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IAEA SAFETY STANDARDS

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Monitoring and Surveillance of Radioactive Waste Disposal Facilities

DRAFT SAFETY GUIDE
DS357

Draft Safety Guide

IAEA
International Atomic Energy Agency

IAEA SAFETY RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

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FOREWORD

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EDITORIAL NOTE

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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 mining and milling of uranium and thorium ores. Radioactive waste also arises in a wide range of industrial and medical activities. It also arises from activities and processes in which radioactive materials of natural origin become concentrated in waste material and safety needs to be considered in its management.

1.2. A monitoring and surveillance programme is an important element in providing reassurance that a disposal facility for radioactive waste provides the required level of safety during its operational period and post-closure period depending on the type of the disposal. The safety principles to be applied in all radioactive waste management activities are set out in the IAEA Fundamental Safety Principles [1]. Within the safety standards series, the safety requirements for Near Surface Disposal of Radioactive Waste [2] and Geological Disposal of Radioactive Waste [3] providing specific monitoring requirements for their respective types of facilities, have been combined to create a single safety standard for Disposal of Radioactive Waste [4].

1.3. The IAEA is also developing a Safety Guide on geological disposal facilities for radioactive waste [5], and is preparing a Safety Guide on near surface disposal facilities for radioactive wastes [6], as well as a Safety Guide on the protection of the public against exposure to natural sources of radiation including NORM residues [7]. The present Safety Guide provides support for these safety standards in the area of monitoring and surveillance.

1.4. Differing kinds of monitoring activities occur in each period of the lifetime of a radioactive waste disposal facility. This Safety Guide covers monitoring and surveillance during pre-operational, operational and post-closure periods for near surface, geological and mine waste disposal facilities. These periods are defined as follows [4]:

– The pre-operational period includes concept definition, site evaluation (selection, verification and confirmation), safety assessment, and design studies. It also includes the development of those aspects of the safety case for safety in operation and after closure that are required in order to set the conditions of authorization, to obtain the authorization and to proceed with the construction of the disposal facility and the initial operational activities. The monitoring and testing programmes that are needed to inform operational management decisions are put in place.

– 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.

Monitoring, surveillance and testing programmes continue to inform operational management decisions, and to provide the basis for decisions concerning the closure of the facility or parts of it. Safety assessments for the period of operation and after closure and the safety case are updated as necessary to reflect actual experience and increasing knowledge. In the operational period, construction activities may take place at the same time as waste emplacement in and closure of other parts of the facility. This period may include activities for waste retrieval — if considered necessary — prior to closure, activities following the completion of waste emplacement, and the final closure and sealing of the facility.

– The post-closure period begins at the time when all 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, together with certain institutional controls, particularly for near surface facilities. Such institutional controls are put in place to prevent intrusion into facilities and to confirm that the disposal system is performing as expected by means of monitoring and surveillance. Monitoring may also be carried out to provide public assurance. The licence will be terminated after the period of active institutional control when all the necessary technical, legal and financial requirements have been fulfilled.

1.5. The International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (the BSS) [8] and the IAEA Safety Guide for environmental and source monitoring for purposes of radiation protection Ref. [9] provide a framework for all generic aspects of radiological monitoring. In particular, Ref. [8] establishes the basic requirements for radiological monitoring of public exposure and Ref. [9] covers pre-operational monitoring, operational monitoring (including decommissioning), and post-closure radiological monitoring. It also acknowledges the need for monitoring a variety of non-radiological variables. The present Safety Guide is intended to elaborate upon the requirements in the BSS and to complement the guidance provided in Ref. [9], in particular in regard to performance monitoring aspects of disposal facility development. On matters pertaining to source and environmental monitoring, the present Safety Guide is subsidiary to and defers to Ref. [9].

1.6. The draft International Basic Safety Standards, currently under development to supersede Ref. [8], will contain an updated and extended set of requirements on the regulatory control and monitoring of public exposure and safety of the radioactive waste management.

1.7. There are presently four IAEA publications concerned with 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 [10], Safety Reports Series No. 35 on Surveillance and Monitoring of Near Surface Disposal Facilities for Radioactive Waste [11], Safety Reports Series No. 64 on Programmes and Systems for Source and Environmental Radiation Monitoring [18] and IAEA-TECDOC-1208 on Monitoring of Geological Repositories for High Level Radioactive Waste [12]. These publications have served as resources for development of the present Safety Guide.

OBJECTIVE

1.8. The objective of this Safety Guide is to provide guidance for monitoring and surveillance of radioactive waste disposal facilities during their entire lifetime. The Safety Guide includes the different objectives that monitoring has at the lifetime periods, from initiation of work on a candidate site, to the period after closure of the disposal facility.

SCOPE

1.9. This Safety Guide considers the monitoring and surveillance of three types of disposal facilities:

- Near surface disposal facilities;
- Geological disposal facilities;
- Disposal facilities for uranium and thorium mine waste.

The three types of disposal facilities listed above are considered to cover all the disposal options as identified in the Safety Requirements on Disposal of Radioactive Waste [4]. In this Safety Guide, borehole disposal facilities are not specifically addressed. However, borehole disposal is not conceptually different from either near surface disposal or geological disposal of radioactive waste. A possible surveillance and monitoring programme suitable for a small scale borehole disposal facility is discussed in other IAEA Safety Standards [20].

1.10. As explained in Ref. [14] the term near surface disposal refers generally to disposal at or within a few tens of metres of the ground surface. The term geological disposal generally refers to disposal in deep, stable geological formations usually several hundred meters or more below the surface. Mining waste disposal facilities cover a spectrum of designs, from above-grade mounds to geological disposal of tailings slimes sometimes used as backfill in old mine workings. The type of disposal is controlled by the waste characteristics and in any case 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. From the safety point of view, disposal depth is one of the factors considered in assessing the safety of disposal: the geological environment, the waste characteristics and engineered features are of equal or more importance than depth of disposal in assessing the safety of disposal facility.

1.11. This Safety Guide places emphasis on an approach to monitoring and surveillance that provides data needed for the development of the safety case. The safety case includes information needed for siting, construct, operate and close the facility, for supporting decisions on managing the disposal programme, as well as information that are of particular interest to interested parties [4]. Technical details on monitoring and surveillance methodologies are beyond the scope of this Safety Guide, however, Refs [10, 11, 12, 18] direct the reader to such information and Annexes I and II give examples of monitoring programmes for geological and near surface disposal programmes.

1.12. This Safety Guide does not specifically address monitoring that will be required for:

- Operating personnel;
- Waste characterization or tracking;
- Nuclear materials control, in the case of facilities that will contain significant quantities of nuclear materials.

Nor does it focus on monitoring for non-radiological contaminants that may be of potential concern. Facility operators, however, should consider such contaminants when designing their monitoring programme.

1.13. This Safety Guide does not address monitoring for occupational exposure; rather the focus is on monitoring for disposal system performance and radiation protection of the public and the environment. Monitoring for occupational radiation protection is discussed in other IAEA safety standards [13].

STRUCTURE

1.14. Section 2 provides an overview of monitoring and surveillance for radioactive waste disposal facilities, and describes overall objectives for a monitoring and surveillance programme. Section 3 addresses roles and responsibilities of the regulatory body and the implementing organizations with regard to monitoring and surveillance. Sections 4, 5 and 6 focus on monitoring. More specifically, Section 4 addresses design of a monitoring programme and includes some consideration of strategic issues for monitoring. Section 5 provides guidance on monitoring according to the type of disposal facility (geological, near surface and facilities for mining and milling waste). Section 6 addresses monitoring according to the stage of facility development. Section 7 provides specific guidance for surveillance activities only. Finally Section 8 is concerned with the use of monitoring and surveillance information in regard to compliance aspects and development and improvement of the safety case and Section 9 provides a brief discussion of the salient issues pertaining to the management system for a disposal facility.

2. OVERVIEW OF MONITORING AND SURVEILLANCE

2.1 The BSS [8] defines 'monitoring' (of public exposure) to be:

> "The measurement of dose or contamination for reasons related to the assessment or control of exposure to radiation or radioactive substances, and the interpretation of the results."

2.2 The IAEA Safety Guide on environmental and source monitoring [9] defines the terms 'source monitoring' and 'environmental monitoring' as:

a. "Source monitoring. The measurement of activity in radioactive materials being released to the environment or of external dose rates due to sources within a facility or activity."

b. "Environmental monitoring. The measurement of external dose rates due to sources in the environment or of radionuclide concentrations in environmental media."

2.3 In the context of this Safety Guide, the term monitoring refers to:

> Continuous or periodic observations and measurements of environmental, engineering, or radiological parameters to help evaluate the behaviour of components of the waste disposal system, or of the impacts of the waste disposal system and its operation on the public and the environment.

2.4 Monitoring involves many characterization activities. Information may have to be collected over a period of time for a number of characterization tasks (e.g. groundwater flow rates, moisture content of soils, daily precipitation). For other types of information, once the parameter has been defined there may be no need to continue with the sampling and measurement, since it is not expected to change in time or with development and closure of the facility (e.g. rock porosity).

2.5 Monitoring is needed to evaluate processes or parameters that are influential in the development of the safety case. The duration and frequency of monitoring may be determined by regulatory requirements, by the time scale of natural variations in a process or parameter, by possible changes associated with the construction and operation of the facility. The need to address public concern should also be considered in defining the monitoring programme.

2.6 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]. In the context of this Safety Guide the term surveillance refers to:

The physical inspection of a waste management facility in order to verify its integrity to protect and preserve the passive safety barriers.

2.7 Some countries do not differentiate between monitoring and surveillance of disposal facilities.

2.8 In this respect the function of surveillance is to contribute to the detection of changes in the engineering structures and systems of the disposal facility, which might affect the radiological performance of the system. The relevant and expected changes can be identified by the post closure safety assessment. The surveillance programme is usually implemented through regular inspections of the critical components of the waste disposal facility.

2.9 Generally there is a need to collect site-specific data, although some relevant monitoring data may be available from other sources. Safety cases are usually supported by data from a number of sources, which includes site-specific measurements, regional data, and generic information.

GENERAL OBJECTIVES FOR MONITORING AND SURVEILLANCE OF DISPOSAL FACILITIES

2.10 Requirement 21 of the Safety Requirements on the Disposal of Radioactive Waste [4] states that "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".

2.11 In addition Requirement 10 of Ref. [4] indicates that "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".

2.12 Monitoring and surveillance programmes begin at site characterization phase of disposal facility development and continue to evolve through to the post-closure period depending on the type of the disposal facility. The data collected and insights derived from monitoring should be integrated into and inform planning decisions made throughout the life-cycle of a disposal facility. As a result, provision should be made to anticipate the needs of monitoring at later periods of the facility lifetime and to gather monitoring data that informs later planning and actions.

2.13 Monitoring and surveillance of disposal facilities for radioactive waste has four broad objectives:

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1. To demonstrate compliance with the regulatory constraints and licence conditions;
2. To verify that the disposal system is functioning as expected. This means that the components fulfil their function as identified in the safety case and that actual conditions are consistent with the assumptions made for post-closure safety;
3. To strengthen understanding of aspects of system behaviour used in developing the safety case for the dispoal facility and to allow further testing of models predicting those aspects;
4. To accumulate an environmental database of the site, the disposal facility and its surroundings for future decisions that are part of a stepwise programme of construction, operation and closure of the disposal facility.

2.14 As mentioned in Ref. [4] “Monitoring programmes are designed and implemented so as not to reduce the overall level of safety of the facility after closure” (para. 5.4). “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” (para. 3.22). “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” (para. 3.23).

2.15 The monitoring programme should be closely tied to the safety case. Even if safety should not rely on monitoring and surveillance, the results of such a programme should be used to strengthen the safety case and build confidence in safety. As well, information needs of the safety case should be used to improve the monitoring program.

2.16 Requirement 7 of Ref. [4] indicates that “The host environment shall be selected, the engineered barriers of the disposal facility shall be designed and the facility shall be operated to ensure that safety is provided by means of multiple safety functions. Containment and isolation of the waste shall be provided by means of a number of physical barriers of the disposal system”. The monitoring and surveillance programme should provide, to the extent practical, the necessary information to ensure that each barrier and its associated safety function(s) performs as planned and indicated in the safety case. In addition, the monitoring and surveillance programme should confirm that the performances of the engineered and natural barriers are not damaged by the operational activities.

2.17 Further to its technical objectives a monitoring and surveillance programme can be a suitable tool for public reassurance. In that sense, consideration of public interest and interested parties concerns may provide useful information to improve the monitoring programme by including social aspects.

3. RESPONSIBILITIES OF THE OPERATOR AND REGULATORY BODY REGARDING MONITORING AND SURVEILLANCE PROGRAMMES

RESPONSIBILITIES OF THE OPERATOR

3.1. The operator of the waste disposal facility should be responsible for implementing the items provided in para. 3.2. If a change in responsibilities occurs after closure of the facility the new responsible organization should also take measures to ensure that the monitoring and surveillance programmes continue in the post-closure phase in a manner that meets national regulatory requirements and policies.

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

a) Design the monitoring and surveillance programme that meets the requirements established by national regulatory bodies. If the programme is a part of the safety case, it should be designed throughout the pre-operational, operational and post-closure periods of the facility;

b) Perform adequate monitoring and surveillance along with the programmes reviewed by national regulatory bodies, as follows:

   i. For the construction stage in pre-operational period. This stage includes baseline monitoring;

   ii. During and after operations that will permit unexpected system behaviour, to be detected;

c) Develop contingency plans to address unexpected system behaviour and emergency plans to address unacceptable system behaviour;

d) Report the status of the monitoring and surveillance to the regulatory body periodically and report unexpected or emergency circumstances where they occur.

RESPONSIBILITIES OF THE REGULATORY BODY

3.3. The regulatory body should provide the necessary requirements on the programme and implementation of the monitoring and surveillance for the disposal facility and should be responsible for implementing the items provided in para. 3.4. The guidance necessary for the disposal facility operator, or responsible organization should be provided, to establish a monitoring and surveillance programmes for all periods of the disposal process, including indications on the duration of monitoring and surveillance in the post-closure period.

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

(a) Periodically review the regulation in force for monitoring and surveillance, the monitoring and surveillance programmes and reporting arrangements, including arrangements for emergency monitoring;

(b) Review the monitoring and surveillance data provided by operators against established requirements;

(c) Provide evidence that waste disposal facility is being appropriately monitored and controlled by operators, this may include independent monitoring and surveillance.

3.5. Specific responsibilities relevant to source and environmental monitoring as well as surveillance may be delegated, by a government or regulatory body, to other agencies. In deciding on the delegation of specific responsibilities to other organizations, the regulatory body should pay due attention to the availability in these organizations of suitably qualified and experienced personnel, appropriate analytical techniques and equipment, and an appropriate management system. The regulatory body, as well as other organizations to which responsibilities have been delegated, should be independent of those organizations that are responsible for the promotion and development of the waste disposal facility.

3.6. Examples of the delegation of authority may concern:

(a) The design and regular performance of the confirmatory programmes of source and environmental monitoring. This may be a programme carried out to assess the cumulative radiological impact of multiple or related facilities when they have an impact on the same areas and the same population groups;

(b) The confirmatory assessment of the doses to members of the public to warrant that they are maintained below the limits established in licences;

(c) Security and emergency response.

3.7. Other agencies may also be responsible for other domains relating to monitoring, such as:

(a) Collection and retention of data provided by operators, governmental or international agencies;

(b) Environmental monitoring at the national level;

(c) Establishing standards.

3.8. The regulatory body should liaise with these agencies as appropriate.

If the potential exists for an accident, the regulatory body should ensure that emergency preparedness arrangements are in place and are routinely tested. The arrangements should include provision for rapid, large scale monitoring if conditions suggest such a possibility. This may be performed by a designated responsible organization with the requisite capability, or by the regulatory body itself. The required monitoring may include both source, environmental and individual monitoring.

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4. DESIGN OF A MONITORING PROGRAMME

4.1. The monitoring programme for a disposal facility should be defined to respond to 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 dealt with in Ref. [9]. The monitoring programme should also assess the functioning of the disposal system with respect to operational and long term safety.

4.2. While initial monitoring plans should address all periods of the disposal project, they should also remain flexible given the time scale of siting, construction, operation and closure of a facility. This should allow integrating lessons learnt from prior periods, to adapt to new technology, and to respond to potential future regulatory requirements, design changes, etc. while at the same time maintaining data continuity and comparability. It should also allow implementing additional monitoring if concerns arise with regard to disposal facility performance. Guidance specific to the three main periods of facility development is provided in Section 6.

4.3. The monitoring programme should be designed using a graded approach so that the most significant efforts are placed in areas where the consequence of a malfunction or failure of a component could have an impact on safety or in areas where an abnormal or unexpected behaviour of the disposal facility can be detected as soon as possible.

4.4. Designing and carrying out a monitoring programme must take into considerations the technical constraints imposed by the context and environment in which monitoring is carried out. In practice, monitoring will rely on on-site 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 disposal system behaviour or of potential impact on public health and environment.

4.5. Indirect measurements of a parameter of interest are another useful approach where direct in-situ measurements cannot be carried out. For example, 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 be deduced from a thermal gradient measurement.

4.6. Monitoring specific evolutions behind engineered barriers should not degrade barrier function. It will be necessary to demonstrate 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 done. Non-intrusive monitoring may provide one alternative approach. The use of wireless signal transmission may provide another alternative approach. In addition monitoring at alternative facility with similar characteristics or pilot facility may also be useful.

4.7. A monitoring programme should ensure that data is analysed promptly to provide the operators and decision makers with timely information on disposal facility management. In particular, the regulator should receive a summary of monitoring results and interpretation at defined intervals, and should be informed promptly of any unexpected results that could have an impact on safety (for example data on significant increase in environmental radiation levels, data suggesting the disposal system may not perform as anticipated).

4.8. The design of the post-closure monitoring programme should be closely linked to and guided by the findings of the safety case and supporting safety assessments so that, in particular in the case of near surface disposal facilities, the results of the monitoring can be applied to confirm the assumptions made for the period after closure

4.9. The design of the monitoring programme should be the result of an optimization process in which costs and benefits from monitoring are taken into consideration. The coverage, intensity and duration of monitoring also translates into a cost, both direct (related to monitoring equipment and activity and ensuing worker risk) and indirect (related to maintaining and operating the facility in a state allowing such activity).

4.10. The monitoring programme considering all periods of the facility lifetime should be early reviewed and approved by the regulatory body. The monitoring programme should begin as early as possible during the initial site selection process and should evolve through the construction, operation and closure of the facility in an ongoing manner informing and updating data used in the safety case and supporting safety assessments of the facility, as illustrated in Fig. 1. In parallel, the monitoring programme should be periodically reviewed by the regulatory body.

4.11. In designing the monitoring programme it should be considered that the credibility of monitoring data need to be verified using sufficient redundancy, independent verification of values, use of robust equipment and design, and to the extent possible use of analogue situations.

4.12. The general objective of monitoring programmes during the pre-operational period is to establish natural background levels of contaminants, and to establish natural characteristics of features, events, and processes (FEPs) occurring in the environment of the disposal facility which may influence the design and subsequent short and long term performance of the facility (e.g. water table fluctuations). In this regard, the monitoring programme should be closely integrated with the safety case and safety assessment and with construction and operation procedures. A database should be developed that allows identification of trends and from which insights can be obtained. This database should allow discrimination of the effects of the presence of the facility as it evolves in time, which can then be used to update the safety case.

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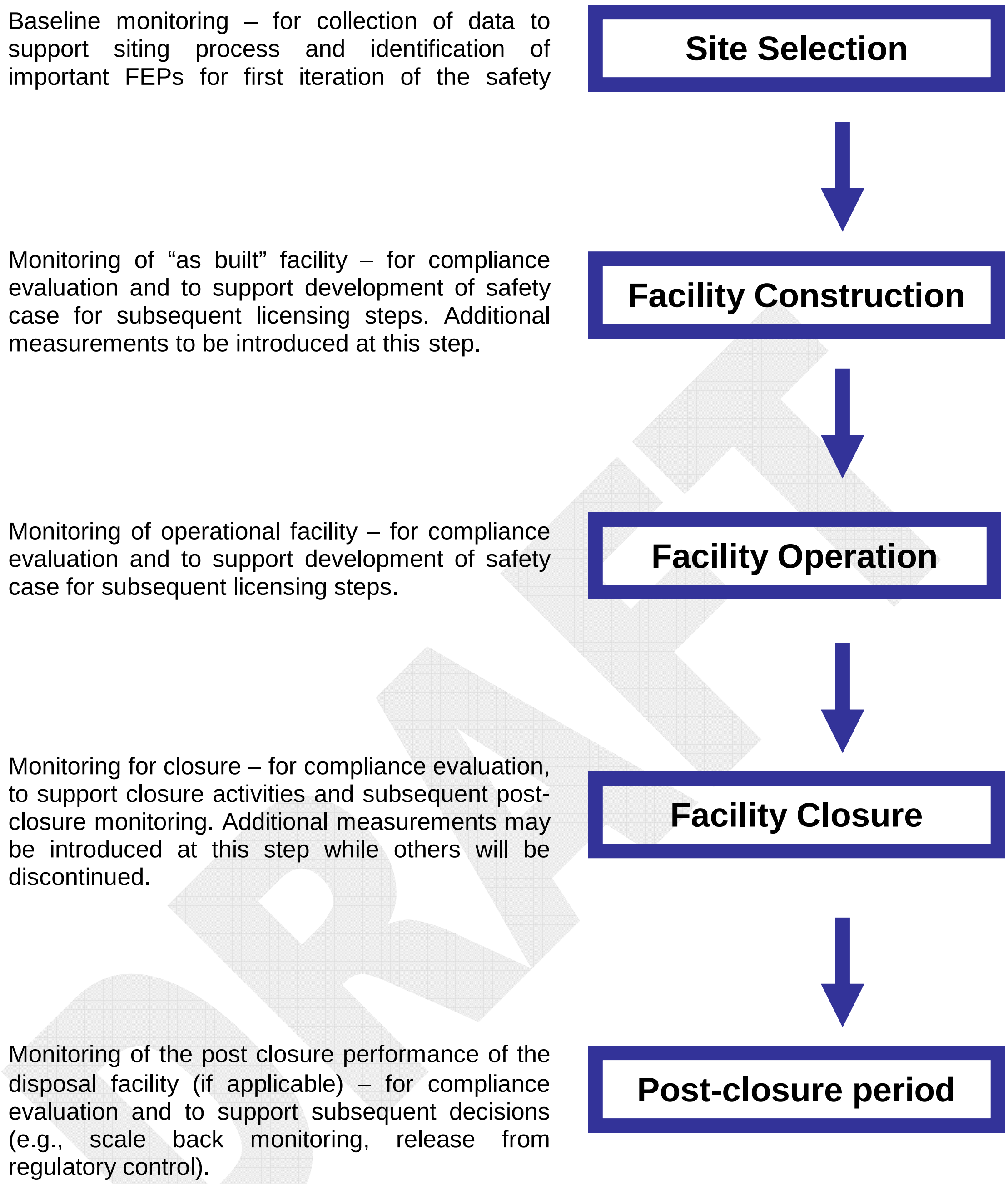

FIG. 1. Role of monitoring in the lifetime of a disposal facility for radioactive waste.

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4.13. The decision to implement monitoring after closure of the facility and its duration should be based on the type of disposal facility and its potential hazard posed over time. The duration of post closure monitoring if any should also depend on confidence in facility performance acquired from monitoring during previous periods. The duration of post-closure monitoring should also depend on reasonable assumptions on the duration of institutional stability and continuity of knowledge, and its consequent ability to ensure ongoing monitoring and maintenance

4.14. After closure, monitoring may be pursued, to assess overall facility function and to periodically assess the potential impacts on the public and environment. However, it should be recognized that properly designed disposal facilities (especially geological disposal facilities) are not expected to have significant releases to the biosphere during any reasonable period of monitoring.

4.15. The design of the monitoring programmes should consider how the results are to be communicated to the public ensuring transparency. Transparency carried with it the responsibility to provide clear interpretation of results and the context for the measurements.

4.16. The 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 the safety, then the safety case and the monitoring programme may need to be revised, and appropriate corrective actions may need to be taken.

4.17. Waste disposal systems are designed on the basis of principles of passive safety and, as a general rule, sudden failures are unlikely to occur; conditions are rare that would necessitate immediate or precipitate action. However, certain circumstances may arise that justify rapid response. For example, the stability of a mine tailings dam may be threatened by an extreme rain storm event. As appropriate, the possibility of a sudden failure should be taken into account in the design of a monitoring programme.

4.18. Key technical factors that influence the design of a monitoring programme are:

- Waste characteristics;
- Facility type and design;
- Site characteristics;
- The stage of development of the facility.

4.19. The waste characteristics, quantity of waste and time-frame of radionuclide release that is to be expected from the disposal facility will influence the design of a monitoring program. Specific performance requirements for waste characteristics in relation to operational safety or safety after closure may give rise to specific monitoring objectives.

4.20. The type and design of the disposal facility influence the type, amount, and time-frame of radionuclide release pathways that are to be expected from the disposal facility. Specific performance requirements for engineered barriers in relation to operational safety or safety after closure may give rise to specific monitoring objectives. 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.

4.21. The site characteristics influence the radionuclide transfer pathways from the disposal facility to the accessible environment. The primary function of monitoring the transfer pathways should be for performance confirmation. The assumptions and conclusions of the safety assessment are a key input to identify technical monitoring objectives in relation to performance confirmation. However, knowledge of transfer pathways may also help specifying a monitoring programme tailored to detect radionuclide migration into the accessible environment.

4.22. The periods of the disposal facility development influences the monitoring programme both in relation to monitoring objectives that are relevant, and in relation to technical constraints of monitoring, as described in Section 6.

4.23. In general the design of the monitoring programme includes the following:

- Identification and justification of the properties, processes, phenomena and observable quantities that are significant to the safety case;
- Establishing the scope and objectives for the monitoring program;
- Identification and justification of the measurement locations;
- Identification and justification of the duration and frequency of monitoring, including criteria for when monitoring may be scaled back or terminate;
- Identification and justification of the methods to be used, based on the above and based on available monitoring technology and its characteristics;
- Assessment of the robustness of the monitoring technology over the relevant time period of the measurements;
- Establishing how the results will be used (for each type of monitoring) and communicated;
- Establishing levels for actions based on existing regulations, and safety case assumptions and models;
- Establishing decisions on what actions should be pursued in case levels for actions are exceeded;
- Specifications of management and reporting of results of monitoring;
- Balancing the benefits of monitoring against its costs;
- Establishing a procedure for decommissioning of monitoring instrumentation.

5. MONITORING BY TYPE OF DISPOSAL FACILITY

5.1. The objectives of the monitoring programme and most of the elements given in this Safety Guide are common for the three types of facilities (near surface, geological and disposal facilities for mining residues). However, there are some differences that need to be addressed in the strategy for disposal, which in turn lead to differences in the practical implementation of the monitoring programme.

Near Surface Disposal

5.2. In general, wastes suitable for disposal in near surface repositories are low level waste [14]. This disposal option is suitable for waste that contains such an amount of radioactive material that robust containment and isolation for limited periods of time, typically up to a few hundred years, are required. The management strategy in this case is to contain the wastes until decay has removed sufficient radioactive material that the risk from migration of the residual radionuclides as the facility eventually degrades is considered as acceptable. In this regard, the disposal philosophy is similar to that of geological disposal for long-lived wastes, but the time scales involved may be shorter. Monitoring activity associated with near surface disposal facilities containing these types of waste will thus focus on the construction, operation and closure of the facility, providing confidence in the function of the system for hundreds of years, as well as monitoring radionuclides in groundwater or in the surrounding environment.

Geological Disposal

5.3. When compared to near surface disposal, geological disposal is suitable for intermediate and high level wastes that need a greater degree of containment and isolation from the accessible environment in order to ensure long term safety. For example, radioactive wastes containing long-lived radionuclides or wastes with specific activities high enough to generate significant quantities of heat from radioactive decay, such as spent nuclear fuel, are generally disposed of within deep geological disposal facilities with engineered barriers such that that contaminant migration into the surrounding geosphere will not begin to occur until a period of thousands of years has elapsed. The safety strategy being employed is to contain 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 the construction, operation and closure of the disposal facility to provide confidence in the containment systems. Monitoring after closure of the facility, if any, may focus on the presence of radionuclides in the environment. As early releases to the environment are highly unlikely, this kind of monitoring is rather for the purpose of social reassurance than for ensuring the performance of the disposal system.

Mining Residue Disposal

5.4 Mining residues can vary greatly with respect to their radiological hazards. The specific activity of the residues will be dependent upon the grade of ore mined and milled. The type of ore and its grade will thus determine the nature of the disposal system. If uranium is mined and milled, the residues will remain almost as radioactive as the parent ore for periods of hundreds of thousands of years. If thorium is mined and milled, the mining residues, absent the parent Th 232, will decay to insignificant levels within 50 years. The disposal systems are not designed to provide absolute containment at all times and 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 long term release of potentially toxic elements and structural failure. As a result, monitoring will consider the construction, operation and closure of the facility but will have greater emphasis on the presence in the surrounding environment of radionuclides and associated chemicals that indicate how well the system is functioning.

5.5. The programme of monitoring of a disposal facility for naturally occurring radioactive material would be similar to that of a disposal facility for uranium or thorium mine waste. The design of such a programme should reflect a graded approach to safety.

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6. MONITORING IN THE DIFFERENT PERIODS OF FACILITY LIFETIME

6.1. Through all periods of the facility lifetime, technological realities limit the robustness and scope of what is achievable in monitoring. In many cases, direct measurements of key parameters or phenomena cannot be made. Instead, inferential method must be used. For instance, regional groundwater flow velocities are deduced from head measurements and pump tests and point measurements. These problems worsen as measurements are required from greater depths below surface, in high radiation fields, or in other situations that make access more difficult. Consequently, expectations about what can be achieved through monitoring should be moderated by technological reality. Monitoring expectations are necessarily limited by certain physical challenges and limitations characteristic of different types of facilities.

6.2. As described in Ref. [12], phenomena to be monitored in a radioactive waste disposal can be separated into different categories:

- Baseline;
- Behaviour of the waste package and its associated buffer 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;
- Radionuclide release detection;
- Provision of an environmental database.

An example of monitoring parameters by categories and periods of a geological disposal facility is provided in Annex I, that lists the corresponding monitoring parameters for such a programme and at which of the lifetime phase these parameters would be measured. The technical complexity of a monitoring programme will vary according to type of disposal facility and in turn potential 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 near surface monitoring programme is given in Annex II.

Pre-operational Period

6.3. Prior to operation, the monitoring programme should first (prior to construction) be focussed on site characterization. This information should be used to determine site baseline conditions and site

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suitability. At the start of construction (but prior to operations), monitoring is used to assess the potential impact of construction activities on the public and environment, and to establish the disposal facility "as built" conditions, to ensure regulatory and safety compliance [15]. The objectives of the monitoring programme during the pre-operational period are to:

- Contribute to evaluate site suitability;
- Provide input data for the design of the facility;
- Provide input data needed for the operational and post-closure safety cases;
- Define baseline conditions for comparison with later monitoring results;
- Aid in designing the operational monitoring programme.

6.4. The safety case and supporting safety assessment provide an iterative framework for progressively improving understanding technical aspects of the disposal system, and for identifying which new monitoring data 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 safety assessment evaluations. Conversely, as monitoring data identifies new information, it may require updating scenarios, conceptual models, or parameters used as part of the demonstration of safety. The progressive adaptation of the safety assessment analysis and the associated monitoring, both directed at reducing uncertainty, is a key feature of the safety assessment methodological approach.

6.5. Baseline monitoring is concerned with 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 basic earth science, engineering and the environment and the operational and post-closure safety assessment of the disposal facility. For example, it 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 during the site investigation stage. A more comprehensive description of establishing baseline conditions can be found in Ref. [15].

6.6. Special attention should be drawn to defining a baseline for mine residue disposal facilities. Such facilities are developed for the disposal of radionuclides naturally occurring in the surroundings. As a result, performance measurements taken later in the facility lifetime must be conducted in reference to the baseline to determine changes in concentrations in environmental media. By contrast, waste disposal facilities developed for the disposal of either low and intermediate level wastes or high level waste and spent nuclear fuel, characteristic radionuclides that could be observed by a monitoring system are more easily distinguished from background. For example, Ref. [11] notes that likely

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examples for detection at near surface disposal facilities are H-3, Cs-137, and C-14. These radionuclides are relatively easy to detect and incremental increases are more easily distinguishable from their low levels in background than are naturally occurring radionuclides of the uranium and thorium decay series in mining districts, making the initial definition of a baseline less crucial, though still important.

Operational Period

6.7. During the operational period, the monitoring programme should contribute to operational safety, measure potential impacts on the public and environment, and assess the functioning of the disposal system. Monitoring should continue to encompass evaluation of FEPs important to the safety case, as part of a confirmatory programme. This provides for strengthening of the understanding of the disposal system behaviour to refine the operational and post-closure safety cases. The monitoring programme should also be focused on collection of data from the short term performance of the 'as built' disposal system to assist in confirming long term system performance. The objectives of the monitoring programme during the operational period are to provide:

- Data 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;
- Data that support the operational safety case, including routine operational releases, and worker protection.

6.8. Performance confirmation monitoring should be conducted on key technical issues of interest for either operational or long-term performance of the disposal system. It should be viewed as an extension of the progressive improvement to the safety case, which continues after the issuance of the operational license to provide progressively better assurance of either operational or long-term safety during the operational period. The monitoring should provide additional support to the data used for the safety assessment, so that the safety assessment is updated and improved through the operational period. Regulatory authorities may require a strong programme of performance confirmation as part of license conditions for an operational license. In this way the operator may be obliged to resolve technical issues during the period of operation rather than as a precursor to receiving an operating license. This approach can be used to manage residual uncertainties about technical issues at the time the construction license is granted, but cannot be a substitute for an appropriate level of early regulatory scrutiny and careful consideration of uncertainties in the safety case.

6.9. The monitoring programme needs to take account of the potential for releases associated with facility operations, as part of the operational safety case. This element of the programme is intended to protect the public and the environment during the operational stage, and may be established to meet regulatory requirements for routine and accidental releases from nuclear facilities. The emergency response programme developed as part of the operational safety case should include an appropriate monitoring strategy that takes account of the suddenness with which emergencies can arise. Monitoring strategies of this kind will be driven by the risk associated with potential accident scenarios envisaged, and monitoring of such events will not generally be part of a routine monitoring programme, and should be considered separately.

6.10. The monitoring programme associated with the operational safety case needs to ensure the safety of workers at the disposal facility. To accomplish this goal, the monitoring programme should be integrated with the operational safety case. This includes updating the operational safety case to ensure that safe operations can continue during the long time period in which the facility is operational.

6.11. Additional regulatory requirements may exist, in addition to radiological monitoring and performance confirmation requirements, depending on national regulations. For instance, requirements may exist to monitor groundwater for the presence of toxic chemicals, and these requirements may be entirely different than similar requirements to monitor for releases of radionuclides.

Post-Closure Period

6.12. One objective of the monitoring programme in the period after closure, if this is part of the safety case is to measure for the presence of contaminants or radiation in the environment that could be attributable to the disposal facility. However, this element of the monitoring programme is only one part of the monitoring programme after closure, and has different importance for the different types of disposal facilities. The intensity, duration, and importance of post-closure monitoring differ among the types of disposal facilities.

6.13. Monitoring in the post-closure period may be used as a tool contributing to take the decision to move from a period of active institutional control to a period of passive institutional control. At this stage of the disposal facility system development, the goal is to identify when conditions at the site would be suitable for a license revision, to allow termination of monitoring, maintenance and active control of the site. To achieve this goal, the monitoring programme should be focused to support the decision processes.

MONITORING FOR EMERGENCY RESPONSE

6.14. Monitoring for emergency response differs from routine monitoring activities in several key regards. Whereas routine monitoring is used to collect information for regulatory compliance and updating the safety case, monitoring for emergency response will have as its focus provision of information to mitigate imminent threats to human health and the environment. The ability to monitor facility and environmental data is a requirement of a comprehensive emergency response plan and arrangements as called for in Ref. [16].

6.15. For some kinds of existing disposal facilities (e.g. past practices as some tailings dams), emergencies can arise rapidly. For instance, extreme weather or seismic events can result in dam failure, with associated rapid releases of large amounts of contaminants into the environment. The safety case cannot be updated in a retrospective manner to make decisions because of the rapidity of the event. Instead, emergency arrangements should be developed for the full range of postulated events to include events with a very low estimated probability of occurrence, which incorporate monitoring, personnel, procedures and equipment and other arrangements that would allow rapid identification of the emergency and imminent threats to human health and the environment as described in Ref. [9] and called for in Ref. [16]. The monitoring arrangements should be able to provide data in a timely way, so that appropriate responses can be taken to include default operation intervention levels (OILs) that have been coordinated with local officials [9, 16].

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7. DEVELOPMENT AND IMPLEMENTATION OF A SURVEILLANCE PROGRAMME

7.1. The purpose of the surveillance programme is to provide for the oversight of a waste disposal facility to verify its integrity to protect and preserve the passive safety barriers, and the prompt identification of conditions that may lead to a migration or release of radioactive and other contaminants to the environment. The surveillance programme is usually implemented through regular inspections of the critical components of the waste disposal facility. The surveillance programme includes but is not limited to inspections. Visual inspections are an important and effective way of detecting anomalies indicative of potential failures. The surveillance programme also includes review and assessment of records, trends and performance of different parameters.

7.2. A site-specific surveillance plan and implementation procedures should be developed early in the facility lifetime, and should be periodically updated, in consultation with the regulatory authority, taking into account changes in conditions at the site, in operations and in technology.

7.3. This plan should show how the surveillance results complement the monitoring programme and site safety and performance requirements. The plan should include:

(a) Description of the site and adjacent area;

(b) Description of components of the waste management system and environmental setting;

(c) Type and frequency of inspections;

(d) Inspection procedures;

(e) Contingency or maintenance actions;

(f) Reporting requirements for inspections;

(g) Management system.

SURVEILLANCE THROUGHOUT THE LIFETIME OF A DISPOSAL FACILITY

7.4. The monitoring and testing programme should start in the pre-operational period during construction to allow detection of early degradation of the components integrity or to find out the quality of the host rock around the excavations. The surveillance programme to be followed when operation of the disposal begin should be defined towards the end of the pre-operational phase [11].

7.5. During the operation of the facility, the surveillance programme should allow the verification that passive safety barriers integrity is protected and preserved. The protective components of the disposal facility could be inspected periodically as part of the surveillance programme, as long as this can be performed on accessible areas and may typically be restricted to disposal infrastructure and those parts of engineered barriers directly accessible from infrastructure.

7.6. During the period after closure, waste disposal areas or cells containing waste and the emplaced waste forms are usually not accessible for inspection. Duration of the post closure surveillance should be based on the type of disposal facility. The duration of post closure surveillance should also depend on confidence in facility performance acquired during previous periods. The duration of surveillance after closure should also depend on reasonable assumptions on the duration of institutional stability and continuity of knowledge.

SURVEILLANCE BY TYPE OF DISPOSAL FACILITY

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 active institutional control period. Barriers that could typically be inspected in the period after closure are covers of the disposal.

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

7.9. For mining residue disposal facilities, surveillance should start in the pre-operational stage and ends either at the end of the active institutional control period or at closure of the facility, depending on the nature of the disposal system - should the access to the engineered barriers be no longer possible. The assumptions on the duration of institutional stability and continuity of knowledge usually are a major factor defining the duration of surveillance after closure. An example of a long term surveillance plan (period after closure) for a uranium mill tailings site is given in annex I of Ref. [10].

TYPE AND FREQUENCY OF INSPECTIONS

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

Visual and physical inspections may be applied to critical components of the waste management systems, thus providing an effective way of detecting anomalies indicative of potential failures. Such inspections should follow a plan including routine, detailed and special purpose inspections.

Routine inspections

7.11. This type of inspection should be undertaken on a periodic basis to ensure that the general condition of all the components of the waste management system is satisfactory. A member of the operator's technical staff with suitable knowledge and experience of the facility will normally perform the inspections.

Detailed inspections

7.12. The purpose of a detailed inspection is to ensure that the waste disposal system is performing in accordance with the design criteria and complying with regulatory requirements. The inspection should be expected to be preceded by a review of the previous inspection report, looking particularly for any items needing follow-up from the previous inspection, and a review of any surveillance data produced since the previous inspection report.

7.13. Detailed inspections should also 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 have not compromised the components of the disposal facility. The frequency of detailed inspections will be determined on a site specific basis.

7.14. Detailed inspections should normally be performed by a suitably qualified individual possessing a thorough knowledge of the disposal facility and the operational requirements.

Special inspections

7.15. Special inspections should be conducted after natural events considered being extreme for the disposal facility environment; such as significant fires, major earthquakes, floods, severe storms, very heavy rainfall or cyclones. Special inspections should also be performed in case of events like incidents. The purpose of these special inspections is to ensure that the components of the waste management system have not been damaged by these events and continue to be fully functional.

7.16. Such inspections are carried out by suitably trained personnel who can determine whether specialised technical assistance is necessary.

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8. USE OF MONITORING AND SURVEILLANCE INFORMATION

8.1. As discussed in previous sections, monitoring and surveillance information is collected for the purpose of reduction of risk or uncertainty, with a view to updating the safety case. The use of monitoring and surveillance information should therefore be in line with these purposes. Users of monitoring and surveillance information should be all interested parties, including the operator, the regulatory body, and other concerned interested parties. By including all interested parties in the use of monitoring and surveillance information, the goal is to achieve improved transparency of the disposal process, the evolution of the disposal facility, protection of the public and environment and barrier performance.

8.2. Monitoring information will always have some degree of uncertainty. Managing the residual uncertainties in measurement and understanding of the disposal facility is a primary function of the safety case development. Issues with the use of monitoring information include difficulties in resolving spatial and temporal variability, inability to directly measure parameters of interest, inability to project future system behaviour, and lack of fundamental understanding of some processes of interest. For example, over the lifetime of many disposal facilities there may be significant changes in climatic patterns and associated shifts in human behaviour and practices. The ability to project system behaviour into the distant future will always be uncertain. These changes could affect the potential release of radionuclides from disposal facilities and the exposure pathways through which biota and representative person exposure to radionuclides may occur.

8.3. Caution should be used in applying available monitoring information. The credibility of monitoring data should be verified using sufficient redundancy (which should be part of the monitoring system design), independent verification of values, use of robust equipment and design, and to the extent possible use of analogue situations.

ANALYSIS OF AND RESPONSE TO MAIN OBJECTIVES

8.4. Monitoring and surveillance, in all periods, should provide data on the disposal system for regulatory compliance, or/and provide data that are used in the development and incremental improvement of the safety case. These two purposes will in some cases overlap, for example, a license condition requiring a deeper understanding of FEPs will lead to improvement of the safety case.

Use of Monitoring and Surveillance Information for Regulatory Compliance

8.5. At the minimum, monitoring and surveillance results should contribute to demonstrate compliance with the regulatory constraints and licence conditions. The operator of a disposal facility may base some parts of a monitoring and surveillance programme on specific prescriptive regulatory requirements. For example, monitoring is necessary for comparison with surface water quality standards, which are often established in advance by the regulator. Uncertainties in meeting this kind of regulatory criterion are limited to uncertainties in the measurement methods.

8.6. However, regulatory compliance for performance-based criteria such as dose will require monitoring to provide insights into features, events and processes (FEPs) and system performance which give information to support the safety case and safety assessment. Since approaches for achieving this type of regulatory requirement do not follow strict rules, there should be good and early communication between regulator, operator, and other interested parties. This communication is needed because the range and type of uncertainties are larger and more subjective than for prescriptive regulatory requirements. The uncertainties are resolved as much by the process by which they are addressed as by the monitoring data that support the analysis.

Use of Monitoring and Surveillance Information in the Safety Case

8.7. The monitoring and surveillance data collected during the pre-operational period should include retrospective data from comparable types of facilities, if possible. The purpose of such data is to provide confidence in the general approach for disposal being proposed. For example, comparisons of the operating records of nearby waste disposal facilities can provide confidence that the technology is safe and sustainable. For near surface and geological disposal facilities, for which there may be less operational history, natural or archaeological analogues may assist in fulfilling this function.

8.8. As the facility moves into the operational period, monitoring and surveillance should continue to provide information about operating performance, which can be used to update the safety case. The operational safety case is developing prior to obtaining a construction and operation license. Residual uncertainties are often managed using conservative estimates of system functions with respect to their implications for safety. Available monitoring information prior to construction, while sufficient to make a safety case, should continue to be updated through the operational stage, as part of a performance confirmation programme. This performance confirmation programme should progressively improve understanding of the 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 performance confirmation monitoring programme may lead to a modification of acceptable inventory limits in a disposal facility. Ideally, if the operational safety case is based on conservative estimates, then changes or improvements in understanding should lead to less restrictive and less costly operating approaches.

8.9. After the completion of the emplacement operations but before the final closure of the disposal facility, monitoring and surveillance data may be collected to confirm the continuing presence of safety functions, either through direct evidence (i.e. a measurable parameter) or through the collection of data that might cast doubt on safety function performance. These data may be used to verify that the disposal system is functioning as expected. This means that the components fulfil their function as identified in the safety case, and that actual conditions are consistent with the assumptions made for safety after closure. For example, these data may be used to help support the decision for termination of active institutional controls, by verifying that the disposal system has remained in a passively safe condition for a specified period of time.

DEVIATIONS FROM EXPECTED RESULTS

8.10. As discussed in the previous section, the operational safety case is often built on a set of conservative assumptions, to manage the uncertainties at that stage in the facility development. Monitoring and surveillance undertaken for performance confirmation would therefore be expected to provide data that may be different than that used in the safety case, and generally is expected to trend toward less conservatism. Similarly, because of the conservatisms incorporated within the safety assessment, environmental monitoring data may be expected to remain within those level forecast within the safety case. However, monitoring results may also provide apparent or actual contradictions such as the appearance of parameters or events not anticipated in the safety assessment. Such types of results could be labelled as ‘unexpected’, as they do not ‘confirm’ prior expectations.

8.11. Unexpected results do not necessarily indicate that disposal system safety 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 may produce counterintuitive results. For instance, a conservatively biased groundwater transport model in a safety assessment may neglect or de-emphasize the leading edge of a contaminant plume. Therefore, monitoring observations of the early arrival of contaminants that are inconsistent with the model results may reflect the conservative bias of the model rather than a failure of the safety case to adequately represent the risk.

8.12. Unexpected results may also be indicative of new information that is not reflected in the safety case. This new information will generally be associated with FEPs that are not well understood, or FEPs that were previously not considered to be of importance. If the unexpected results are determined to fall in this category, a revised monitoring and/or surveillance programme should be developed to further investigate the issue, and in some cases it may be appropriate to initiate new research to better understand it. The safety case should be updated to reflect the new knowledge. When unexpected results occur, they may raise questions with the regulator, and may influence interested parties confidence. In this regard, proper communication, transparency, and honesty should be emphasized to maintaining credibility.

8.13. During the period between the decision to go for a waste disposal facility and facility closure, decisions will need to be made about how, when and if to license and implement various periods of the development of the disposal facility system. 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 and will be embedded into the national legal and regulatory system. The decision making process should be supported by an adequate organizational framework and corresponding technical and administrative measures.

8.14. For reasons such as those given in the example above in para. 8.11, failure of performance criteria would not necessarily imply that remedial actions or protective measures would be needed. For example, a decision process for retrieval 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. safety of workers during retrieval of waste). The mission 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.

8.15. A graded approach should be taken in responding to unexpected results. Many issues can be resolved by an appropriate level of response, which may vary from no action at all, increased sampling frequency for confirmation, through design or procedural changes, all the way to significant remedial action or even retrieval of wastes. Emphasis should be placed on identifying trends rather than assigning too much significance to individual measurements. Actions, such as waste retrieval, should only be undertaken after very careful study and justification, including consideration of risks associated with the remedial activity.

PERIODIC REVIEW OF THE MONITORING AND SURVEILLANCE PROGRAMME

8.16. Design of monitoring and surveillance programmes should be an iterative process, allowing for periodic changes to the programmes. The safety case and safety assessments are useful tools to be exploited to review the monitoring and surveillance programmes. The monitoring and surveillance programmes should be designed with flexibility in mind, to incorporate new sources of data, new types of data, new technologies, and new regulatory requirements.

9. MANAGEMENT SYSTEM

9.1. The monitoring and surveillance programmes should adhere to the management system principles established in Refs [17, 19]. Elements of the management programme that should receive particular attention with regard to monitoring and surveillance are:

- Ensure the continuity of resources over long time periods;
- Establish processes leading to qualification of the monitoring and surveillance programmes and data derived from it in the regulatory process;
- Control of records over the duration of the project.

9.2. Monitoring and surveillance systems for waste disposal should be capable of providing data to support decisions that will occur over the entire lifetime of the facility. Since disposal facility lifetimes are so long, it follows that management systems must be established to maintain continuity of data collection, data management, and adaptability to new approaches for 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 continuity. For instance, many field experiments may require years before they produce credible and useful data. Such experiments may be important to establishing a credible safety case, but they may also be subject to transitory funding restrictions that can end the experiment too early, limiting their worth. The management system should establish provisions to ensure proper planning for financial and qualified human resources when necessary.

9.3. Management processes are necessary to establish the qualification of data in a regulatory setting. The qualification of data should constitute a set of procedures that permit traceability and transparency of 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 project subject to the management system;
- Data collected as part of a research programme that are not part of the management system;
- Data collected historically, which predate the existence of the management system;
- Literature information that reflects general knowledge, understanding, or measurements, not necessarily specifically associated with the project under consideration.

9.4. 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 it is correct and traceable.

9.5. The management system should accommodate data management (record keeping, archiving) over the duration of the project lifetime. Since disposal facility programmes have particularly long lifetimes, and since and surveillance data collected throughout the lifetime of the disposal facility will be needed for decisions taken late in the lifetime, there is a particularly stringent requirement on the management system to provide long-lasting traceability and transparency of monitoring and surveillance data.

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Annex I

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

I-1. As described in [12], parameters to be monitored in a radioactive waste disposal can be separated into different categories.

- Baseline;
- Behaviour of the waste package and its associated buffer 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;
- Radionuclide release detection;
- Provision of an environmental database.

Baseline

I-2. 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-3. Baseline monitoring is concerned with 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 basic earth science, engineering and the environment and the operational and post-closure safety assessment of the disposal facility. The scope of this monitoring needs to be sufficiently broad to allow issues not foreseen today to be considered in the future [15]. For example, it 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 during the site investigation stage.

I-4. 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 (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 making part of the disposal facility system;
- Geomechanical properties of the host-rock participating to the stability of the disposal facility structure;
- Retention properties & hydraulic properties of the host-rock making part of the disposal facility system;
- Characterization of the discontinuities (including fractures) of the host-rock making part of the disposal facility system;
- Background levels of natural radioactivity in groundwater, surface waters, air, soils and sediments, animal and plant life;
- Meteorological and climatic conditions;
- Hydrology of surface water systems, including drainage patterns and infiltration rates;
- Ecology of natural habitats and ecosystems;

I-5. Baseline data needs to be established as part of the site characterization activity, e.g. measurements from local and regional boreholes and surface investigations. 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, it is to be appreciated that invasive investigations will themselves perturb the natural groundwater system to a degree based 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.

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Monitoring conditions of emplaced waste packages

I-6. Waste package conditions are relevant to waste retrievability and monitoring of parameters that indicate the integrity or the status of waste packages would be particularly important. The behaviour of emplaced waste packages will depend upon degradation phenomena such as corrosion and effects such as waste stack stability, resaturation (e.g. of buffer and waste), and gas production.

I-7. The parameters that could be monitored for use as indicators of the condition of waste packages fall into two categories: direct measurements (e.g. corrosion current, strain, swelling pressure for clay buffers); and environmental measurements (e.g. temperature, humidity, resaturation pressure). In some disposal facility designs, particularly for low and intermediate level waste, the analysis of waste-derived gases, as close as possible to the waste packages, may provide useful indications about their integrity and/or about the performance of already emplaced engineered barriers.

Monitoring of the disposal facility structures and engineered barriers

I-8. Changes in the structural stability of disposal facility may occur as a result of natural processes and human activity. Continuing monitoring of the surrounding area may contribute to assess its stability and to detect any movement of the disposal facility structure or the surrounding host rock.

I-9. The parameters that could be monitored are:

- Mechanical properties;
- Stresses;
- Strain;
- Conventional observation of underground openings:
    - Rock stresses;
    - Deformations and loads on rock supports;
    - Deformations in walls and lining;
    - Fractures.

I-10. 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 backfills and seals and in some cases parts of the disposal facility structure.

Disturbances created by the disposal facility

I-11. 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, an important aspect of 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;
- Thermo-mechanical effects, caused by the emplacement of heat-producing waste;
- Geochemical disturbance due to chemical reactions caused by the disposal facility construction and operation (primarily the introduction of air but also of backfill, materials for strengthening like grouts/shotcrete, seal materials and of the waste itself).

I-12. The parameters that could be monitored in the engineered barriers are:

- Mechanical disturbance in the host rock:
    - Stress field;
    - Deformation;
    - Fractures.
- Hydraulic disturbance:
    - Permeability;
    - Water pressure;
    - Saturation degree.
- Geo-chemical disturbances:
    - Composition (interstitial water + mineralogy);
    - pH;
    - Redox;
    - Retention properties;
    - Biological changes.
- Thermal disturbances:
    - Temperature distribution;
    - Conductivity.

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Monitoring of radionuclide release

I-13. The following parameters measured through the engineered barriers, the host-rock and the geosphere can provide information on the potential for mobilization and release of contaminants:

- Leachate monitoring;
- Activity concentration in ground water;
- Extent of the potentially contaminated zone;
- The hydraulic gradients and the velocity and direction of the flow in the potentially contaminated zone;
- The level of the water table;
- River flow rate (which could influence the hydrological conditions);
- Recharge of aquifer;
- The chemical composition of the water.

Changes to the geosphere

I-14. 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, 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 site characterization and underground investigation phases. Many mineralogical changes in response to disposal facility ventilation are likely to be confined to the immediate vicinity of the disposal facility.

I-15. 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 site characterization and underground investigation phases.

I-16. For disposal facilities in the saturated zone, groundwater will flow around or through the disposal facility while the disposal facility remains open. However, following disposal facility resaturation (or perhaps resaturation 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.

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Accumulation of an environmental database

I-17. The accumulation of environmental data over a period of several decades may be of great assistance in assessing the suitability of the land above a disposal facility for alternative land uses.

I-18. Parameters of potential relevance are:

- Meteorology;
- Hydrology, drainage, water usage, 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, slope evolution;
- Tectonic activity such as vertical and lateral earth movement rates, seismic events; geothermal heat flow;
- Land use in the surrounding region.

I-19. All these parameters may be measured from the surface. The data is expected to be continuous and extend over many years.

I-20. If no method can be identified that respects all monitoring constraints, 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, avoiding thus any breaching of the real isolation barriers, could be evaluated. Logically this demonstration would 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 anticipated advantage of such strategy would be to provide additional confirmation of the reliability of assumptions about overall system performance.

Table I-1 below describes the importance of the different monitoring parameters during the different periods of development of a geological disposal facility

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

Parameters/process to be monitored	Pre-operational	Operational	Post-closure[1]
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	X		
Geochemical characteristics of ground water: - redox - salinity - major and trace element concentrations - natural radionuclide content / background activity	X		
Mineralogy of the host-rock making part of the disposal facility system	X		
Geomechanical properties of the host-rock participating to the stability of the disposal facility structure	X		
Retention properties & hydraulic properties of the host-rock making part of the disposal facility system	X		
Characterization of the discontinuities (including fractures) of the host-rock making part of the disposal facility system	X		
Background levels of natural radioactivity in groundwater, surface waters, air, soils and sediments, animal and plant life	X		
Meteorological and climatic conditions	X		

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Parameters/process to be monitored	Pre-operational	Operational	Post-closure[1]
Hydrology of surface water systems, including drainage patterns and infiltration rates	X		
Ecology of natural habitats and ecosystems	X		
Mechanical properties of the disposal facility structure		X	
Mechanical properties of the engineered barriers		X	
Retention & hydraulic properties of the engineered barrier		X	
CONTINUED MONITORING OF BASELINE PARAMETERS		X	X
INTEGRITY OF WASTE PACKAGES			
Direct measurement - corrosion - strain - pressure on the waste package (i.e. swelling pressure for clay buffer)		X	(X)
Environmental measurements - temperature - humidity - resaturation - analysis of waste derived gases		X	(X)
DISPOSAL FACILITY STRUCTURES AND ENGINEERED BARRIERS			
Structural stability of disposal facility structure and engineered barrier - mechanical properties		X	(X)

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Parameters/process to be monitored	Pre-operational	Operational	Post-closure[1]
- stresses			
- strain			
- 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)			
- resaturation rate			
- changes in:			
- hydraulic properties		X	(X)
- mechanical properties (including swelling)			
- chemical properties			
- thermal properties			
Prevent water ingress into the disposal facility - water infiltration through the disposal facility		X	(X)
DISTURBANCES CREATED BY THE DISPOSAL FACILITY (CONSTRUCTION, EMPLACEMENT OF WASTE AND ENGINEERED BARRIERS, …)			
mechanical disturbance in the host rock			
- stress field			
- deformation		X	(X)
- fractures			
geo-chemical disturbances			
- composition (interstitial water + mineralogy)			
- PH		X	(X)
- redox			

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Parameters/process to be monitored	Pre-operational	Operational	Post-closure[1]
- retention properties			
- biological changes			
hydraulic disturbance - permeability - water pressure - saturation degree		X	(X)
thermal disturbances - temperature distribution - conductivity		X	(X)
Monitoring of radionuclide release			
Leachate monitoring		X	(X)
Activity concentration in ground water		X	X
Extent of the potentially contaminated zone		X	X
Hydraulic gradients, velocity and direction of the flow in the potentially contaminated zone		X	X
The level of water table		X	X
Recharge/discharge of aquifer		X	X
Chemical composition of water		X	X
Changes to geosphere			
Mechanical - stresses		X	X

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Parameters/process to be monitored	Pre-operational	Operational	Post-closure[1]
- strain - fractures (connectivity which could create preferential pathway)			
Hydraulic - ground water pressure		X	X
Chemical - solute chemistry - mineralogy		X	X
Thermal - temperature		X	X
ACCUMULATION OF AN ENVIRONMENTAL DATABASE			
Meteorology	X	X	X
Hydrology, drainage, water usage, water quality;	X	X	X
concentration of radionuclides and other pollutants in various environmental compartments including biota, sediments and waters;	X	X	X
local ecology;	X	X	X
geomorphological processes, such as denudation, localized erosion, slope evolution;	X	X	X
tectonic activity such as vertical and lateral earth movement rates, seismic events; geothermal heat flow;	X	X	X
land use in the surrounding region.	X	X	X

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[1] Parameters measured during the operational phase may continue to be monitored during the post-closure phase but to a less extent, as long as it will not affect the long term safety.

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Annex II

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

HUNGARY: ENGINEERED DISPOSAL FACILITY AT PÜSPÖKSZILÁGY

INTRODUCTION

II-1. The Radioactive Waste Treatment and Disposal Facility (RWTDF) have been operated by Hungarian national radioactive waste management company (PURAM) since July 1998. Earlier it was operated by National Health Public Officers Service since 1976 when the site was commissioned. The task of the facility is to accommodate the low- and intermediate level institutional radioactive waste arisen in Hungary from small-scale producers.

II-2. The site is located some on the ridge of a hill at an altitude of 200-250 m above Baltic Sea level laying on approximately 30 m thick heterogeneous Quaternary rocks (silt and clay, low permeability) above the ground water table. It is bounded to SW by the Nemedi and to NE by the Szilagyi stream. The facility is 1.5 km far from the nearest village (Püspökszilágy).

II-3. The layout of the facility monitoring system is shown in Figure II-1.

II-4. The installation is a Radon type near surface disposal facility. Reinforced concrete storage vault (Type A and C) and carbon steel/stainless steel storage wells (Type B and D) are provided for the disposal of radioactive wastes in RWTDF.

II-5. "A" type system which is a reinforced concrete structure (40 cm thick walls) serves for disposal of solid radioactive waste. There are four vaults (AI - AIV), each vault consists of cells of 70 m^3 each. It is covered by protective roof during the filling, then sealed and temporarily covered by 2 m thick clay layer Final cover is still to be designed.

II-6. "C" type disposal system serves for storage of solidified organic solvents and biological waste, but it is recently used for temporary storage of neutron sources. It consists of 8 cells of 1.5 m^3 each and is covered by protective roof.

II-7. "B" type system serves for storage of disused sealed sources (DSRS). There are 16 wells with a diameter of 40 mm, and 16 wells with a diameter of 100 mm (6 m depth) is located inside a concrete monolith structure.

II-8. "D" type system serves for storage of DSRS with a half-life greater than 30 years (^{226}Ra ^{241}Am). It consists of 4 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-9. Between 1974-1976, before the disposal facility start the operations, reference levels (i.e. background values prior to the operation) were identified for the most significant points of the environments (along the water courses and in the ground water) around the disposal facility.

II-10. Sampling points were determined in the village nearby, along the two brooks flowing around the hosting hill, on the slopes of the hill, and in the territory of facility.

II-11. Monitoring included ^{137}Cs measurement, the total gamma- and the total beta activity-concentration in different environmental samples.

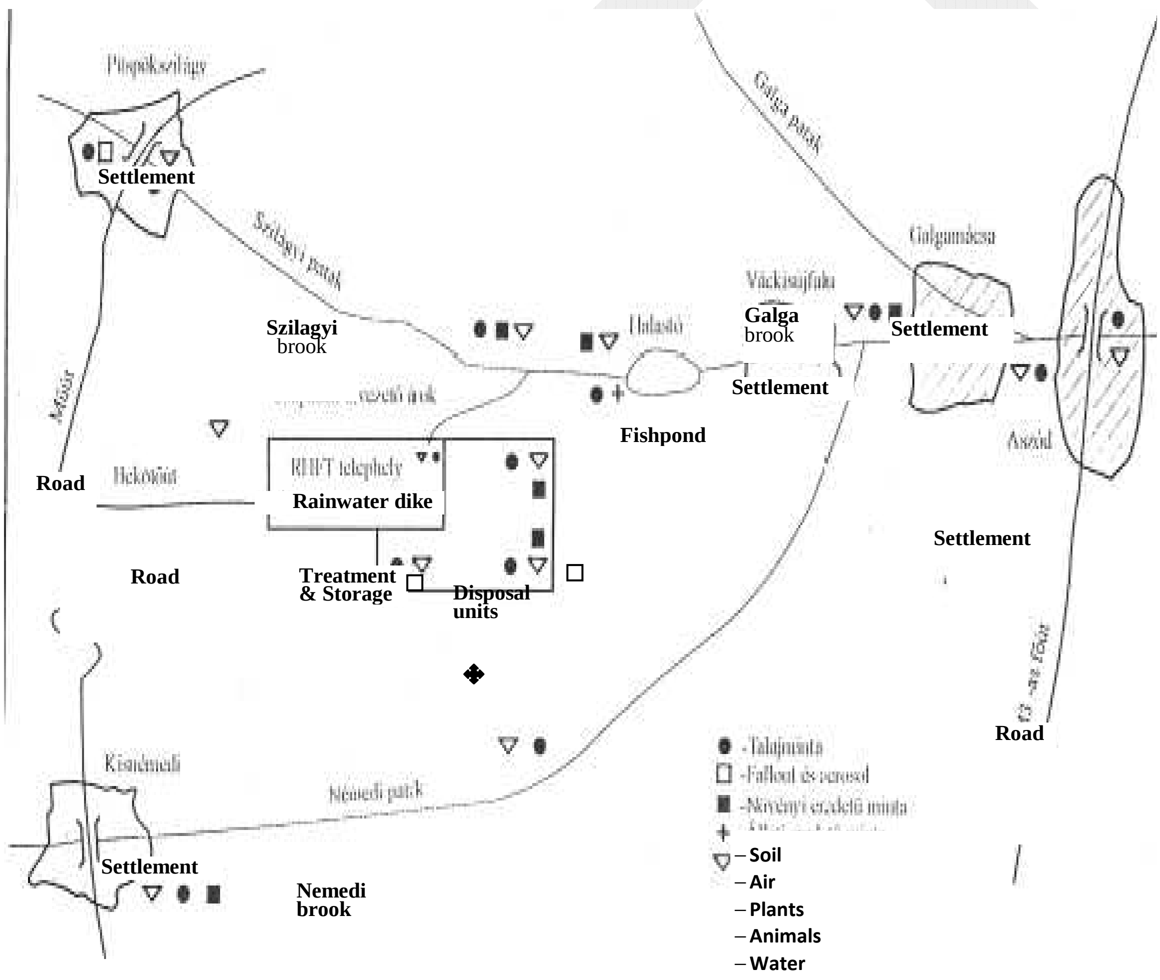

FIG. II-1. Layout of RWTDF monitoring system
Only the most important sampling points are illustrated. Not to scale.

I–3 EARLY OPERATIONAL MONITORING AND SURVEILLANCE ACTIVITIES

II-12. In the first stage of the disposal facility operation the monitoring programme consisted of sampling in:

- 10 groundwater monitoring wells (water);
- 8 points along surface water flows (water and sediment);
- In the rainwater collector (water and sediment);
- At 6 points for vegetation sampling;
- At two places for aerosol and fall-out;
- At two places for food samples (fish and milk).

II-13. In 1991 the site was extended from 3360 m^3 to 5040 m^3. In accordance with it an extended monitoring system was implemented:

- Hydrogeological (underground water) monitoring: additional 18 wells were constructed and in total 28 wells has been used for monitoring of changes of groundwater table level;
- Surface monitoring system (4 fixed measurement point);
- Near surface radiation monitoring (16 wells each of 7 m depth around the disposal vaults to monitor the radiation 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 section along both brooks;
- Involving the new rainwater collector basin.

II-14. The basic levels were calculated using 2-year average of data collected (1990-1991).

II-15. The new results were built in the operational monitoring programme.

II-16. The first safety evaluation of the system was performed in 1995, and parallel with it a meteorological system was located aiming at collecting further input data.

I–4. OPERATIONAL MONITORING AND SURVEILLANCE

II-17. The radiological monitoring programme is broadly similar to the pre-operational, but sampling frequencies are generally reduced. Based on periodic review of the results and on new recommendations for sampling and measurement procedures there were some changes in the sampling frequencies, in the range of nuclides measured, and the monitoring wells used.

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II-18. The sampling operations required for the measurements extend over the entire area of the site, and for water courses within a perimeter of 20 km.

II-19. The first comprehensive safety assessment was performed in 2000 which was based on the geological investigations carried out in the 70's and the monitoring data collected 1976-2000. Some concerns were raised related to the slope stability as a result of the safety assessment therefore erosion investigation of the slopes was introduced in the monitoring programme.

II-20. Later, during the re-licensing process of the site the regulatory body requested further geological investigations, which were performed between in 2006-2007.

II-21. In 2000 elevated tritium concentration were measured in a few groundwater monitoring wells. Although it has had no impact on the local population's exposure, 6 monitoring wells for continuos monitoring have been implemented to make detailed investigations, in addition to the operational ones. The source and main pathways of the tritium were identified, and has been further monitored.

II-22. In 2004, following the refurbishment of the treatment and storage building, new aerosol and soil sampling points were installed.

II-23. During normal operation of the facility, airborne or liquid radioactive discharge may only occur from the operations building and the storage building both situated within the controlled zone. The generated small amount of liquid waste is stored in sealed tanks; no discharge from these thanks occurred during these years.

II-24. The airborne discharge monitoring is carried out by emission measurements, 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 prevailing wind direction.

II-25. The environment monitoring operations of the facility are composed of work of several laboratories. The most essential basic measurements are carried out by the internal laboratory of RWTDF. The special measurements and the detection of difficult to measure isotopes in the environmental samples are undertaken by Hungarian laboratories. Vegetation, animal, soil, sediment/mud, aerosol, fall-out, surface water and ground water samples are collected on regular basis typically from 40 different sampling locations by the environment monitoring laboratory of the facility for the purpose of gamma-spectrometry measurement and total beta counting.

II-26. Samples are also taken from additional 30 ground water monitoring wells. The highly-sensitive measurements of the vegetation, soil and animal samples taken in the direct vicinity of the facility are analysed by external institution

II-27. The data of the monitoring system are compared to the reference levels identified in 1976 –77.

II-28. 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-29. The gathered radiological information in the surroundings of the facility are recorded in a computer based national database.

II-30. The summary of the monitoring system is showed in Table II-1.

TABLE II-1. SUMMARY OF MONITORING SYSTEM.

Media sampled	**Place**	**Type of monitoring**	**Sampling method**	**Measurement**	**Evaluation**
Air	in the centre of the nearest village	environmental	air-filter changed weekly fall-out sampling basin	gross beta & gamma-spectrometry	base level
Air	at the down-wind side of disposal area	environmental / source	air-filter changed weekly, fall-out sampling weekly, adsorption of ^{3}H on silica gel and ^{14}C in barium hydroxide every 2 months	gross beta & gamma-spectrometry / gross alpha/beta gross beta & gamma spectrometry / tritium, radiocarbon, ^{90}Sr	base level
Air	at the down-wind side of the treatment-storage building 100m	environmental / source	filter tape periodically forwarded, adsorption of ^{3}H on silica gel and ^{14}C in barium hydroxide	gross alpha/beta tritium, radiocarbon, ^{90}Sr	base level
Air	in the ventilation chimney of the treatment-storage building	source	air-filter changed weekly, adsorption of ^{3}H on silica gel and ^{14}C in barium hydroxide	gross beta & gamma-spectrometry, tritium, radiocarbon, ^{90}Sr	discharge limit

			every 2 months		
Air	in the basement and the 1st floor in treatment and storage building	source	filter tape periodically forwarded	continous measurement of l alpha and beta aerosol concentration	radiation protection limits
Surface water	brook-1 upstream in the centre of the nearest village	environmental	hand sampling half a year	gamma- spectrometry, gross beta, ^{3}H	base level
Surface water	brook-1 upstream to the site	source	hand sampling and pumping half a year	gross beta & gamma-spectrometry, tritium, radiocarbon, ^{90}Sr, ICP	base level
Surface water	brook-1 downstream to the site	environmental	hand sampling half a year	gross beta & gamma-spectrometry, tritium	base level
Surface water	fishpond along brook-1	environmental	hand sampling a year	gross beta & gamma-spectrometry	base level
Surface water	brook-2 upstream in the centre of the nearest village	environmental	the same like brook-1	the same like brook-1	base level
Surface water	brook-2 upstream to the site	environmental	the same like brook-1	the same like brook-1	base level
Surface water	brook-2 downstream to the site	environmental	the same like brook-1	the same like brook-1	base level
Surface water	before and after water collection river	environmental	hand sampling once a year	gross beta & gamma-spectrometry	base level
Surface water	20 km along the water collection river	environmental	hand sampling a once year	gross beta & gamma-spectrometry	base level
Rain water	rainwater collection basin 90 m^{3} (control zone)	source	hand sampling when the basin is filled	gross beta & gamma-spectrometry, tritium, radiocarbon,	discharge limit

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				^{3}H	
Rain water	rainwater collection basin 60 m^3 (control zone)	source	hand sampling when the basin is filled	gross beta & gamma-spectrometry	discharge limit
Ground water	on the slopes around the site (23 wells)	environment	hand sampling and pumping half a year	^{3}H, ^{14}C, gorss beta, gamma spectrometry, ^{90}Sr, ICP	base level
Ground water	inside facility (10 wells)	source	hand sampling and pumping half a year	^{3}H, ^{14}C, gorss beta, gamma- spectrometry., ^{90}Sr, ICP	base level
Ground water	on the ridge upward (background) (3 wells)	environment (background)	hand sampling and pumping half a year	^{3}H, 14C, gorss beta, gamma- spectrometry, ^{90}Sr, ICP	base level
Ground water	in control zone (6 wells)	source	hand sampling and pumping monthly for ^{3}H, half a year for others	^{3}H, ^{14}C, gorss beta, gamma- spectrometry, ^{90}Sr, ICP	base level
Sediments	along the springs	environmental	sampling the mad from the water, without benthos	gorss beta, gamma-spectrometry	base level
Soil	Inside the site (11 places)	source	hand sampling once a year	gorss beta, gamma-spectrometry	base level
Soil	inside the site (6 places)	source	hand sampling once a year	^{90}Sr, gorss beta, gamma- spectrometry	base level
Soil	outside of the site (4 places)	environmental	hand sampling once a year	gorss beta, gamma-spectrometry	base level
Plant	along the springs	environmental	hand sampling half a year	gorss beta, gamma spectrometry	base level
Plant	inside the site (5 places)	environmental	hand sampling half a year	gorss beta, gamma-spectrometry, ^{90}Sr	base level
Animal	from the lake	environmental	sampling the whole fishes, only native	gorss beta, gamma-	base level

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			fishes half a year	spectrometry, ^{90}Sr	
Animal	inside the site	environmental	sheeps at the site, once a year	gorss beta, gamma spectrometry, ^{90}Sr	base level
Hydroge-ology	26 wells	environmental	measurements by hand devices twice a year	level of the water surface in the wells	base level
Hydroge-ology	8 wells	environmental	installed detectors continuously	level of the water surface in the wells	base level
Hydroge-ology	2 cross-section on both brooks	environmental	measurements by hand devices half a year	monitor the runoff of the brooks upstream and downstream to the site	base level
Radiation	in-situ at 6 places	environmental	once a year	In-situ gamma-spectrometry	base level
Radiation	dose rate meters at the disposal (7)	source	installed detectors continuously	continuous gamma dose rate measurement	radiation protection limits
Radiation	dose rate meters in the building (23)	source	installed detectors continuously	continuous gamma dose rate measurement	radiation protection limits
Meteorology	next to the disposal vaults	environmental	automatic meteorology station	wind, temperature, vapour, precipitation	-
Geodesy	4 fixed measurement points	environmental	measurements by hand devices	monitoring of the earth surface, monitor the moving of the surface	base level
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, half a year	tritium, gamma-spectrometry	-

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II-31. At present, the post-operational monitoring requirements 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 surrounding area.

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