its surroundings. This database is used to support future decisions when proceeding from siting to construction, operation, closure and the period after closure. The database is also used to support decisions relating to updating concepts and procedures for monitoring.
(v) To provide information for the public.

2.14. In general, the monitoring and surveillance programmes should be driven by, and should inform, the safety case. The results of the programmes should be used to strengthen the safety case and to build confidence in safety.

2.15. During the period between the decision to develop a waste disposal facility and closure of the facility, decisions will need to be made about how, when and whether to grant a licence and implement the various stages of the development of the disposal facility. One of the objectives of monitoring and surveillance, and of the analysis of the data, is to provide information to assist in making these decisions. Decision making is strongly influenced by societal and political considerations as well as by safety issues, and the process will be embedded in the national legal and regulatory system. The decision making process should be supported by an adequate organizational framework and corresponding technical and administrative measures.

2.16. The monitoring and surveillance programme should be used to confirm that the performance of the engineered and natural barriers is not compromised by operational activities.

2.17. In addition to its technical objectives, a monitoring and surveillance programme can be a suitable tool for enhancing public confidence. In that sense, consideration of public and societal interests and the concerns of interested parties may provide useful information to complement the monitoring programme.

2.18. Monitoring involves balancing the benefits of gains in information on the behaviour of certain components of the disposal facility against any detriment that might result from monitoring. A common feature of many investigations relating to the behaviour of the engineered barriers and the natural development of the environment around the disposal facility is that these measurements can affect the disposal system in an undesirable manner. In the operational period, when the waste is directly accessible, the benefits of monitoring need to be balanced against the additional radiation exposure of the operating personnel and the potential for conventional accidents to occur [18].

3. RESPONSIBILITIES OF THE OPERATOR AND THE REGULATORY BODY

RESPONSIBILITIES OF THE OPERATOR

3.1. The operator of the waste disposal facility should be responsible for carrying out the activities listed in para. 3.2. If a change in responsibilities occurs during operation or after closure of the facility, the new operator should also take measures to ensure that the monitoring and surveillance programmes continues, including in the period after closure, in a manner that meets national regulatory requirements and policies.

3.2. With regard to responsibilities relating to monitoring and surveillance, the operator:

(a) Should design a monitoring and surveillance programme (including record keeping and archiving) that meets the requirements established by the regulatory body. The programme should be designed and refined throughout the pre-operational, operational and post-closure periods of the facility, and should be customized appropriately to each of these periods.

(b) Should perform adequate monitoring and surveillance in agreement with the regulatory body, as follows:
   (i) Baseline monitoring before and during the construction stage and during pre-operational periods;
   (ii) Timely detection of any abnormalities of system performance during the operational and post-closure periods.

(c) Should develop contingency plans to address unexpected or abnormal system behaviour and should coordinate plans with responsible authorities involved in the event of a nuclear or radiological emergency, including off-site responders.

(d) Should report periodically on the status of the monitoring and surveillance programme to the regulatory body; should provide evidence to the regulatory body that the waste disposal facility is appropriately monitored and controlled; and should report promptly on unexpected or hazardous circumstances, when detected, to the responsible regulatory body, organization or institution, specifying the place and time of occurrence.

(e) Should retain, store, maintain and administer data acquired by means of monitoring and surveillance.

(f) Should, during the time of concept definition in the pre-operational period, ensure that financial guarantees are in place for the monitoring and surveillance.

RESPONSIBILITIES OF THE REGULATORY BODY

3.3. The regulatory body should establish the necessary requirements for implementation of the monitoring and surveillance programme for the disposal facility and should be responsible for carrying out the activities listed in para. 3.4. The necessary guidance should be provided to the operator of the disposal facility, to enable monitoring and surveillance programmes to be established for all periods of the disposal process. The guidance should include recommendations on the duration of monitoring and surveillance in the post-closure period. The regulatory framework should ensure that an appropriate mechanism is established that will ensure the availability of adequate financial means for implementation of the monitoring and surveillance programme.

3.4. With regard to specific responsibilities relating to monitoring and surveillance, the regulatory body:

(a) Should periodically review the regulations in force for monitoring and surveillance, the monitoring and surveillance programmes and reporting arrangements, including arrangements for monitoring in an emergency. The times at which reviews are conducted should be sufficiently flexible to allow for changes arising from scientific and technological advancements in the relevant fields and from the needs of the regulatory body.
(b) Should review the monitoring and surveillance data provided by the operator against established requirements.
(c) Should verify that the waste disposal facility is being appropriately monitored and controlled by the operator; this may include the independent conduct of monitoring and surveillance. To some extent, and without prejudice to its independence, the monitoring programme of the regulatory body will need to be consistent and compatible with the monitoring strategy of the operator regarding safety aspects (both long term safety and operational safety) and practical considerations relating to management of the disposal process (including dismantling of the monitoring instrumentation).
(d) Should ensure that financial guarantees are in place in the pre-operational period for long term monitoring and surveillance.

3.5. Specific tasks relevant to source and environmental monitoring as well as surveillance may be delegated to other organizations by the government or by the regulatory body using a transparent and auditable process that is subject to independent scrutiny. In deciding on the delegation of specific tasks to other organizations, the regulatory body should give due consideration to the availability of suitably qualified and experienced personnel, appropriate analytical techniques and equipment, and an appropriate management system. Examples of tasks that may be delegated are the following:

(a) The design and implementation of source and environmental monitoring programmes, such as programmes conducted to assess the cumulative radiological impact of multiple or related facilities on the same areas and the same population groups;
(b) The assessment of doses to members of the public, to verify that they are maintained below the limits established in the licence;
(c) Tasks relating to safety and emergency response.

3.6. Other organizations may also be made responsible for other domains relating to monitoring, such as:

(a) The collection and retention of data provided by the operator, governmental agencies or international agencies;
(b) Environmental monitoring at the national level;
(c) The establishment of standards.

The regulatory body should liaise with these organizations as appropriate.

3.7. Provision should be made for rapid, large scale monitoring in the event of an accident. Such monitoring may be performed by a designated organization with the requisite capability, or by the regulatory body itself. The required monitoring may include source monitoring (monitoring at the source of the discharge), environmental monitoring (monitoring in the vicinity of the facility) and individual monitoring (monitoring of individual exposure) [7].

4. DESIGN OF A MONITORING PROGRAMME

4.1. The monitoring programme for a disposal facility should be designed to meet the objectives stated in Section 2. It should include source and environmental monitoring programmes to assess public exposure and impact on the environment as well as to assess potential release pathways. Generic aspects of source and environmental monitoring for waste disposal facilities are described in Ref. [7]. The monitoring programme should include assessment of the performance of the disposal system for the operational and post-closure periods.

4.2. The safety case should be used to establish the monitoring programme for confirmation of the performance of the disposal facility. The responses of the disposal system should be monitored and the results should be compared to predictions made in the safety assessment in order to demonstrate the quality of the site characterization data and to confirm the assumptions made and the models used in the safety case.

4.3. Data from the monitoring programme should be analysed promptly to provide the operator and decision makers with timely information on management of the disposal facility. In particular, the regulatory body should be provided with a summary of monitoring results and their interpretation at defined intervals in time, and should be informed promptly of any unexpected results that could have an impact on safety (for example, data indicating a significant increase in environmental radiation levels, or data suggesting that the disposal system might not perform as anticipated).

4.4. The monitoring programme should be designed in accordance with a graded approach. This means that the extent of the monitoring programme should be commensurate with the level of risk associated with the disposal facility. Accordingly, the most significant efforts should be placed in areas in which the consequence of a malfunction or failure of a component could have an impact on safety or in areas in which abnormal or unexpected behaviour of the disposal facility could be detected easily.

4.5. The monitoring programme should be designed using an optimization process in which the costs and benefits of monitoring are taken into consideration. The extent and duration of monitoring all contribute to the cost, both directly (costs for monitoring equipment and monitoring activity and for mitigating any ensuing risks to workers) and indirectly (costs relating to maintaining and operating the facility in a manner that allows such activity). In determining the costs of monitoring, an assessment should be carried out of the financial risks associated with missing important information that could lead to performance failure or failure to be able to retrieve waste. The benefits of monitoring also have to be considered against any detriment that might result from monitoring.

4.6. An important part of designing a monitoring programme in a step by step manner is the initial assessment to establish what needs to be known and how this knowledge is to be gained. In general, the design of the monitoring programme should include the following:

— Identification and justification of the selection of the properties, processes, phenomena and observable quantities that are significant to the safety case;
— Establishment of the scope and objectives for the monitoring programme;
— Establishment of processes for independent assessment of the monitoring programme;
— Identification and justification of the selection of the methods to be used, based on the properties, processes, phenomena and observable quantities significant to the safety case, the scope and objectives for the monitoring programme and on available monitoring technology and its characteristics;
— Establishment of a process to verify the qualifications and certifications of equipment vendors;

— Identification of and justification of the selection of the locations for measurements;
— Identification of and justification of the selection of the duration and frequency of monitoring, including criteria according to which monitoring may be scaled back or terminated;
— Identification and justification of the selection of the instruments to be used (on the basis of their accuracy, measurement range, etc.);
— Assessment of the robustness of the monitoring technology over the relevant time period of the measurements;
— For each type of monitoring, specification of how the results will be used and communicated;
— Establishment of levels for action on the basis of existing regulations and the assumptions and models used in the safety case;
— The taking of decisions on what actions should be pursued in the event that levels for actions are exceeded;
— Establishment of specifications for management and for reporting of the results of monitoring;
— Balancing of the benefits of monitoring against its costs or any detriment that might result from monitoring (see para. 4.5);
— Specification of acceptable ranges (tolerances) for monitoring results, and establishment of a clear action plan in the event that any results collected fall outside these ranges;
— Establishment of procedures for the dismantling of monitoring instrumentation;
— Establishment of an appropriate documentation and archiving system for monitoring data.

4.7. The following key technical factors influence the design of a monitoring programme:

— The waste inventory;
— Characteristics of the waste;
— The type and design of the facility;
— Site characteristics;
— The stage of development of the facility.

4.8. These factors influence the release pathways, the amount released and the time periods over which releases of radionuclides and other contaminants from the disposal facility are expected. Specific performance requirements with respect to the waste form and other engineered barriers may give rise to specific monitoring objectives in relation to operational safety or safety after closure. The monitoring programme should also be designed to evaluate whether any changes in the environment associated with construction of the disposal facility have reduced favourable properties of the environment.

4.9. The general objective of monitoring programmes during the pre-operational period is to establish a baseline of pre-existing levels of contaminants, to enable evaluation of the impact of the waste disposal system and to identify parameters that may be indicative of performance in the post-closure period. Site characterization programmes (as conducted in the pre-operational period) typically establish natural characteristics of features, events, and processes occurring in the environment of the disposal facility (e.g. water table fluctuations) that may significantly influence the design and subsequent short term performance (i.e. in the operational period) and long term performance (in the post-closure period) of the facility. In this regard, the monitoring programme should be closely integrated with the safety case and supporting safety assessment and with procedures for construction and operation. The baseline should be developed to allow the identification of trends. The baseline should also enable the impact of the facility as it evolves over time to be discerned; this information can then be used to update the safety case.

4.10. Knowledge of pathways may help in specifying a monitoring programme tailored to detect the migration of radionuclides into the accessible environment. Predictions of transient phenomena, such as groundwater draw-down associated with excavation and operation of a disposal facility and groundwater recovery associated with closure of the disposal facility, and hydro-chemical changes associated with both transients, are also important inputs for monitoring.

4.11. Monitoring should be carried out in areas that are suspected to be contaminated with long lived radionuclides [7]. The objective of such monitoring is to provide inputs into decisions on whether intervention is justified and whether further monitoring is necessary. If the results show that, according to the intervention levels and action levels established by national authorities, remedial actions may be required, adequate monitoring should be carried out to help establish the appropriate actions. Monitoring should also be carried out during and after the taking of remedial actions to assess their effectiveness.

4.12. While monitoring plans should address all periods of development of the disposal project, they should also remain flexible given the different timescales associated with siting, construction, operation and closure of parts of the facility or the facility as a whole. Such flexibility should enable the integration of lessons learned from prior periods, adaption to new technology, and response to new regulatory requirements, design changes, etc., while at the same time maintaining data continuity and comparability. It should also enable the implementation of additional monitoring if concerns arise with regard to performance of the disposal facility. Moreover, international experience on monitoring activities should also be taken into account. Guidance specific to the conduct and objectives of monitoring at each of the three main periods of development of the disposal facility is provided in Section 6.

4.13. Throughout all periods in the lifetime of the disposal facility, technological realities will limit the robustness and scope of what monitoring can achieve. Expectations about what monitoring can achieve are also necessarily limited by certain physical challenges and limitations characteristic of different types of facilities, such as the necessary longevity of monitoring equipment and power sources.

4.14. The design and implementation of a monitoring programme should take into consideration the technical constraints imposed by the context and the environment in which the monitoring is carried out. In practice, monitoring will rely on on-site instrumentation or remote instrumentation (e.g. sensors), visual inspections, sampling and analysis of samples, as well as analysis and interpretation of data to ensure that information gained from monitoring is representative of the behaviour of the disposal system or of the impact of the disposal system on public health and on the environment.

4.15. In many cases, direct measurements of key parameters or phenomena cannot be made. Instead, inferential methods will need to be used. Monitoring of one parameter may involve interpretation of the results of many separate measurement activities (e.g. groundwater flow rates, moisture content of soils, daily precipitation) over different periods of time. For instance, regional groundwater flow velocities and material properties such as transmissivity and hydraulic conductivity are deduced from head measurements and point measurements. Additional challenges arise for measurements that need to be taken at greater depths below the surface, in high radiation fields or in other situations that make access more difficult. Similarly, it may be easier to monitor a temperature gradient than relative saturation of a swelling clay buffer or host rock. Thermal conductivity, and ultimately relative saturation, can then be deduced from measurement of the temperature gradient. Another example of non-intrusive monitoring is the application of wireless signal transmission, although this technology is still at a developmental stage for application to waste disposal facilities. Monitoring at an alternative facility with similar characteristics or at a demonstration or ‘pilot’ disposal facility may also provide useful information.

4.16. The conduct of monitoring should not degrade the performance of barriers. The design of the monitoring programme should therefore consider the need for subsequent dismantling of instrumentation. Special attention should be given to the feasibility of removing devices and cables that could lead to detrimental effects (e.g. by introducing materials to the system that can chemically interact with the system components) and of sealing properly monitoring access holes in order to avoid the formation of preferential release pathways. It should be demonstrated either that any remaining physical links (such as wiring) respect this constraint or that such links can be removed, leaving an undisturbed barrier once monitoring is completed.

4.17. Other possible detrimental effects of monitoring activities could include the following [18]:

- The degradation of barriers resulting from the delayed emplacement of engineered barriers;
- The formation of pathways through the barrier system, leading to the enhanced flow of groundwater within the disposal facility;
- Changes in geochemical conditions due to the extended opening of the underground workings;
- An increased likelihood of human intrusion, especially if the underground structure remains open and institutional control is no longer continued.

Monitoring is therefore a question of balancing the benefits of gaining information against any detriment that might result from monitoring.

4.18. The locations for monitoring should be chosen in such a way that uncertainties in the spatial correlation of parameter values are reduced to acceptable levels so that there is a high degree of confidence in the results of modelling of flow and transport processes. Such an arrangement can be determined by various statistical methods. For example, groundwater monitoring wells are usually located in the following locations:

- At the source and immediately down-gradient of the source;
- In zones with high transmissivity or hydraulic conductivity, or zones with the highest concentrations of contaminants;
- In fringe portions and at the boundary of the plume;
- In areas representative of contaminated and uncontaminated geochemical settings;
- In areas supporting the monitoring of site hydrogeology;
- At locations that meet the requirements of the regulatory body.

4.19. The appropriate frequency of monitoring can be determined on the basis of the rate at which concentration levels of contaminants are predicted to change as a consequence of phenomena such as groundwater flow and natural attenuation processes, the degree to which the causes of this variability are known, the types of evaluations to be performed, the locations of possible receptors, and the objectives for remediation of the site. In situations where the hydrological, geochemical and contaminant trends are stable and the conceptual model of the site can be verified by existing monitoring data, a reduction in monitoring frequency may be possible. In situations where the variability is high, an increase in monitoring frequency may be warranted. If the data trends appear to be stable over a period of several years, a reduction in monitoring frequency may be possible. On the other hand, for example, more frequent monitoring of groundwater elevations may be warranted, particularly during the establishment of baseline conditions, to improve the characterization of groundwater flow patterns. Other factors for determining the appropriate frequency of monitoring include the relevance of parameters and any redundancy in information. If monitoring of a specific parameter is not expected to influence the performance assessment of a site significantly, then the monitoring frequency for that parameter could be greatly reduced or monitoring of that parameter could even be eliminated.

4.20. The monitoring programme should consider all stages of the lifetime of the facility and should be established and reviewed during the early stages of development of the disposal facility and, if required, should be made subject to approval by the regulatory body while accommodating the societal needs of the State. The monitoring programme should begin as early as possible during the initial process of site selection and should evolve through the construction, operation and closure of the facility in an ongoing manner, and should be used to inform and update data used in the safety case and supporting safety assessment of the facility, as described in Section 6. In parallel, the monitoring programme should be periodically reviewed by the regulatory body. Monitoring technology should be updated and refurbished when possible and when necessary.

4.21. In designing the monitoring programme, it should be considered whether the credibility of monitoring data needs to be verified by means of sufficient redundancy of information, independent verification of values, use of robust equipment and design, and, to the extent possible, use of natural analogues. For example, natural analogues can provide information for understanding the evolution of natural systems and material behaviour over long timescales (e.g. natural analogues exist for the corrosion of metals). This may help in the interpretation of the monitoring results, such as those relating to corrosion products in monitored water. It is also important, when considering monitoring of a given parameter, to clearly understand and communicate to the regulatory body and to interested parties what type of results would be expected and how the monitoring results will be interpreted. Ranges of expected values should be provided in order to assess uncertainties.

4.22. The decision regarding the extent and duration of monitoring after closure of the facility should be based on the following:

(a) The type of disposal facility and its potential hazard over time, which will depend on the presence of long lived radionuclides;
(b) The confidence placed in the performance of the disposal facility, as indicated by results from the monitoring of past performance;
(c) Reasonable assumptions regarding the duration of institutional stability and 'institutional and societal memory', and the ability to ensure ongoing monitoring and maintenance.

4.23. The aim should be to ensure ongoing monitoring and maintenance of equipment, if feasible for the post-closure period. As uncertainties will increase in time, especially with regard to institutional stability and continuity of knowledge, it should be anticipated that post-closure monitoring efforts will be scaled down or will even be terminated in a planned or unplanned manner.

4.24. After closure, monitoring may be continued in order to assess the overall performance of the disposal facility and to periodically assess the potential impacts on the public and the environment. However, it should be recognized that properly designed disposal facilities are not expected to have significant releases to the biosphere in the short term, i.e. several hundreds of years for surface based repositories and several thousands of years for geological disposal facilities, which is already beyond any period for which ongoing monitoring can reasonably be expected.

4.25. In order to ensure transparency, in the design of the monitoring programme consideration should be given to how the results are to be communicated to the public. Transparency includes the responsibility to provide a clear interpretation of results and the context for the measurements.

4.26. Monitoring data can also serve to indicate when investigation of an actual or potential inadequacy in the safety of the disposal facility is warranted. If monitoring indicates unanticipated changes that affect safety, then the safety case and the monitoring programme may need to be revised, and appropriate corrective actions may need to be taken.

5. MONITORING FOR DIFFERENT TYPES OF DISPOSAL FACILITY

5.1. The objectives of the monitoring programme, and most of the recommendations provided in this Safety Guide, are common for the three types of disposal facility set out in para. 1.10, namely near surface disposal facilities, geological disposal facilities and disposal facilities for waste from mining and mineral processing. However, the application of a graded approach will lead to differences in the practical implementation of individual monitoring programmes.

NEAR SURFACE DISPOSAL FACILITIES

5.2. In general, waste suitable for disposal in near surface disposal facilities is low level waste (LLW) [3]. LLW contains such limited amounts of long lived radionuclides that robust containment and isolation are required for limited periods of time, typically up to a few hundred years. The management strategy in this case is to contain the waste until its activity has decreased by decay to sufficiently low levels such that the risk from migration of the residual radionuclides as the facility eventually degrades is considered acceptable. In this regard, the approach to disposal is similar to that for geological disposal of waste containing large amounts of long lived radionuclides, but the timescales involved may be shorter. Monitoring activity associated with near surface disposal facilities containing LLW will aim to provide confidence in the performance of the system for hundreds of years. Examples of safety related features, events and processes for near surface disposal facilities that, in practice, could be detected by monitoring are any released radionuclides in groundwater or in the surrounding environment, and intrusion by humans or animals.

GEOLOGICAL DISPOSAL FACILITIES

5.3. Geological disposal is suitable for waste, such as ILW and high level waste (HLW), that require a greater degree of containment and isolation from the accessible environment in order to ensure long term safety. For example, radioactive waste containing long lived radionuclides or waste with levels of activity content high enough to generate significant quantities of heat from radioactive decay, such as spent nuclear fuel (when it is considered waste) or HLW from reprocessing, are generally disposed of within deep geological disposal facilities with engineered barriers such that migration of contaminants into the surrounding geosphere will not begin to occur until a period of thousands of years has elapsed. The safety strategy employed is the containment of the radioactive material for a sufficient period to ensure that any release to the biosphere occurs in a slow and controlled manner. In this case, monitoring is focused on providing confidence in the containment system. Monitoring after closure of the facility, if required and stipulated by the regulatory body, may focus on detection of the presence of radionuclides in the environment. As early releases to the environment are highly unlikely, this kind of monitoring is implemented generally for reassurance of the public rather than for ensuring the performance of the disposal system. Examples of safety related features, events and processes for deep geological disposal facilities that, in practice, could be detected by monitoring are the generation of corrosion gases, water inflow and human intrusion.

DISPOSAL FACILITIES FOR WASTE FROM MINING AND MINERAL PROCESSING

5.4. Waste from mining and mineral processing is usually disposed of on or near the ground surface, but the manner and the large volumes in which the waste arises, its physicochemical form and its content of long lived radionuclides of natural origin distinguish it from other radioactive waste. The waste is generally stabilized in situ and covered with various layers of rock and soil. Such disposal systems cannot be designed to provide absolute containment at all times and, thus, the strategy is to control any release of radionuclides to the environment such that an unacceptable dose does not occur. Risks associated with this type of facility may be dominated by chemical and physical risks, such as the long term release of potentially toxic elements and structural failure of the facility. As a result, greater emphasis will be placed on the presence of radionuclides and associated chemicals in the surrounding environment, which act as a reliable indicator for the performance of the disposal system.

5.5. The programme for monitoring of a disposal facility for NORM is similar to that of a disposal facility for waste from uranium or thorium mining.

6. MONITORING AT DIFFERENT PERIODS IN THE LIFETIME OF A DISPOSAL FACILITY

6.1. Throughout its lifetime (see Fig. 1), a disposal facility is monitored for different purposes, as follows:

— To establish a baseline.
— To monitor the behaviour of, and changes to, the disposal system barriers:
  - Changes to waste packages;
  - Near field chemical and physical changes induced by the construction of the disposal facility and by interactions between introduced materials, groundwater and host rock;
  - Chemical and physical changes to the surrounding geosphere and in the atmosphere;
  - Changes to associated buffer and sealant materials.
— To monitor radionuclide transport and the release of radionuclides to the biosphere.
— To establish a database of information on the surrounding environment.

6.2. Examples of monitoring parameters for each of these purposes are provided in Annex I, together with an indication of the period of development of the disposal facility in which each type of monitoring might be deployed. The technical complexity of a monitoring programme will vary according to the type of disposal facility and the associated risk. For a near surface disposal facility, the list of parameters to be monitored would typically be less complex than the example provided in Annex I. An example of a monitoring programme for a near surface disposal facility is provided in Annex II.

MONITORING IN THE PRE-OPERATIONAL PERIOD

6.3. Prior to construction, the monitoring programme should be focused on establishing a baseline for the site. During construction (but prior to operation), monitoring should be used to assess the ongoing impact of construction activities on the public and environment, to document the ‘as-built’ conditions, and to help ensure that the performance will meet regulatory requirements and comply with

Baseline monitoring — for collection of data to support the site evaluation process and for identification of important features, events and processes for the first iteration of the safety assessment.

Monitoring of the as-built facility — for evaluation of compliance with regulatory requirements, to support operational activities, and to support the development of the safety case for subsequent licensing steps. Additional measurements may be introduced at this step.

Monitoring of the operating facility — for evaluation of compliance with regulatory requirements and to support development of the safety case for subsequent licensing steps.

Monitoring for closure — for evaluation of compliance with regulatory requirements, to support closure activities, and subsequent post-closure monitoring. Additional measurements may be introduced at this step, while others will be discontinued.

Monitoring of the post-closure performance of the disposal facility (if applicable) — for evaluation of compliance with regulatory requirements and to support subsequent decisions (e.g. scaling down of monitoring activities, release of the site from regulatory control).

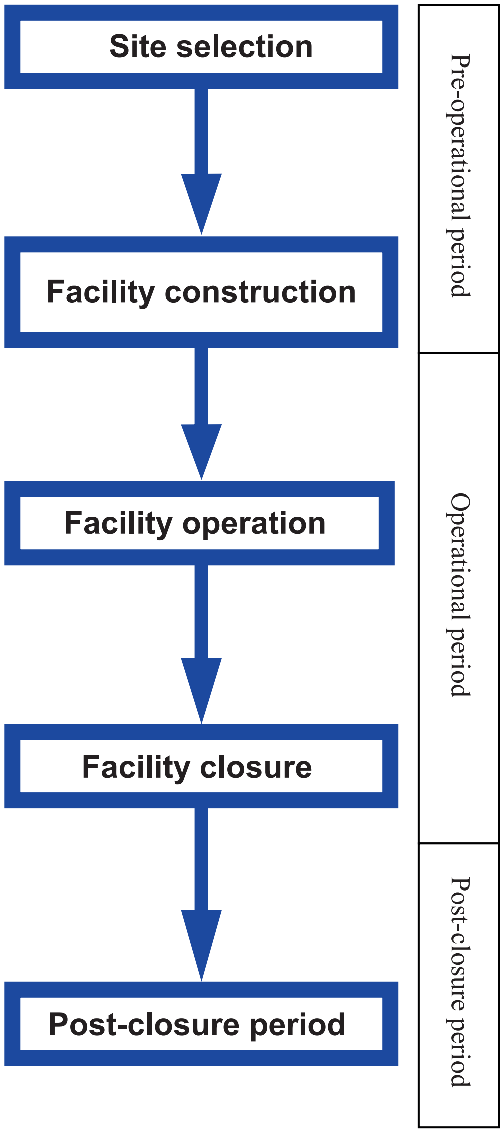

FIG. 1. Monitoring activities throughout the lifetime of a disposal facility.

safety requirements. The objectives of the monitoring programme during the pre-operational period are the following:

— To contribute to the evaluation of suitability of the site;
— To provide input data for the design of the facility;

- To provide input data necessary for the operational and post-closure safety cases;
- To establish baseline conditions for comparison with later monitoring results;
- To aid in designing the monitoring programme for the operational period.

6.4. The safety case and the supporting safety assessment and the environmental impact assessment provide an iterative framework for the progressive improvement in understanding of the technical aspects of the disposal system, and for the identification of new monitoring data that should be collected. As the safety case and safety assessment progress through successive iterations, and as key issues are identified or resolved, the monitoring system should be adapted to accommodate the needs of the safety assessment. Conversely, as new information is identified from monitoring data, scenarios, conceptual models, or parameters used as part of the demonstration of safety may need to be updated. The progressive adaptation of the safety assessment and the associated monitoring, which are both directed at reducing uncertainty, is a key feature of the methodological approach to safety assessment.

6.5. Baseline monitoring is concerned with measurement of the initial values of parameters that will continue to be monitored by either continuous or periodic observations. The scope of baseline monitoring includes the determination of conditions and parameters of potential interest for the understanding of basic earth science, engineering and the environment, and for informing the operational safety assessment and the post-closure safety assessment for the disposal facility. For example, baseline monitoring is used to evaluate changes that occur in the rock and the groundwater system during the construction and operational periods and, at the post-closure stage, to evaluate any significant impacts that the presence of the disposal facility may have on natural processes and the environment. In practice, the monitoring programme will begin during the site investigation stage. A more comprehensive description of establishing baseline conditions can be found in Ref. [18].

6.6. Special attention should be paid to the establishment of a baseline for disposal facilities for waste from mining and mineral processing. Such facilities are developed for the disposal of radionuclides naturally occurring in the surroundings, such as radionuclides from the uranium and thorium decay chains. Measurements made later in the lifetime of the facility should therefore be compared with the baseline, in order to determine changes in concentrations of such radionuclides in environmental media. By contrast, the surroundings of facilities for the disposal of either LLW and ILW or HLW and spent nuclear fuel contain characteristic radionuclides that are more easily distinguished from background levels of radiation. For example, it is noted in Ref. [9] that ^{3}H, ^{137}Cs and ^{14}C are likely to be present at detectable levels in the surroundings of near surface disposal facilities. Given their low background levels, incremental increases in amounts of these radionuclides may be more easily detected than is the case for the radionuclides characteristic of disposal facilities for waste from mining and mineral processing. In the case of mining waste, such as covered tailings, low grade ore or waste rock, the radionuclide most likely to be detectable on the surface is naturally occurring radon, ^{222}Rn.

MONITORING IN THE OPERATIONAL PERIOD

6.7. During the operational period, the monitoring programme should contribute to operational safety, should measure potential impacts on the public and environment, and should assess the performance of the disposal system. Monitoring should continue to encompass evaluation of the features, events and processes important to the safety case, as part of a programme for confirming the performance of the facility. This will enhance understanding of the behaviour of the disposal system for refining the operational and post-closure safety cases. The monitoring programme should also be focused on collection of data from the short term (operational) performance of the as built disposal system to assist in prediction of the long term performance of the system in the post-closure phase. The objectives of the monitoring programme during the operational period are the following:

- To provide data on the as-built properties of materials and structures, for confirmation of the performance of elements of the disposal system, which may be used to revise, improve or build confidence in the post-closure safety case;
- To provide information necessary for checking whether systems for effluent treatment and control are performing properly;
- To provide early warning of any deviations from normal operation;
- To provide data on the discharge of radionuclides to the environment, for use in predictive modelling for estimating radiation levels and activity concentrations in the environment and exposure of the public (e.g. rates of discharge and radionuclide compositions).

6.8. For the purposes of confirming performance of the disposal facility, monitoring should be carried out for key technical parameters of interest in both the operational and post-closure periods. This can be viewed as a part of the step-by-step process of development of the safety case, which continues after the issue of the operational licence during the operational period to progressively improve the predictability of the operational and/or post-closure performance of the disposal system. Such monitoring should provide additional data in support of the data used for the safety assessment, to enable the safety assessment to be updated and improved through the operational period. The regulatory body may require that a programme for performance confirmation is in place as part of the licence conditions for operation. In this way the operator may be obliged to resolve technical issues only during the period of operation rather than as a condition for the granting of a licence for operation. This approach can be used to manage residual uncertainties about technical issues at the time that the licence for construction is granted, but should not be a substitute for an appropriate level of regulatory scrutiny and careful consideration of uncertainties in the safety case early in the development of a disposal facility.

6.9. The monitoring programme should take account of the potential for radiological releases associated with operation of the disposal facility, and the programme should form part of the operational safety case. This element of the monitoring programme is intended to protect the public and the environment during the operational period, and may be established to meet regulatory requirements in respect of releases of radioactive material from the disposal facility during normal operation and under accident conditions. The emergency preparedness and response programme developed as part of the operational safety case should include an appropriate strategy for monitoring that takes account of the suddenness with which emergencies can arise. Monitoring strategies of this kind will be dependent on the risk associated with the accident scenarios envisaged, including events with broad spatial extent (such as earthquakes or cyclones) that may affect access to the site and the provision of off-site support.

6.10. Independent of the monitoring programme associated with the operational safety case, the protection of workers at the disposal facility must be ensured in accordance with the national regulations and international recommendations on radiation safety. However, the protection of workers is not within the scope of this Safety Guide.

6.11. In addition to requirements for monitoring for radionuclides and for the purposes of performance confirmation, national regulations may establish additional requirements. For instance, requirements may exist to monitor groundwater for the presence of toxic chemicals.

MONITORING IN THE POST-CLOSURE PERIOD

6.12. One objective of the monitoring programme for the period after closure, if this is part of the post-closure safety case, is to detect radioactive material and/or other toxic material in the environment that could be attributable to the disposal facility. However, this is only one part of the monitoring programme after closure, and its importance differs for different types of disposal facility. The extent, duration and importance of post-closure monitoring vary among the different types of disposal facilities and the type of waste disposed of. Institutional controls applied after closure of the disposal facility may be of an active or passive nature. Examples of active institutional controls are the monitoring of radionuclide concentrations in the environment and the monitoring of the performance and integrity of barriers, which is important in particular for near surface disposal facilities.

6.13. Monitoring in the post-closure period should include informing the relevant stakeholders of the decision to move from active institutional control to passive institutional control (established by means of, for example, site markers and maintenance of ‘corporate memory’). At this stage in the development of the disposal facility, the goal is to identify when conditions at the site are suitable for a revision of the licence, to allow termination of monitoring activities and maintenance and active control of the site. For example, for surface based disposal facilities, a decision to initiate passive institutional control could be taken when it is considered that long term safety can be ensured by reliance on restrictions on landfill usage, and when the reduction in radiotoxicity of the waste means that the radiological risk associated with human intrusion is reasonably low. This could be considered a step-by-step approach to full long term passive safety.

MONITORING FOR EMERGENCY RESPONSE

6.14. Monitoring for emergency response differs from routine monitoring activities in several key aspects. Routine monitoring is used to verify that performance of the disposal facility is as documented in the safety case, while monitoring for emergency response aims to provide information to mitigate the consequences of an accident for human health and the environment. Requirements for establishing arrangements for promptly conducting facility and environmental monitoring are established in Ref. [19].

6.15. Waste disposal facilities are required to be designed, constructed and operated in such a way that safety is ensured by passive means [2] and, as a general rule, sudden failures are unlikely to occur; conditions that would necessitate immediate or prompt action are unlikely. However, for some types of existing disposal facility (e.g. past practices at some tailings dams), emergencies can arise rapidly. For instance, extreme weather conditions or seismic events can result in failure of a tailings dam, leading to the rapid release of large amounts of contaminants to the environment. Therefore, emergency arrangements should be established for the full range of postulated events, including events with a very low estimated probability of occurrence. Such arrangements should include arrangements for monitoring, deployment of personnel, establishment of procedures, provision of equipment and other arrangements that would allow rapid declaration of the emergency and imminent threats to human health and the environment as described in Ref. [7] and as required in Ref. [19]. The monitoring arrangements should be able to provide data in a timely way, so that appropriate responses can be undertaken in the event that default operational intervention levels[2], which have been coordinated with local officials, are exceeded [7, 19]. Operational intervention levels should be such that they can be used immediately and directly (without further assessment) to determine appropriate protective actions on the basis of measurements of environmental parameters.

7. DEVELOPMENT AND IMPLEMENTATION OF A SURVEILLANCE PROGRAMME

7.1. The purpose of a surveillance programme is to provide oversight of a waste disposal facility, in order to verify the integrity of the passive safety barriers, and to enable the prompt identification of conditions that may lead to a migration or release of radionuclides or other contaminants to the environment. In addition, surveillance includes the review or audit of records, in order to periodically inspect product specifications, and to check the results of such inspections. The surveillance programme is applicable primarily to the operational period and is usually implemented through regular inspections of components of the waste disposal facility that have been identified as critical to the safety case.

[2] An operational intervention level is a calculated level, measured by instruments or determined by laboratory analysis, which corresponds to an interventional level or action level. It is typically expressed in terms of dose rates or activity of radioactive material released, time integrated air concentrations, ground or surface concentrations, or activity concentrations of radionuclides in environmental, food or water samples [20].

The surveillance programme includes, but is not limited to, inspection of these components of the waste disposal facility.

7.2. A site specific surveillance plan and implementation procedures should be developed early in the lifetime of the disposal facility, and should be updated periodically, in consultation with the regulatory body, with account taken of changes in conditions at the site, in operation of the facility and in technology. The plan should show how the surveillance results complement the monitoring programme and site safety and performance requirements. The plan should include:

(a) A description of the site and adjacent area;
(b) A description of components of the waste disposal facility and its environmental setting;
(c) The type and frequency of inspections;
(d) Inspection procedures;
(e) Contingency plans or maintenance actions;
(f) Reporting requirements for inspections;
(g) A description of the management system.

SURVEILLANCE THROUGHOUT THE LIFETIME OF A DISPOSAL FACILITY

7.3. Surveillance programmes should be commenced at the construction stage and should continue to evolve up to the post-closure period, depending on the type of the disposal facility.

7.4. During operation of the facility, the surveillance programme should allow verification that the integrity of the passive safety barriers is protected and preserved. The protective components of the disposal facility should be inspected periodically as part of the surveillance programme, as long as these are located in accessible areas. Such periodic inspections may typically be restricted to directly accessible installations and engineered barriers.

7.5. In the period after closure, waste disposal areas or cells containing waste and waste packages are usually not accessible for inspection. The duration of post-closure surveillance should be determined on the basis of the type of disposal facility and the types of waste it contains. The duration of post-closure surveillance should also depend on confidence in the facility’s performance acquired during previous periods. It should be anticipated that the surveillance after closure of the facility may change in character, or even be terminated as a result of changes in institutional stability.

SURVEILLANCE BY TYPE OF DISPOSAL FACILITY

7.6. “To some extent, the safety of a disposal facility can depend on some future actions such as maintenance work or surveillance. However, this dependence has to be minimized to the extent possible” [2]. “For a geological disposal facility, it is possible to provide for safety after closure by means of passive features…. In the case of a near surface disposal facility, actions such as maintenance, monitoring or surveillance may be necessary for a period of time after closure to ensure safety” [2].

7.7. For near surface disposal facilities, surveillance should start in the pre-operational period and should continue in the period after closure until the end of the period of active institutional control. Barriers that should typically be inspected during the post-closure period are surface covers of the disposal facility.

7.8. For geological disposal facilities, surveillance should start in the pre-operational period and will typically end at closure of the facility, when access to the engineered barriers is no longer possible.

7.9. For disposal facilities for waste from mining and mineral processing, surveillance should start in the pre-operational period and should finish either at the end of the period of active institutional control or at closure of the facility, depending on the nature of the disposal system, for example, if access to the engineered barriers is no longer possible. The assumptions regarding the duration of institutional stability and continuity of knowledge are usually a major factor in defining the duration of surveillance after closure. An example of a long term surveillance plan (for the period after closure) for a uranium mill tailings site is provided in annex I of Ref. [8].

TYPE AND FREQUENCY OF INSPECTIONS

7.10. The programme of inspections should be based on site specific conditions and the potential risk to humans and on other societal, socioeconomic, environmental and regulatory impacts associated with the failure of the waste disposal facility. A surveillance programme will usually include routine inspections and inspections for special purposes.

7.11. If feasible, visual and physical inspections should be applied to components of the waste disposal facility that have been identified as being critical to the safety case, thus providing an effective method of detecting anomalies indicative of potential failures.

7.12. Inspections under the surveillance programme should cover observation of the surface conditions of the facility and of the containment, when accessible, of the integrity of buildings and drainage channels, of the state of vegetation and of any anomalous features (e.g. surface water pounding, erosion of surface covers, and evidence of intrusion into the facility by plants or animals).

7.13. Such inspections should be carried out by suitably qualified personnel who can determine whether specialized technical assistance is necessary.

ROUTINE INSPECTIONS

7.14. Routine inspections should be undertaken on a periodic basis to ensure that the general condition of all the components of the waste disposal facility is satisfactory. A member of the technical staff of the operator with suitable knowledge and experience of the facility will normally perform routine inspections.

7.15. The purpose of a routine inspection is to ensure that the waste disposal system is performing in accordance with the design criteria and complies with regulatory requirements. The inspection should be preceded by a review of the previous inspection report, in which any items requiring follow-up should be noted, and a review of any surveillance data collected since the previous inspection report.

7.16. Routine inspections should be performed at regular intervals throughout the construction of a waste disposal facility, and during any periods of major modification, as well as during any remediation work. This is to ensure that the construction or modification is performed according to approved plans, and has not compromised the performance of the components of the disposal facility. The frequency of routine inspections should be determined on a site specific basis.

INSPECTIONS FOR SPECIAL PURPOSES

7.17. Special inspections should be conducted following extreme natural events, such as major fires, severe earthquakes, floods, severe storms, very heavy rainfall or cyclones. Special inspections should also be performed in the event of a deviation from normal operating conditions. The purpose of special inspections is to ensure that the components of the waste disposal system have not been damaged by these events and continue to be fully functional.

8. USE OF INFORMATION FROM MONITORING AND SURVEILLANCE

8.1. As discussed in previous sections, information from monitoring and surveillance is collected for the purpose of building confidence in the safety of disposal facilities and the reduction of risk or uncertainty, and in support of updating of the safety case, if deemed necessary. The users of monitoring and surveillance information should include all interested parties, including the operator, the regulatory body, local interested parties and the public, or any other interest group. The inclusion of all concerned parties in the use of monitoring and surveillance information will lead to improved transparency in the disposal process and operational performance, increased understanding of the evolution of the disposal facility, its surroundings and the performance of the barriers, as well as enhanced protection of the public and the environment. The aim of a disposal facility for radioactive waste is to provide for passive safety in the long term. Disposal facilities are designed so that active management in the long term is not required for safety.

8.2. Information from monitoring will always contain some degree of uncertainty. Management of the residual uncertainties in measurement and in understanding of the disposal facility is a primary function of the development of the safety case. Challenges associated with the use of monitoring information include difficulties in resolving spatial and temporal variability, an inability to measure certain parameters of interest directly, an inability to project future behaviour of the disposal system, and a lack of fundamental understanding of some processes of interest.

8.3. Caution should be applied in using available monitoring information. The credibility of monitoring data should be verified by means of sufficient redundancy (which should be part of the design of the monitoring system), independent verification of values, the use of well designed, robust equipment, and, to the extent possible, the use of natural analogues. Specifically, only well trained and experienced staff should be permitted to undertake monitoring and associated activities. It is recognized that monitoring will not be feasible beyond a certain time frame. In the distant future there will be significant changes in climatic patterns and associated shifts in human behaviour and practices. Projection of the behaviour of the disposal system into the distant future on the basis of current monitoring information will always be uncertain. Future changes could affect the potential for release of radionuclides from the disposal facility and the exposure pathways through which exposure of biota and representative persons may occur.

ANALYSIS OF AND RESPONSE TO THE MAIN OBJECTIVES

8.4. At all periods in the lifetime of a disposal facility, monitoring and surveillance should provide data on the disposal system to develop and improve the safety case and to verify compliance with regulatory requirements. These two purposes will overlap in some cases; for example, a licence condition requiring a deeper understanding of features, events and processes will lead to improvement of the safety case.

8.5. Results from monitoring and surveillance should contribute to the demonstration of compliance with regulatory constraints and licence conditions. The operator of a disposal facility may base some parts of the monitoring and surveillance programme on specific prescriptive regulatory requirements. For example, monitoring is necessary for comparison of surface water quality with standards, which are often established in advance by the regulatory body. Uncertainties in meeting this kind of regulatory requirement will be limited to uncertainties in the numerical values obtained by measurement.

8.6. Verification of compliance with performance based regulatory criteria, such as dose limits, will necessitate monitoring that provides insights into features, events and processes and system performance, and which provides information to support the safety case and safety assessment. Since approaches for meeting regulatory requirements of this type do not follow strict rules, there should be good and early communication between the regulatory body, operator and other concerned parties. This communication is necessary because the range and types of uncertainty are larger and more subjective than is the case for prescriptive regulatory requirements. Such uncertainties are resolved as much by the process by which they are addressed as by the monitoring data that support the analysis.

8.7. Existing monitoring and surveillance data from comparable types of facility should also be collected and evaluated during the pre-operational period. This will facilitate the development of monitoring and surveillance programmes for the new facility. Comparisons of operating records at comparable facilities can also provide information on the technology used at these facilities, which can aid in establishing proper requirements on safety functions and long term performance for the new disposal facility.

8.8. During the pre-operational period, emphasis should be placed on confirming that as-built conditions are consistent with assumptions made in the safety assessment. In addition, ranges of expected as-built conditions should also be identified.

8.9. As the facility moves into the operational period, monitoring and surveillance should be continued in order to provide information about operating performance, which can be used to update the safety case. The operational safety case is developed prior to the granting of a licence for construction and operation. Residual uncertainties are often managed using conservative estimates of system functions with respect to their implications for safety. Available monitoring information prior to construction, which may be sufficient to develop the safety case, should continue to be updated throughout the operational period, as part of a monitoring programme for confirming performance of the disposal facility. This programme should lead to progressive improvement in understanding of the disposal system, which in turn should be used to improve operating approaches, definition of safety functions, facility design, and design of the monitoring programme. For example, monitoring data on the corrosion rate of a material collected as part of a monitoring programme for confirming performance may lead to a modification in the acceptable inventory limits in the disposal facility. Ideally, if the operational safety case is based on conservative estimates, then changes or improvements in understanding will lead to less restrictive and less costly operating approaches.

8.10. After completion of the emplacement operations, but before the final closure of the disposal facility, monitoring and surveillance data should be collected to confirm the continuing performance of key safety functions as identified in the safety case, either through direct evidence (i.e. by means of a measurable parameter) or indirect evidence (i.e. by enhancing the scientific basis used to develop predictive models or through the collection of data from pilot/demonstration disposal facilities). The data obtained should be used to verify that the disposal system is functioning as expected. This means that the key components are fulfilling their functions, as identified in the safety case, or as stipulated by the regulatory body, and that actual conditions are consistent with the key assumptions made for safety after closure. For example, the data obtained may be used to help support a decision to terminate active institutional control, by verifying that the disposal system has remained in a passively safe condition for a specified period of time.

DEVIATIONS FROM EXPECTED RESULTS

8.11. As stated in para. 8.9, the operational safety case is often built on a set of conservative assumptions in order to manage the uncertainties at that stage of development of the facility. Monitoring and surveillance undertaken to confirm performance are therefore expected to provide data that may be different from those used for the safety case, and are generally expected to be more realistic. Similarly, because of the conservatisms in the safety assessment, environmental monitoring data may be expected to remain within those levels forecast in the safety case. However, monitoring results may also provide apparent or actual contradictions, such as variations in parameters or the occurrence of events not anticipated in the safety assessment. Such results could be labelled as ‘unexpected’, as they do not appear to confirm prior expectations. Communication of monitoring results and their related uncertainties to the regulatory body and other interested parties should be started early in the process, as it is generally easier to explain uncertainties before beginning a monitoring programme than to try to provide an explanation after monitoring has started.

8.12. Unexpected results from monitoring do not necessarily indicate that safety of the disposal system has been compromised. Once possible measurement errors are excluded, the information should be analysed with care to determine its significance within the existing safety case. The complexity of the safety assessment means that comparison with monitoring results might produce counterintuitive results. For instance, a groundwater transport model with conservative bias employed in a safety assessment may ignore or de-emphasize the importance of the leading edge of a plume of contaminants. Although this has to be taken into account in the safety case, monitoring observations of the early arrival of contaminants that are inconsistent with the model results may require careful interpretation.

8.13. Unexpected results may also be indicative of new information that is not reflected in the safety case. Such new information will generally be associated with features, events and processes that are not well understood, or features, events and processes that were previously not considered to be of importance. If it is determined that the unexpected results fall within this category, the monitoring and surveillance programme should be revised and implemented to further investigate the issue. In some cases it may be appropriate to initiate new research to better understand the unexpected results. The safety case should be updated to reflect the new knowledge. When unexpected results occur, they may raise concerns with the regulatory body, and may influence the confidence of concerned parties in the safety of the disposal facility. In this regard, the need for proper, transparent and honest communication should be emphasized to maintain credibility.

8.14. For reasons such as the example provided in para. 8.12, the failure of performance criteria does not necessarily imply that remedial actions or protective measures are necessary. For example, a decision to retrieve emplaced waste could be linked to factors where an exposure situation is not apparent (e.g. a corrosion indicator), and other factors may be more important to the decision than the performance indicator (e.g. protection of workers during retrieval of waste).

8.15. A graded approach should be taken in responding to unexpected results. The response may vary from no action at all to increased sampling frequency for identifying, and/or confirming, spatial and temporal trends, through to changes in design or procedures, all the way to significant remedial action or even retrieval of emplaced waste. Emphasis should be placed on identifying trends rather than assigning too much significance to individual measurements. Actions such as retrieval of waste should be undertaken only after very careful study and justification, including consideration of risks associated with the remedial action. A decision to retrieve the waste should be made dependent on the timely availability of appropriate facilities and infrastructure for handling, processing and storing the waste and, if the waste is to be relocated, on the availability of a suitable disposal site.

PERIODIC REVIEW OF THE MONITORING AND SURVEILLANCE PROGRAMMES

8.16. The design of a monitoring and surveillance programme should be an iterative process that allows for periodic changes to the programme. The safety case and supporting safety assessment are useful tools that should be used in the review of the monitoring and surveillance programme. The monitoring and surveillance programme should be designed to be flexible, to enable new sources of data, new types of data, new technologies and new regulatory requirements to be incorporated. The results of research and development may influence the focus and the nature of the monitoring and surveillance programme.

9. MANAGEMENT SYSTEM

9.1. The monitoring and surveillance programme should meet the requirements for the management system established in Ref. [21] and the recommendations provided in Ref. [17]. Elements of the management system that should receive particular attention with regard to monitoring and surveillance are:

— Ensuring the continued availability of resources over long time periods;
— The establishment and documentation of processes leading to qualification of personnel, processes for conduct of the monitoring and surveillance programme and processes for use of data derived from it in the regulatory process;
— The control of records over the duration of the disposal facility project.

9.2. It may be neither feasible nor necessary for the government to make special provisions for ensuring the continued availability of resources for tens or hundreds of years. In fact, private companies are frequently the party responsible for ensuring resources for waste disposal facilities. Financial guarantees might be required by the regulatory body as a licence condition. Nevertheless, ultimate ownership of the disposal facility by, and responsibility of, the government is considered a durable institutional control and constitutes the requisite provision of resource availability.

9.3. The monitoring and surveillance programme for a waste disposal facility should be capable of providing data in support of decisions that will be made over the entire lifetime of the facility. Since the lifetime of a disposal facility is very long, it follows that the management system established should be such as to maintain continuity of data collection, continuity of data management, and adaptability to new approaches for the collection and interpretation of data. Some types of monitoring and surveillance require consistent, long term funding to be useful, and the management system should establish approaches to ensure the necessary continuity of funding. For instance, many field experiments may require years before they produce credible and useful data. Such experiments can be important to establishing a credible safety case, but they might also be subject to transitory funding restrictions that can end the experiment too early, limiting its usefulness. The management system should additionally establish provisions to ensure proper planning for financial resources and qualified human resources when necessary.

9.4. Management processes are necessary to establish the quality of data. The qualification of data should constitute a set of procedures that permit traceability and transparency of the data and their interpretation, when such data are to be used in regulatory decisions. Data used in a safety case may be derived from one of several origins:

- Data collected within the disposal facility project that is subject to the management system;
- Data collected as part of a research programme that is not subject to the management system;
- Data collected historically, which predate the existence of the management system;
- Information from the literature that reflects general knowledge, understanding or measurements, and which is not necessarily specifically associated with the disposal facility project under consideration.

9.5. The management system should establish clear processes for qualifying each of these types of information. For example, to qualify historical data, it may be necessary to establish management processes for review of the original data to ensure that they are correct and traceable.

9.6. The management system should establish processes for data management, record keeping and archiving over the duration of the disposal facility project. Specific recommendations regarding the management system are provided in Ref. [17]. Since programmes for the development of a disposal facility have very long lifetimes, and since surveillance data collected throughout the lifetime of the disposal facility will be needed for decisions taken later in the lifetime of the facility, the management system should provide long lasting traceability and transparency of monitoring and surveillance data.

9.7. Provision should be made to anticipate needs for monitoring and surveillance at later periods in the lifetime of the facility and to gather monitoring data that can inform later planning and actions.

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Annex I

EXAMPLE OF MONITORING AND SURVEILLANCE INFORMATION COLLECTED FOR A GEOLOGICAL DISPOSAL PROGRAMME

I–1. A monitoring programme has to be developed and carried out prior to and during the construction and operation of a geological disposal facility. The aim of such a programme is to collect and update the information necessary to confirm the conditions necessary to ensure the protection of workers and the public and for 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. A prerequisite of a monitoring programme is that the functions of the (passive) safety barriers are not to be compromised in the course of monitoring.

I–2. As described in Ref. [I–1], parameters to be monitored in a radioactive waste disposal facility can be separated into different categories:

- Parameters necessary for establishment of baseline trends;
- Behaviour of the waste packages and of the associated buffer and sealant material;
- Degradation of disposal facility structures and engineered barriers;
- Near field chemical and physical disturbances induced by the construction of the disposal facility and the interactions between introduced materials, groundwater and host rock;
- Chemical and physical changes to the surrounding geosphere and in the atmosphere;
- Levels of radioactive contamination and other contamination.

I–3. The monitored parameters are to be recorded in an environmental database. It is emphasized that the monitoring of any engineered structure or natural barrier, features and processes is required if these are identified as being critical to the safety case.

ESTABLISHMENT OF BASELINE TRENDS

I–4. Certain monitoring activities are expected to begin at the earliest possible time within a disposal facility development programme, before the perturbations caused by disposal facility construction and operation begin to accumulate. This early information is important because it allows an understanding to be developed of the nature and properties of the natural, 'undisturbed' environment of the disposal system.

I–5. Baseline monitoring is concerned with the initial values of parameters that will continue to be monitored by either continuous or periodic observation. The scope of baseline monitoring includes the determination of conditions and parameters of potential interest for basic earth science, engineering and the environment and for the operational and post-closure safety assessment of the disposal facility. The scope of this monitoring needs to be sufficiently broad to allow for recording parameters for the baseline that are subject to investigations regarding their significance and thus may become an issue in the future [I–2]. For example, monitoring will be used to evaluate changes that occur in the rock and groundwater system during the construction and operational periods and, in the post-closure stage, to evaluate any impacts that the presence of the disposal facility may have on natural processes and the environment. In practice, the monitoring programme will begin at the site investigation stage.

I–6. The characteristics of primary interest in the context of establishing baseline information are:

- The groundwater flow field in the host rock and in the surrounding geological environment (material properties, groundwater pressure distributions, hydraulic gradients, regions of recharge and discharge, etc.).
- Geochemical characteristics of groundwater (redox, salinity, major and trace element concentrations, natural radionuclide content, etc.).
- Mineralogy of the host rock that makes up part of the disposal facility.
- Geomechanical properties of the host rock that contributes to the stability of the disposal facility structure.
- Transport and retention properties of the host rock that makes up part of the disposal facility, if applicable.
- Characterization of discontinuities (including fractures) in the host rock that makes up part of the disposal facility.
- Background levels of natural radioactivity in groundwater, surface waters, air, soils and sediments, and animal and plant life.
- Meteorological conditions and climatic conditions.
- Hydrology of surface water systems, including drainage patterns and infiltration rates.
- Ecology of natural habitats and ecosystems.

Baseline data need to be established. Where important parameter values are found to follow an increasing or decreasing trend, baseline monitoring will need to be continued until that trend is established with confidence and the reasons for the trend are sufficiently well understood. The establishment of baseline values for surface environmental indicators is relatively straightforward, because the process of measurement will, in general, not affect the parameters being measured (e.g. measurements relating to climatic factors and surface hydrology). However, invasive investigations will themselves perturb the natural groundwater system to a degree that depends on site specific conditions. In order to establish baseline conditions with which to judge later impacts, e.g. changes to groundwater pressures and hydrochemical conditions in response to disposal facility construction, sufficient information needs to be collected in the surface exploration stage to have confidence that the undisturbed conditions have been adequately characterized, both spatially and temporally.

MONITORING OF THE CONDITION OF EMPLACED WASTE PACKAGES

I–7. Waste package conditions are relevant to waste retrievability, and therefore monitoring of parameters that indicate the integrity or the status of waste packages is particularly important. The condition of emplaced waste packages will depend upon degradation phenomena such as corrosion and effects such as waste stack stability, re-saturation (e.g. of buffer and waste), and gas production.

I–8. The parameters that could be monitored for use as indicators of the condition of waste packages fall into two categories: parameters that can be measured directly (e.g. corrosion current, strain, swelling pressure for clay buffers); and environmental parameters (e.g. temperature, humidity, re-saturation pressure). In some disposal facility designs, particularly for LLW and ILW, the analysis of waste derived gases, as close as possible to the waste packages, provide useful indications about their integrity and/or about the performance of already constructed engineered barriers.

MONITORING OF THE STRUCTURES AND ENGINEERED BARRIERS OF THE DISPOSAL FACILITY

I–9. Changes in the structural stability of the disposal facility may occur as a result of natural processes and human activity. Continuing monitoring of the surrounding area may contribute to assessment of its stability and to the detection of any movement of the disposal facility structure or the surrounding host rock.

I–10. The parameters to be monitored are:

- — Mechanical properties;
- — Stresses;
- — Strains;
- — By means of conventional observation of underground openings:
  - • Rock stresses;
  - • Deformations and loads on rock supports;
  - • Deformations in walls and lining;
  - • Fractures.

I–11. The engineered barriers comprise all the materials placed around the waste to isolate and contain it, including any low permeability or intrusion resistant components. Engineered barriers include seals and part of backfills and parts of the disposal facility structure.

DISTURBANCES CREATED BY THE DISPOSAL FACILITY

I–12. The construction of a disposal facility will disturb the pre-existing natural system. The subsequent stage of disposal facility operations will cause further changes. Some of these changes may take many years to manifest themselves. Therefore, the monitoring programme will be concerned with changes to the disposal facility environment resulting from effects such as:

- — Mechanical disturbance, as a result of the excavation activities;
- — Hydraulic and hydrochemical disturbances, resulting from excavation and drainage;
- — Thermomechanical effects, caused by the emplacement of heat generating waste;
- — Geochemical disturbances due to chemical reactions caused by construction of the disposal facility and operation (primarily the introduction of air, but also of backfill, materials for strengthening such as steel reinforcements, grout and shotcrete, sealing materials, the waste itself and/or the components of the waste package).

I–13. The parameters to be monitored in the host rock are:

- Mechanical disturbances in the host rock:
  - Stress field;
  - Deformation;
  - Fractures.
- Hydraulic disturbances:
  - Permeability;
  - Water pressure;
  - Degree of saturation.
- Geochemical disturbances:
  - Composition (interstitial water and mineralogy);
  - pH values;
  - Redox values;
  - Retention properties;
  - Biological changes.
- Thermal disturbances:
  - Temperature distribution;
  - Thermal conductivity, obtained from temperature distribution.

MONITORING OF THE RELEASE OF RADIONUCLIDES

I–14. In practice, and assuming normal evolution of a geological disposal facility, it will not be feasible to monitor the release of radionuclides from the waste packages, the engineered barriers or the disposal galleries, the reason being that the anticipated lifetimes of the waste containers are several thousands of years. Only in the case of an alternative evolution of the facility is it possible that radionuclides may be released within a shorter time frame. In order to obtain baseline conditions against which the impacts of any mobilization and release of contaminants can be compared, it is necessary to obtain information on the following parameters, measured through the engineered barriers, the host rock and the geosphere:

- Leachate levels;
- Activity concentration in groundwater;
- Hydraulic gradients and the velocity and direction of the flow in the potentially contaminated zone;
- The level of the water table;
- The river flow rate (which could influence hydrological conditions);
- Recharge of aquifers;
- The chemical composition of the water.

CHANGES TO THE GEOSPHERE

I–15. The geosphere surrounding a disposal facility will respond in a number of different ways to the presence of the disposal facility (e.g. mechanically, hydraulically and chemically). Relevant measurable parameters are temperature, stress, groundwater chemistry, groundwater pressure, solute chemistry and mineralogy. These parameters will often be measurable using boreholes drilled during the above ground site characterization and the underground investigation of the host rock. Many mineralogical changes in response to ventilation of the disposal facility are likely to be confined to the immediate vicinity of the disposal facility.

I–16. Geophysical methods may be employed, for instance:

- Ground electromagnetic geophysics to delineate plumes of above background electric conductivity in groundwater due to presence of electrolytes;
- Radon emanometry;
- Airborne radiometrics.

I–17. Of particular interest are changes to the hydraulic and mechanical behaviour of rock structures that may have a direct bearing on the long term performance of the isolation system, e.g. the connectivity of major water conducting fractures. Again, investigation of these features is likely to be by boreholes drilled during the above ground site characterization and the underground investigation of the host rock.

I–18. For disposal facilities in the saturated zone, groundwater will flow around or through the disposal facility while the disposal facility remains open. However, following re-saturation of the disposal facility (or perhaps re-saturation of part of the disposal facility) groundwater will flow through the disposal facility back into the geosphere. This will produce geochemical changes in the geosphere. For some disposal facility concepts, e.g. those that make extensive use of cement, the changes may be profound.

DEVELOPMENT OF AN ENVIRONMENTAL DATABASE

I–19. The accumulation of environmental data over a period of several decades facilitates the assessment of the suitability of the land above a disposal facility for alternative land uses.

I–20. Parameters of potential relevance are:

- — Meteorology;
- — Hydrology, including drainage, water usage and water quality;
- — Concentration of radionuclides and other pollutants in various parts of the environment, including biota, sediments and waters;
- — Local ecology;
- — Geomorphological processes, such as denudation, localized erosion and slope evolution;
- — Tectonic activity such as vertical and lateral earth movement rates, seismic events and geothermal heat flow;
- — Land use in the surrounding region.

I–21. All these parameters may be measured from the surface. The data collection is expected to be continuous and extend over many years.

ALTERNATIVE METHODS OF DATA COLLECTION

I–22. If no method can be identified that respects all constraints on monitoring, alternative strategies will have to be used. The option of constructing, within the confines of the disposal facility or nearby in the same host rock, an extensively instrumented demonstration or pilot facility could be evaluated. This will avoid any breaching of the real isolation barriers. Logically, this demonstration would need to take place before the authorization of disposal facility operations; however, in some geological disposal programmes, the continuation of demonstration, and thus the associated monitoring, concurrently with disposal operations in the disposal facility, has been suggested. One advantage of such a strategy is that it would provide additional confirmation of the reliability of assumptions about the overall performance of the disposal system.

I–23. Table I–1 summarizes the parameters that need to be monitored during the different periods of development of a geological disposal facility.

TABLE I–1. PARAMETERS TO BE MONITORED DURING VARIOUS PERIODS OF THE DEVELOPMENT OF A GEOLOGICAL DISPOSAL FACILITY

Parameters/process to be monitored	Pre-operational period (including site selection and facility construction)	Operational period (including closure)	Post-closure period[a]
BASELINE (INITIAL VALUE)			
Groundwater flow field in the host rock and the surrounding geosphere:			
— Groundwater pressure distributions			
— Hydraulic gradients			
— Flow directions			
— Permeabilities			
— Regions of recharge and discharge			
Geochemical characteristics of groundwater:			
— Redox reactions	×		
— Salinity	×		
— Major and trace element concentrations	×		
— Natural radionuclide content/background activity	×		
	×		
Mineralogy of the host rock that makes up part of the disposal facility	×		
Geomechanical properties of the host rock that contribute to the stability of the disposal facility structure	×		

TABLE I–1. PARAMETERS TO BE MONITORED DURING VARIOUS PERIODS OF THE DEVELOPMENT OF A GEOLOGICAL DISPOSAL FACILITY (cont.)

Parameters/process to be monitored	Pre-operational period (including site selection and facility construction)	Operational period (including closure)	Post-closure period[a]
Retention and hydraulic properties of the host rock that makes up part of the disposal facility	×		
Characterization of the discontinuities (including fractures) of the host rock that makes up part of the disposal facility	×		
Background levels of natural radioactivity in groundwater, surface waters, air, soils and sediments, and animal and plant life	×		
Chemical and physical changes to the surrounding geosphere and in the atmosphere	×		
Meteorological and climatic conditions	×		
Hydrology of surface water systems, including drainage patterns and infiltration rates	×		
Ecology of natural habitats and ecosystems	×	×	
Mechanical properties of the disposal facility structure		×	

For footnote, see p. 58.

TABLE I–1. PARAMETERS TO BE MONITORED DURING VARIOUS PERIODS OF THE DEVELOPMENT OF A GEOLOGICAL DISPOSAL FACILITY (cont.)

Parameters/process to be monitored	Pre-operational period (including site selection and facility construction)	Operational period (including closure)	Post-closure period[a]
Mechanical properties of the engineered barriers		×	
Retention and hydraulic properties of the engineered barriers		×	
ONGOING MONITORING OF BASELINE PARAMETERS		×	×
INTEGRITY OF WASTE PACKAGES			
Parameters that can be measured directly: — Corrosion — Strain — Pressure on the waste package (i.e. swelling pressure for clay buffer)		×	(×)
Environmental parameters: — Temperature — Humidity — Re-saturation — Characteristics of waste derived gases		×	(×)

TABLE I–1. PARAMETERS TO BE MONITORED DURING VARIOUS PERIODS OF THE DEVELOPMENT OF A GEOLOGICAL DISPOSAL FACILITY (cont.)

Parameters/process to be monitored	Pre-operational period (including site selection and facility construction)	Operational period (including closure)	Post-closure period[a]
DISPOSAL FACILITY STRUCTURES AND ENGINEERED BARRIERS			
Structural stability of disposal facility structure and engineered barrier:			
— Mechanical properties			
— Stresses			
— Strains			
— By means of conventional observation of underground openings:		×	(×)
• Rock stresses			
• Deformations and loads on rock supports			
• Deformations in walls and lining			
• Fractures			
Behaviour of engineered barrier (i.e. backfill and seal):			
— Re-saturation rate			
— Changes in:			
• Hydraulic properties		×	(×)
• Mechanical properties (including swelling)			
• Chemical properties			
• Thermal properties			

For footnote, see p. 58.

TABLE I–1. PARAMETERS TO BE MONITORED DURING VARIOUS PERIODS OF THE DEVELOPMENT OF A GEOLOGICAL DISPOSAL FACILITY (cont.)

Parameters/process to be monitored	Pre-operational period (including site selection and facility construction)	Operational period (including closure)	Post-closure period[a]
In order to prevent water ingress into the disposal facility, or water infiltration through the disposal facility		×	(×)
DISTURBANCES CREATED BY THE DISPOSAL FACILITY (CONSTRUCTION, EMPLACEMENT OF WASTE AND ENGINEERED BARRIERS)			
Mechanical disturbances in the host rock: — Stress field — Deformation — Fractures	×	×	(×)
Geochemical disturbances: — Soil composition (interstitial water and mineralogy) — pH levels — Redox reactions — Retention properties — Biological changes	×	×	(×)

TABLE I–1. PARAMETERS TO BE MONITORED DURING VARIOUS PERIODS OF THE DEVELOPMENT OF A GEOLOGICAL DISPOSAL FACILITY (cont.)

Parameters/process to be monitored	Pre-operational period (including site selection and facility construction)	Operational period (including closure)	Post-closure period[a]
Hydraulic disturbances: — Permeability — Water pressure — Degree of saturation	×	×	(×)
Thermal disturbances: — Temperature distribution — Thermal conductivity		×	(×)
MONITORING THE RELEASE OF RADIONUCLIDES			
Leachate levels		×	(×)
Activity concentration in groundwater		×	×
Extent of the potentially contaminated zone		×	×
Hydraulic gradients, velocity and direction of the flow in the potentially contaminated zone		×	×

For footnote, see p. 58.

TABLE I–1. PARAMETERS TO BE MONITORED DURING VARIOUS PERIODS OF THE DEVELOPMENT OF A GEOLOGICAL DISPOSAL FACILITY (cont.)

Parameters/process to be monitored	Pre-operational period (including site selection and facility construction)	Operational period (including closure)	Post-closure period[a]
Level of the water table		×	×
Recharge of and discharge from aquifers		×	×
Chemical composition of water		×	×
Changes to geosphere			
Mechanical properties: — Stresses — Strains — Fractures (connectivity that could create a preferential pathway)		×	×
Hydraulic properties: — Groundwater pressure			×
Chemical properties: — Solute chemistry — Mineralogy		×	×

TABLE I–1. PARAMETERS TO BE MONITORED DURING VARIOUS PERIODS OF THE DEVELOPMENT OF A GEOLOGICAL DISPOSAL FACILITY (cont.)

Parameters/process to be monitored	Pre-operational period (including site selection and facility construction)	Operational period (including closure)	Post-closure period[a]
Thermal properties			
— Temperature		×	×
DEVELOPMENT OF AN ENVIRONMENTAL DATABASE			
Meteorology	×	×	×
Hydrology, including drainage, water usage and water quality	×	×	×
Concentration of radionuclides and other pollutants in various environmental compartments, including biota, sediments and waters	×	×	×
Local ecology	×	×	×
Geomorphological processes, such as denudation, localized erosion and slope evolution	×	×	×
Tectonic activity such as vertical and lateral earth movement rates, seismic events and geothermal heat flow	×	×	×

For footnote, see p. 58.

TABLE I–1. PARAMETERS TO BE MONITORED DURING VARIOUS PERIODS OF THE DEVELOPMENT OF A GEOLOGICAL DISPOSAL FACILITY (cont.)

Parameters/process to be monitored	Pre-operational period (including site selection and facility construction)	Operational period (including closure)	Post-closure period[a]
Land use in the surrounding region	×	×	×

[a] Parameters measured during the operational period may continue to be monitored during the post-closure period but to a lesser extent, as long as it will not affect long term safety. This is denoted by (×).

REFERENCES TO ANNEX I

[I–1] INTERNATIONAL ATOMIC ENERGY AGENCY, Monitoring of Geological Repositories for High Level Radioactive Waste, IAEA-TECDOC-1208, IAEA, Vienna (2001).

[I–2] EUROPEAN COMMISSION, Thematic Network on the Role of Monitoring in a Phased Approach to Geological Disposal of Radioactive Waste, Final Report, Rep. EUR 21025 EN, EC, Luxembourg (2004).

Annex II

EXAMPLE OF A MONITORING AND SURVEILLANCE PROGRAMME FOR A NEAR SURFACE DISPOSAL FACILITY

INTRODUCTION

II–1. The radioactive waste treatment and disposal facility at Püspökszilágy has been operated by the Hungarian national radioactive waste management company (PURAM) since July 1998. Earlier, from 1976, when the site was commissioned, it was operated by the National Health Public Officers Service. The task of the facility is to accommodate the low level and intermediate level institutional radioactive waste arising in Hungary from small scale producers.

II–2. The site is located on the ridge of a hill at an altitude of 200–250 m above the level of the Baltic Sea, and lies on approximately 30 m thick heterogeneous Quaternary sediments (silt and clay, low permeability) above the groundwater table. It is bounded to the south west by the Nemedi stream and to the north east by the Szilagyi stream. The facility is 1.5 km away from the nearest village (Püspökszilágy).

II–3. The facility is a radon type near surface disposal facility. Reinforced concrete storage vaults (Types A and C, see paras II–4 and II–5) and carbon steel/stainless steel storage wells (Types B and D, see paras II–6 and II–7) are provided for the storage and disposal of radioactive waste.

II–4. The A type disposal system, which is a reinforced concrete structure (with 40 cm thick walls), serves as the disposal of solid radioactive waste. There are four vaults (AI–AIV), with each vault consisting 70 m^3 cells. It is covered by a protective roof during the emplacement of waste, then sealed and covered temporarily by a 2 m thick clay layer. The final cover is still to be designed.

II–5. The C type system serves as the storage of solidified organic solvents and biological waste, but it has recently been used for the temporary storage of neutron sources. It consists of eight cells, each 1.5 m^3, and is covered by a protective roof.

II–6. The B type system serves as the storage of disused sealed sources. It consists of 16 wells with a diameter of 40 mm, and 16 wells with a diameter of 100 mm (6 m depth) located inside a concrete monolithic structure.

II–7. The D type system serves as the storage of disused sealed sources with a half-life greater than 30 years (^{226}Ra and ^{241}Am). It consists of four wells with a diameter of 200 mm, and 16 wells with a diameter of 100 mm (steel lined and 6 m depth).

PRE-OPERATIONAL MONITORING AND SURVEILLANCE ACTIVITIES

II–8. Between 1974 and 1976, before the disposal facility started operations, reference levels (i.e. background values prior to the operation) were identified for the most significant points of the environment around the disposal facility (i.e. along the water courses and in the groundwater).

II–9. Sampling points were determined in the village nearby, along the two brooks flowing around the hill in which the facility is located, on the slopes of the hill, and in the territory of the facility.

II–10. Monitoring included measurement of ^{137}Cs, and the total gamma and beta activity concentrations in different environmental samples.

EARLY OPERATIONAL MONITORING AND SURVEILLANCE ACTIVITIES

II–11. In the first stage of the operation of the disposal facility, the monitoring programme consisted of sampling in the following locations:

— In ten groundwater monitoring wells (water);
— At eight points along the surface water flows (water and sediment);
— In the rainwater collector (water and sediment);
— At six points for vegetation sampling;
— At two places for aerosol and fallout;
— At two places for food samples (fish and milk).

II–12. In 1991, the site was extended from 3360 m^3 to 5040 m^3. Accordingly, an extended monitoring system was implemented with the following features:

— Hydrogeological (underground water) monitoring: An additional 18 wells were constructed, and in total 28 wells have been used for the monitoring of changes of the groundwater table level.
— Surface monitoring at four fixed measurement points.
— Near surface radiation monitoring (16 wells, each of 7 m depth around the disposal vaults to monitor the activity of gamma emitting isotopes in the soil).
— Isotope hydrology measurement: ^{3}H, ^{14}C, ^{90}Sr and chemical composition in the groundwater and in the surface waters.
— Water flow measurements in two cross-sections along both brooks.
— Monitoring of the new rainwater collector basin.

II–13. The basic levels were calculated using two year averages of the data collected (1990–1991).

II–14. The new results were built into the operational monitoring programme.

II–15. The initial safety evaluation of the system was performed in 1995, and in parallel with it a meteorological system was established aiming at collecting further input data.

OPERATIONAL MONITORING AND SURVEILLANCE

II–16. The radiological monitoring programme for operation is broadly similar to the pre-operational monitoring programme, but sampling frequencies are generally reduced. Based on a periodic review of the results and on new recommendations for sampling and measurement procedures, there were some changes in the sampling frequencies, the range of nuclides measured and the monitoring wells used.

II–17. The sampling operations required for the measurements extend over the entire area of the site, and along water courses within a perimeter of 20 km.

II–18. The first comprehensive safety assessment was performed in 2000, and was based on geological investigations carried out in the 1970s and monitoring data collected from 1976 to 2000. As a result of the safety assessment, some concerns were raised relating to the stability of the slope, and therefore investigation of the potential for erosion of the slopes was included in the monitoring programme.

II–19. Later, during the relicensing process of the site, the regulatory body requested further geological investigations, which were performed in 2006 and 2007.

II–20. In 2000, elevated tritium concentration levels were measured in a few groundwater monitoring wells. Although this has had no impact on exposure of the local population, six monitoring wells for continuous monitoring were implemented to make detailed investigations, in addition to the wells constructed for operational monitoring. The source and main pathways of the tritium were identified, and further monitored.

II–21. In 2004, following the refurbishment of the treatment and storage building, new aerosol and soil sampling points were installed.

II–22. During normal operation of the facility, airborne or liquid radioactive discharges are expected to occur only from the operations and storage buildings, both of which are situated within the controlled zone. The small amount of liquid waste generated is stored in sealed tanks; no discharge from these tanks has occurred to date.

II–23. The airborne discharge monitoring is carried out by measurements of emissions, with the use of a sampling unit installed into the ventilation stack. Under normal operational conditions, the discharge is minimal and cannot be distinguished from the background values. The discharge from the storage building and the operational building is also monitored by monitoring devices installed in different locations along the direction of the prevailing wind.

II–24. The environmental monitoring operations of the facility are conducted by several laboratories. The most essential basic measurements are carried out by the internal laboratory of the facility. The special measurements and the detection of difficult to measure isotopes in the environmental samples are undertaken by other Hungarian laboratories. Vegetation, animal, soil, sediment/mud, aerosol, fallout, surface water and groundwater samples are collected on a regular basis, typically from 40 different sampling locations, by the environmental monitoring laboratory of the facility for the purposes of measurement using gamma spectrometry and total beta counting.

II–25. Samples are also taken from an additional 30 groundwater monitoring wells. The highly sensitive measurements of the vegetation, soil and animal samples taken in the direct vicinity of the facility are analysed by an external institution.

II–26. The data of the monitoring system are compared with the reference levels identified in 1976 and 1977.

II–27. Nearly 600 samples are taken annually from the surroundings of the facility. The results of nearly one thousand tests did not show any detectable deviation from the natural background values. This fact was also confirmed by control tests undertaken by competent authorities and independent institutes.

II–28. The radiological information gathered from the surroundings of the facility is recorded in a national database.

II–29. A summary of the monitoring system is shown in Table II–1.

PLANS FOR POST-CLOSURE MONITORING

II–30. At present, requirements for post-closure monitoring are not well defined. Eventually, they will be specified by the regulatory body with due consideration being given to the physical, biological and geochemical features of the disposal site and the surrounding area.

TABLE II–1. SUMMARY OF THE STORAGE AND DISPOSAL MONITORING SYSTEM

Environmental media sampled	Location of monitoring	Type of monitoring	Sampling method	Measurement method	Comparison with
Air	In the centre of the nearest village	Environmental	Air filter changed weekly Fallout sampling basin	Gross beta counting and gamma spectrometry	Base level
Air	At the downwind side of the disposal area	Environmental/source	Air filter changed weekly Fallout sampling weekly Adsorption of ^{3}H on silica gel and ^{4}C in barium hydroxide every two months	Gross alpha and beta counting, as well as gamma spectrometry tritium, radiocarbon, and ^{90}Sr measurement	Base level
Air	At the downwind side of the treatment and storage building, 100 m distant	Environmental/source	Filter tape periodically forwarded to the laboratory Adsorption of ^{3}H on silica gel and ^{14}C in barium hydroxide	Gross alpha and beta counting, as well as tritium, radiocarbon and ^{90}Sr measurement	Base level
Air	In the ventilation chimney of the treatment and storage building	Source	Air filter changed weekly Adsorption of ^{3}H on silica gel and ^{14}C in barium hydroxide every two months	Gross beta counting, as well as gamma spectrometry Tritium, radiocarbon and ^{90}Sr measurement	Discharge limit

TABLE II–1. SUMMARY OF THE STORAGE AND DISPOSAL MONITORING SYSTEM (cont.)

Environmental media sampled	Location of monitoring	Type of monitoring	Sampling method	Measurement method	Comparison with
Air	In the basement and the first floor in the treatment and storage buildings	Source	Filter tape periodically forwarded to the laboratory	Continuous measurement of alpha and beta aerosol concentrations	Radiation protection limits
Surface water	Brook 1 upstream in the centre of the nearest village	Environmental	Hand sampling twice a year	Gamma spectrometry, as well as gross beta and ^{3}H measurement.	Base level
Surface water	Brook 1 upstream from the site	Source	Hand sampling and pumping twice a year	Gross beta counting and gamma spectrometry, as well as tritium, radiocarbon, ^{90}Sr and inductively coupled plasma (ICP) measurement	Base level
Surface water	Brook 1 downstream from the site	Environmental	Hand sampling twice a year	Gross beta counting and gamma spectrometry, as well as tritium measurement	Base level
Surface water	Fish pond along Brook 1	Environmental	Hand sampling twice a year	Gross beta counting and gamma spectrometry	Base level

TABLE II–1. SUMMARY OF THE STORAGE AND DISPOSAL MONITORING SYSTEM (cont.)

Environmental media sampled	Location of monitoring	Type of monitoring	Sampling method	Measurement method	Comparison with
Surface water	Brook 2 upstream in the centre of the nearest village	Environmental	Same as Brook 1	Same as Brook 1	Base level
Surface water	Brook 2 upstream from the site	Environmental	Same as Brook 1	Same as Brook 1	Base level
Surface water	Brook 2 downstream from the site	Environmental	Same as Brook 1	Same as Brook 1	Base level
Surface water	Before and after water collection river	Environmental	Hand sampling once a year	Gross beta counting and gamma spectrometry	Base level
Surface water	20 km along the water collection river	Environmental	Hand sampling once a year	Gross beta counting and gamma spectrometry	Base level
Rainwater	Rainwater collection basin 90 m^3 (in the control zone)	Source	Hand sampling when the basin is filled	Gross beta counting and gamma spectrometry, as well as tritium, radiocarbon and ^3H measurement	Discharge limit

TABLE II–1. SUMMARY OF THE STORAGE AND DISPOSAL MONITORING SYSTEM (cont.)

Environmental media sampled	Location of monitoring	Type of monitoring	Sampling method	Measurement method	Comparison with
Rainwater	Rainwater collection basin 60 m^3 (in the control zone)	Source	Hand sampling when the basin is filled	Gross beta counting and gamma spectrometry	Discharge limit
Groundwater	On the slopes around the site (23 wells)	Environmental	Hand sampling and pumping twice a year	^{3}H, ^{14}C, gross beta counting, gamma spectrometry, ^{90}Sr and ICP measurement	Base level
Groundwater	Inside the facility (ten wells)	Source	Hand sampling and pumping twice a year	^{3}H, ^{14}C, gross beta counting, gamma spectrometry, ^{90}Sr and ICP measurement	Base level
Groundwater	On the ridge upward from the facility (background) (three wells)	Environmental (background)	Hand sampling and pumping twice a year	^{3}H, ^{14}C, gross beta counting, gamma spectrometry, ^{90}Sr, and ICP measurement	Base level
Groundwater	In the control zone (six wells)	Source	Hand sampling and pumping monthly for ^{3}H, twice a year for others	^{3}H, ^{14}C, gross beta counting, gamma spectrometry, ^{90}Sr and ICP measurement	Base level
Sediments	Along the springs	Environmental	Sampling the mud from the water, without benthos	Gross beta counting, and gamma spectrometry	Base level

TABLE II–1. SUMMARY OF THE STORAGE AND DISPOSAL MONITORING SYSTEM (cont.)

Environmental media sampled	Location of monitoring	Type of monitoring	Sampling method	Measurement method	Comparison with
Soil	Inside the site (11 places)	Source	Hand sampling once a year	Gross beta counting, gamma spectrometry	Base level
Soil	Inside the site (six places)	Source	Hand sampling once a year	^{90}Sr, gross beta counting, gamma spectrometry	Base level
Soil	Outside the site (four places)	Environmental	Hand sampling once a year	Gross beta counting, gamma spectrometry	Base level
Plant	Along the springs	Environmental	Hand sampling twice a year	Gross beta counting, gamma spectrometry	Base level
Plant	Inside the site (five places)	Environmental	Hand sampling twice a year	Gross beta counting, gamma spectrometry, ^{90}Sr measurement	Base level
Animal	From the lake	Environmental	Sampling of whole fish, only native fish, twice a year	Gross beta counting, gamma spectrometry, ^{90}Sr measurement	Base level
Animal	Inside the site	Environmental	Sheep at the site, once a year	Gross beta counting, gamma spectrometry, ^{90}Sr measurement	Base level

TABLE II–1. SUMMARY OF THE STORAGE AND DISPOSAL MONITORING SYSTEM (cont.)

Environmental media sampled	Location of monitoring	Type of monitoring	Sampling method	Measurement method	Comparison with
Hydrogeology	In 26 wells	Environmental	Measurements by hand-held devices twice a year	Level of the water surface in the wells	Base level
Hydrogeology	In eight wells	Environmental	Installed detectors, continuous	Level of the water surface in the wells	Base level
Hydrogeology	Two cross-sections on both brooks	Environmental	Measurements by hand-held devices twice a year	Monitoring the runoff of the brooks upstream and downstream to the site	Base level
Radiation	In situ at six places	Environmental	Once a year	In situ gamma spectrometry	Base level
Radiation	Dose rate meters at the disposal site (seven)	Source	Installed detectors, continuous	Continuous gamma dose rate measurement	Radiation protection limits
Radiation	Dose rate meters in the building (23)	Source	Installed detectors, continuous	Continuous gamma dose rate measurement	Radiation protection limits
Meteorology	Next to the disposal vaults	Environmental	Automatic meteorology station	Wind, temperature, vapour, precipitation	—
Geodesy	At four fixed measurement points	Environmental	Measurements by hand-held devices	Monitoring of the Earth’s surface, monitoring movement of the surface	Base level

TABLE II–1. SUMMARY OF THE STORAGE AND DISPOSAL MONITORING SYSTEM (cont.)

Environmental media sampled	Location of monitoring	Type of monitoring	Sampling method	Measurement method	Comparison with
Erosion	On the slopes	Environmental	Installed detectors, continuous measurement	Monitoring the amount of rain, and the eroded soil	—
Drainage	Below the disposal vaults	Surveillance	Hand sampling the water twice a year	Tritium measurement, gamma spectrometry	—

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