

# **P**reservation of Records, Knowledge and Memory across Generations (RK&M)

Monitoring of Geological  
Disposal Facilities –  
Technical and Societal  
Aspects

NUCLEAR ENERGY AGENCY

**Radioactive Waste Management Committee****Preservation of Records, Knowledge and Memory across Generations (RK&M)****Monitoring of Geological Disposal Facilities: Technical and Societal Aspects**

*This report is based on two studies: an NEA internal report entitled “Monitoring of Geological Disposal Facilities (August 2013)” which provides an overview on technical aspects of monitoring and an NEA public report entitled “Local Communities’ Expectations and Demands on Monitoring and the Preservation of Records, Knowledge and Memory of a Deep Geological Repository (October 2013)”, which is a contribution of an NEA RWM Working party, the Forum on Stakeholder Confidence (FSC), to the RK&M project. The latter study draws on a questionnaire survey of FSC members in July and August 2012, followed up by structured interviews with a range of involved stakeholders from both national and local levels from seven countries and also comprises a literature review on the subject.*

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**MONITORING OF GEOLOGICAL DISPOSAL FACILITIES:  
TECHNICAL AND SOCIETAL ASPECTS**

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## EXECUTIVE SUMMARY

The OECD Nuclear Energy Agency (NEA) Radioactive Waste Management Committee (RWMC) Project on “Preservation of Records, Knowledge & Memory across generations (RK&M)” (2011-2014) explores and aims to develop guidance on regulatory, policy, managerial, and technical aspects of long-term preservation of records, knowledge and memory of deep geological disposal facilities [1]. While official responsibility for the preservation of records, knowledge and memory must remain with institutions, it is likely that local communities do or will have an important pragmatic role in maintaining the memory of a repository, e.g., by engaging at some level in its continued oversight [2]. Monitoring – by collecting, interpreting and keeping data on a continuous basis – would serve the purpose of preserving records, knowledge and memory and continuous oversight.

In order to tackle the subject it is important, on the one hand, to describe the role of monitoring in a technical perspective and, on the other, to understand the expectations of local stakeholders regarding monitoring.

The present study report should therefore meet three objectives:

- To present in a comprehensive way the general monitoring information, practices and approaches used in the various national geological disposal programmes and elaborated in a number of international projects;
- To explore the role, needs and expectations of local communities regarding monitoring and RK&M preservation of deep geological repositories;
- Based on the above review, to identify lessons learned and the rationale for monitoring geological disposal projects throughout their lifecycle stages.

This report is based on two studies: an NEA internal report entitled “Monitoring of Geological Disposal Facilities (August 2013)” [3] which provides an overview on technical aspects of monitoring and an NEA public report entitled “Local Communities’ Expectations and Demands on Monitoring and the Preservation of Records, Knowledge and Memory of a Deep Geological Repository (October 2013)” [4], which is a contribution of an NEA RWMC Working party, the Forum on Stakeholder Confidence (FSC), to the RK&M project. The latter study draws on a questionnaire survey of FSC members in July and August 2012, followed up by structured interviews with a range of involved stakeholders from both national and local levels from seven countries and also comprises a literature review on the subject.

### **Rationale for monitoring**

Each and every geological disposal project requires the collection of large amounts of information on its progress throughout the facility’s lifecycle. This information is based on the monitoring and surveillance of the selected site, built structures and their surrounding environment. Monitoring is carried out to assist in the decision-making process, to collect site-relevant information for the creation of an environmental database, to gain an understanding and to verify the performance of the disposal system, to

demonstrate compliance with regulatory requirements and to provide information for the various stakeholders.

The task of monitoring can, in principle, be addressed by answering a number of simple questions such as why, what, how and when to measure, and how to use/interpret the results. The monitoring programme begins in the initial phases of disposal facility siting and may continue following closure. Even if the scope and extent of the programme changes with respect to the specific requirements of particular lifecycle stages, certain parameters should be verified continuously. However, the completeness of the selection of such parameters cannot yet be verified since, except for seldom cases, as WIPP in the USA [27], most of the advanced geological disposal projects have not yet reached the facility construction stage.

### **Monitoring, RK&M and oversight**

Monitoring is understood principally as the collection of technical data. Nevertheless, there may be parameters that are not strictly technical or that may be technical but the measurement of which is carried out by players other than the regulator or operator; all these parameters involve the provision of information that supports RK&M preservation. Specific concerns and expectations on RK&M emerge as siting draws near, and are clearly on the agenda in countries that in 2012-13 are undergoing a licensing phase. So far, informal and formal discussions have been on-going in several countries regarding the best way to pass on information on to future generations. This brings us to the useful concept of oversight as “keeping an eye” on the repository system and on the implementation of decisions as outlined by ICRP [5, 40]. The concept embraces both long-term monitoring and preservation of RK&M. Oversight can be exercised not only through monitoring of technical parameters and administrative provisions but also through monitoring agreements made with the local hosts and other stakeholders. The decisions on the levels and evolution of oversight would be based on various factors, like the degree of confidence in the behaviour of the facility, societal, economic factors, etc. Being aware of the views of the implementer, the regulator and the concerned stakeholders on these issues may provide further insights on the nature and role of oversight of geological disposal. As stated by ICRP (2013) [5], “decisions related to the organisation and evolution of the oversight should be discussed with the stakeholders”.

### **Planning a monitoring programme**

The key aim of planning a monitoring programme is to determine its objectives and how to address them via the various projects implemented, either in parallel or sequentially, targeted at gaining an understanding of technical, safety and socioeconomic developments. The selection process should be flexible enough so as to accommodate the potential need for revision during the repository’s lifecycle. Ideally, the whole of the programme should be outlined in the initial stages of the facility development, although this is difficult with respect to the duration of the disposal project, which could extend into several centuries. Currently, the most important technical information regarding monitoring is being accumulated by underground research laboratories as a result of the conducting of experiments lasting several years or indeed, in some cases, a decade. There are certain challenges that call for additional research and international consensus such as the long-term management of data, the durability of the material/equipment employed, the selection of representative parameters for long-term facility surveillance, gaining a complete understanding of the processes occurring within the system including potential coupling effects, the extent and content of post-closure monitoring, etc.

Nevertheless, techniques and procedures already exist for the monitoring of the various parameters during the pre-operational and operational phases, particularly with regard to disposal system characterisation and evolution, safety case development, operational safety and the assessment of environmental impacts. There is broad consensus that, following closure, the disposal system must be safe by itself independently of monitoring by any institutional or non-institutional body.

It is foreseen, however, that after facility closure, indirect forms of oversight will still be required by the authorities such as the maintaining of records and ultimately even the memory of the site; this may also include certain forms of monitoring, the extent of which is still under discussion.

As the concept of oversight (cf. ICRP, 2013) [5] is elaborated further, it is useful to examine current stakeholder views on monitoring and RK&M preservation as part of the oversight function. According to the FSC study [4], there is relatively little work or guidance on how monitoring might contribute to the creation and preservation of RK&M and to what extent local communities might play a role in this process, as part of a general oversight approach. The FSC study [4] reveals that local stakeholders have an interest in monitoring and RK&M preservation in RWM facilities. Local stakeholders would like to know how monitoring will take place and which processes it is important to monitor and why. In addition, local communities recognise that monitoring should be undertaken in the early stages of the siting procedure and might be continuously refined and may not end with the closure of the facility. The nature and extent of monitoring required by local stakeholders depends on their understanding or definition of monitoring.

### **Current status of monitoring**

Current status of monitoring can briefly be summarised as follows:

- Techniques and procedures currently exist for monitoring various parameters required during the repository lifecycle;
- Long-term data management systems need to be prepared and developed from the early stages of repository development on;
- An acceptable monitoring system is one that shall not deteriorate in any way the overall safety of a facility;
- The long-term monitoring of an underground facility faces significant technical problems and uncertainties exist in the monitoring and evaluation of slow and coupling processes: these require further R&D efforts;
- The need for and forms of post-closure monitoring are still under consideration, but following closure, the disposal system must be safe by itself without reliance on monitoring;
- The current technical desire would be to terminate monitoring soon after facility closure, while stakeholder preference is to continue the monitoring. Reaching consensus on how to address this problem is vital in attaining stakeholder confidence; however safeguards monitoring (if applicable) requires the site be monitored even during the post-closure period;



- The requirement, by the ICRP, for continued oversight of the closed facility itself (incl. maintaining records and memory keeping) introduces the general issue of societal monitoring, since RK&M aspects of monitoring serves to support oversight;
- Further research to identify both how monitoring could contribute to confidence in geological disposal, and how local communities in different national contexts may be involved in oversight activities could consolidate understanding of roles, demands and expectations.

## 1. INTRODUCTION

The definitions of monitoring vary within the nuclear waste community, often depending on the circumstances in which monitoring is designed (definitions used by various national programmes and international organizations are listed in Appendix 1). Most of the time monitoring is restricted to technical monitoring using the definition suggested by the IAEA [6]:

*“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.”*

A broader definition of monitoring is the following one, taken from the Cambridge Dictionaries Online:

*“...watching and checking a situation carefully for a period of time in order to discover something about it” [7].*

Monitoring and surveillance of radioactive waste disposal facilities typically has four broad objectives [6]:

1. To demonstrate compliance with regulatory constraints and licensing conditions;
2. To verify that the disposal system is functioning as required, which would also indicate that the various components are fulfilling their functions as identified in the safety case and that actual conditions are consistent with the assumptions made regarding post-closure safety;
3. To strengthen the understanding of certain aspects of the behaviour of natural systems and their relationship to repository construction, operation and closure as employed in the development of the safety case for the disposal facility and to allow further testing of the models designed to predict such aspects;
4. To develop an environmental database on the site, the disposal facility itself and its surroundings for future decision-making purposes that will form part of the stepwise programme for the construction, operation and closure of the disposal facility.

These objectives may be extended to:

5. Collect site-relevant information during the pre-disposal stage so as to better understand the potential performance of the disposal system and hence to optimize the design of the repository.
6. Provide information to the various stakeholders involved (technical, environmental and societal) so as to enhance confidence.
7. Include other forms of monitoring related to information on societal and economic impacts of the disposal project.

The task of monitoring may, in principle, be addressed by answering the following questions:

- Why to monitor (purpose and process identification)?
- What to monitor (parameter and/or human activities)?
- How to monitor (measurement and observation procedures and corresponding equipment)?
- When to monitor (timing, frequency and duration)?
- How to use/interpret the results (modelling, synthesis of the inputs, records)?

The monitoring of disposal facilities typically focuses on the collection of technical and environmental information at all stages of the disposal system. However, for non-technical stakeholders or decision-makers, they may also require information on societal and economic impacts of the disposal project during its progress. Since non-technical drivers should be considered when assessing stakeholder motivation and the goals of monitoring, and some of the technical demands for monitoring a disposal facility may stem from societal demands, this study not only covers technical aspects which are of interest to technical specialists but also societal aspects related to expectations of local communities.

In order to tackle the subject it is important, in the one hand to describe the role of monitoring in a technical perspective, and on the other hand to understand the expectations of local stakeholders regarding monitoring.

The present report has been prepared for meeting three objectives:

- To present in a comprehensive way the general technical monitoring information, practices and approaches used in the various national geological disposal programmes and elaborated in a number of international projects.
- To explore the role, needs and expectations of local communities regarding monitoring and RK&M preservation of deep geological repositories.
- Based on the above review, to identify lessons learned and the rationale for monitoring geological disposal projects throughout their lifecycle stages from both a technical and societal standpoint.

This report is based on two studies: an NEA internal report entitled “Monitoring of Geological Disposal Facilities (August 2013)” [3] which provides an overview on technical aspects of monitoring and an NEA public report entitled “Local Communities’ Expectations and Demands on Monitoring and the Preservation of Records, Knowledge and Memory of a Deep Geological Repository (October 2013)” [4], which is a contribution of an NEA RWMC Working party, the Forum on Stakeholder Confidence (FSC), to the RK&M project. The latter study draws on a questionnaire survey of FSC members in July and August 2012, followed up by structured interviews with a range of involved stakeholders from both national and local levels from seven countries and also comprises a literature review on the subject.

## Organization of the report

This report is structured as follows:

Chapter 2 summarizes the reviews of the literature on technical and societal monitoring published in the past decade. Technical monitoring is a key subject in several international radioactive waste disposal programmes and a number of national publications. Documents have been published by the IAEA, EC, NEA/FSC. The ICRP developed the concept of oversight which includes forms of monitoring that are not only technical and involve society and RK&M preservation [5]. National publications have focused on the practicalities relevant mostly to national underground research laboratory programmes. Many of these programmes have progressed to develop technical monitoring programmes for the operational and closure phases of a repository. They therefore act as the main drivers in applying research and development (R&D) outcomes to realistic industrial applications.

Chapter 3 reviews the monitoring goals relevant to the entire repository lifecycle and evaluates a few major monitoring projects. There is a large number of reasons for establishing national monitoring programmes; they have been indicated in the Appendix 2. They may be based on technical grounds as outlined by the IAEA and on societal grounds since monitoring can become a part of general oversight measures after closure. One of the motivations is to keep memory of the disposal facility. It should be noted that monitoring activity comprises several levels:

1. National survey programmes,
2. An integrated facility monitoring programme which consists of a series of monitoring projects,
3. Monitoring projects (sub-programmes) which address particular stages of the repository lifecycle, tasks and purposes.

The chapter describes the different monitoring aspects in the different lifecycle stages of the geological disposal program and the different monitoring projects.

Chapter 4 outlines a logical scheme for developing a monitoring programme based on the three levels outlined above. This selection should be flexible enough to accommodate probable later needs for revisions during the repository lifecycle.

Chapter 5 identifies and analyses the major challenges involved in technical monitoring which include: data management, material and equipment durability, parameter selection, identification of processes to be monitored, coupling processes, monitoring after repository closure.

Chapter 6 presents the results of a questionnaire survey of members of the Forum of Stakeholders Confidence from the NEA (FSC) on expectations of local communities regarding monitoring and RK&M preservation of radioactive waste management (RWM) facilities. It was followed up by structured interviews with a range of involved stakeholders from both national and local levels. In addition, a literature review was carried out, focussing on FSC publications and other documents and publications found through internet or suggested by interviewees. The report identifies concerns and expectations of local communities regarding monitoring in the different phases of the repository life cycle and in the

different national contexts. After a brief presentation of the methodology set up by the FSC in section 6.1., section 6.2 reviews the FSC findings on aspects related to RK&M and monitoring. In section 6.3 the report identifies concerns and expectations of local communities regarding monitoring in the different phases of the repository life cycle and in the different national contexts, according to the results gathered from the survey and interviews undertaken as part of this project. Section 6.4 discusses how RK&M preservation may emerge as a subject of debate with local stakeholders in different countries in the years to come. Section 6.5 recognises that monitoring and RK&M preservation potentially serve to build and maintain confidence in the long-term safety of deep geological repositories. Finally, the concept of oversight is considered in section 6.6 as a term that embraces monitoring and RK&M, and its interpretation in different reports is illustrated.

Chapter 7 covers the observations and results of the 2013 International Repository Monitoring Conference and workshop (organised within EC MoDeRn project [16]).

Chapter 8 identifies the overall lessons learned and the rationale for monitoring geological disposal projects throughout their lifecycle stages. Final reflections and conclusions are presented.

The appendix and 4 attachments provide further background information and lessons learnt from ongoing international projects.

## 2. A REVIEW OF THE LITERATURE OVER THE PAST DECADE

Monitoring of geological disposal facilities has been a key subject in several international radioactive waste disposal programmes and a number of national publications: while the former have attempted to sort the issue in principle, the latter have focused on the practicalities relevant mostly to national underground research laboratory programmes. Certain information is also available from existing subsurface disposal facilities which, however, is limited by the fact that these facilities present different conditions of accessibility for monitoring and deal with intermediate and low level waste only.

The IAEA published a technical document [10] in 2001 presenting the Agency's opinion on the practicalities and technical aspects of monitoring geological repositories for high level radioactive waste. A Safety Standard is currently being prepared to provide guidance and examples of good practice related to monitoring and surveillance programmes for radioactive waste disposal facilities [6]. More specific guidance and recommendations relating to the development and regulatory control of geological disposal of radioactive waste in meeting IAEA safety requirements are also provided in their 2011 Specific Safety Guide SSG-14 [14].

The European Commission (EC), through its various Framework Programmes, has provided substantial support to international programmes which aim at, through research, enhancing understanding of the role of monitoring in the staged development of geological disposal facilities [16, 17, 18]. As the disposal programmes reach industrial maturity in some countries (Finland, France, Sweden) and the construction of disposal facilities becomes increasingly topical, programmes tend to arrive at a consensus on the monitoring techniques and technologies to be employed and the practicalities involved in the implementation of monitoring programmes.

The Forum of Stakeholder Confidence (FSC), created by the Nuclear Energy Agency (NEA) of the OECD, has been active in dealing with the societal aspects of monitoring; non-technical involvement is seen as a tool for enhancing stakeholder trust in disposal programmes [4,19]. Another working group of the NEA, the Integration Group for the Safety Case (IGSC), had also explored the strategies and how to handle monitoring in developing a safety case in 2004 [33].

Those national programmes which involve the operation of underground research facilities and are preparing for the construction of disposal facilities have already implemented monitoring practices relevant to the initial phases of repository development. Many of these programmes have progressed to develop monitoring programmes for the operational and closure phases of a repository. They therefore act as the main drivers in applying research and development (R&D) outcomes to realistic industrial applications. A selection of published results and monitoring plans are documented in References 20-29.

The International Commission on Radiological Protection (ICRP) has released its new recommendations related to geological disposal of long-lived solid radioactive waste [5]. The ICRP report outlines that, from a radiological viewpoint, the application of the protection system is influenced by the level of oversight or 'watchful care' of the disposal facility that is present. Monitoring – by collecting, interpreting and keeping data on a continuous basis – serves the purpose of preserving records, knowledge

and memory. As the concept of oversight is elaborated, it is useful to examine current stakeholder views on monitoring and RK&M preservation as part of the oversight function.

Appendix 2 provides further information and review of the afore-mentioned international and national references.

### 3. OVERVIEW OF NATIONAL MONITORING GOALS AND PROJECTS

There is a large number of reasons for establishing national monitoring programmes; they have been indicated in the Appendix 2. Further incentives for monitoring may appear as such programmes continue to evolve during the individual stages of the repository lifecycle. The following text suggests motivation for initiating monitoring projects throughout the disposal programme and sorts out major monitoring projects.

Tenets of geological repository monitoring are outlined in the final report of the EC Thematic Network on Monitoring [11]. The monitoring of a geological disposal system during the phased implementation process is based on a small number of basic principles grounded in existing international consensus, for example as set out in IAEA documentation [6, 10] and include the following:

- The operational safety of a geological disposal facility (both radiological and conventional) must be underpinned and verified by monitoring.
- Long-term (post-closure) safety cannot rely on monitoring after closure.
  - This is for reasons of principle – undue burdens should not be placed on future generations – and for practical reasons – it cannot be assumed that future generations will have the technical capability or interest in carrying out monitoring.
  - Therefore, long-term safety must be assured by the disposal system design (including the choice of site) and the quality of its implementation. After closure, the disposal system must be passively safe without reliance on monitoring.
  - To this end, a convincing long-term safety case has to be developed prior to the emplacement of the waste (i.e. monitoring in the post-emplacement phase is not part of the safety case, although it may provide an opportunity to confirm its conclusions; it may be ongoing because of several other drivers, not willing to forget the facility being the first one).
- All monitoring must be implemented in such a way as not to be detrimental to long-term safety.
  - That is, no significant detrimental disturbance of the long-term performance should be introduced by monitoring. Similarly, there must be no compromise with respect to long-term safety in order to facilitate the retrievability of the waste.
- The societal role of monitoring must be acknowledged.
  - Monitoring may be carried out for non-technical reasons, for example related to public reassurance. Such monitoring may be continued so long as it is required by future generations, who may not consider this an ‘undue burden’. Furthermore, monitoring can become a part of general oversight measures after closure.



- The motivation for monitoring has been summarised (based on information from Appendix 2) according to different criteria and is shown in Table 1.

**Table 1: Examples of the motivation for national monitoring programmes**

Motivation	Ref.	Items
Lifecycle approach	[6]	<ul style="list-style-type: none"> <li>• site selection,</li> <li>• facility construction,</li> <li>• facility operation,</li> <li>• facility closure,</li> <li>• post-closure period</li> </ul>
Key purposes	[10]	<ul style="list-style-type: none"> <li>• input for management decision-making,</li> <li>• understanding of system behaviour,</li> <li>• information for society, stakeholder confidence,</li> <li>• environmental database,</li> <li>• nuclear safeguard requirements</li> </ul>
Elements to be monitored		<ul style="list-style-type: none"> <li>• Baseline conditions,</li> <li>• behaviour of the waste package and its associated buffer material,</li> <li>• degradation of disposal facility structures and engineered barriers,</li> <li>• near-field chemical and physical disturbances induced by construction,</li> <li>• interaction between introduced materials, groundwater and host rock,</li> <li>• chemical and physical changes to the surrounding geosphere and in the atmosphere,</li> <li>• radionuclide release detection,</li> <li>• provision of an environmental database</li> </ul>
Mission	[11]	<ul style="list-style-type: none"> <li>• monitoring that forms part of the scientific and technical investigation programme,</li> <li>• monitoring of the acceptable operation of facilities,</li> <li>• confirmation of key assumptions of the disposal concept,</li> <li>• maintaining the confidence of present and future generations,</li> <li>• nuclear material safeguards</li> </ul>
Topics		<ul style="list-style-type: none"> <li>• the establishment of a baseline and evolution of environmental conditions,</li> <li>• compliance monitoring,</li> <li>• monitoring to support the evaluation and assessment of repository performance,</li> <li>• the broader (non-technical) aspects of monitoring</li> </ul>
General rationale	[13]	<ul style="list-style-type: none"> <li>• describe the primary baseline conditions of the repository site,</li> <li>• develop and demonstrate an understanding of the evolution of the repository site (impact of construction and the</li> </ul>

Specific rationale		behaviour of engineered barriers),
		<ul style="list-style-type: none"> <li>• assist in the decision-making process,</li> <li>• show compliance with int. &amp; nat. guidelines and regulations</li> </ul>
		<ul style="list-style-type: none"> <li>• obtain knowledge of undisturbed conditions,</li> <li>• obtain a better understanding of the function of the deep repository system,</li> <li>• monitor the environmental impact,</li> <li>• provide evidence that the working environment is safe,</li> <li>• show that safeguard requirements are fulfilled</li> </ul>
Rationale categories		<ul style="list-style-type: none"> <li>• engineering (repository design),</li> <li>• safety case,</li> <li>• environmental impact,</li> <li>• external effects on baseline conditions</li> </ul>
Environmental monitoring	[21]	<ul style="list-style-type: none"> <li>• physical environment ,</li> <li>• biological environment,</li> <li>• human environment</li> </ul>
Major categories	[26]	<ul style="list-style-type: none"> <li>• monitoring of processes and parameters that support the adequacy of a site,</li> <li>• monitoring the operation of a repository to demonstrate its expected performance and long term safety (safety case)</li> </ul>
		<ul style="list-style-type: none"> <li>• baseline information for an Environmental Assessment and licence approval,</li> <li>• design and layout of the repository,</li> <li>• safety assessment inputs,</li> <li>• analysis and confirmation of repository performance,</li> <li>• indication of a need to retrieve waste from the repository</li> </ul>
Keeping memory	[35]	<ul style="list-style-type: none"> <li>• oversight of a closed disposal facility</li> <li>• memory as a part of maintaining safety, e.g., vis-à-vis human intrusion</li> </ul>

Dozens of parameters have been identified and the relevant measurement techniques developed for accumulating the data required in order to characterise particular items from Table 1; a number of them are listed in the Attachments. Their selection varies depending on the extent of the requirements and purposes of monitoring. This selection may require updating in later repository lifecycle stages.

It should be noted that monitoring activity comprises several levels and it is evident that establishment of a lower level activity should not compromise the higher level one(s). The monitoring hierarchy can be specified as follows:

1. National survey programmes,
2. An integrated facility monitoring programme which consists of a series of monitoring projects,

3. Monitoring projects (sub-programmes) which address particular stages of the repository lifecycle, tasks and purposes.

### **National survey programmes**

Different national survey programmes have been established in a number of countries (e.g. Germany, USA) in order to evaluate and assess national developments, in particular the environmental and socio-economic impacts of human activities. These surveys are often conducted as part of international studies, such as the World Health Survey organised by the World Health Organisation (WHO) which has been completed in 70 countries. Even though they are usually intended to be a one-off activity, they may be performed periodically. A specific example consists of safeguard monitoring which falls into this category. Every country operating a relevant national programme is subjected to international supervision (IAEA, EC).

An integrated monitoring programme shall ensure all relevant projects are coordinated and harmonised in order to both prevent mutual disturbance and to optimise implementation. Monitoring projects shall have clear work scopes and purposes so as to ensure the monitoring results obtained can come to a full use.

### **Integrated facility monitoring programmes and monitoring projects**

The basis of any integrated monitoring programme shall be periodically reviewed, particularly prior to the commencement of a monitoring project in order to ensure the goals of the project are consistent with the overall programme. Monitoring details as well as a monitoring plan are also essential in a monitoring project. The planning of monitoring projects and their integrated programme should be carried out in the initial phases of repository development.

The mutual links between the various stages of the repository lifecycle and potential monitoring projects are illustrated in Table 2; particular items shown in the table are subsequently explained and discussed in the following text.

#### **3.1 Technical Monitoring in repository lifecycle stages**

A sequence relating to geological repository lifecycle stages has been developed over the last few decades [14, 34]. The so-called monitored retrievable disposal proposed in Switzerland consists of the phases shown in Table 2 and discussed below. However, not all stages suggested need to be implemented in individual national disposal programmes.

Originally, geological disposal was studied at generic underground research laboratories (URLs). Some countries have also conducted experiments in several such facilities (France, Japan, Sweden, Switzerland).

As the properties of various types of host rock commonly considered suitable for geological disposal (e.g. salt, clay/claystone, granite) already have been studied in detail at a number of URLs and the host rocks have been shown to be potentially suitable for disposal purposes, many countries plan to skip this stage and instead rely on internationally available data gathered at existing facilities. However, it is

generally accepted that such generic information must be shown to be applicable to a selected repository site and therefore further information will usually be required. Consequently, national programmes propose the construction of site specific underground laboratories (also referred to as ‘confirmation laboratories’) at selected repository sites; they are designed for use as an early stage of repository construction itself. It should be noted that final authorisation for repository construction may well be dependent on the results of research conducted at such site-specific confirmation URLs.

Conversely, some generic URL sites may in time become final repositories: in such cases the confirmation testing facility stage will be omitted. It is obvious that such URLs are designed and operated from the outset in a manner that will not compromise the safety of the repository.

**Table 2: The relevance of monitoring projects to repository lifecycle stages**

Lifecycle stage	Generic underground research laboratory	Siting	Construction	Testing facility (confirmation lab)	Main facility operation	Monitoring facility operation (**)	Post-closure
Project							
Monitoring R&D	*)			*)			
Baseline monitoring (site investigation)	*)	*)					
Characterisation of the host formation							
Development of host formation characteristics during the repository lifecycle							
Performance of the barrier system within the host media	*)		*)				
Construction impacts	*)		*)				
Compliance monitoring							
Environmental monitoring	*)	*)					
Safeguard monitoring							
Socio-economic aspects	*)	*)					

\*) indicates separate monitoring projects (distinguished by colour) unless the URL subsequently becomes a part of the repository

\*\*\*) valid for programmes planning construction of a monitoring facility

Finally, some programmes (e.g. Switzerland) suggest the construction and operation of ‘Monitoring facilities’ in parallel with the main disposal facility whereas other national disposal programmes intend to omit this stage.

### **3.1.1. Underground research laboratory**

A URL is an underground facility for acquiring expertise to develop a nuclear waste repository. URLs allow for building technical teams and for gaining practical experience in obtaining geological data and

testing the techniques as well as relevant engineering solutions and materials in a manner that is transferable to actual repository operation. They enhance understanding of the performance and historical development of a considered host rock formation.

Two broad categories of URLs may be distinguished: generic and site specific URLs [36]. *Generic URLs* help create expertise for acquiring technical data in an underground environment but not necessarily such that closely mimics the one of the final repository, while *site-specific URLs* are built in the same, or similar, environment as is the planned repository. In most cases, site specific URLs are seen as the precursors or the initial stage of developing a repository in the same geological formation. Such URL's then provide two sets of data: those gathered for scientific purposes (monitoring of experiments) and those characterising the host formation (monitoring of the site).

URL's were initially established mostly in pre-existing mines/tunnels (Stripa, Asse, Grimsel, Mont Terri, Tono). However, the more complex results have been obtained from experiments carried out at purpose-built facilities (WIPP, Gorleben, Whiteshell, Aspö, Mol, Bure). Their construction in undisturbed but well-studied geological systems has led to the gathering of valuable information for use in terms of the planning and construction of the final disposal facility.

The experiments and measurements performed at generic URLs are aimed at furthering the basic scientific understanding of the disposal system as a whole, including interactions between the host media and potential engineered barrier materials. URLs serve a very specific purpose with regard to the testing and demonstration of investigation and measurement techniques as well as the various technologies which are being developed for both repository construction and operation; naturally, monitoring processes are included.

The development of a dedicated site-specific URL features phases similar to those followed in the development of the repository itself, i.e. siting, construction, operation and closure (the so-called research, development and demonstration - RD&D - programme) which might well be used in the design of a 'model' repository monitoring programme.

All URL's are subject to compliance monitoring by mining, environmental and nuclear (if using radioisotopes) regulators and, thus, are required to include the relevant monitoring projects.

URL programmes include the testing and application of techniques and technologies which will eventually be employed in the final disposal facility, but the main value of the laboratories is in the search for and subsequent optimisation of approaches which allow scientists and engineers to better understand the behaviour and interaction of the disposal system with the geosphere and, consequently, to put forward suggestions as how to achieve the required level of long term disposal system safety (a facility suitably designed for a suitable site).

One of the most important aspects of URL monitoring consists of the testing of predictions and models aimed at increasing understanding of the host geological formation; this is best performed at research laboratories since it is a typical task for R&DD programmes. Clearly, monitoring forms the main source of the input data for such exercises.

URLs are also significant in terms of facilitating discussion with stakeholders: their development and operation is opened to public (Aspö, Bure, Grimsel, Mont Terri, Mol) and this could be used as a test case for establishing subsequent sociological monitoring projects.

### **3.1.2. Siting**

Selecting a site for the construction of a repository typically consists of four distinct phases: project planning (including establishing criteria for site suitability), the screening of an area of interest (e.g. a country), the investigation of one or more candidate sites, and the confirmation of the final location [30].

Monitoring commences in the screening phase although the more significant monitoring projects form part of the final two siting stages; some parameters will be measured through from outset to closure. A wide variety of geological disciplines, affecting both the surface and subsurface, and the monitoring of geotechnical, climatic, and sociological parameters are involved. In this phase information is gathered on the host rock system which then provides the basis for the design and the formulation of the repository safety case.

### **3.1.3. Construction**

Repository construction may lead to substantial disruption both of the surface areas and the host geological system, the characteristics of which (hydrogeological, geochemical, geotechnical, environmental), may be affected importantly. Any alterations to these characteristics should be systematically monitored in order to provide data for the prediction of the development and final status of the disposal system. Repository construction also impacts the environment due to the construction of surface facilities and access roads/railways, the installation of utilities and the storage and handling of huge amounts of material, waste water etc.; there may also be substantial social consequences. All these aspects must be carefully monitored.

Regulators will, of course, be active during the construction phase of the repository; they will require evidence of compliance with the approved design of the facility and, therefore, will need to verify whether all the procedures are in accordance with the conditions of the construction licence. Also, they will request all inputs relevant to the safety case be tracked and proven.

Construction also includes the cold testing of all the technologies and procedures to be employed in the operational phase; their performance will be evaluated based on purpose-tailored monitoring projects.

According to most national programmes, this stage will include the construction and operation of a test facility (confirmation laboratory). Tests performed at such facilities will provide evidence that all the predicted characteristics of the site, including the various interactions between the barrier and local natural systems, is as stated in the safety assessment part of the construction application documentation. The ongoing evaluation of site specific parameters provides an opportunity to alter the design of the disposal system according to the actual state of the host geological media. In addition, it would be advisable to avoid constructing the entire repository at the outset before the method of waste emplacement has been determined: delaying the construction of the disposal vaults until they are required will allow for the updating of or alterations to the disposal system so as to reflect operational experience.

#### ***3.1.4. Operation of the underground facility***

The operation of the disposal facility commences once the operational licence comes into force (commissioning, i.e. the facility is ready for disposal operations) and ends with the closure of all the excavated disposal and service/access areas and the demolition/decommissioning of those surface facilities which will not be used during the post-closure phases. The termination of operations will ultimately be confirmed by the regulator (final safety report and initiation of the post-closure monitoring phase should it be required).

The period between the issuance of the licence and the first emplacement of radioactive waste provides time for preparatory activities, i.e. it allows for the ‘cold regime’ testing and verification of the operational systems, including the launching of potential new monitoring projects. However, the majority of the monitoring projects commenced in the previous phases of repository development will continue uninterrupted.

Certain monitoring projects are specific to the operational phase, e.g. those dealing with the operational safety of the staff and the public/environment and verifying procedures/processes occurring in this stage, such as waste acceptance and emplacement, sealing, the buffering and backfilling of emplacement drifts and corridors, engineered barrier performance, etc. However, some of them might be performed in a dedicated monitoring facility instead (see Section 3.1.5).

A number of programmes may well concern the co-disposal of different waste categories (e.g. high and intermediate level waste) which requires the launch of specific monitoring projects since the engineered systems in the two parts of the repository will differ considerably (composition, potential consequences).

#### ***3.1.5. Operation of a monitoring facility***

In order to better address public concerns, some disposal programmes are considering ‘monitored retrievable disposal’ which consists of the construction of a monitoring facility (referred to in the Swiss programme as a ‘pilot facility’) adjacent, at depth, to the main disposal complex. Such facilities use identical technologies, are built in the same geological systems, consist of the same barrier system and accept the same waste as the main facility. The only differences are its size and the extent of the monitoring programme, which allows experts both to follow and evaluate in detail the principal processes underway within the disposal system. Based on such information, the monitoring programme provides the input for decision-making on the termination of institutional control (e.g. when passive safety status is attained), on the introduction of new measures (to improve the performance of the disposal system), or on the retrieval of waste (should the system failures discovered prove to be of significance).

Unlike at the main facility, such monitoring allows for the use of multiple monitoring techniques; the introduction of techniques which cannot be applied or which would not be effective in the main facility; the reconstruction of measuring systems should they fail or be damaged in any way; and the partial retrieval and re-disposal of waste used in the research of destructive testing methods all of which will enhance both the understanding of the post-closure development of the disposal system and public support for facility construction through offering a retrieval alternative to final disposal.



All of the above call for the development and operation of a sophisticated monitoring system together with the establishment of decision-making mechanisms and criteria for the selection and final endorsement of the most suitable and effective set of monitoring projects.

Similar results can be achieved by incorporating a compromise monitoring system built in separate cells of the main facility (a strategy currently proposed by Andra [38]). The advantage is seen as being able to gain more representative information from the actual facility; however, there are obvious limitations in terms of the need to minimise the extent of disturbance of barrier performance.

### **3.1.6. Post-closure**

The geological disposal system will be required to provide for the determined safety levels for a period of at least tens of thousands years: the containment of radionuclides within the engineered disposal system is typically designed for a number of millennia although some concepts accept that the earlier release of radionuclides from the engineered system may occur (e.g. gas release or canister design that accepts a small number of failures). Therefore, the monitoring of nuclear parameters in the time frame of a number of decades or centuries seems to be of little use. Rather, the long-term safe performance of geological repositories will be guaranteed by the attainment of ‘passive safety’ status which does not rely on human intervention. However, providing a practical demonstration of having achieved such status is far from easy: the lack of certain criteria and suitable measuring techniques require the involvement of indirect proof developed at research and test facilities. Facility monitoring programmes should build upon research axioms and adequately address the appropriate requirements and approaches with due consideration of transferability of techniques from a research to the main disposal system.

Nevertheless, society may demand the on-going monitoring of certain parameters, typically those which provide for the assessment of environmental impacts following final repository closure and sealing. Consequently, the selection of parameters might well be driven by socio-political rather than technical considerations. The extent of such post-closure monitoring programme will essentially be determined by decisions made at the time of closure; indeed, it would seem appropriate that such decisions be taken by the generation responsible for final disposal.

On the contrary, when technical reasons exist for post-closure monitoring, such monitoring projects should be planned from initial phases of a repository development. For example, this approach has been implemented in WIPP [28].

One of the specific post-closure monitoring tasks will concern the ensuring of safeguard obligations: the various principles and techniques have been determined, the only question will concern exactly when such a project should be terminated.

There may be memory obligations as well, as the EC recent Directive seems to require: the concepts or plans for the post-closure period of a disposal facility’s lifetime, including the period during which appropriate controls are retained and the means to be employed to preserve knowledge of that facility in the longer term [36].



### **3.2. Major technical monitoring projects**

Monitoring projects are designed and carried out for a number of reasons: in principle, they collect data for particular technical disciplines employed in repository lifecycle, often according to standardised schemes and/or local custom and practice, allow observations on and the evaluation of the direction of the various experiments and activities, provide assessment inputs (technical, safety, sociological), etc.

The exact duration of each monitoring project depends on its purpose: it might serve a single experiment while others might extend through several repository lifecycle stages.

Whatever the reason for its introduction, the appropriate coordination of planning and implementation is crucial for the successful compilation of a common disposal facility monitoring programme.

#### **3.2.1. Baseline monitoring**

The general principle of establishing baseline conditions for monitoring is to create a set of reference data against which changes brought about by repository development and operation can be evaluated and distinguished from natural and other man-made temporal and spatial variations in the repository environment.

Baseline conditions are understood to consist of ‘undisturbed data’ from the site of interest, both surface and subsurface. Therefore, the relevant monitoring project should commence prior to the start of repository construction (before underground invasion), ideally as one element of surface and underground investigation. The acquired data will serve throughout the entire repository lifecycle specifically as input for the earth science, engineering, environmental, operational and post-closure safety assessment of the repository (safety case). Examples of baseline conditions which might be monitored include man-made impacts, the surface ecosystem, geology, rock mechanics, hydrogeology and hydro-geochemistry of the area and societal values.

It is expected that updated information based on ‘disturbed conditions’ will be required in the later stages of repository construction, e.g. prior to final closure and sealing. Consequently, a period of baseline monitoring (aimed at evaluating undisturbed conditions) will generally be followed by monitoring projects that assess the impacts of disturbance in the long term.

Knowledge of the initial characteristics of any system under investigation is also vital in terms of the surveillance and evaluation of R&D experiments (an understanding of the host geology and the behaviour of engineered barriers) or other activities initiated in the later stages of repository development; details of such characteristics might well be gathered in a disturbed environment; however, even though they provide initial reference data they cannot be considered baseline information in the sense described in this section of the report.

A detailed enumeration of baseline parameters can be found in the Appendices to this publication [13].

### ***3.2.2. Host formation development during the repository lifecycle***

Prior to the commencement of the investigation stage, a repository site is usually undisturbed or has only sporadically been affected by human activity. The disposal facility is constructed after a detailed characterisation of the host geological environment has been performed which includes extensive surface and subsurface exploratory and excavation work which will significantly alter the host rock formation conditions (geo-scientific characteristics, the introduction of new materials, biological contamination, redox conditions, temperature, etc.) especially since the construction and operational periods of the repository may extend to several decades. Following closure, every effort should be made to re-establish the original state of the host geological system. However, since this is impossible in practice, the engineered barrier system must be designed to optimize the quality of the original undisturbed host rock formation.

The process outlined above will need to be systematically monitored, documented and evaluated in order to provide convincing evidence of the disposal system having attained ‘passive safety’ status. Monitoring should be initiated at the time of initial site investigation and end following the closure of the facility at which time evidence must be provided on having fully met the conditions stipulated in the facility’s safety case.

This particular monitoring project is one of the most challenging in terms of duration – a hundred years or more – and the requirement to select a limited number of parameters which will, nevertheless, provide all the information needed.

### ***3.2.3. Characterisation of the host formation***

The general geo-scientific investigation techniques which will allow a detailed description of the characteristics of the geological system to be obtained are already available in other industries (e.g. mineral mining, oil and gas, etc). The requirements of radioactive waste disposal, however, differ in a way that the use of intrusive methods must be minimized in order to protect the host system from unnecessary disruptions, and repositories will be constructed in low permeability rock generally considered to be devoid of significant reserves of natural resources which limits the selection of monitoring techniques. Therefore, a combination of geophysical techniques and in-situ monitoring and evaluation in excavated areas or research and test facilities have been deemed preferable in this context.

There are numbers of parameters which might be followed; on the other hand, the detailed elaboration of measuring techniques, the existence of verified procedures and the application of well-established customised processes developed and applied outside the realm of disposal facility research render the selection of the relevant parameters and the execution of monitoring projects significantly easier.

### ***3.2.4. Performance of the barrier system within the host media***

Understanding the performance of barrier materials under real disposal conditions is a major challenge for scientists and designers involved in developing disposal concepts; most of such experiments have been carried out at laboratory scale and at underground research facilities. Nevertheless, laboratory findings still require verification in conditions as much as possible approximating to those expected in real disposal systems. Consequently, a number of so-called mock-up experiments have been performed in

different host rocks, an example of which is the EC LUCOEX project, a full-scale emplacement experiment that will allow for the assessment of engineered barrier system performance in clay, claystone and granite environments [31].

The development and testing of both effective monitoring methodology and the relevant instrumentation form inseparable parts of the design of such complex experiments which typically involve the detailed measurement of thermal, hydraulic, mechanical, geotechnical, and geochemical parameters. The final confirmation of the efficacy of the barrier system might be provided at a test facility should it form part of a national disposal concept. The experience gained will, naturally, be subsequently employed in the design of monitoring systems for the main disposal facility.

### ***3.2.5. Construction impacts***

During facility construction the host formation will be disturbed; the nature and level of impacts will depend on the type of rock and the excavation technologies used. Mining activity affects the hydrogeological, chemical and geotechnical characteristics of the system and leads to the formation of a so-called excavation damaged zone (EDZ). All these developments must be carefully monitored, compared to baseline characteristics and the results incorporated into the safety case.

The detailed mapping of the damage caused must be assessed and, where necessary, adequate remedial measures applied which require the thorough observation of the processes at work through the monitoring of the relevant parameters identified prior to the commencement of facility construction.

### ***3.2.6. Compliance monitoring***

Repository siting, construction, operation/closure and institutional control (if applicable) are all subject to regulatory assessment. Approval includes the conditions under which the licence is granted. In most cases, the licence specifies which parameters should be monitored (including the technical conditions of monitoring) and the facility operator is required to document in detail the ways in which licence requirements have been fulfilled.

The operator or operator's supervisor might also apply extra, self-imposed criteria in order to further ensure the quality of construction and subsequent operation compliance, which must also be well documented by means of an effective monitoring system.

In practical terms, compliance monitoring constitutes in principle the revision of the work performed using an approved pre-determined list of parameters and requirements.

The observation of the running of the repository during the operational phase principally involves compliance monitoring, the aim of which is to attain the required level of operational safety when emplacing the waste and installing the engineered barriers. Operational procedures are described in documentation approved by the regulator and include the relevant monitoring projects. This system also ensures adherence with prescribed quality assurance procedures while disposing of the waste. The results of monitoring will then be used as input for updating the safety case, particularly the final safety assessment of the facility. Thus, operational monitoring has a direct impact on the demonstration of post-closure safety.

Some programmes consider the co-siting of an encapsulation plant for spent fuel or high level waste with the repository in which case this nuclear facility will require its own monitoring programme which will have to be coordinated with that of the repository. Certain monitoring projects however, e.g. those concerning the environment and radiation protection, might be common to both facilities.

### ***3.2.7. Safeguards monitoring***

This specific type of monitoring, which consists of the verification of the authorised management of nuclear materials, is related to the implementation of the non-proliferation treaty and is prescribed by national authorities in parallel with and supervised by international institutions (IAEA, EC etc.).

Safeguards monitoring of a closed geological repository is based on tracking any unauthorised activities at the repository site.

### ***3.2.8. Environmental monitoring***

Repository development and operation will result in changes to the local environment to a greater or lesser extent, not only due to the management of highly radioactive materials, but also as a result of extensive mining and surface construction activities. Chemical pollution, dust, noise, exhaust gases and water management must all be subject to monitoring, as well as the impact on local flora and fauna and the health of local population. This monitoring may become a part of national epidemiological surveys, once they have been initiated.

Environmental monitoring should be initiated in the early stages of repository site selection (as a part of baseline monitoring) and continue during repository construction and operation and possibly beyond facility closure. This is a typical example of a monitoring project which might be governed by a broader national survey programme.

### ***3.2.9. Monitoring in relation with oversight by public stakeholders***

Public stakeholder interests are twofold: they require information on the progress of the disposal project and, at the same time, they want to be notified of the outputs of the facility monitoring programme. Public stakeholders seldom have the capacity to form an objective evaluation of the data gathered, therefore they rely upon the results of compliance monitoring which has been assessed by independent institutions, such as the regulatory authority. Alternatively, the public or the involved community may hire their own consultant(s) to gather and analyse data; the cost of such expertise might be covered by the disposal facility operator within public involvement projects (Belgium).

To overcome potential distrust of information and data interpretation supplied by the operator, clear rules governing the planning and performance of monitoring as well as the sharing of the results thereof should be agreed with stakeholder representatives in cooperation with regulators where appropriate. Public stakeholders may request that certain parameters which would appear not to have any sound technical justification (such as radioactivity levels in underground water following facility closure) be monitored or that the monitoring programme be extended beyond the planned institutional control period. Therefore, in order to avoid damaging disputes, to build social reassurance and trust, it might be advisable to

pragmatically seek a compromise on such issues. In any case, even if we do not have evidence that this approach adds to scientific understanding, they do add to robustness.

Even though socioeconomic issues might not at first sight seem relevant to repository monitoring, they are worth mentioning since they might significantly influence the implementation of a disposal programme. Socioeconomic monitoring projects might involve broader studies regarding employment, lifestyle, workforce migration, etc. which are often initiated at the national level and, as such, are formulated and evaluated by external bodies. Nevertheless, repository monitoring programme managers should be aware of their existence and briefed on the results.

The main findings on these components of monitoring which are part of societal monitoring as opposed to technical monitoring are detailed in chapter 6.

#### 4. OUTLINING A LOGICAL SCHEME FOR DEVELOPING A MONITORING PROGRAMME

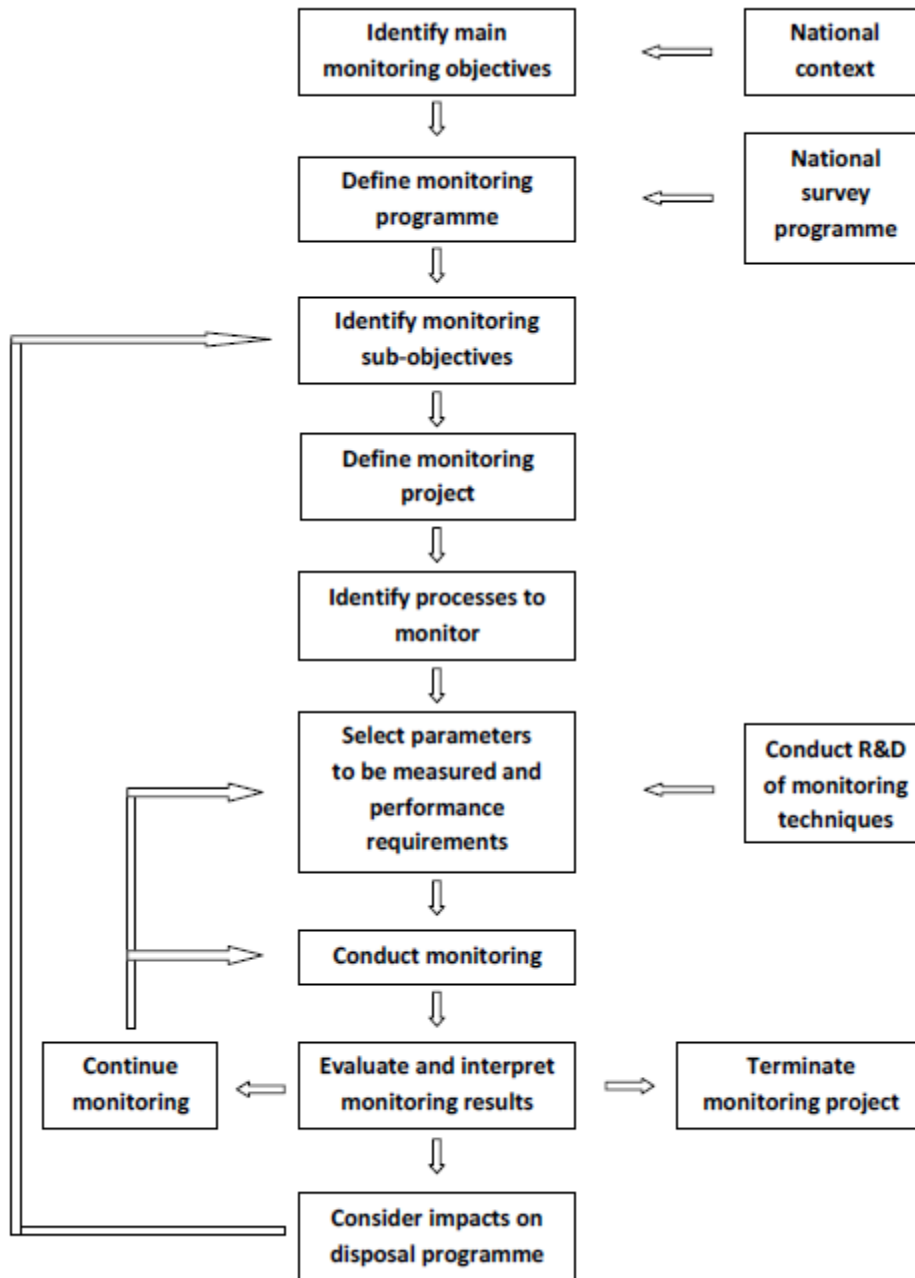
Attachment II developed for the MODERN project [18] sets out the major steps involved in establishing a monitoring programme and making effective use of the results.

With regard to the three monitoring levels (proposed in Section 3), the scheme works with two of them: it fits well with the national context (including national survey programmes) and the formulation of monitoring projects. Thus, it might be amended by introducing an interfacing ‘Monitoring programme’ level. A simplified scheme including all three monitoring levels is outlined in Fig. 1.

The key task of planning is to determine initial monitoring objectives and their addressing by the various monitoring projects. This selection should be flexible enough to accommodate probable later needs for revisions during the repository lifecycle. There are three main reasons for such revisions, varying in terms of significance and potential impact: (i) new technical activities initiated in the later stages of repository development, (ii) the introduction of new measurement methods (the monitoring programme will last roughly a century), and (iii) new or revised stakeholder (including regulator) requirements.

Such changes may result in the need for the revision or significant update of the integrated monitoring programme whereupon it is important to ensure the continuity of the measured parameters and the possibility of interpreting them under newly-established conditions.

Figure 1: A simplified scheme of developing a monitoring programme - adapted from MoDerN project [16]



## 5. MAIN MONITORING CHALLENGES

There are a number of well-elaborated approaches to the monitoring of deep geological industrial facilities including those regarding disposal. However, since monitoring may last for many decades, several issues need to be solved prior to the launching of such programmes with regard particularly to selection of monitoring system materials, the lifetime of the monitoring equipment, the optimal choice of parameters to be monitored and their required redundancy, the compatibility of data, methods used, analyses and interpretation of results etc. These challenges will be discussed in the following sections.

### 5.1. Data management

Monitoring has been performed in many national programmes, mainly in those that have connection with underground research facilities, but also in programmes that have existing geological repositories or at sites which have been selected for hosting repositories. During the monitoring process, hundreds of different parameters are often recorded for long period (i.e. many decades). In order to collect data, interpret it and provide it to third parties in a user-friendly form, a suitable data collection and management system must be in place from the very outset of the disposal programme; positive experience has been acquired through the use of the Geographic Information System (GIS). A robust data management system is therefore essential in ensuring the long-term safety of a radioactive waste repository throughout its lifetime. Data management involves multiple disciplines to combine data managing efforts to develop a valuable resource. Technical and scientific data are fundamental bases for long-term safety assessment of a repository. Societal and cultural information are crucial in maintaining confidence and transparency in the environmental safety of the repository system. To ensure future generations have the pertinent data to make their decisions, data management is indispensable in radioactive waste disposal programmes. The objective of data management is not only preserving data but ensuring their effective transformations which allow future generations to re-use them for their own purposes.

Moreover, the results of monitoring will be needed in the distant future. Since it is anticipated that monitoring methods and procedures will evolve over time, new techniques will be introduced and, in parallel, data formats will change. It is imperative therefore to ensure data compatibility throughout the repository lifecycle [32]. These aspects are subject of ongoing NEA/OECD project on Preservation of Records, Knowledge and Memory (RK&M) Across Generations [35] (see chapter 6).

### 5.2. Material and equipment durability

Certain monitoring projects must be designed to continue for several years (e.g. in relation to experiments carried out at URLs), others to run for many decades (e.g. environmental or hydrogeological monitoring). With an increase in surveillance duration, both material durability and the lifetime of the measuring equipment, need to be thoroughly assessed; the most exposed detectors and sensors may have to work under high pressure, elevated temperatures and, sometimes, in radiation fields. Once a measuring system has been installed in a full-scale facility, it will have to work for the required period of time without the possibility to replace any of its component parts. Experience from mock-up experiments indicates that sensor durability could well become a crucial issue for monitoring projects. Thus, future efforts to further



develop and test the long-term performance and service lifetime of the measuring systems and techniques are required.

Data transfer lines may also suffer from severe conditions within the repository system, e.g. the use of optical cables may be preferable to classic metal wiring (can be smaller, insensitive to electromagnetic perturbations, may avoid polymer uses). The development, testing and use of wireless systems might also be of benefit in this context, however it will be necessary to devote resources to the extensive research of such technologies.

Monitoring strategies could rely on a combination of in-situ and non-intrusive techniques. The latter can continue over a longer time period although they are less accurate and/or only partially applicable to certain parameters.

Ideally, when designing a monitoring project, its duration should be determined. The techniques and materials selected for such projects must have the durability and longevity adequate to the task.

### **5.3. Parameter selection**

The current, and justifiable, tendency is to measure as many parameters as possible so as to contribute in the most comprehensive way towards both the compilation of a complex description of the disposal system and the understanding of its performance under real conditions. With the transition from the repository development stage to implementation, it becomes necessary to optimise the selection of the parameters to be monitored which is motivated by practical reasons since it would be difficult to install and operate such a large number of monitoring systems over long time periods in the final disposal system. Thus, the identification of those parameters which would sufficiently demonstrate the attainment or approach to the passive safety status of the disposal system would be of substantial benefit. This issue has also been addressed in Section 3.2.2.

This optimisation approach is analogous to the establishment of a waste acceptance system. After an initial period involving a detailed and exhaustive description of the physical, chemical and biological properties and potential degradation mechanisms of the waste forms and an assessment of their suitability for disposal (waste form qualification), only a small number of parameters need to be selected in order to verify the quality of the waste subsequently delivered to the repository (waste acceptance). The still unanswered challenge is identification of an optimal set of parameters which would sufficiently illustrate the disposal system and its performance.

### **5.4. Identification of processes to be monitored**

Monitoring parameters and techniques have to date been selected based mainly on non-disposal practical experience and experiments conducted at URLs. The selection of easily recognisable monitoring processes has allowed for the collection of sufficient information over relatively short time intervals of a maximum of a few years. A number of URL experiments were intentionally designed for and performed within disturbed zones so as to accelerate the deterioration of the structures tested; others included the artificial acceleration of natural processes (heating or wetting the tested system).

However, a number of processes will affect the disposal system slowly over long periods of time and are unlikely to be amenable to measurement using the usual techniques. The effects of such processes might be insignificant during repository development/operation but, should they occur over a time-scale of thousands of years, they may well significantly influence the performance of the repository barrier system. Thus, the recognition and quantification of such processes would be of great use in ensuring the long-term safety of the disposal system.

POSIVA identifies 21 of these 'slow' processes, most of which are geochemical [20]. Several alternative monitoring approaches have been proposed for the assessment of such processes; nevertheless, these processes require more attention from the international disposal community in order to determine an understanding of their nature and, if necessary, to eliminate their occurrence and potentially negative impact on disposal systems.

### **5.5. Coupling processes**

In the initial phase of geological disposal research studies, R&D projects were designed to assist in understanding the effects of major processes envisaged within the repository system. However, such processes do not occur separately but rather act in concert with a number of other processes which could bring about a significantly different impact on the system performance. These coupling effects may affect the disposal system adversely or favourably. In response, scientists have conducted mock-up and full-scale emplacement tests aimed at assessing the combined impact of disposal conditions on disposal system performance (see e.g. LUCOEX project [31]).

The role of monitoring in this case is to be able to credibly describe and distinguish between the influences affecting each particular process. It will be a difficult task to identify the coupled effects of parallel processes which, while coinciding, may influence a single monitored parameter. Therefore, the identification of the coupling or multiplying effects of various processes, namely those identified as 'slow' in the previous section, should be an issue of significant scientific interest.

### **5.6. Monitoring following repository closure**

There is clear consensus in the disposal community that once a facility is closed (including the access tunnels and shafts), it attains the status of passive safety and, as a consequence, no longer needs to be monitored. Nevertheless, as indicated in Section 3.1.6, a decision on post-closure monitoring may depend more on socio-political than technical considerations or regulatory requirements. The technical drivers for post-closure monitoring may include willingness to keep reviewing selected baseline data, monitoring supporting closed facility oversight period and keeping the memory of the facility. Several approaches have been considered by different disposal programmes, however – accepting that this issue will become topical after a period of many decades – without any clear output being defined.

Most programmes are following a pragmatic approach so as to avoid the prognosis today of stakeholder anticipations next century built on present-day analysis and recommendations, and, in parallel, so as to develop technology that might address societal needs if ultimately required (wireless transmission, long-lasting power sources, etc.). However, it is evident that the monitoring of certain parameters should be planned and incorporated in the siting/construction or, at least, operational phase (baseline and

radiological data respectively) to ensure continuity in determining the relevant information from the beginning of the project up to post-closure.

The closure of disposal facilities should include the sealing of the boreholes drilled in the vicinity, including those used for monitoring. This will not take place however if clear reasons are identified for post-closure monitoring (such as a societal demand, a regulatory decision or a request for the demonstration of steady state conditions within the hydrogeological structure hosting the facility). Ideally, whatever the purpose, the relevant monitoring project and the selection of adequate parameters should be designed in the baseline monitoring stage in order to ensure the required continuity in terms of gathering the input data. In this sense, therefore, postponing a decision on post-closure monitoring might prove counter-productive.

Indeed, post-closure monitoring should commence after answering two simple questions: why and how long? The disposal community should continue to search for consensus in terms of answering these questions. Chapter 6 is an overview of the attempts to answer these questions.

## **6. LOCAL COMMUNITIES' EXPECTATIONS AND DEMANDS ON MONITORING AND THE PRESERVATION OF RECORDS, KNOWLEDGE AND MEMORY OF A DEEP GEOLOGICAL REPOSITORY**

Local communities are recognised as key stakeholders in radioactive waste management. The working definition of “stakeholder” adopted by the FSC is “any actor – institution, group or individual – with an interest or a role to play in the radioactive waste management process” [44]. The present chapter based on a report prepared by the FSC, will focus on local communities as representatives of a societal group whose members reside in a specific locality and share a government and often have a common cultural and historical heritage (*ibid*). Related terms also used are civil society, local stakeholders or actors.

As the concept of oversight is elaborated (*cf.* ICRP, 2013) [5], it is useful to examine current stakeholder views on monitoring and RK&M preservation as part of the oversight function.

### **6.1. Methodology**

A questionnaire survey of FSC members was undertaken in July and August 2012. Replies were received from 11 countries. The ad hoc survey was considered to be illustrative and did not aim to be representative. It was followed up by structured interviews with a range of involved stakeholders from both national and local levels, for a total of 25 individuals from seven countries. In addition, a literature review was carried out, focussing on FSC publications and other documents and publications found through internet or suggested by interviewees. A brief update survey, formulated according to the structure of the original survey, was performed in August and September 2013. A subset of FSC countries contributed.

While official responsibility for the preservation of records, knowledge and memory must remain with institutions, local communities likely do have an important pragmatic role in maintaining the memory of a repository. The most advanced programmes for implementing geological disposal facilities for radioactive waste, like those in France, Sweden and USA, have produced some discussions, formal or informally, around the contribution of local stakeholders to monitoring and memory preservation. The FSC [19] listed tools by which local stakeholders may contribute to maintaining memory, such as land registers, markers, oral history, added value features or development of the culture of memory in institutions and territories. In the present study and report, the focus is on the position of local communities regarding the preservation of knowledge and memory of a radioactive waste management (RWM) facility particularly through the tool of monitoring, and how this may affect confidence in RWM. The rationale behind the present study as an FSC contribution to the OECD NEA RK&M initiative is that alongside its other functions, monitoring – by collecting, interpreting and keeping data on a continuous basis – serves the purpose of preserving records, knowledge and memory.

Local communities are interested in discussing information preservation, monitoring, knowledge management and memory as “control” measures that increase safety [45]. The FSC has documented in various topical sessions and study reports the ways in which local communities can contribute to the preservation of records, knowledge and memory. More extensively, the issues of environmental monitoring and memory were considered in the national workshop held in Bar-le-Duc (France) in 2009 [19]. Round-

table discussions served to explore the ways in which local communities can contribute to monitoring and to maintaining the memory of the repository.

In July and August 2012, a brief online survey was conducted with members of the NEA Forum on Stakeholder Confidence on monitoring and preservation of records, knowledge and memory. The aim was to identify local communities' position on the preservation of knowledge and memory of radioactive waste management facilities, notably to learn if this is a high-profile subject among involved local stakeholders. The ad hoc survey was considered to be illustrative and did not aim to be representative. Replies were received from 11 countries, submitted by individuals from 17 organisations, including regulators, implementers and governmental institutions, whose role brings them into close contact with local stakeholders. The countries, organisations and number of responses (in brackets) received to the survey were: FANC from Belgium (1), RAWRA from Czech Republic (1), POSIVA from Finland (1), ANDRA from France (1), PURAM from Hungary (1), SOGIN from Italy (1), ENRESA from Spain (1), SKB, SSM and the Swedish National Council for Nuclear Waste in Sweden (3), SFOE from Switzerland (1), NDA and Environmental Agency for the United Kingdom (2) and DoE, NRC, EPA in the United States (4).

The 2012 online survey determined whether the respondent's national programme involved specific local communities, or if only general information pertinent to local or civil society stakeholders could be shared. Then it asked whether local communities request monitoring of (future) RWM facilities, and if so in which domains and on which time scales (or in regard to which repository life cycle phases). The survey also asked whether communities showed interest in extended memory of a facility, and whether the national-level actors acknowledged a role for local communities in monitoring and RK&M preservation. In addition, twenty-four interviews were conducted with representatives of implementers, regulators, governmental agencies and local stakeholders from seven countries. Their input complemented the survey data on local communities' demands and confidence in monitoring and the preservation of RK&M.

## **6.2. Review of FSC findings on monitoring and RK&M preservation**

The FSC organises an international exchange of experience through annual meetings including topical sessions, national workshops and community visits, and desk studies. All of these are documented and the resulting literature is available online at the FSC website, [www.oecd-nea.org/fsc/](http://www.oecd-nea.org/fsc/). The present section summarises the experience of the FSC with regard to monitoring and memory preservation. Continued monitoring, information preservation, knowledge management and memory are all issues that figure partially in the main body of work produced by the FSC. Three reports [19, 47, 48], stand out in their exploration of the role and expectations of local communities in monitoring and the preservation of RK&M.

Other FSC documents also record an interest of local communities and stakeholders in monitoring, transferring knowledge to future generations and keeping the memory of the site. National examples too are drawn in this section from topical sessions and workshops where monitoring and memory preservation have been addressed. Beyond the FSC literature, a desk study was undertaken to analyse whether and how local stakeholders are involved in debating monitoring and record keeping in the context of radioactive waste management facilities and more specifically, geological disposal.

In the FSC reports cited above and other relevant FSC documents, the main findings may be summarised as follows.

### ***a) Local communities' monitoring concerns and expectations***

The FSC recognises the importance of monitoring potential impacts involved in the different phases of the implementation of radioactive waste management facilities - the feasibility study phase or recording the baseline situation prior to construction, construction, operation phase or post-operational phase. Changes in quality of life – meaning physical, psychological and social well-being - over the phases of a facility project should be monitored [81].

In Hungary the concept of “social control” is understood as the active participation by members of civil society in the technical monitoring of activities [46]. Each municipality carries out monitoring and control of nuclear facilities. In both of the low and intermediate level waste repositories (at Püspökszilág and in Bataapáti) and in the Interim Spent Fuel Storage facility in Paks trained municipal groups perform regular control of incoming materials and carries out other measurements. In addition, also local group will be trained to perform this monitoring in the future high level waste repository near Boda.

The workshop in Bar-le-Duc [19] revealed that monitoring is a key issue, mainly regarding environmental concerns, to ensure safety and guarantee transparency. In some countries, like in France, health concerns are crucial. The Local Information and Oversight Committee (CLIS) attached to the Bure underground laboratory expressed a strong interest in monitoring the epidemiological status of the local population (in the perspective of a possible future deep repository at the site). However, specialists indicated that establishing a methodology and meaningful baseline measures was not feasible, given the low population density of the local area. Apart from health impacts, monitoring socio-economic variables, like property values or economic development, was also considered important by local stakeholders. For local communities in France, it is not sufficient that the implementer and the regulator undertake monitoring tasks. Like the CLIS, the Local Information Committee (CLI; one is attached to each nuclear installation) is an extremely relevant actor with the ability to identify pertinent questions and engage independent expertise. Thus, becoming involved in monitoring has benefits, like learning and fostering confidence. In addition, it enables the committees to feed the information to everyone in the community and to contribute to monitoring, if they want to. Nevertheless, the need to institutionalise monitoring is crucial, i.e. provide resources, establish a legal framework, etc.

There are two aspects where local communities in different countries have different viewpoints: the level of involvement of local stakeholders in monitoring and who interprets monitoring results. On the former, some communities want to be actively involved in monitoring whilst others just want to know the results but not monitor by themselves. In the case of Canada, Sweden, UK and the USA, FSC workshop delegates in Bar-le-Duc were of the opinion that communities did not want to monitor by themselves but want to know whether results fit with early safety and environmental assumptions. This raises a point which will be addressed also later in Section 6.5 and refers to taking responsibility for participating in monitoring activities. On the latter (i.e. who interprets monitoring results), Swedish communities think that environmental courts and EIA procedures are sufficient to interpret monitoring results, whereas in France, independent auditors or specific monitors, chosen by local communities, are seen to be most adequate. French local communities point not only at the role of regulators or independent bodies in performing monitoring on baseline conditions but also the CLIs for confidence building. The role of the regulatory body seemed clear and authoritative in all these cases.



### ***b) Local communities and memorialisation***

Memorialisation is understood as a cultural feature, meaning that both physical and cultural measures are taken to mark the site and tell its story, so that people will grasp and remember what is there [47]. The artist Cécile Massart underlines the importance of archiving information for the future and marking repository sites or facilities through symbolic, artistic means (ibid). It is important to preserve the memory of disposal, not just for safety reasons, but also because radioactive waste has unique societal significance [48]. In this way, a relationship can be established between the community and the facility. Massart suggests multiplying the means through which a visitor may approach and form a relationship with the repository site. Considering the experience with memorialisation in the World Heritage programme may be helpful for conceiving and designing waste management facilities whose memory needs to be preserved. It might be possible to associate the inclusion criteria of monuments identified for protection by the UNESCO World Heritage Commission (e.g. testimony to a time and place associated with significant ideas, beliefs, events, etc.) with values that a local community and society attach to the repository project (such as artistic, historic, social and scientific dimensions) [47].

Within the FSC, there is an interest to understand how to develop a stewardship process, how to conceptualise a 'rolling present' in which each generation takes responsibility to ensure continuity and safety for the succeeding several generations, including a need for flexibility and adaptability to circumstances as they change. For this, the role of local communities is crucial for maintaining the memory of the site, once the period of institutional monitoring is over [19]. Local communities can even build their own new markers to replace old ones that have become obsolete or are fading away [49]. One of the solutions for memory preservation, as identified by the STORA partnership in Belgium, is to build a radioactivity theme park or a nuclear clearing house to promote knowledge and awareness of nuclear energy and waste.

As put forward in an NEA report from 2008 [50] recent generations can carry out duties that reasonably can be performed, while transferring others to subsequent generations, along with resources needed to fulfil them. This means that the stepwise decision-making appears to be the only feasible way to proceed (ibid). The features of the stepwise approach to decision-making allow stakeholders to gain familiarity with technical options and institutions and therefore, to build confidence in the safety and trust in the institutions managing waste.

Andra recognised that maintaining exchanges with the local public, and in particular with the CLI, is crucial for an active memorialisation of a site, since markers may not be readable in the future [19]. The term 'living history' was also suggested to maintain the memory of a repository composed by records based on local experience, communal archives, like photos and written material (ibid). Future generations can become guardians of these facilities through political and economic partnerships as well as by integrating the facilities socially and scientifically in their environment [51].

Apart from being able to transfer knowledge to future generations, it is also important that it is understandable [49]. At WIPP, for instance, scientists claimed that a message will not be understood the same way as society evolves and therefore, maintaining meaning is one challenge in maintaining information [45]. It is important that there is a strategy to maintain awareness of the repository and one simple way to do that maybe through using maps [49]. Also pictorial record is needed in case words are

lost [52]. Nevertheless, it should be borne in mind that symbols and icons may not be readable after some generations and we do not necessarily understand what is being communicated (ibid). Thus, the “notion of stability in time has also a symbolic component” since “to build ‘forever’ is often interpreted to mean building as soundly as possible and then adapting ‘as the need arises’” [50].

The issue of archives and markers for geological disposal is important. The recording technology when dealing with large timescales should be as basic as possible [53]. Physical markers and archives may be complemented by - or integrated within - a cultural tradition that could be sustained over time starting with the planning of a repository and continuing through its implementation and beyond its closure. Because a radioactive waste management repository and site will be a permanent presence in a host community for a very long time, a fruitful, positive relationship must be established with those residing there, now and in the future. The challenge is to design and implement a facility (with its surroundings) that is not only accepted, but in fact becomes a part of the fabric of local life [49]. Hence, marking the facility can also be a means to add not only cultural but also amenity value to preserve the site over many generations into the future [47]. However, markers may not only attract people to the facility for memory purposes but intrusion (unintentional and deliberate) should also be contemplated [52].

In some countries, monitoring and memory preservation are jointly considered with the topic of reversibility and retrievability. In France, for instance, monitoring and human presence over several hundred years is mandated by law and will be further specified in the Reversibility Act by 2015. Monitoring is considered important to enable reversibility, as pointed out by Mr. Krieguer from Andra in the Bar-le-Duc workshop, as it provides essential information on the engineered facility and its performance [19]. Monitoring also allows the implementer to periodically re-examine reversibility, apart from contributing to safety and security [54].

### **6.3. Concerns and expectations on monitoring expressed by local communities**

The survey results and the interviews undertaken for this study found that local communities have concerns and expectations on monitoring over the different phases of a facility project, prior to construction, operation and post-operational periods, even if these concerns are often vague and ill-defined.

#### ***a) Demands for monitoring of DGR***

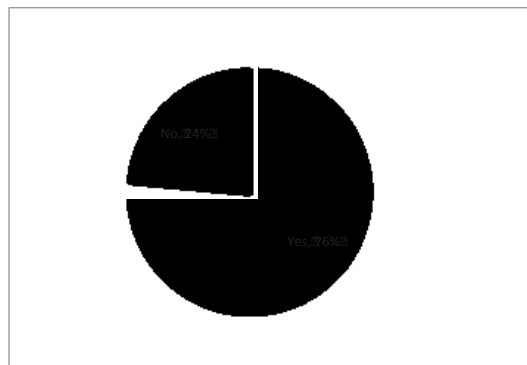
Slightly more than two thirds of the survey responses indicate that local communities ask for monitoring of RWM facilities (Fig. 1). In countries like Hungary or Finland, the respondent assessed that local communities did not demand monitoring of RWM facilities. In other countries, it was noted that demands were not clear at the current stage of the RWM programme.

#### ***b) Areas of concern on monitoring expressed by local communities***

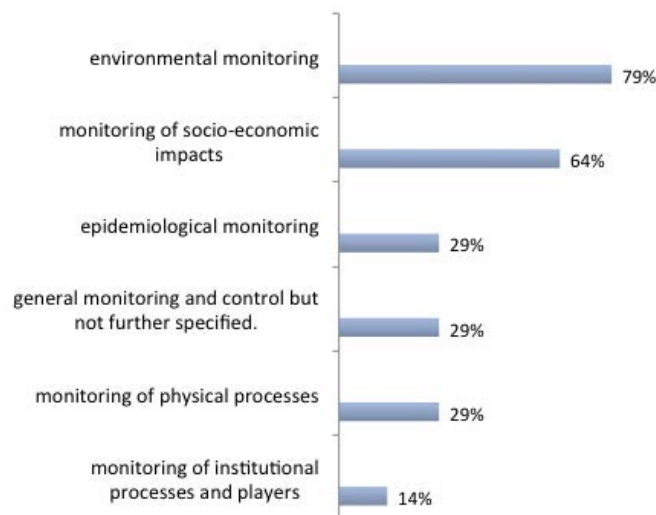
In most countries, monitoring demands refer to environmental monitoring in the first place and then to monitoring of socio-economic impacts. Epidemiological monitoring is considered by less than one third of respondents whilst monitoring of institutional processes and players is seldom requested (Figure 2).



**Figure 1. Local communities' demand for monitoring of RWM (according to FSC members in 2012 survey; 17 respondents)**



**Figure 2. Areas in which local communities demand monitoring of RWM facilities (according to FSC members in 2012 survey; 17 respondents)**



In some cases, local communities are not asking today for a specific topical area to be monitored, but according to an interviewee, all areas are likely to feature on the agenda if and when a decision is taken to commit to next stages of the RWM programme.

***c) Main concerns during the lifecycle of a DGR facility***

The following sub-sections identify the main concerns and expectations in the pre-operational, operational and post-operational periods. When considering long-term, different time scales can be used, from several decades (to transfer information to succeeding generations for managing decisions), one to two centuries (referred to actual operations and continuous data checking and re-certification of data and licenses) or a few centuries for memory keeping and reviews of license. Pescatore [45] states that “in order to achieve the long-term objective we must focus on the timescale for transferring the information and knowledge to the next generation in a way that it does not foreclose their options for managing it in turn,

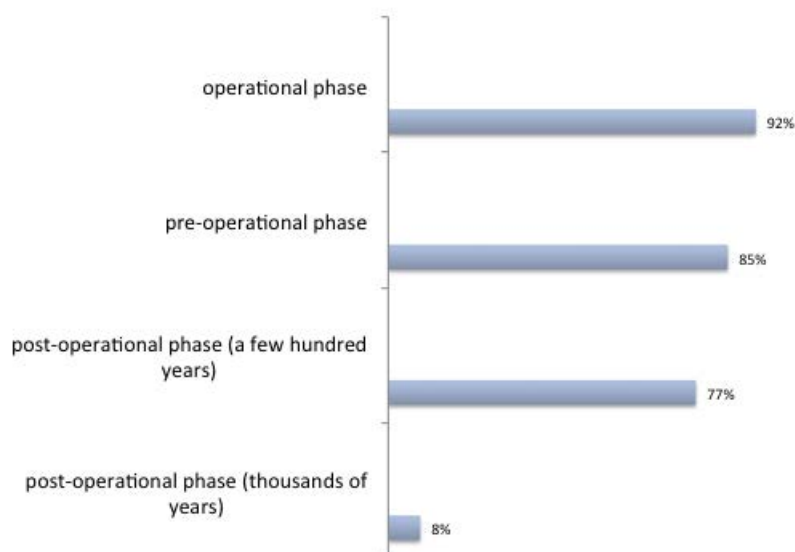
which we characterise as a timescale of the order of 30 years”. A plan for thousands of years is not credible, and therefore, it is important to think short to medium term (from generation to generation) in order to prepare the long-term.

The distinction between different timescales is not clear-cut when trying to assess stakeholders’ concerns and expectations on monitoring. Rather, we argue that monitoring is recognised as a long timescale activity that needs to be undertaken early on and will continue far in the future. Nevertheless, in order to better structure the information on monitoring concerns and challenges, we separate between “pre-operational and operational phases” and “post-operational phase”.

#### *d) Concerns and expectations in the pre-operational and operational phases*

In this section, the concerns and expectations of local communities regarding monitoring in the pre-operational and operational phases are described. The results presented in this section rely on the written survey, desk studies and interviews. When we asked in the survey on which time scales monitoring is demanded, the respondents assessed that most demands focus on the pre-operational and operational phases (Figure 3).

**Figure 3. Time scales for local demands on monitoring of RWM facilities (according to FSC members in 2012 survey; 17 respondents)**



#### *e) Status of the issue and target of monitoring among local communities in the different countries*

In Sweden, little attention has been paid to monitoring until recently. It is a fairly new topic that is emerging. According to interviews with Swedish representatives, there is not yet any relevant documentation on this specific topic from the point of view of the local level. However the issue of monitoring is among the issues that have been raised as part of the review of SKB’s application for a geological repository. Several representatives of local communities from Sweden have been involved both in the MoDeRn project and in the RK&M project, namely to learn how oversight and monitoring can be prepared.

In Canada, participants in the dialogue workshops held to develop a management approach for the long-term care of used nuclear fuel, requested to NWMO the need “to elaborate on the nature and extent of monitoring envisioned in the implementation of the Adaptive Phased Management approach” [55]. Participants considered that monitoring is important for the following reasons:

- To ensure long-term protection of human and ecological health;
- To provide the public with assurances that the facility continues to be safe;
- To allow future generations to measure and assess their stewardship over the used nuclear fuel;
- To allow for continuous learning and provide well-informed decision-making; and
- As a precondition for future retrieval of the material, regardless of the intended purpose [55].

In France, monitoring is one of the key themes identified by ANCCLI (the national federation of Local Information Committees and Commissions), CLIS de Bure and IRSN (France’s technical support organisation) in the framework of their "technical dialogue on intermediate and high level long-lived radioactive waste". This initiative launched in 2012 by the three actors sought to identify the main challenges associated with the decision-making process regarding these categories of waste, as well as to anticipate key issues that could arise during the 2013 public debate on the “Cigéo” project (the proposed industrial implementation of a deep repository in Meuse/Haute Marne) or regarding subsequent development of the French geological disposal programme. Apart from the themes on “radioactive waste inventory”, “storage versus disposal and reversibility”, questions on the theme of “safety, radiological protection and environmental and health monitoring” have been raised to be further investigated.

#### ***f) Environmental monitoring***

The interpretation and the target of monitoring vary among countries and among the groups of stakeholders considered. The topics for which monitoring is demanded are mainly environmental monitoring and to a much lesser extent, epidemiological monitoring and socio-economic monitoring. The latter will be discussed further below.

All respondents to the FSC survey indicate that environmental monitoring appears to be one of the main concerns in the pre-operational and operational phases from the point of view of local stakeholders in all countries.

With a view to preparing for the environmental monitoring to be performed during the operational phase of Cigéo, the geological repository industrial implementation, over a period of approximately 100 years, France’s operator Andra established the Permanent Environmental Observatory (OPE) in 2007. OPE is situated in the area of Meuse and Haute-Marne departments, where the site for the construction of the deep geological repository is planned and the Underground Research Laboratory is situated.

In the US, CEMRC at New Mexico State University is conducting an environmental monitoring program and an in vivo radiobioassay research project in the vicinity of WIPP. This project began implementation during the WIPP pre-operational phase and is continuing during the operational phase.

During the 1990s, surveys undertaken in the vicinity of WIPP showed that the public were concerned about health and environmental impacts of WIPP. Thus, CEMRC, as an oversight independent body, informs the public and the environmental science community.

Hungary is probably one of the European countries where public oversight and information associations around radioactive waste management (interim storage of spent fuel) and disposal sites (LILW disposals) are most active with regards to oversight and monitoring. Members of civil society are trained for one year to actively undertake technical monitoring activities [52].

### ***g) Socio-economic monitoring***

Other concerns raised by local stakeholders regarding monitoring include changes in quality of life and socio-economic variables. In the US, socio-economic impacts of WIPP were evaluated during the Environmental Impact Assessment [56], but are not being monitored during operation.

In the case of Yucca Mountain, Nye County proposed a comprehensive programme of environmental monitoring, including monitoring of socioeconomic factors [57]. Clark County set up a Monitoring Program to collect information on economic, fiscal, environmental, and public health and safety information as a baseline for Yucca Mountain Project policy discussions.

In the UK, the West Cumbria partnership recommends scoping and monitoring economic impacts from an early stage and on an on-going basis. The partnership points out that impacts might include changes in investment in the area, traffic impacts, possible effects on visual or physical environment and on tourism and changes in employment [58]. Monitoring institutional players was mentioned also in the case of the UK. According to an interviewee, the partnership in West Cumbria was also interested in institutional monitoring. Thus, the members were interested in working with the radioactive waste management agency to see for instance, how they behave, how the interaction is, if there is a sense of trust and confidence or if they are transparent.

In Switzerland, the Sectoral Plan for Deep Geological Repositories [59] under the lead of the Swiss Federal Office of Energy establishes the need to monitor socio-economic impacts in the siting regions in the pre-operational phase. Thus, in Stage 1 (i.e. selection of geological siting areas), socio-economic studies are prepared, together with the siting regions, to evaluate social, demographic, environmental and economic impacts of a geological repository. Later on, in Stage 3 (i.e. site selection and general license procedure), in-depth monitoring of socio-economic and environmental impacts is carried out.

### ***h) Concerns in the post-operational phase***

In this section, the main observations from the FSC survey, interviews and desk study raised by local communities regarding concerns relative to monitoring and oversight in the post-operational phase are identified. Generally, we can argue that requests for monitoring during the post-operational phase are not so clearly articulated by local communities, compared to monitoring during the pre-operational and operational phases. However, a general view that we should not “walk away” from these facilities, even when we think they will be safe [49], appears to be confirmed through interviews.

In France, the “permanent group on radioactive materials and waste” of the national association of local information committees and commissions (ANCCLI) puts forward specific questions regarding monitoring during the operational and post-operational phases within the framework of the dialogue on medium and long-term radioactive waste [60]. The questions address environmental and health monitoring, as follows:

- Which are the monitoring needs in the pre-operational, operational and post-operational phases of the geological repository facility? Which will be the measures undertaken and where?
- How would stakeholders be involved in the different types of monitoring?
- How will memory be preserved? Will memory be available in 50, 100 or even 1000 years?
- Which are the objectives of post-closure monitoring? Will safety monitoring be maintained after closure?
- What does “passive oversight” mean?

Hence, French local stakeholders clearly demand more information on monitoring in the different phases of the geological disposal facility as well as more information on memory preservation. At present, these are issues being discussed in seminars organised by the national association with the support of the TSO IRSN, to assist the local level and build local stakeholders’ capacities for the current and future debates on the Cigéo project.

In the case of Sweden, according to the safety case, SKB maintains that post-closure monitoring is not necessary and that any decisions on post-closure monitoring need to be taken by the generation that is the decision-maker at the time of closure. The requirements and possibilities for post-closure monitoring will depend on social conditions and development of technology. SKB plans for and expects demands for environmental monitoring from the community at least during operation period until sometime after closure. These demands will be further defined as part of the on-going licensing procedures. They may respond to concerns regarding the definition of critical issues to be monitored on the different time scales and responsibilities after closure.

For the West Cumbria Partnership in the UK, waste must be monitored while it is in the facility and there will also be a period of institutional control and monitoring during the post-closure phase [61]. However, according to several interviewees from the UK, it seemed far too early in the UK, during the lifetime of the partnerships, to discuss these issues.

The case of the WIPP is different since “monitoring will continue for as long as practicable during the period of active institutional control (100 years) and/or until the DoE can demonstrate to EPA that there are no significant concerns to be addressed by further monitoring. The post-closure monitoring program will have to be responsive to societal concerns at the time of closure” [62]. In fact, one interviewee from Carlsbad mentioned that the community may want to extend that period of time and that the definition of parameters to be monitored should be based on science.

Indigenous people in Canada have been very explicit about the need to monitor both the environment and the nuclear waste management system. For instance, they recommended setting up a specific oversight agency to be active as long as possible. It is also interesting to note that in the dialogue workshops held in Canada to develop a management approach for the long-term care of used nuclear fuel, a small group of participants “objected to long-term monitoring, particularly if it were to be intrusive in nature” since intrusive monitoring, they argued, “may detract from the integrity of the storage system and is, in fact, unnecessary given that breaches of containment are very unlikely” [55].

In Finland, according to Posiva, there are no local community demands on monitoring in the post-operational phase. Posiva is running a monitoring programme as part of the repository project at Olkiluoto, the site selected for the repository. The Olkiluoto monitoring programme has been conducted since 2004, when the construction started on Onkalo, the underground rock characterisation facility [63]. During the Environmental Impact Assessment procedure, before the Decision in Principle, the municipality of Eurajoki had an active role in expressing their concerns and demands. Nevertheless, the role of the municipality with regards to monitoring is rather passive and a high degree of trust in the managing institutions is in place, according to Posiva representatives.

#### **6.4. RK&M preservation**

Apart from the case of France, there is hardly evidence of a strong formal demand on the preservation of records, knowledge and memory by the local level. The largest part of interviewees suggests that not much formal discussion has taken place on this issue, but there seems to be an implicit interest by local communities, as implementation of a geological repository approaches. At that stage, it is expected that higher demands will arise to plan record keeping and memory preservation. Informally, these discussions have been taking place and RK&M preservation seems to be an emerging area of work in the field of geological disposal for the years to come. In this context, participants at the FSC workshop in Bar-le-Duc (France) developed the concept of “living history”, reflecting on the need to maintain the memory of a repository through records based on local experience, communal archives (photos, written material, etc) [19].

Stakeholders in France have expressed the wish to have a continued memory keeping beyond centuries. Discussions have been held on the contribution of local people to preserve memory and will be more important in the future. The memory issue is an integral topic addressed at CLIS meetings [64] and the role of local communities is regarded as crucial for maintaining the memory of the site, once the period of institutional monitoring is over [19]. Andra also deemed necessary in 2010 to launch a project on memory preservation based on the following topics [64]:

- Work to reinforce the reference solution;
- Preliminary work to prepare the memory preservation of a future deep geological repository;
- Theoretical studies;
- Three reflection groups with local population around Andra sites (Centre de la Manche, Centre de l’Aube and Cigéo facility);

- Opportunity studies to create dedicated buildings for memory preservation.

It is interesting to note that the three reflection groups are aimed to attract the interest of local populations in the issue of memory preservation, but also to collect their views on the best approach for them to actually preserve memory (ibid).

According to current regulations, Andra must maintain and pass on the memory of the repository to future generations for at least five centuries after its final closure. The approach followed in surface disposal facilities, like Centre de la Manche, can be applied to Cigéo during this timescale [65]. Charton and Ouzounian [66] argue that “easements and exchanges with the representatives of the populations concerned” are complementary to archives for memory preservations. Charton recognised that maintaining exchanges with the local public, and in particular with the CLIS, is crucial for an active memorialisation of the site, since markers may not be readable in the future [19].

At Andra facilities, different mechanisms are in place for communicating with the local population – local information committees, hearings, newsletters, etc - and hence, maintaining collective memory (ibid). In the post-closure safety case for a geological repository, Andra’s reference solution includes the development of active memory among local stakeholders based on a general knowledge of the repository. A synthesis memory is planned to be widely distributed to support this knowledge. In addition, Andra plans to open an “Ecotheque” in Bure in 2013 where all samples taken as part of the OPE will be stored at least 100 years. The Ecotheque is part of the project to preserve the memory of the environment (Andra, 2013).

In the US, apart from the monitoring requirements included in the regulations, the need to maintain active institutional controls for as long as practicable possible, are also established by the US EPA. Passive institutional controls (PICs) are also required by EPA regulation to indicate the danger of the wastes and their location [62]. At the local level, one interviewee stated that the community of Carlsbad has not intensively focused on long- term issues, but is part of the agreement with EPA and also a legal requirement. Although he claimed that the RK&M discussion has been ‘on and off’ at local level, the community will be addressing these issues in a more focused way in the next years. Also representatives of DoE acknowledge that as closure of the facility approaches, the opportunity will arise for the community to participate in planning for the permanent markers to be installed, determining monitoring to continue into the post-closure and deciding record storage requirements. This is expected to take place during public participation in regulatory changes that will be initiated by the facility with the regulator for the WIPP PICs program.

In Sweden, SKB has considered the issue of preservation of information for future generations [67, 68, 69]. In the license application for the deep geological disposal facility, SKB explains that it will prepare an action plan for long-term preservation of information in international cooperation [70]. The International Review Team of SKB’s post-closure radiological safety case notes that SKB needs to address the transfer of knowledge and skills by the repository operator, supervisory authority and the community in charge of the repository site. The International Review Team suggests mechanisms that SKB could consider to preserve knowledge and memory of the site (ibid). Similarly, the Swedish Radiation Safety Authority’s General Advice on the Application of Regulations (SSMFS, 2008:37) concerning the protection of human health and the environment in connection with the final management of spent nuclear



fuel and nuclear waste partly considers these issues and states that ‘a strategy for preservation of information should be produced so that measures can be undertaken before closure of the repository’. In addition, local representatives in Sweden also consider that RK&M preservation should be a concern at all levels: local, regional, national and even international. According to Erik Setzman from SKB, Östhammar demands more specific plans or strategies not only for monitoring but also for RK&M within the licensing procedures for the planned spent fuel final repository in Forsmark. According to him, the interest in monitoring, RKM in general as well as the potential combination between the subjects is gradually rising (personal communication, 2013).

In its review of SKB application for constructing and managing a geological repository, the Swedish National Council for Nuclear Waste, National Archives and Östhammar municipality have made comments on memory keeping. In the UK, according to an interviewee, the fact that Sellafield maintained poor records in the past involved more complexity in decommissioning legacy nuclear sites. This lack of consideration of record keeping in the early days of nuclear development has probably increased awareness that records and knowledge preservation is a key area to tackle in the future. There are 19 nuclear sites in the UK all owned and operated by different companies with different types of information collected in different ways, with differing quality and format [82]. The UK Nuclear Archive project aims to deliver a memory facility which addresses this problem. As such, it is understandable that West Cumbria partnership was concerned about preserving information and knowledge for future generations and demanded further information to the NDA. They also point out in the Final report that “records of the location and general contents of the facility would be held by the National Nuclear Archive” [61].

In other countries, like in Finland, there are currently no demands on the preservation of records, knowledge and memory from the local community, according to Posiva representatives.

Also in Canada, the need to preserve memory is also raised by indigenous people. In the regional dialogue with Métis, it was acknowledged that “the next 4000 generations must understand how we worked together to come to this decision, and what we hoped their future might look like as a result of our decision-making” [72]. In addition, people participating in NWMO engagement activities in 2012 questioned the ability to inform future generations about the repository’s presence, as connected to security. Some people felt that knowing the exact location of the facility would not contribute to increasing security, whilst others were more concerned about how to transmit the knowledge about the facility to future generations [73].

## **6.5. Building local stakeholders’ confidence**

This section points out how confidence may be built and reinforced through monitoring and RK&M preservation, as revealed in interviews and documentary data. As acknowledged in the interviews, monitoring contributes to creating trust, ensuring transparency and maintaining local stakeholders’ confidence. Monitoring seems also important to meet expectations on long-term safety and security, in some cases, as well as for long-term stewardship. Some stakeholders also refer to independent oversight bodies (e.g. academics, experts or local committees) as important factors to build public confidence. In addition, we see that in some countries the discussion on reversibility and retrievability is linked to monitoring and RK&M preservation, for safety and confidence building purposes.



Firstly, for local communities, monitoring is a key issue to both ensure safety and guarantee transparency. Most interviewees stated that monitoring has a function for ensuring safety as well as for strengthening confidence that the repository does not have undesirable impacts on human health and the environment. In fact, an interviewee indicated that both, safety and confidence, are interlinked and only if people believe it is safe, they will have confidence. Similarly, another interviewee mentioned that “monitoring itself is not enough to build confidence, but helps to achieve it”. An interviewee from France expressed that safety does not rely on surveillance and for this reason, monitoring has to do more with achieving confidence. In Sweden, the representative of the Swedish National Council for Nuclear Waste Monitoring argues that, with respect to monitoring, not only technical, but also societal aspects are important to get trust and confidence.

One aspect that we may consider critical at this point and was raised earlier in Section 6.3 is the role of local communities in monitoring activities. There are different views depending on national contexts. Some interviewees emphasised that local stakeholders should not be delegated the responsibility for conducting monitoring activities but just provide them with information on a regular basis during the operational and post-operational period for confidence building purposes. In different institutional contexts, local stakeholders have a different view and think that they should be involved actively in monitoring activities, like in the French case. Thus, even if monitoring may contribute to building confidence in geological disposal, local expectations and roles with regard to monitoring depend very much on national contexts.

Secondly, the involvement of independent bodies in performing monitoring is important for contributing to public confidence. In the US, the interviewees noted that the majority of people around the WIPP have confidence in the safety of the facility. According to an interviewee from DoE, the main rationale for requesting monitoring would be the need to verify in action. Additionally, the role of CERMC and the autonomous professors involved, who “may speak out without feeling oppressed by the political environment” is crucial for building confidence, as raised by one interviewee from the local community. He added that the establishment of this oversight body was done in collaboration with State representatives who discussed on what to monitor, who would be in charge or how much would it cost, among other issues. However, he criticised the fact that the State does not receive any financial support for accommodating the repository and they do not pay for their time spent to review, to be involved, travel expenses, etc. The case of Yucca Mountain is different, since the Nuclear Waste Policy Act (1982) provided for the Affected Units of Local Government within the vicinity of the site to oversee and participate in the Yucca Mountain project. The aim of Congress was “to increase public confidence in the scientific integrity of the repository programme, provide citizens the means to interact with the federal government, and demonstrate a commitment to external oversight”.

Furthermore, according to most interviewees, local communities tend to want a role in engaging in monitoring programmes. As pointed out by Pescatore and Mays [53] “when local communities [...] participate in monitoring site development and operations, they are building their capacity to act as guardians and therefore ensure another layer of defence in depth”. Enhanced oversight by both authorities and stakeholders may be part of a confidence-building process.

Finally, monitoring and memory preservation are an inextricable part of the discussions on reversibility and retrievability in some countries, like France or the UK. Monitoring is essential to enable

reversibility as it provides information on the engineered facility and its performance [19]. Within Andra Memory Project, a theoretical study examines the interactions between memory and reversibility of storage in order to identify the memorisation requirements for the various reversibility phases and what could be the consequences of these phases if the memory of the centres were to disappear [74, 64].

The West Cumbria Partnership indicated that “a lack of trust appears to us to be at the root of many of the key concerns raised by the public and stakeholders” [58]. They recognise that research on the best ways of monitoring is in the early stages and further work needs to be done. As raised by a UK interviewee, trust is a confidence factor and monitoring is needed to build confidence. Also in the UK, the concerns from local communities on monitoring were linked to retrievability. Monitoring is essential as far as it helps to understand if the repository operates safely and if not, if waste can be retrievable. It is noted that local communities would want to know exactly how monitoring will happen if a facility is ever built. In addition, any site- specific safety cases would need further monitoring and independent reviews before they are considered adequate by the regulators and other stakeholders [61].

## **6.6. Reflections on the concept of oversight**

This report brings together the concepts of monitoring and RK&M. As put forward by Nachmilner [3] monitoring is mostly understood as collecting technical data and one of the motivations for this is to keep memory as part of maintaining safety and oversight of a closed disposal facility. So far, monitoring and RK&M are generally regarded in general as separate topics and there is no connection between both. The concept of oversight considered here suggests that monitoring plays an important role for the active keeping of records, knowledge and memory.

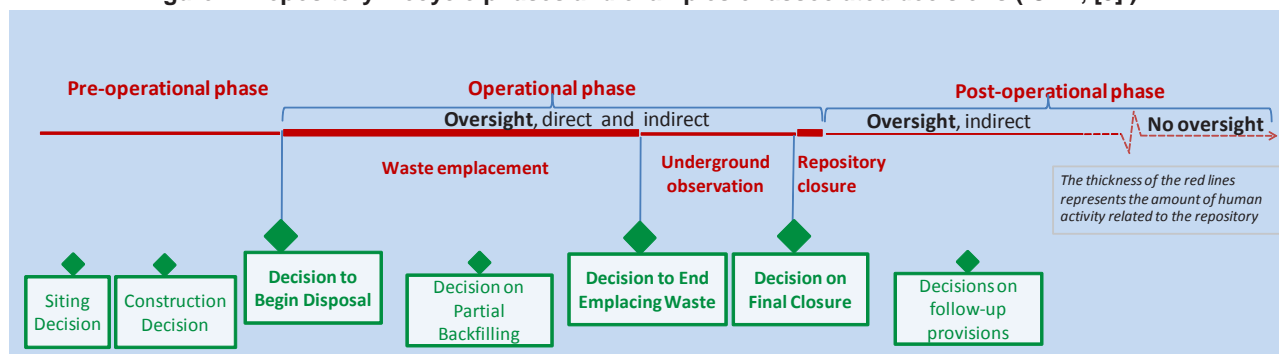
The concept of ‘oversight’, as suggested by Pescatore et al. [40] and put forward by the ICRP (2013), is useful as an overarching term which embraces both monitoring and RK&M. As stated by ICRP (2013) [5] and NEA [39; 75] “oversight is the more general term that refers to society ‘keeping an eye’ on the technical system and the actual implementation of plans and decisions”. In a nutshell, oversight is the general term for “watchful care” [40].

The ICRP report on radiological protection in geological disposal [5] outlines that, from a radiological viewpoint, the application of the protection system is influenced by the level of oversight or ‘watchful care’ of the disposal facility that is present (p. 6). Oversight can be exercised through different activities, like monitoring technical parameters, monitoring institutional provisions or even monitoring the implementation of agreements made with local hosts. The ICRP guidance states: “The different decisions to be made relating to the evolution of the oversight should be discussed with stakeholders” ([5], p. 18). The different actors – implementers, regulators, policy makers and local communities, outside experts, etc. – may be engaged in planning and undertaking oversight and monitoring activities at the different phases of the disposal facility development and implementation. Thus, monitoring serves the purpose of oversight and, as such, is part of oversight. When direct oversight ceases, in tens to hundreds of years after the start of operations, the ICRP suggests that other forms of passive control may be in place, like memory, records or other measures decided jointly by the authorities and stakeholders ([5], p. 18).

The ICRP report indicates that there are three main levels or types of oversight: direct oversight when access to the waste is possible, i.e., when disposal galleries are still open; indirect oversight when direct access to the waste is no longer possible without re-excavation, i.e, for some parts of the disposal facility or

for the full facility after sealing; and absence of oversight in case the memory of the disposal facility was lost (see Fig. 4). The periods of indirect oversight and no oversight correspond to the post-operational phase, when the human presence is no longer required to directly manage the facility.

**Figure 4: Repository lifecycle phases and examples of associated decisions (ICRP, [5] )**



The term “oversight”, as defined above, is marginally covered in FSC documents. Most references to “oversight” are related to the Local Information and Oversight Committee (CLIS) around the Underground Research Laboratory set up in Bure, in the area of Meuse / Haute-Marne “departements” (France), the public oversight and information associations established in the vicinity of nuclear sites (storage, disposal, construction or investigation area) in Hungary or linked to monitoring. Furthermore, the term “community oversight schemes” is proposed as referring to non-financial incentives to increase confidence, and in turn possibly support for siting the facility within the potential host community [52]. In addition, “expert oversight groups” are also considered by the FSC as mechanisms to promote the interaction between stakeholders and specialists [76]. In all these cases, oversight would involve any systems or actions to watch and check a situation carefully to make sure it is done correctly.

Furthermore, during the interviews, “oversight” was barely used, apart from in interviews from the US. It is interesting to mention here that an interviewee acknowledged that there seems to be an overlap between monitoring and RK&M preservation. Providing perpetual care will help to maintain the memory of the site and pass knowledge on to future generations so that they can decide how the facility is managed. According to the US Nuclear Waste Policy Act “oversight and monitoring are different in nature but complementary in practice” [77]. In the case of Yucca Mountain, the geological repository for high-level radioactive waste in the US that is currently defunded, Nye County refers to the oversight activities as “those related to institutional or policy oversight and involving predecisional review and comment on DoE policy regarding Yucca Mountain Project-related transportation, waste handling, storage and /or emplacement”. In contrast, “monitoring involves the assessment of local conditions that could be affected by the Yucca Mountain Project and assessment and reporting of actual or potential impacts on those conditions” [77].

During the MoDeRn international conference held in Luxembourg from 19-21 March 2013, the word “oversight” was presented as a term embracing both monitoring and control and going beyond these concepts, a term which recognizes the coexistence of technical and societal factors. It includes regulatory supervision and control, but also the preservation of societal records and societal memory of the presence of the facility. Whilst some participants at the conference seemed at first confused by this new terminology, it opened some avenues for further reflection afterwards during the working group sessions.

As mentioned above, ‘oversight’ has different connotations depending on the country and on the person who uses the term. In the US, for instance, there are several technical oversight groups that can carry out scientific, radiological, financial or other forms of monitoring of nuclear. Representative of the Department of Energy in WIPP claimed that oversight was part of the pre-operational consideration for the Compliance Certification Application. The Waste Isolation Pilot Plant Land Withdrawal Act resulted from political discussions at the state and federal levels, limiting waste types and quantities, and mandating oversight by the Environmental Protection Agency for long-term radiological safety and by the State’s New Mexico Environment Department for overseeing the implementation of the laws regulating the disposal of hazardous constituents in the waste.

Communities ask for oversight in perpetuity, active safety and prolonged stewardship, including monitoring (Kotra in [78]). A State representative in Carlsbad points out that numerous organisations are involved in the oversight of Waste Isolation Pilot Plant (WIPP) that safely disposes defense-related transuranic radioactive waste. Among others, the Environment Department of the State of New Mexico regulates the handling of the hazardous components of mixed waste under the Hazardous Waste Act and the Resource Conservation and Recovery Act; the U.S. Environmental Protection Agency (EPA) is responsible for certification and enforcing waste facility permits; the Department of Energy (DoE) is responsible for oversight and monitoring health and safety operations and Carlsbad Environmental Monitoring & Research Centre (CERMC) independently monitors health and environmental parameters during the pre-disposal and operational disposal phases. This Centre also carries out the ‘lie down and be counted’ programme, which characterises and monitors internally deposited radionuclides in the general population living around WIPP on a routine basis.

The Nye County community clearly advocates for permanent oversight of facilities. Participation in and updating of local, state, federal and international archives and land record systems is required along with an active programme for continuing oversight of the facility (Kotra in [78]). According to the Nye County Board of Commissioners, they have the “core duty” of oversight of DoE’s Yucca Mountain Project policy, “now and for the indefinite future”. For them, the purposes of oversight are to:

- Monitor federal policy regarding Yucca Mountain project and ensure the citizens are of informed of policy decisions as well as the consequences of those decisions;
- Give Nye County the opportunity to provide predecisional input on all aspects of future DoE activity in Nye County and
- Provide DoE and the federal government with input from the community’s perspective [77].

In this capacity, the Nye County Nuclear Waste Repository Project Office set up various initiatives over the years to follow the project. They conducted oversight of Yucca Mountain Project, comprising five programme elements: 1) socio-economic, transportation and emergency response; 2) regulatory and licensing oversight; 3) government and community relations; 4) programme management and 5) independent scientific investigations programme.

## **7. OBSERVATIONS FROM THE 2013 INTERNATIONAL REPOSITORY MONITORING CONFERENCE AND WORKSHOP [43]**

Participants of the MoDeRn conference and workshop assessed the current status of the programmatic, regulatory, stakeholder and technological aspects of repository monitoring.

Monitoring consists of the follow-up of qualitative (observations) and quantitative (data) parameters which can be measured underground in the facility or in its vicinity (boreholes, laboratories, disposal spaces), on the surface, or remotely. Their role differs in particular stages of the facility's lifecycle; nevertheless, their mutual links and dependencies have not yet been fully defined. There is general agreement on what type of monitoring is required in the early stages of facility development and extensive sets of data are being collected, but the extent of monitoring in the operational and post-closure periods has not been determined to date and, thus, is far from being optimised. It is not possible to directly measure real facility performance in the long term; however, strong transient transfer processes can be identified.

While most disposal programmes do not currently plan for post-closure monitoring (despite the fact that in several countries it is required by legislation), it is evident that a number of, at least qualitative, follow-up activities will be in place to address public concerns and, especially, oversight requirements. In addition, the lack of clarity with regard to what constitutes long-term safety and how it is linked to post-closure monitoring adds to the various uncertainties regarding this matter. Clearly, monitoring objectives are guided by what is feasible today. There are inherent technical limits which do not allow for direct (in-facility) measurement for more than several decades following facility closure; scientific advances (new materials and methods) promise the extension of this time period to a century at best. Limitations have been diagnosed principally in terms of energy supply, data transfer and the longevity of the materials employed, particularly sensors.

Monitoring is understood as a socio-technical issue; it generates data and information on repository system performance as well as on its natural and social environments. Complex scientific arguments are difficult for society to understand, thus society should be made aware on what can be done, e.g. the sharing of technical information, the establishment of scientific and technological baselines and the enhancement of interaction between experts and society at large, and what cannot be done, e.g. ensuring long-term safety and direct proof of facility performance and the provision of unlimited meaningful data. The role of monitoring in building public confidence is clear but it is understood as one of a series of elements which serve this purpose.

A further issue worthy of attention is the governance of monitoring projects which consists of defining objectives and requirements, evaluating implications, considering impacts on the disposal programme and relevant decision-making. This requires the allocation of responsibilities, the creation of a sustainable structure, planning, the identification of the various parties involved and the hierarchy thereof, the proper dislocation of tasks and activities, the establishment of control and review mechanisms, the adequate management of the independence of certain institutions, the determination of processes and criteria and the setting of trigger/alarm levels for decision-making purposes.

Finally, recently formulated ICRP oversight requirements need to be set out in the form of implementing measures. There is an obvious link between oversight and knowledge & memory keeping as formulated by the OECD/NEA [35]. Questions such as who makes up an oversight body, who it is dependent on, who drives the relevant programme, etc., deserve thoughtful and clearly-elaborated decisions. When determining the oversight system due attention should be devoted to preventing confusion between monitoring (gaining data) and oversight (broader societal activity).

It can be concluded therefore that there is no single, international prescription for designing and implementing national monitoring programmes: national specifics such as the geological and natural settings, the concept and design of the facility, the waste inventory and legislative and societal environments will be decisive in terms of their design and establishment.



## 8. LESSONS LEARNED AT TECHNICAL AND SOCIETAL LEVEL

Current status of technical monitoring geological disposal facilities can be briefly summarised as follows:

- It is evident that techniques and procedures currently exist for monitoring various parameters required during the pre-operational and operational phases, particularly in the areas of disposal system characterisation and evolution, safety case development, safety in operating a repository, and assessment of environmental impacts. However, while a repository matures to the construction optimisation of parameter selection becomes topical to effectively estimate the long-term performance of the facility.
- Data management systems shall be developed in the early stage of repository development as it involves multiple disciplines. To ensure future generations have the pertinent data to make their decisions, data management must be maintained throughout the lifetime of a repository.
- The long-term monitoring of an underground facility faces significant technical problems, including how to ensure that a material will resist the various deterioration processes at work (corrosion, temperature, radioactivity, pressure); this requires further R&D efforts.
- Uncertainties exist in the monitoring and evaluation of slow processes that may appear within the closed system both in terms of their identification and quantification. Long-term full-scale demonstration experiments may significantly decrease the level of such uncertainty.
- It is preferable that any monitoring system, whether devised for use during operation or after closure, should not assist in the development of preferential pathways for radionuclide migration or otherwise affect overall safety. Suitable technical responses, including wireless data transmission technology, are currently under investigation.
- Slow and coupling processes, which will occur within a disposal system, deserve attention of the safety case developers so as to find out effective methods for their monitoring and evaluation allowing to realistically assess their relevancy and potential long term impacts.
- Deep geological disposal facilities for HLW have not yet been put into operation; thus, the need for post-closure monitoring and how it should be implemented are still under consideration, even if in some countries it is legislatively required. There is however broad consensus that, following closure, the disposal system must be passively safe without reliance on monitoring. The current technical tendency is to terminate monitoring soon after facility closure, while local stakeholders' preference tends to continue the monitoring of the closed facility. In any case, the need for oversight of the closed facility itself introduces a certain kind of monitoring since monitoring serves to support oversight and is an indivisible part thereof.
- Local stakeholders demand simple proof that the closed disposal facility has attained passive safety status which is difficult to provide in general: the evidence is based on a complex and

extremely long term monitoring programme and its scientific evaluation and interpretation. Reaching consensus on how to address this problem is vital in attaining full stakeholder confidence.

- Safeguard monitoring is a specific case: if a repository contains nuclear materials that are “practicably” recoverable, the site must be monitored even during the post-closure period.
- Even after the facility closure indirect forms of oversight by authorities will be needed, such as maintaining records and ultimately maintaining the memory of the site. This may also include some forms of monitoring; its extent is still under discussion.

The study on societal aspects reviewed various sources of knowledge and viewpoints concerning monitoring, preservation of records, knowledge and memory (RK&M), and oversight, in the context of local community involvement with a deep geological repository for radioactive waste. It provides insights on the challenges raised in the description of the current status.

- The findings suggest that at present, monitoring and preservation of RK&M are concepts whose interpretation may be specific to a country or a site. These concepts may evolve over time and may also have different meanings depending on who defines them. Clarification and common understanding might have to be developed in consultation with stakeholders. The process of reflecting on these concepts may already help different stakeholders to grasp their meaning and engage the community in discussing their role and expectations in monitoring and preserving RK&M.
- According to survey, literature and interview findings, there is relatively little work or guidance on how monitoring might contribute to the creation and preservation of RK&M and to what extent local communities might play a role in this process. The study seeks to provide input to this debate and provide examples of initiatives or dialogues undertaken in this field. This report does not offer a prescriptive plan, but provides a first glance into how these concepts are considered by local communities on the international level.
- The study shows that local stakeholders have an interest in monitoring and RK&M preservation in RWM facilities. Local stakeholders would like to know how monitoring will take place and what it is important to monitor and why. In addition, local communities recognise that monitoring should be undertaken in the early stages of the siting procedure and might be continuously refined and may not end with the closure of the facility. The nature and extent of monitoring required by local stakeholders depends on the understanding of monitoring.
- For local stakeholders, broad areas of interest to be monitored include environmental impacts, socio-economic factors and health issues in specific cases. In parallel, there is a vague, not clearly defined, interest in RK&M preservation.
- In some countries, like France, monitoring and RK&M are conceived as inextricably linked together and both national and local actors are closely working on these matters. The implementer, Andra, undertakes specific research programmes, studies and initiatives, like the



Permanent Environmental Observatory. In parallel, the national technical support organisation IRSN helps recognized local stakeholder groupings (ANCCLI, and CLI) to exchange, build competence and identify questions and challenges regarding the geological repository project in France. Future challenges cover issues related to monitoring and preservation of RK&M.

- In most countries, demands and expectations on monitoring are more clearly defined than those on RK&M, where there is hardly evidence reported on a formal demand. This study has provided several examples of local demands and expectations in monitoring and RK&M in Canada, Sweden, UK and US. In other countries, like Finland or Eastern countries, these demands are not so clearly articulated. Nevertheless, it has become apparent that there is an interest by local communities in various countries to explore these concepts further as they become involved in different phases of the radioactive waste management programme.
- The challenge, as recognised during the FSC National Workshop and Community Visit in Hungary [46] is to design and implement a facility which becomes part of the fabric of local life and even something of which the community can be proud, that provides added cultural and amenity value across the generations. As countries advance in the implementation of underground repositories, the extent to which local communities can contribute to maintaining the memory of a repository will remain a subject for discussion and development in the next years. Local communities may seek participation in continued oversight as a means of building and sustaining their confidence in safety. However, this interest is often not specific enough to define critical aspects to be monitored nor over which time scales. Further research to identify both how monitoring could contribute to confidence in geological disposal and how local communities in different national contexts may be involved in oversight activities may help to clarify roles, demands and expectations.
- The results from the study of Bergmans et al. [79] undertaken in the context of the MoDeRn project are complementary to those of the project presented here. Bergmans et al. observe that the meaning of monitoring and the extent to which it contributes to long-term safety differs from experts to lay stakeholder groups. For the experts, monitoring is about collecting information on the repository system, observing through measurements its behaviour and impact. For lay stakeholder groups, the interpretation of monitoring is much wider and touches upon the relationship between stakeholders and the development of repository monitoring programmes, confidence building and trust. From Bergmans [80], lay stakeholders consider that monitoring would cover any data gathering related to the behaviour of a repository and its natural and social environment, from the site investigation to post-closure. She argues that citizens seem to be less concerned about what parameters to monitor and where, and more interested in the comprehensiveness of the monitoring programme. Therefore, monitoring would require keeping an eye on the facility, even after closure, and having a response plan in case action needs to be taken.
- The MoDeRn project suggests that monitoring should be recognised as a “socio-technical activity” that involves the “pursuit of social and institutional innovations as much as technical and industrial innovation” (Bergmans et al. [79]). This approach can be strengthened by recognising that RK&M can play a role as a means to support monitoring activities. We observe

that specific concerns and expectations on RK&M emerge as siting draws near and are clearly on the agenda in countries that in 2012-13 are undergoing a licensing phase. So far, informal and formal discussions have been on-going in several countries regarding the best way to pass knowledge on to future generations. This takes us to the useful concept of oversight as “keeping an eye” on the system and on the implementation of decisions (Pescatore et al., [40]).

- Oversight can provide a useful conceptual framework that embraces long-term monitoring and preservation of RK&M. The decisions on the levels and evolution of oversight would be based on different factors, like the degree of confidence in the behaviour of the facility, societal, economic factors, etc. Being aware of the views of the implementer, the regulator and the concerned stakeholders over these issues may contribute to provide further insights on the nature and role of oversight of geological disposal. As considered by ICRP (2013) [5]. “decisions related to the organisation and evolution of the oversight should be discussed with the stakeholders”. In summary, oversight can be exercised not only through technical parameters and administrative provisions but also through monitoring agreements made with the local hosts and other stakeholders.

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## APPENDIX: MONITORING DEFINITIONS

Definitions of monitoring differ within the nuclear waste community (the overview from different sources is given in Table A1-1). This is due to the existing, country-specific legal context as well as different views on the role of monitoring, and purposes of published documents.

**Table A1-1: Monitoring definitions as specified in different projects**

<b>Source</b>	<b>Definition</b>	<b>Comment</b>
Oxford Advanced Genie	To watch and check something over a period of time in order to see how it develops, so that you can make any necessary changes	General definition
Merriam-Webster	To watch, keep track of, or check usually for a special purpose	General definition
IAEA Radioactive waste management 2003 [2]	Continuous or periodic measurement of radiological and other parameters or determination of the status of a system.  Environmental monitoring: The measurement and evaluation of external dose rates due to sources in the environment or of radionuclide concentrations in the environmental media.	General definition
IAEA Safety Glossary 2007 [3]	1. 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. Continuous or periodic measurement of radiological or other parameters or determination of the status of a structure, system or component. Environmental monitoring: The measurement of external dose rates due to sources in the environment or of radionuclide concentrations in environmental media.	Safety driven definition
IAEA draft Safety Guide (DS 357) [1]	Monitoring: 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	Safety driven definition for all types of disposal

	<p>on the public and the environment.</p> <p>Surveillance: The physical inspection of a waste management facility in order to verify its integrity to protect and preserve the passive safety barriers.</p>	<p>facilities</p> <p>Some MS's do not distinguish between M&amp;S</p>
IAEA TECDOC 1208 2001 [4]	Continuous or periodic observations and measurements of engineering, environmental or radiological parameters, to help evaluate the behaviour of components of the repository system, or the impacts of the repository and its operation on the environment.	Facility lifecycle definition
CEC Thematic Network 2004 [5]	Continuous or periodic observations and measurements of engineering, environmental, radiological or other parameters and indicators/characteristics, to help evaluate the behaviour of components of the repository system, or the impacts of the repository and its operation on the environment, and to help in making decisions on the implementation of successive phases of the disposal concept.	Facility lifecycle definition
SKB 2001 [6]	Repeated measurements or observations during a longer period of time, generally extending over several stages of repository development.	Repository development
SKB 2004 [7]	Continuous or repeated observations or measurements of parameters to increase the scientific understanding of the site and the repository, to show compliance with requirements or for adaptation of plans in light of the monitoring results.	Repository development

## ATTACHMENT I

## Parameters to be monitored during various periods of development of a geological disposal facility [1]

Parameters/process to be monitored	Repository development phase		
	Pre-operational	Operational	Post-closure <sup>(1)</sup>
<b>BASELINE (INITIAL VALUE)</b>	*		
Groundwater flow field in the host-rock and the surrounding geosphere <ul style="list-style-type: none"> <li>groundwater pressure distributions</li> <li>hydraulic gradients</li> <li>flow directions</li> <li>permeabilities</li> <li>regions of recharge and discharge</li> </ul>	*		
Geochemical characteristics of ground water: <ul style="list-style-type: none"> <li>redox</li> <li>salinity</li> <li>major and trace element concentrations</li> <li>natural radionuclide content / background activity</li> </ul>	*		
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			
Mechanical properties of the disposal facility structure		*	
Mechanical properties of the engineered barriers		*	
Retention & hydraulic properties of the engineered barrier		*	
<b>CONTINUED MONITORING OF BASELINE PARAMETERS</b>		*	*
<b>Integrity of waste packages</b>			
Direct measurement <ul style="list-style-type: none"> <li>corrosion</li> <li>strain</li> <li>pressure on the waste package (i.e. swelling pressure for clay buffer)</li> </ul>		*	(*)
Environmental measurements <ul style="list-style-type: none"> <li>temperature</li> <li>humidity</li> <li>resaturation</li> <li>analysis of waste derived gases</li> </ul>		*	(*)
<b>Disposal facility structures and engineered barriers</b>			
Structural stability of disposal facility structure and engineered barrier <ul style="list-style-type: none"> <li>mechanical properties</li> <li>stresses</li> </ul>			

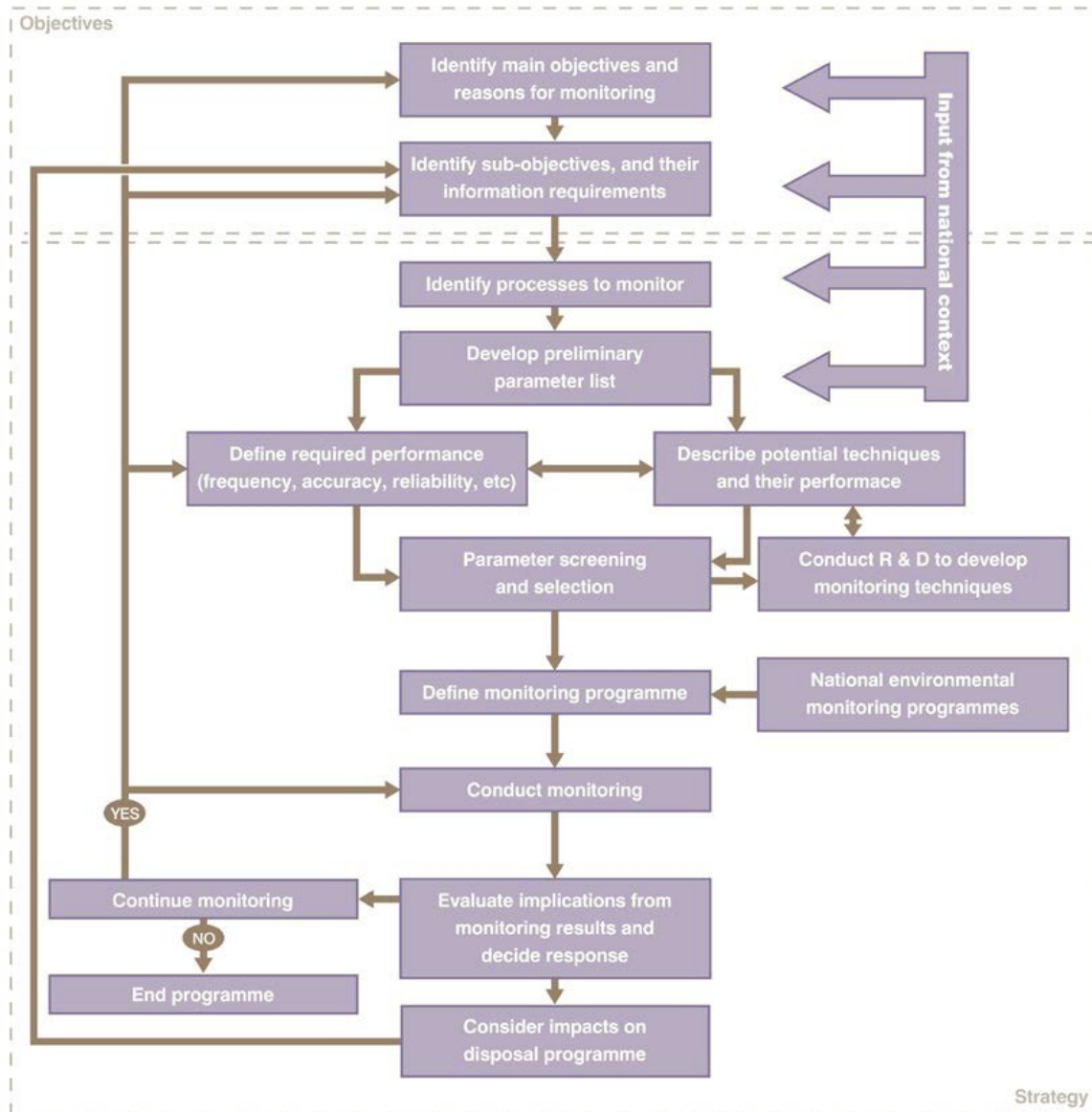
<ul style="list-style-type: none"> <li>• strain</li> <li>• conventional observation of underground openings <ul style="list-style-type: none"> <li>- rock stresses</li> <li>- deformations and loads on rock supports</li> <li>- deformations in walls and lining</li> <li>- fractures</li> </ul> </li> </ul>		*	(*)
Behaviour of engineered barrier (i.e. backfill and seal) <ul style="list-style-type: none"> <li>• resaturation rate</li> <li>• changes in: <ul style="list-style-type: none"> <li>- hydraulic properties</li> <li>- mechanical properties (including swelling)</li> <li>- chemical properties</li> <li>- thermal properties</li> </ul> </li> </ul>		*	(*)
Prevent water ingress into the disposal facility - water infiltration through the disposal facility		*	(*)
<b>Disturbances created by the disposal facility (construction, emplacement of waste and engineered barriers, ...)</b>			
Mechanical disturbance in the host rock <ul style="list-style-type: none"> <li>• stress field</li> <li>• deformation</li> <li>• fractures</li> </ul>		*	(*)
Geo-chemical disturbances <ul style="list-style-type: none"> <li>• composition (interstitial water + mineralogy)</li> <li>• pH</li> <li>• redox</li> <li>• retention properties</li> <li>• biological changes</li> </ul>		*	(*)
Hydraulic disturbance <ul style="list-style-type: none"> <li>• permeability</li> <li>• water pressure</li> <li>• saturation degree</li> </ul>		*	(*)
Thermal disturbances <ul style="list-style-type: none"> <li>• temperature distribution</li> <li>• conductivity</li> </ul>		*	(*)
<b>Monitoring of radionuclide release</b>			
Leachate monitoring		*	(*)
Activity concentration in ground water		*	*
Extent of the potentially contaminated zone		*	*
Hydraulic gradients, velocity and direction of the flow in the potentially contaminated zone		*	*
The level of water table		*	*
Recharge/discharge of aquifer		*	*
Chemical composition of water		*	*
<b>Changes to geosphere</b>			
Mechanical <ul style="list-style-type: none"> <li>• stresses</li> <li>• strain</li> <li>• fractures (connectivity which could create preferential pathway)</li> </ul>		*	*
Hydraulic <ul style="list-style-type: none"> <li>• ground water pressure</li> </ul>		*	*
Chemical <ul style="list-style-type: none"> <li>• solute chemistry</li> <li>• mineralogy</li> </ul>		*	*
Thermal <ul style="list-style-type: none"> <li>• temperature</li> </ul>		*	*
<b>ACCUMULATION OF AN ENVIRONMENTAL DATABASE</b>			
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	*	*	*

<sup>(1)</sup> 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.

ATTACHMENT II

The Preliminary MoDeRn Monitoring Workflow [10]



## ATTACHMENT III

## Possible monitoring activities for different repository phases [7]

Site investigation phase	Construction and detailed characterization phase	Initial operation, regular operation, closure phases	Post-closure phase during institutional control
<b>Environmental monitoring programme</b> - disturbance of surface investigations	<b>Environmental monitoring programme</b> - disturbance of supplementary surface investigations - impact of repository construction (soil, groundwater, gas, noise)	<b>Environmental monitoring programme</b> - disturbance of supplementary surface investigations - impact of repository construction (soil, groundwater, gas, noise)	<b>Environmental monitoring programme</b> - impact of rise of groundwater level  <b>Documentation is preserved</b>
<b>Climate</b> - temperature, atmospheric pressure, precipitation, evaporation, runoff, sea level changes	<b>Climate</b> - temperature, atmospheric pressure, precipitation, evaporation, runoff, sea level changes	<b>Climate</b> - temperature, atmospheric pressure, precipitation, evaporation, runoff, sea level changes	<b>Climate</b> - temperature, atmospheric pressure, precipitation, evaporation, runoff, sea level changes
<b>Biosphere</b> - flora, fauna, soil layer land use etc	<b>Biosphere</b> - flora, fauna, soil layer land use etc	<b>Biosphere</b> - flora, fauna, soil layer land use etc	<b>Biosphere</b> - flora, fauna, soil layer land use etc <b>Documentation is preserved</b>
<b>Boreholes from the ground surface</b> - groundwater chemistry and pressure, temperature	<b>Boreholes from the ground surface</b> - groundwater chemistry and pressure, temperature	<b>Boreholes from the ground surface</b> - groundwater chemistry and pressure, temperature	<b>Documentation is preserved</b>
	<b>Boreholes from underground</b> - groundwater chemistry and pressure, temperature - deformations in the rock	<b>Boreholes from underground</b> - groundwater chemistry and pressure, temperature - deformations in the rock	<b>Documentation is preserved</b>
<b>Seismic events</b> - time, location and type of local earthquakes	<b>Seismic events</b> - time, location and type of local earthquakes - micro-seismic events	<b>Seismic events</b> - time, location and type of local earthquakes - micro-seismic events	<b>Seismic events</b> - time, location and type of local earthquakes - micro-seismic events  <b>Documentation is preserved</b>
	<b>Surveillance of the repository</b> - fire, - floods, seeping water, pumped-out water (quantity, quality) - ventilation (temperature, quantity, quality) - noise - monitoring of conditions for preventive maintenance - stability of underground openings	<b>Surveillance of the repository</b> - fire, - floods, seeping water, pumped-out water (quantity, quality) - ventilation (temperature, quantity, quality) - noise - monitoring of conditions for preventive maintenance - stability of underground openings - radiation monitoring - safeguards	<b>Surveillance of the repository</b> - safeguards  <b>Documentation is preserved</b>



## ATTACHMENT IV

List of processes with high significance for either site understanding (Site) or repository performance (Perform). H = high (red shaded), M = medium and L = low [14].

Process number	Process name	Site	Perform
<b>Physical processes:</b>			
P1	Development of an excavation damaged zone (EDZ)	H	H
P2	Evolution of the fracture network		
P2.1	Reactivation of existing fractures in the rock mass	H	H
P2.2	Generation of new fractures in the rock mass	H	H
P3	Aeration of the rock mass	H	M
P4	Planned introduction of foreign fluids	H	L
P5	Planned introduction of foreign solid materials	H	H
P6	Microseismicity	M	L
P7	Sinking of satellite boreholes	H	M
P8	Temperature changes		
P8.1	Temperature changes in the rock mass	L	L
P8.2	Temperature changes in the groundwater	M	L
P8.3	Temperature changes in the air	M	L
P9	Degassing of groundwater	M	M
P10	Ground subsidence	L	L
P11	Isostatic uplift	M	H
P12	Inadvertent introduction of foreign substances	M	L
P13	Degassing of rock mass	L	L
<b>Hydrogeological processes:</b>			
H1	Evolution of hydraulic network	H	H
H2	Evolution of hydraulic heads	H	H
H3	Evolution of fracture properties	H	H
H4	Ingression of water	M	L
H5	Egression of water	M	L
H6	Density-driven flow	H	H
H7	Release of rock matrix brines	M	L
H8	Seismic pumping	M	L
H9	Perturbation of the hydrology	M	L
H10	Evolution of the saline water interface	H	H
<b>Geochemical processes:</b>			
<i>Solids:</i>			
GS1	Redistribution of rock mass	M	L
GS2	Evolution of fracture-coating materials	H	H
GS3	Evolution of rock matrix	H	H
GS4	Maturation of cement	L	L
GS5	Degradation of cement	M	M
GS6	Cement-rock interaction	M	L