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## Expert Stakeholders Workshop report


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## Executive Summary

The EC Seventh Framework Programme Monitoring Developments for Safe Repository Operation and Staged Closure (MoDeRn) Project aims to develop the understanding of the role of monitoring in staged implementation of geological disposal to a level of description that is closer to the actual implementation of monitoring than previously achieved through collaborative international projects.

As part of MoDeRn Work Package 5 (Dissemination of Results), a workshop involving expert stakeholders (the MoDeRn Expert Stakeholders Workshop) was held in Oxford, United Kingdom, on 4-5 May 2011. Thirty-one participants attended the meeting, including representatives from:

- Regulatory organisations in Belgium, Finland, Switzerland and the United Kingdom.
- Advisory bodies in the UK.
- A public stakeholder group in Germany.
- The Belgian agency for radioactive waste and enriched fissile materials (ONDRAF/NIRAS).
- MoDeRn Project partners who had personally not been significantly involved in the project previously.
- MoDeRn Partner organisations.

The objective of the meeting was to inform the expert stakeholders of the work being undertaken in the MoDeRn Project and to obtain feedback on the scope of the work. The workshop consisted of a plenary session on the first day in which information was provided on the project, and two themed sessions on the second day. The themed sessions focused on two themes, monitoring processes and monitoring technologies respectively. For each theme, break-out groups discussed a series of questions and reported the conclusions of their discussions in a plenary session.

Valuable feedback was gained from the discussions, both on the MoDeRn Project scope and direction, and on setting the context for monitoring. This feedback will be used to help guide the future direction of the MoDeRn Project. The expert stakeholders were supportive of the work being undertaken in the project, and made constructive suggestions for the scope of work to be considered in the forward work programme.

Key recommendations identified during the workshop were:

- There is a need to clearly explain the relationship of the monitoring programme to the safety case and to engineering design.
- There is a need to clearly communicate assumptions about why monitoring is undertaken.
- There is a need to define acceptable ranges (tolerances) for monitoring results, and to have a clear plan in place to respond to any results collected that fall outside these ranges.
- The Preliminary MoDeRn Monitoring Workflow diagram provides a valuable overview of what must be considered when developing a monitoring programme.

- There is a need for a flexible, adaptable monitoring programme to support decision making and to respond to future changes in monitoring requirements/technology developments.
- There may be benefit in considering the issue of post-closure monitoring further within the MoDeRn Project.
- There is a need to acknowledge the benefits of independent scrutiny of monitoring programmes, and monitoring results in particular, in order to build the trust of the public.
- There should be a clear strategy, from the outset of implementing a monitoring programme, on when and how to communicate with lay stakeholders on monitoring.
- There is a need to identify what monitoring technologies need to be developed or might be available in the future.

## List of Acronyms

| | |
|---|---|
| Andra: | Agence Nationale pour la Gestion des Déchets Radioactifs, France |
| DoW: | Description of Work |
| EBS: | Engineered Barrier System |
| EDZ: | Excavation Damaged Zone |
| EC: | European Commission |
| ESDRED: | Engineering Studies and Demonstration of Repository Designs (EC Project) |
| ETN: | European Thematic Network |
| EU: | European Union |
| EURIDICE: | European Underground Research Infrastructure for Disposal of Nuclear Waste in Clay Environment, Belgium |
| GSL: | Galson Sciences Ltd., UK |
| GTS: | Grimsel Test Site |
| HADES: | High Activity Disposal Experimental Site. A URL in Mol, Belgium. |
| HLW: | High-level Waste |
| IAEA: | International Atomic Energy Agency |
| ILW: | Intermediate-level Waste |
| MoDeRn: | Monitoring Developments for Safe Repository Operation and Staged Closure |
| NDA: | Nuclear Decommissioning Authority |
| NEA: | Nuclear Energy Agency |
| PRACLAY: | Preliminary demonstration test for clay disposal of highly radioactive waste |
| ONDRAF/NIRAS: | Organisme national des déchets radioactifs et des matières fissiles enrichies/Nationale instelling voor radioactief afval en verrijkte splijtstoffen (Belgian agency for radioactive waste and enriched fissile materials) |
| R&D: | Research and Development |
| RAWRA: | Radioactive Waste Repository Authority, Czech Republic |
| RTD: | Research and Technological Development |

| | |
|---|---|
| RWMC: | Radioactive Waste Management Funding and Research Center, Japan |
| STUK: | Radiation and Nuclear Safety Authority, Finland |
| TECDOC: | Technical Document |
| URL: | Underground Research Laboratory |
| WP: | Work Package |

# 1. Introduction

## 1.1 Background to the MoDeRn Project

The successful implementation of a repository programme relies on both the technical aspects of a sound safety strategy, and scientific and engineering excellence, as well as on social aspects such as public acceptance. Monitoring has the potential to contribute to all of these aspects and thus has an important role to play as national radioactive waste disposal programmes move forward towards a successful conclusion, i.e. safe and accepted implementation of geological disposal.

The role of monitoring through the staged implementation of geological disposal has been considered on an international basis through production of an International Atomic Energy Agency (IAEA) Technical Document (TECDOC) on monitoring of geological repositories (the IAEA Monitoring TECDOC) (IAEA, 2001) and by the European Commission (EC) within a Thematic Network on the Role of Monitoring in a Phased Approach to Geological Disposal of Radioactive Waste (the Monitoring ETN) (EC, 2004). These two documents have described how monitoring can support the implementation of geological disposal in a broad sense. The EC Seventh Framework Programme "Monitoring Developments for Safe Repository Operation and Staged Closure" (MoDeRn) Project aims to further develop the understanding of the role of monitoring in staged implementation of geological disposal to a level of description that is closer to the actual implementation of monitoring.

Work in the MoDeRn Project is undertaken in a comprehensive and coherent programme of research structured into six interrelated work packages:

- **Work Package 1: Monitoring Objectives and Strategies:** Work Package 1 will provide a clear description of monitoring objectives and strategies that (i) appear suitable in a given physical and societal context, (ii) may be implemented during several or all phases of the radioactive waste disposal process, (iii) appear realistic in light of available monitoring technology, (iv) take into account feedback from both expert and lay stakeholder interaction, and (v) provide information to support decision-making processes, while developing the licensing basis.

- **Work Package 2: State-of-the-art and RTD of Relevant Monitoring Technologies:** The second work package will result in a description of the technical requirements on monitoring activities as well as an assessment of the state-of-the-art of relevant technology responding to these requirements. In addition to technological R&D, WP2 includes a technical workshop, held in June 2010, involving other monitoring Research and Technological Development (RTD) projects (EC, 2010), leading to the identification of RTD techniques that enhance the ability to monitor a repository.

- **Work Package 3: *In situ* Demonstration of Innovative Monitoring Technologies:** The third work package will develop *in situ* demonstration of innovative monitoring techniques and provide a description of innovative monitoring approaches specifically responding to some of the design requirements of a repository.

- **Work Package 4: Case Study of Monitoring at All Stages of the Disposal System:** The fourth work package will be dedicated to a series of case studies illustrating the process of mapping objectives and strategies onto the processes and parameters that need to be monitored in a given context, the possible design of corresponding monitoring

systems, possible approaches to prevent and detect measurement errors, and the handling of "unexpected" repository evolutions.

- **Work Package 5: Dissemination of Results:** The fifth work package will provide a platform for communicating the results of the MoDeRn Project. WP5 includes an international workshop with safety, regulatory and advisory authorities and other stakeholders to communicate current state-of-the-art monitoring approaches and to engage expert stakeholders with broad expertise in geological disposal in the further development of repository monitoring objectives and strategies (the subject of this document). WP5 also includes an international conference on repository monitoring, and production and maintenance of a project web site.

- **Work Package 6: Reference Framework:** The final work package will consolidate results from the previous work packages and provide a shared international view on how monitoring may be conducted at the various phases of the disposal process. Early work in the MoDeRn Project has contributed to the reference framework by drafting a generic structured approach to monitoring - the MoDeRn Monitoring Workflow, which provides a methodology for developing and implementing a monitoring programme under specific national boundary conditions (Figure 1.1). The relationship of the MoDeRn Monitoring Workflow to work being undertaken in the project is illustrated in Figure 1.2.

As part of WP 5, a workshop involving expert stakeholders (the MoDeRn Expert Stakeholders Workshop) was held in Oxford, United Kingdom, on 4-5 May 2011. Thirty-one participants attended the meeting, including representatives from:

- Regulatory organisations in Belgium, Finland, Switzerland and the United Kingdom.
- Advisory bodies in the UK.
- A public stakeholder group in Germany.
- The Belgian agency for radioactive waste and enriched fissile materials (ONDRAF/NIRAS).
- MoDeRn Project partners who had personally not been significantly involved in the project previously.
- MoDeRn Partner organisations.

In the context of this meeting, the external participants are regarded as experts, where "experts" indicates individual expertise and experience in geological disposal of radioactive waste, and not necessarily in the development of repository monitoring programmes.

This document provides a record of the workshop. It has been prepared by Galson Sciences Ltd. (GSL) and has been reviewed by workshop participants.

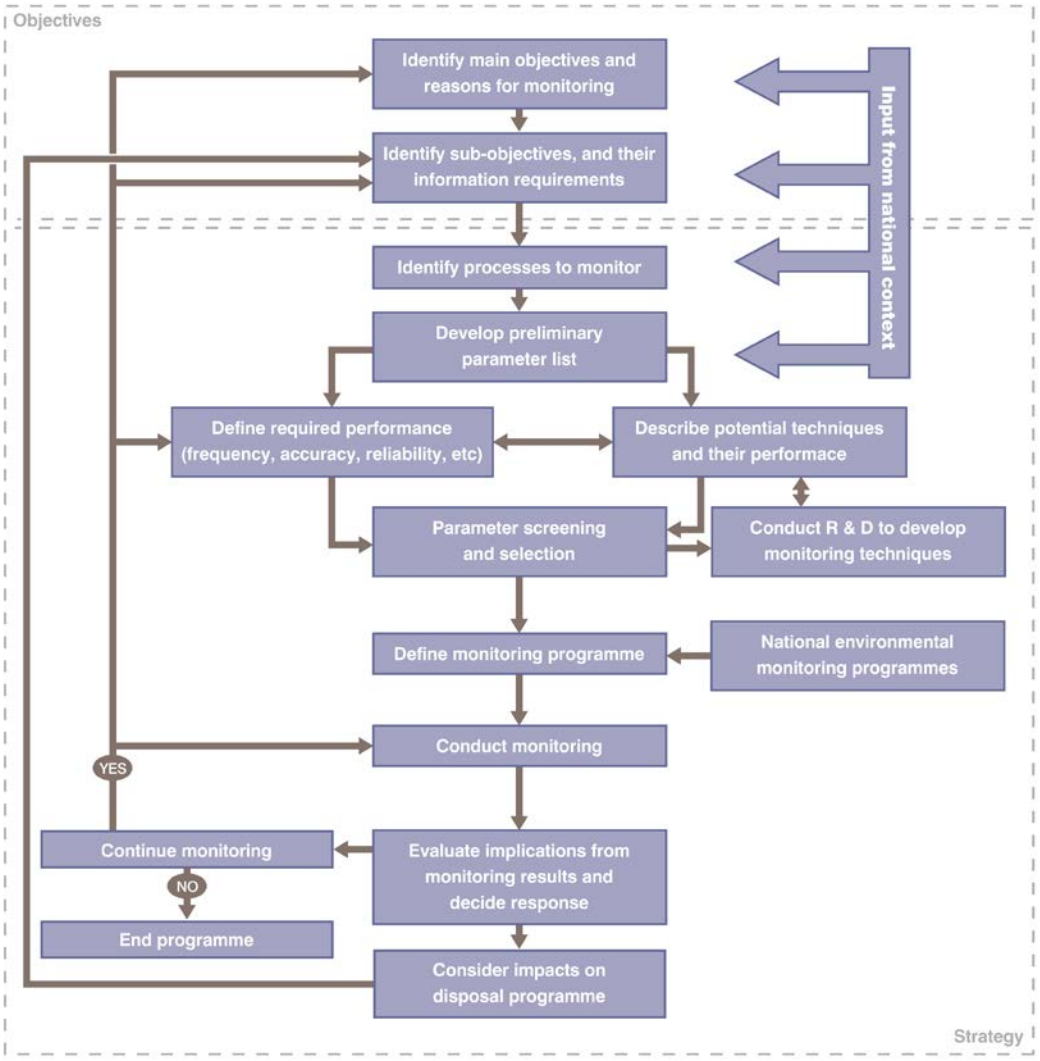


Figure 1.1: The Preliminary MoDeRn Monitoring Workflow.

## 1.2 Workshop Objectives

The objectives of the workshop were:

- To present the objectives and scope of the MoDeRn Project to interested experts, and to report progress achieved to date under the MoDeRn Project.
- To engage expert stakeholders not involved in the MoDeRn Project in the further development of repository monitoring objectives and strategies, with a view to obtaining feedback, challenges and advice to aid the direction taken in completing the MoDeRn work programme.
- To communicate current state-of-the-art monitoring approaches, including techniques being developed and demonstrated under the MoDeRn Project and other technologies relevant to repository monitoring from within and outside the nuclear industry.

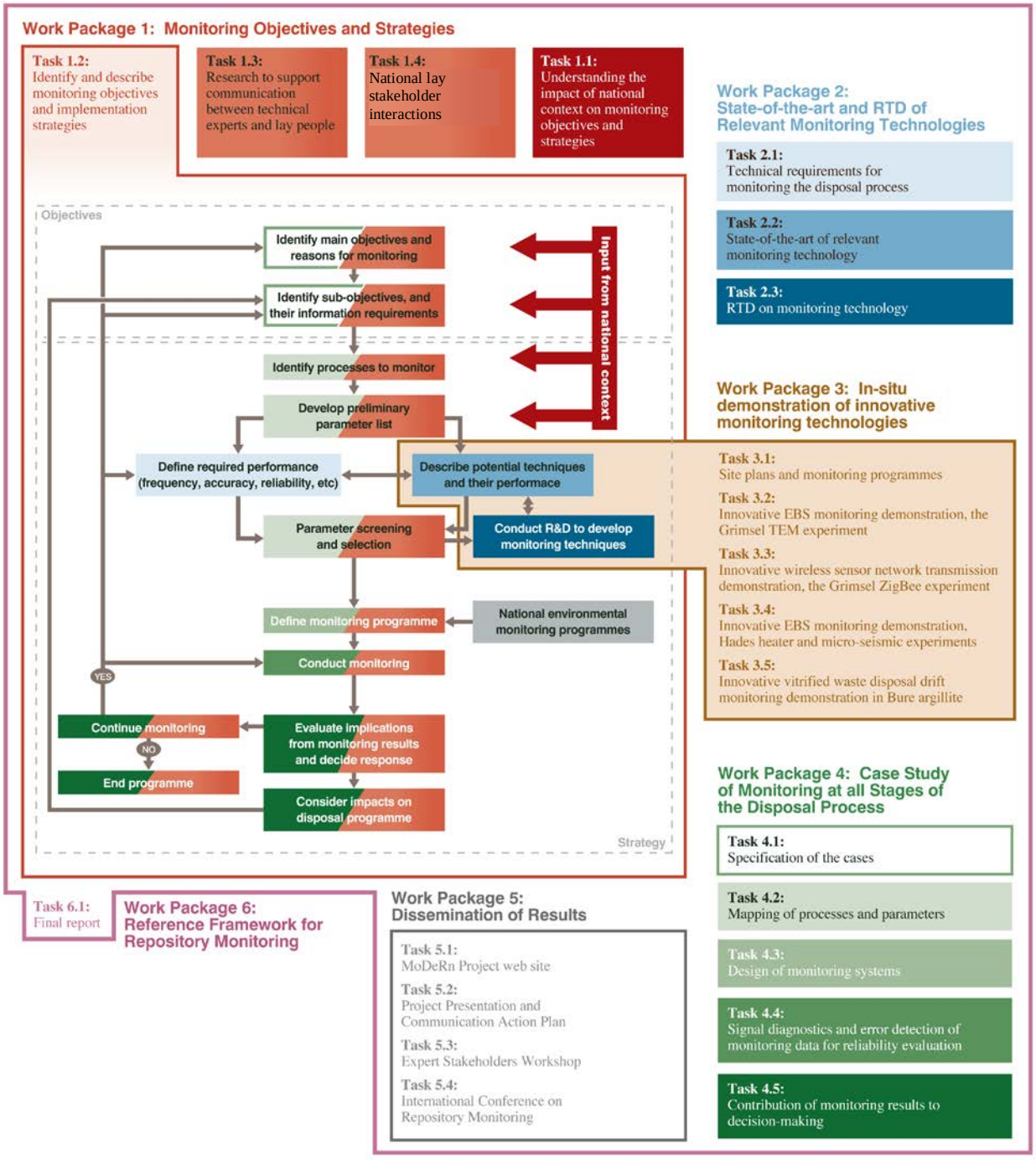


**Figure 1.2:** Relationship of the Preliminary MoDeRn Monitoring Workflow to MoDeRn Project work package tasks.

## 1.3 Workshop Organisation

The workshop was organised by a sub-committee of MoDeRn Partners, and was hosted by the Nuclear Decommissioning Authority (NDA). It took place over one-and-a-half days, and incorporated plenary presentation and discussion sessions, and breakout group discussions.

During the first afternoon, a series of introductory presentations were provided to inform external participants about the MoDeRn Programme, as well as providing an overview of related IAEA Safety Standards, with opportunities for questions and discussions.

The second day provided an opportunity to consider two themes of the MoDeRn Project: monitoring processes and monitoring technologies. Three parallel breakout group discussions were held under each theme, covering the following topics:

***Process Theme***

- **Topic 1:** Expectations and requirements of a monitoring programme (with distinction of aspects pertaining to pre-closure management and to support the basis for long-term safety).

- **Topic 2:** The relationship between a monitoring programme and managing the disposal process.

- **Topic 3:** A structured approach to developing a generic monitoring roadmap.

***Technology Theme***

- **Topic 4:** How to get representative monitoring information across a repository.

- **Topic 5:** Confidence in monitoring results.

- **Topic 6:** Monitoring techniques/technologies.

An emphasis was placed on receiving input from external participants, as well as individuals from MoDeRn Partner organisations who did not normally attend MoDeRn internal workshops. MoDeRn Partners were on hand to provide information on MoDeRn Project activities, and acted as scribes throughout the workshop, but discussion during the breakout groups was led by external participants, who were also responsible for providing feedback to plenary sessions.

External participants were invited to provide feedback and to challenge the direction that is being followed within the MoDeRn work programme, in order to ensure that the MoDeRn Project follows a balanced approach that captures the key issues associated with development of a repository monitoring programme.

## 1.4 Report Objectives

The objectives of this report are to:

- Provide a record of the MoDeRn Expert Stakeholders Workshop.
- Summarise the material presented at the workshop.
- Summarise workshop discussions on monitoring processes and monitoring technologies, by reporting the key issues identified in the breakout group discussions, together with any associated discussion during plenary sessions.
- Highlight key messages reiterated throughout the MoDeRn Expert Stakeholders Workshop by multiple groups and/or individuals.

Comments made by external participants during group discussions have not been attributed to individuals. Comments made by MoDeRn Partners during plenary discussion have been attributed.

A draft of this report was reviewed by workshop participants prior to completion.

## 1.5 Report Structure

The report is structured as follows:

- Section 1 provides some background to the EC MoDeRn Project, outlines the objectives and organisation of the workshop, and presents the objectives and structure of the report.
- Section 2 describes the introductory presentations given by MoDeRn Partners during the afternoon of 4 May, together with associated discussion. It also records plenary discussion concerning monitoring processes following these introductory presentations.
- Section 3 records the key points identified through breakout group discussions focusing on monitoring processes during the morning of 5 May.
- Section 4 records the key points identified through breakout group discussions focusing on monitoring technologies during the afternoon of 5 May.
- Section 5 records the closing remarks at the end of the workshop.
- Section 6 provides a summary of key recommendations identified through discussion at the MoDeRn Expert Stakeholders Workshop. These points were reiterated by multiple groups and/or individuals.
- Section 7 provides a list of references.

The workshop agenda and a list of participants are provided in Appendix A and Appendix B respectively. A workshop brief provided in advance to all workshop participants is provided in Appendix C. PowerPoint slides presented at the MoDeRn Expert Stakeholders Workshop will be published separately on the MoDeRn website.

# 2. Introductory Presentations on Day One

This section provides a summary of the presentations given during the afternoon of 4 May 2011 to provide context to the MoDeRn project and subsequent activities during the MoDeRn Expert Stakeholders Workshop. It also records the associated plenary discussion.

## 2.1 MoDeRn Project Overview

Stefan Mayer of Andra provided an overview to the MoDeRn Project. His presentation outlined:

- The objectives, scope and Partners involved in the MoDeRn Project.
- Stakeholder engagement activities on the subject of repository monitoring within and beyond the MoDeRn project, including:
  - The MoDeRn workshop on Monitoring Technologies held in June 2010 (EC, 2010).
  - The present MoDeRn workshop for external stakeholders.
  - The international conference on Repository Monitoring, to be held in March 2013.
  - A topical session on International Performance Confirmation Strategies for Geologic Repositories, to be held at the Waste Management 2012 conference in Phoenix, Arizona.
- Other methods available for communication between MoDeRn Partners and stakeholders interested in repository monitoring. These include the MoDeRn Project website and existing/planned project publications.
- Prior developments in the field of repository monitoring, which set the scene for the MoDeRn Project and other ongoing activities in this field that are running in parallel with the MoDeRn project, such as preparation of an IAEA safety guide on repository monitoring (IAEA, 2011).
- The context to the MoDeRn Project, including the project scope, societal and physical boundary conditions for monitoring, typical monitoring objectives, key steps in a monitoring programme, and relevant sources of information that can help develop a monitoring strategy.
- Key goals for the MoDeRn Project, which include:
  - Development of a knowledge base on national monitoring contexts.
  - Development of a common understanding of monitoring objectives and implementation strategies.
  - Recommendations for engagement with lay stakeholders in the context of knowledge production and confidence building for repository development.
  - Review of the state-of-the-art of relevant monitoring technologies (developed within and outside the nuclear industry), and an identification of knowledge gaps where further research and development is needed.
  - Demonstration of the use of non-intrusive monitoring techniques.
  - Development of a roadmap to identify processes and parameters that may need to be monitored within each stage of the disposal process.

## 2.2 IAEA Safety Standards for Monitoring

A presentation on IAEA safety standards relevant to monitoring and surveillance of radioactive waste disposal facilities was given by Bernd Frieg of Nagra. Bernd gave the presentation in place of Gerard Bruno of the IAEA, who was unable to attend the MoDeRn Expert Stakeholders Workshop. The presentation described:

- The role of the IAEA safety standards (including the Fundamental Safety Principles, Safety Requirements and Safety Guides).
- The mechanism for development of safety standards, including the role of the Commission on Safety Standards and associated committees.
- IAEA requirements set out in safety standards and other IAEA documents that are relevant to development of a repository monitoring programme.
- Progress in preparation of a new Safety Guide (DS 357) on monitoring and surveillance of disposal facilities for radioactive waste. The Safety Guide is currently under development, and is planned for publication in 2013. The scope of Safety Guide DS 357 includes the broad objectives for repository monitoring, key technical factors that influence the design of a monitoring programme, and periods in repository development where monitoring should be considered. The Safety Guide will apply to mining facilities and near-surface disposal facilities, as well as geological disposal facilities.

Bernd Frieg commented that the upcoming Safety Guide is due to be published at approximately the same time as the MoDeRn Project is due to be completed. With this in mind, he suggested that the MoDeRn Project should put forward a group of representatives to review and comment on the draft Safety Guide (between April-August 2011) in order to ensure that there is a link between the two activities. Stefan Mayer commented that the outcomes of the MoDeRn Project and the IAEA Safety Guide should be consistent, but he noted that the wider scope of the IAEA Safety Guide compared to the MoDeRn Project could lead to some differences.

## 2.3 Process Theme and Case Example

Michael Jobmann of DBE TEC presented an overview of the components of the MoDeRn Project focused on the process for developing a monitoring programme.[1] These are mainly included within MoDeRn WP1 and WP4. His presentation covered:

- The MoDeRn Monitoring Workflow, which provides a reference approach for the development of a monitoring programme.
- Key objectives for monitoring considered within the MoDeRn Project, including supporting the basis of the long-term safety case and supporting pre-closure management of a repository.

[1] Note that in this context, the word "Process" refers to the overall approach followed to develop a monitoring programme, which may include some or all of the steps illustrated in the Monitoring Workflow in Figure 1.1 (as well as additional considerations). Within the Monitoring Workflow, "Process" is also used to refer to specific physical phenomena that it could be desirable to monitor.

- The role of monitoring as a vital tool for communication with lay stakeholders, and planned dialogue with stakeholders in Belgium and the United Kingdom through exploratory engagement activities.

- A theoretical test case of the application of the MoDeRn Monitoring Workflow to the particular example of a repository in an evaporite rock, with the objective of supporting the basis of the long-term safety case (based on the German disposal concept for spent fuel). This example will examine how relevant processes, parameters and measurement locations for monitoring could be identified, based on the safety functions of the different components present in the disposal system. In the case considered, a monitoring programme will be designed to meet the requirements of confirming the performance of shaft, drift and borehole seals. In the German disposal concept, these engineered barriers have a key containment role in support of long-term safety, by sealing potential radionuclide migration pathways.

Michael Jobmann suggested that the MoDeRn Monitoring Workflow could be used as the basis for developing a Monitoring Roadmap to be presented under MoDeRn WP6.

### 2.4 Outline of Technology Programme

Brendan Breen of the NDA presented an overview of the technology-focused components of the MoDeRn Project. These are mainly included within MoDeRn WP2 and WP3. The technology programme includes:

- Identification of the technical requirements for monitoring.

- Review of the state-of-the-art of relevant technologies for repository monitoring, including identification of relevant technologies developed within and outside the nuclear industry.

- Development of monitoring systems and *in situ* demonstration of remote and non-intrusive monitoring techniques in underground rock laboratories (URLs). *In situ* demonstrators carried out as part of the MoDeRn Project include:
    - Development and testing of magneto-induced wireless data transmission networks at the High Activity Disposal Experimental Site (HADES) URL in Belgium.
    - Use of fibre optic sensors for distributed temperature sensing and monitoring the performance of cement-based materials within a repository environment (also carried out at the HADES URL).
    - Monitoring of bentonite saturation behind a low pH shotcrete plug using cross-hole seismic tomography at the Grimsel Test Site (GTS) in Switzerland.
    - Development of ZigBee technology for high-frequency wireless monitoring and data transmission, including tests at the GTS.
    - Testing the installation and performance of systems developed for monitoring an emplacement tunnel liner at the Bure URL in France.

Brendan Breen noted that assessing the status of what can be feasibly monitored with currently available technology allows decisions to be made now about what information could be obtained through a monitoring programme in the future.

## 2.5 Events at the Fukushima Daiichi Nuclear Power Plant

Kei Suzuki of RWMC, Japan, provided an overview of events at the Fukushima Daiichi nuclear power plant, following the earthquake and tsunami on 11 March 2011. Stefan Mayer commented that it was too early to fully understand the consequences of the nuclear accident at this stage for the people of Japan or for the nuclear waste management industry. He suggested that the siting of repositories away from the potentially deleterious effects of seismic activity, and their situation at depth, would ensure that the impact of such events on a geological disposal facility did not give rise to any safety concerns. He noted that a monitoring programme could, if desired, incorporate monitoring of natural processes such as seismic activity.

## 2.6 Plenary Discussion

Following the introductory presentations (including the introduction to the break-out groups to be held the following morning), the first day was concluded with a plenary discussion.

***Focus on monitoring to confirm expected behaviour***

An external participant asked why the scope of monitoring considered within the MoDeRn Project focused on confirmation of, rather than checking of, expected behaviour. He observed that this approach came across as rather arrogant, since the system might not perform as expected, and implementers should not assume that monitoring will only confirm their expectations. Stefan Mayer agreed and noted that there had been extensive discussion on this point within the MoDeRn Project. He explained the basis for focusing on confirming expected behaviour by noting that in order to gain an authorisation for construction of a repository (and subsequently, for disposal of waste), there would already need to be a high degree of confidence in the safe performance of the disposal system. Stefan Mayer emphasised that there would not be reliance on monitoring as a basis for ensuring safety. Monitoring would therefore not be used to check that a system could provide adequate safety – this would be addressed through site selection, site characterisation and development of the disposal system design. Submission of a robust safety case would always be the principal method for demonstrating confidence in the safety of the disposal system. However, data collected through a monitoring programme could be incorporated into the safety case, and hence, would help to support the basis for having confidence in safety.

Another external participant suggested that implementers should consider the possibility that monitoring data would not always confirm the expected behaviour of the repository system. He suggested that acceptable tolerances, or ranges in expected behaviour, should be defined before undertaking monitoring, and that there was a need to think about what actions could be taken in response to unexpected monitoring results. Stefan Mayer agreed that monitoring might not always confirm expected behaviour, and agreed that it was important to consider, in advance, how to address unexpected monitoring results. He noted that there were many possible reasons why unexpected results might be collected (e.g. sensor malfunction or failure, or as a result of the repository evolving in an unexpected manner), and indicated that several different response modes could be envisaged, including retrieval of the waste from the repository. Stefan Mayer suggested that the recent NEA project on reversibility and retrievability, which considered a step-wise decision-making process and balanced the extent of reversible decision-making against the level of passive safety of a repository, drew conclusions that are also relevant for repository monitoring.

Brendan Breen also acknowledged the need for monitoring programmes to account for the range of expected behaviour, and noted that tolerances needed to be set at acceptable levels based on the capabilities of the monitoring equipment, so that unreasonable expectations were not created. Stefan Mayer suggested that there should be a substantial margin between the limits of tolerable behaviour defined within a monitoring programme, and behaviour that would indicate a real safety issue.

Michael Jobmann noted that the test cases to be considered under MoDeRn WP4 would address the issue of unexpected behaviour. This will include developing examples of unexpected behaviour, consideration of how these examples would impact a monitoring programme and possible changes in the repository programme as a result.

***Wider role of monitoring***

An external participant commented that monitoring had a much wider role than performance confirmation alone, and that monitoring should be carried out to provide confidence in the safety of the disposal system to all stakeholders. He suggested that it was not always possible for lay stakeholders to be confident in the information provided by waste management organisations. Michael Jobmann indicated that a monitoring programme should consider how to undertake monitoring and communicate the results of monitoring effectively to all stakeholders, in order to contribute to confidence building. Stefan Mayer invited workshop participants to provide their perspectives on what was required in order to build confidence through monitoring. He noted that societal issues may be specific to particular national contexts.

Stefan Mayer indicated that the broad principles for monitoring have been established for some time and are recorded in documents such as the IAEA Monitoring TECDOC (IAEA, 2001) and the report of the Monitoring ETN (EC, 2004). He noted that the MoDeRn Project was focusing on a small number of monitoring objectives and sub-objectives in order to consider the more detailed components of developing a monitoring programme.

An external participant suggested that monitoring could support the decision-making process during repository siting, but would only provide confidence to lay stakeholders if more than one site were available to choose between. He suggested that monitoring would not provide confidence in the safety of a candidate repository site if it were only applied to one site, because related siting criteria would be selected to be favourable for that site. The participant also noted that a lack of confidence was closely linked to a lack of transparency in the activities of a repository implementing body. There was broad agreement for the need to provide access to and transparency of monitoring information.

Another external participant emphasised the importance of monitoring to lay stakeholders, noting that potential volunteer communities in his country had been asking detailed questions about repository monitoring well before potential sites for a repository had been identified.

***Scope and feasibility of post-closure monitoring***

An external participant asked about the feasible scope of post-closure monitoring, and asked whether only remote monitoring techniques should be considered for this period[2]. Stefan Mayer noted that post-closure monitoring represents a particular technical challenge, because of the need to ensure that the barrier properties of disposal system components are not undermined by the monitoring infrastructure. Brendan Breen agreed, and commented that there was a need to be realistic about the extent of post-closure monitoring that is possible. He noted that feasible timescales for monitoring were relatively short, compared to the timescales over which the waste remains hazardous. He also commented that there were limits to the usefulness of data that could be achieved through non-intrusive monitoring over long timescales. Brendan Breen emphasised that these limitations should be taken into account when designing a monitoring programme and setting acceptable tolerances for monitoring results.

An external participant commented that non-intrusive monitoring is challenging regardless of the stage in repository development during which it is applied. He noted that it may be difficult to identify feasible parameters to monitor that are directly related to a process that there is a desire to monitor. He also commented that the highly coupled nature of many repository processes would increase the complexity of interpreting monitoring results. Stefan Mayer suggested that monitoring to support the basis for long-term safety should draw on the wider safety assessment activities of a disposal programme to identify key safety-related components of a disposal system that could be monitored.

An external participant questioned whether post-closure monitoring was truly valuable given the limitations identified. Bernd Frieg noted that different countries' national contexts place different requirements on post-closure monitoring. He suggested that in order to obtain regulatory approval for closure of a repository, there would need to be a high level of confidence in the safety of a repository. Therefore, the MoDeRn Project places an emphasis on pre-closure monitoring, and draws a distinction between post-emplacement and post-closure monitoring. Stefan Mayer suggested that most of the monitoring of technical interest for post-closure performance of a repository is carried out prior to closure, but indicated that it was impossible to predict at this stage the rationale for future decision-making regarding monitoring and repository closure that could occur many decades in the future. Michael Jobmann commented that the public perception of repository monitoring often focuses on monitoring a closed repository to ensure that no radioactivity escapes. He noted that implementers and other expert stakeholders understand that post-closure monitoring is not necessary to ensure safety, although it could play a role in providing wider confidence in continued safety. However, communicating this to the public is difficult and does not always provide reassurance.

Jan Verstricht suggested that post-closure monitoring of a repository could be supported by measurements and monitoring routinely carried out by different organisations for various purposes not connected with the repository. For example, the Boom Clay in Belgium[3] is

[2] It is a principle of geological disposal that assurance of safety does not require post-closure monitoring. The IAEA emphasise that post-closure safety is provided by means of engineered and geological barriers; it does not depend on monitoring or institutional controls after the facility has been closed (IAEA 2006b; IAEA, 2001). Furthermore, any post-closure monitoring should be designed in such a way that no negative impacts on the performance of the containment barriers and therefore on the long-term safety of the repository would occur (IAEA, 2001).

[3] The Boom Clay is a potential host rock for a geological repository in Belgium.

overlain by aquifers that provide drinking water. The quality of this drinking water supply is likely to be monitored for as long as it provides a resource. Repository monitoring therefore takes place within a wider monitoring context. However, this does not imply a shift in responsibilities for ensuring safety, or for monitoring to confirm safety.

An external participant argued that post-closure monitoring of a repository would not be performed until a long time into the future. On this basis, they argued that there is little benefit from considering how a post-closure monitoring programme might be implemented at present, since such an evaluation would be limited by currently available technologies, many of which may be redundant by the time a repository is constructed, filled with waste and closed. Brendan Breen accepted that this was a valid point, but suggested that in order to ensure that monitoring was non-intrusive, it might be necessary to implement sensors and other monitoring equipment within a repository before it is closed, which requires and justifies a consideration of currently available technologies. He suggested that the potential complexity of post-closure monitoring supports the need to consider it at an early stage of repository development, but cautioned against making commitments at this stage that prove impossible to fulfil.

Jan Verstricht commented that it would not be publicly acceptable to do nothing now. He suggested that monitoring approaches should be considered now that can be modified and refined in future. Brendan Breen noted that an aim of considering post-closure monitoring at an early stage was to develop ideas for how to address associated issues, and to consider the types of decision-making that could be appropriate. He emphasised that current stakeholders will not be the actual decision-makers because of the timescales involved. Assen Simeonov suggested that safety analysis and site characterisation prior to and during construction should be used to develop an appropriate approach to post-closure monitoring.

External participants and MoDeRn Partners from Switzerland described the requirement in Switzerland for a Pilot Facility containing waste. This needs to be situated in the same geological environment as the repository, but should be hydraulically and physically separated from the main facility. It would be instrumented for monitoring (unlike the main facility), and would be constructed, filled and sealed before the main facility, so that there could be a period of monitoring prior to operation and closure of the main facility. Bernd Frieg noted that a Pilot Facility provides an opportunity to check performance of a system that is as similar as possible to the full repository, and suggested that this aids decision-making concerning the management of the main facility. Stefan Mayer asked whether there had been engagement with lay stakeholders in Switzerland concerning this approach, and if so, what kinds of feedback had been received. An external participant responded that there had been widespread debates with government, non-governmental organisations, and non-technical stakeholders regarding this approach.

An external participant suggested that monitoring will mean different things to different people, despite carefully worded definitions available in published literature. This should be addressed by providing clear explanations of what is meant during discussion. The participant agreed with Michael Jobmann that the public focus is often on post-closure monitoring, and agreed with other participants that post-closure monitoring should be considered at the time of siting.

# 3. Monitoring Processes

## 3.1 Introduction to Process Theme

Stefan Mayer gave an introductory presentation to breakout group discussions on the process for developing a monitoring programme during the afternoon of 4 May 2011. He noted that the emphasis of the MoDeRn project is on the main monitoring objective of verifying/confirming expected repository system evolution (of both the natural and engineered system), over the periods of construction, operation and closure of a repository, and possibly during the post-closure period. Monitoring in support of this objective would be conducted to support pre-closure management and to support the basis for the long-term safety case. Key issues to be further developed under the MoDeRn project include:

- How to enhance confidence in the disposal process.
- How to use monitoring to inform decision-making and thereby help manage the disposal process.

Breakout groups considered one of the following three topics:

1) Expectations and requirements of a monitoring programme with a focus on aspects pertaining to pre-closure management and supporting the basis for long-term safety (Breakout Group Topic 1).
2) The relationship between a monitoring programme and managing the disposal process (Breakout Group Topic 2).
3) A structured approach to developing a generic monitoring roadmap (Breakout Group Topic 3).

A series of questions was presented to help guide discussion within each breakout group. However, Stefan Mayer noted that participants should feel free to discuss issues that they felt were of particular importance, and should not feel constrained to only focus on these questions.

Breakout group discussions focused on the process theme were held during the morning of 5 May 2011. The subsequent plenary discussion was chaired by Bernd Frieg.

## 3.2 Breakout Group Topic 1: Expectations and requirements of a monitoring programme with a focus on aspects pertaining to pre-closure management and supporting the basis for long-term safety

The following questions related to this topic were posed to help guide discussion:

- Do you agree with the MoDeRn Project's main objectives?
- Would you use monitoring differently than the implementer?
- What are your priorities for monitoring?
- What do you see as others' priorities?
- What level of flexibility should there be in defining the monitoring programme now for future stages? Could monitoring be reduced or augmented over time?

The group was chaired by Doug Ilett, who also provided feedback to the plenary group. Stefan Mayer provided information to this group on behalf of the MoDeRn Partners. The group scribe was Alastair Clark.

This group held general discussions relating to expectations and requirements of a monitoring programme, rather than addressing each of the questions in order. Key suggestions proposed by the breakout group are recorded below.

The breakout group suggested that it will be necessary to interpolate between monitoring data collected, because there are limitations on the amount of monitoring equipment that can be employed within a repository and the spatial scales over which it can be employed. It will also be necessary to extrapolate monitoring results to longer timescales, because of the relatively limited timescale over which monitoring can be carried out, compared to the timescale over which the facility will be required to isolate and contain the waste.

The breakout group proposed that a monitoring plan should describe how monitoring results would be managed and the potential responses to unexpected data. A well thought out monitoring response plan would give confidence to regulators and lay stakeholders that the implementer had considered different possibilities for repository performance and knew how to use monitoring to best effect, taking account of the limitations of available monitoring technologies. It was suggested that a monitoring response plan could have similarities with a nuclear safety fault analysis, such as the consideration of different scenarios (based on possible monitoring results) and development of response plans associated with these scenarios.

The breakout group concluded that the types of response required would not be strongly dependent on whether monitoring is carried out in support of operational (pre-closure) safety or long-term safety.

Different scales of response are possible, depending on the nature of any unexpected monitoring results. Certain deviations observed through monitoring could require corrections, whilst some unexpected results might not require a response. This links to optimisation of the disposal process.

The scope of the MoDeRn project requires clarification, particularly regarding the extent to which the project considers post-closure monitoring aspects. The breakout group felt that post-closure monitoring was both challenging and important, and should therefore be included within the scope of the MoDeRn Project, even if the project could not resolve all issues associated with post-closure monitoring.

The breakout group emphasised the value and importance of work within the MoDeRn Project to establish the state-of-the-art of relevant technologies for monitoring a repository, noting that there would be significant demand for this information in future, as more repository programmes progress towards implementation. It was suggested that work in this area should summarise what technologies are available now and what technologies are likely to be available in the future.

Care should be taken not to over-state what can be achieved through monitoring, particularly given the spatial and temporal scales involved. There is a need for early and ongoing dialogue between the implementer and the regulator(s) to ensure that monitoring is carried out where possible and appropriate, but unreasonable demands are not placed on the implementer.

A monitoring programme should be flexible and adaptable from the outset, so that changes can be made as the repository development programme progresses, if new requirements for monitoring are identified. Monitoring should be carried out in a phased manner.

Collection of monitoring data should start early in the repository development process, so that the longest possible period for collecting data and monitoring behaviour of the disposal system is utilised. It was noted that closing part of a repository relatively early would allow *in situ* monitoring of evolving conditions similar to those likely to occur during the early post-closure period.

In developing a monitoring programme, implementers should try to consider what monitoring information is likely to be needed to inform future decision-making, so that steps can be taken to obtain this information. In particular, the breakout group suggested that it was important to try to anticipate (as far as possible) future monitoring needs, in order to install, at an early stage, monitoring equipment that could be needed later, when it might not be possible to install such equipment (e.g. if a tunnel had been backfilled or a seal emplaced).

Early and ongoing dialogue with the regulator(s) was recommended, to maintain a feasible, realistic working basis and thus to prevent the implementer from being subjected to unrealistic demands. Early-on, a monitoring programme should aim to be comprehensive. A more focused, streamlined programme can be developed over time, as understanding of key monitoring requirements becomes clearer.

Overall, the breakout group felt that the MoDeRn Project was providing a useful contribution to understanding issues associated with repository monitoring, and how to address these issues.

***Associated plenary discussion***

An external participant suggested that contrary to the observations of the breakout group, there should be differences in the response plan to monitoring in support of pre-closure (operational) safety and long-term safety. He suggested that some types of response would only be possible during certain periods of the repository lifetime. For example quality control measures routinely carried out during operational activities would be different to what might be feasible following repository closure. The session chair clarified that the breakout group had felt that the same processes would be monitored through the different periods of the repository lifetime, in order to see changes in behaviour. The external participant agreed that there would be some similarities in what was monitored during different periods, but there would also be differences.

Bernd Fried asked the breakout group what their recommendations for monitoring over a 100-year period prior to repository closure were. An external participant in the breakout group suggested that the timescales for monitoring and closure should be left open, to be decided on a case-by-case basis. However, he suggested that leaving a repository open for long timescales could create additional technical challenges, so it might be difficult to justify doing so purely to carry out repository monitoring. The participant suggested that the ability to respond to the results of monitoring will change over time. He indicated that there would be a limited ability to respond to the results of post-closure monitoring.

An external partner commented that in order to authorise a decision to close a repository, there would need to be a high degree of confidence in long-term safety. Post-closure monitoring would therefore not be required to demonstrate safety for any technical purposes, and was

therefore not necessary. Another external participant suggested that post-closure monitoring might still be carried out for public reassurance.

### 3.3 Breakout Group Topic 2: Relationship between a monitoring programme and managing the disposal process

The following questions related to this topic were posed to help guide discussion:

- What is the relative importance of monitoring to you?
- How do you view monitoring and what would you require for your own confidence building, i.e. in order to agree to further progress in the disposal implementation?
- How do you view monitoring in the context of others' (e.g. general public) confidence building?
- What type of decisions should be supported by monitoring information?
- What types of decisions do not require support by monitoring information?
- What are the key stages of repository implementation requiring monitoring input for your decision making? In particular, does monitoring play a key role in allowing a decision to close a repository? Do we know enough to completely define what will be required for closure? Can we, or do we have to, decide today on post-closure monitoring, if any?
- What are the responsibilities of the different actors (implementer, regulator, other stakeholders) in the monitoring programme (expectations, development, implementation, use...)?
- What advice would you give us in communicating our programme to lay stakeholders?
- What do you think is your role in communicating on monitoring to lay stakeholders?

The group was chaired by Erik Frank and feedback to the plenary group was provided by Florian Amann. Brendan Breen provided information to this group on behalf of the MoDeRn Partners. The group scribe was Liz Harvey.

Discussions in this group were initiated by working around the table so that each participant was able to contribute their perspectives on a monitoring programme and management of the disposal processes. Key suggestions proposed by breakout group members during this discussion were:

- Monitoring should be carried out at all stages of repository development. The spatial distribution and timing of monitoring activities may change over the periods of repository development.
- Monitoring can be used to improve the disposal system design and, hence, to support the basis for confidence in long-term safety. It can also be used as an input to risk assessment.
- It is crucial to understanding what constitutes the "normal" behaviour of the system, so that deviations from normal behaviour can be identified. Normal conditions should be

identified through baseline monitoring, which should begin as soon as a potential site is identified, in order to maximise the time available to gather data.

- Baseline monitoring needs to be carried out without disturbing the natural conditions around a potential repository site.

- Some baseline conditions at a site may be dynamic, and in such circumstances, it could be difficult to know how long to carry out baseline monitoring, or whether any trends observed reflect normal behaviour.

- A monitoring programme needs to include plans for data management over the short-term and long-term (since large volumes of data may be produced), and plans for communicating monitoring results. There should also be a clear strategy for responding to unexpected results. This could include several levels of response (e.g. alert, alarm, action), depending on the nature and quantity of unexpected results and their implications for repository safety.

- Use of a Pilot Facility for monitoring has associated advantages and disadvantages. It allows intensive monitoring to be carried out (e.g. using wide arrays of sensors) without affecting the passive safety of the main repository. However, there is a need to demonstrate that the behaviour of a Pilot Facility is representative of the wider repository in order to be confident in the transferability of monitoring data obtained in this area.

Following the round-table discussion, some of the questions posed by the MoDeRn Partners were considered. Key points from this discussion are recorded below.

***Use of a Pilot Facility***

In Switzerland, it is planned that a URL and a Pilot Facility will be developed at the repository site to provide evidence to support the decision-making process and to build confidence in long-term safety, as part of a staged process for authorisation. The URL is used for site characterisation, and will also be used for experiments to confirm key phenomena. The Pilot Facility is filled with radioactive waste, then closed and monitored, prior to operation of the main disposal facility. Once emplacement of waste has been completed in the main disposal facility, all emplacement drifts are sealed and monitoring is concentrated firstly on the Pilot Facility, and secondly on the geological environment of the repository by means of observations from the (still open) access tunnels. This approach facilitates monitoring over several decades or hundreds of years (the timescale can be decided by future generations). It is intended to provide representative information on the behaviour of the repository system for confidence building and to support the decision-making process for final closure of the repository.

Participants noted that it may be difficult to use a Pilot Facility to monitor processes at some scales (e.g. repository-wide scales) and careful planning would be needed to ensure that a Pilot Facility is fully representative of the repository itself.

***Requirements for confidence building***

Requirements for confidence building will depend on the national context. However, in general, confidence building is reliant on understanding what is being measured and what results are expected (both when equipment performs as expected, and when it malfunctions), and having a clear strategy for responding to unexpected monitoring results. There are many reasons why

unexpected results may be collected, which include the potential for the accuracy/reliability of monitoring equipment to fall over years of use in a repository environment.

There are limitations on what can be monitored and understood through a relatively short period of monitoring (compared to the lifetime of the repository), even through the use of a URL and/or Pilot Facility to collect data. Such limitations should be clearly stated, e.g. that monitoring over 100 years may only provide a "snapshot" of repository behaviour, rather than evidence of long-term trends. Nevertheless, data collected through a monitoring programme can be used to update our understanding of processes during periodic updates of the repository safety case.

***What types of decisions should/should not be supported by monitoring?***

Many decisions relating to repository development can be supported by some form of monitoring. Continuous or periodic monitoring can be used to iteratively update understanding of a disposal system. Clear definitions are required to distinguish between monitoring and site characterisation/investigation, so that the varying principles driving associated programmes of work are clearly understood, and can be readily communicated to stakeholders.

There should be clear bases for decisions about the processes and parameters to be monitored, and about the timescales and spatial scales over which monitoring should be carried out.

***Can we or do we have to decide today on post-closure monitoring?***

Monitoring technologies are likely to develop rapidly in the coming years and it is difficult to predict what will be available in future. However, some monitoring components (such as *in situ* sensors for non-intrusive monitoring) may need to be implemented in the near future. Therefore, post-closure monitoring should be considered at the early stages of planning for repository monitoring, but should also take into consideration ongoing developments in the monitoring state-of-the-art. R&D in this area should focus on non-intrusive monitoring technologies.

Any requirements for post-closure monitoring should be implemented early enough so that sensors/detectors can be emplaced in the disposal system where required without affecting the passive safety of the facility.

***Communicating monitoring to lay stakeholders***

It is important to communicate:

- What is going to be monitored.
- Why it is important to monitor this parameter.
- How it will be monitored.

Other issues that require clear communication are:

- Definitions to be used.
- The need to monitor baseline conditions at the outset of a repository development programme, in order to obtain an initial understanding of the undisturbed environment of a potential repository site.

- The strategy to respond to unexpected results.

It is important not to create a false impression of what can be achieved by monitoring. Care is also needed to communicate why monitoring is likely to focus on confirming, rather than checking performance.

A catalogue of monitoring activities could be prepared, detailing the responses that will be taken in the event of collecting certain monitoring data. The catalogue should be flexible and not over-ambitious.

Lay stakeholders often associate monitoring with the need for retrievability (perhaps because the two subjects have often been considered in conjunction). Their perspective is often that monitoring is carried out so that a leak from the repository can be identified, and waste can be retrieved. However, monitoring is not just about responding when something goes wrong. From the implementers' perspective, it is focused on increasing understanding of the disposal system, and as this understanding grows, confirming that performance of the disposal system is as expected and that the safety case is robust. With this in mind, it was suggested that monitoring and retrievability should be considered separately, where possible, to avoid the link between the two from becoming artificially strong in stakeholders' minds.

***Associated plenary discussion***

Bernd Frieg noted that when considering post-closure monitoring, a distinction should be drawn between "what should be done" and "what should be considered", since non-intrusive monitoring technologies (and particularly wireless data transmission equipment) currently have a relatively short lifetime and limited application. An external participant from the breakout group clarified that the group had focused on the need to consider post-closure monitoring at an early stage, so as to demonstrate that potential requirements had been identified.

Bernd Frieg acknowledged that there are limitations on what can feasibly be monitored, particularly over the long term and noted that these limits should be communicated. He suggested that experts should not be too negative in their communication of this point. Many different options for repository monitoring are possible and the limitations of monitoring technologies might be interpreted by some stakeholders as an inability to control the disposal system and ensure safety, which could potentially reduce stakeholder confidence.

An external participant agreed with the need to have a clear basis for the detailed development of the monitoring programme, in order to build confidence that it has been derived systematically and transparently, and that it focuses on the performance of key components of the system. The participant also agreed with the need for a monitoring response plan incorporating different possible levels of response according to the nature of unexpected results that are collected.

### 3.4 Breakout Group Topic 3: A structured approach to developing a generic monitoring roadmap

The following questions related to this topic were posed to help guide discussion:

- How useful is the monitoring workflow diagram?
- Does the workflow represent a structured approach for monitoring developments?
- What steps in the workflow need clarification?

- Will the approach provide a basis for development of a generic monitoring roadmap?
- What would you do differently – could you suggest items to improve the workflow?
- Is the workflow complete as presented or should something be added?
- Is the monitoring workflow applicable (truly generic) to your national context?

The group was chaired by Christophe Depaus, who also provided feedback to the plenary group. Michael Jobmann provided information to this group on behalf of the MoDeRn Partners. The group scribe was Matt White.

Discussion in this breakout group focused on the usefulness of the MoDeRn Monitoring Workflow (shown in Figure 1.1). Several comments were made on the current structure of the diagram, and breakout group participants recommended that the purpose of each stage in the workflow was clarified.

***Usefulness of the Monitoring Workflow and applicability to national contexts***

Breakout group participants agreed that the current MoDeRn Monitoring Workflow provides a useful starting point for development of a monitoring programme, and captures most of the key considerations relevant to this process. The experts stated that development of a workflow was useful as it provided a method for structuring a monitoring programme and provided an overview of the issues that should be addressed. Participants agreed that the MoDeRn Monitoring Workflow was broadly applicable to different national contexts for monitoring, although some adaptation might be required to optimise the workflow for a particular national context.

Breakout group participants suggested that the main objectives for monitoring a repository should take account of international recommendations (such as those made by the IAEA). However, sub-objectives would take account of the national context of the disposal programme.

Steps in the MoDeRn Monitoring Workflow were compared with the approach followed to develop a monitoring programme within the Belgian radioactive waste disposal programme. In Belgium, current planning assumes that repository monitoring will focus on performance confirmation. Monitoring requirements are derived based on a hierarchy of safety statements, which is an integral component of the Belgian safety strategy for geological disposal. The safety statements related to the safety concept, themselves are derived from the safety functions applicable to different components of the proposed disposal system.

The approach to develop a long-term testing and monitoring programme in Belgium is reported in detail elsewhere (ONDRAF/NIRAS, 2009) and is summarised in Figure 3.1. Breakout group participants noted that there were broad similarities between the Belgian approach and the framework provided by the MoDeRn Monitoring Workflow, although specific components were different to reflect the Belgian national context.

It was suggested that there are three different levels of decision-making applicable to development of a monitoring programme:

- Decisions about the objectives of the monitoring programme.
- Decisions about the engineering and technology to be used to carry out monitoring.

- Decisions during the evaluation of monitoring results.

Upstream and downstream activities within the disposal programme would link in with the MoDeRn Monitoring Workflow. Such activities will be country-specific and would be developed independently of the monitoring programme.

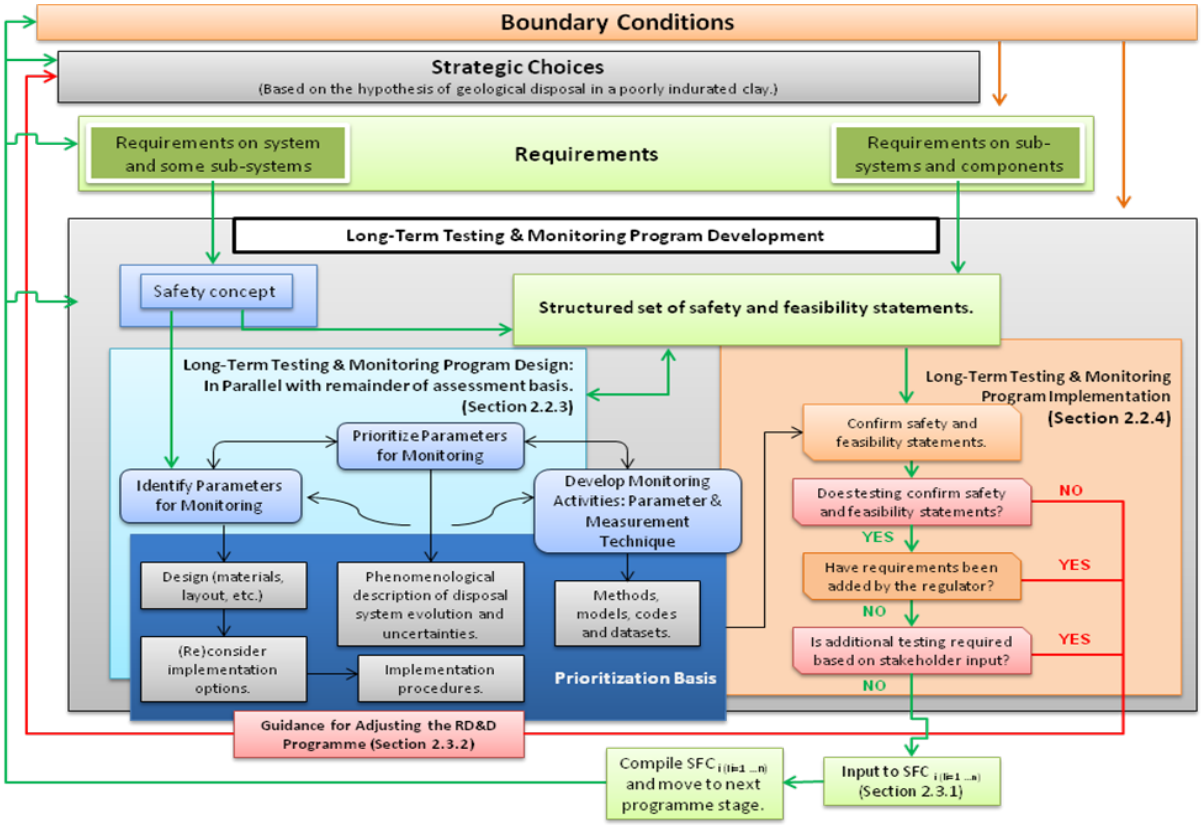


**Figure 3.1:** Overarching strategy for development of a long-term testing and monitoring programme of a geological repository in Belgium (ONDRAF/NIRAS, 2009).

***Suggestions for improvement and adaptation of the MoDeRn Monitoring Workflow***

Participants suggested that the MoDeRn Monitoring Workflow should clearly identify who would be responsible for carrying out each step in the process to design a monitoring programme (although this might vary from country to country). Sub-workflows could be developed to provide additional detail on relevant considerations associated with each step in the main MoDeRn Monitoring Workflow. In parallel, "participation" workflows could be developed, which would specify the responsibilities for each step in the workflow. The breakout group agreed, however, that responsibilities will be specific to the national context and it may therefore not be possible to identify responsibilities in a generic workflow.

A further suggestion was to state the phase(s) of a repository programme that the MoDeRn Monitoring Workflow was intended to be applied to. The MoDeRn Project representatives explained that the workflow was intended to be applicable to all phases of repository development (from site identification to post-closure).

A key requirement is that the link with the safety case needs to be shown in the MoDeRn Monitoring Workflow, since a goal of monitoring is to support the safety case, and to reduce

uncertainties associated with the expected performance of the repository, thereby making the safety case more robust. The link with the safety case should be made at the process and parameter level in the MoDeRn Monitoring Workflow. Monitoring should focus on parameters that are crucial to safety, in order to confirm that key elements of the disposal system are performing as required. Breakout group participants felt that the identification of potential monitoring parameters should be driven by the safety case, and not, in the first instance, by current technological monitoring capabilities (although these would need to be considered at some stage).

The breakout group suggested that the MoDeRn Monitoring Workflow needs to incorporate the following considerations:

- The process to be followed should the monitoring programme show that the disposal system is not performing as expected, or should the monitoring programme fail to provide useful information that fulfils the objectives of monitoring.

- The process to be followed in response to the collection of unexpected monitoring results. This step is a programme decision, and it was suggested that this could be added after the existing evaluation box in the MoDeRn Monitoring Workflow.

It was also suggested that the MoDeRn Monitoring Workflow should include steps to consider the relative benefit or detriment of monitoring certain processes and parameters, and steps to consider the level of effort required to implement a particular approach to monitoring. This last point is an important consideration to ensure that a monitoring programme is optimised to fulfil monitoring objectives within the constraints of a national context.

The experts were asked whether the level of detail in the MoDeRn Monitoring Workflow was appropriate. The breakout group felt that the level of detail provided (e.g. the number of stages shown in the diagram) was appropriate; additional detail would make the workflow too complicated, whereas less detail would reduce the value of the workflow. However, the breakout group did suggest that additional detail should be accessible (e.g. by presenting sub-workflows for one or more of the steps in the workflow).

***Associated plenary discussion***

Bernd Frieg commented that the breakout group had made some novel and useful suggestions for further developing the MoDeRn Monitoring Workflow. Matt White suggested that a short explanation of each component of the MoDeRn Monitoring Workflow was needed, to accompany the diagram and provide additional context that was difficult to capture on the diagram itself. He added that many of the suggestions made by the breakout group had already been considered in development of the MoDeRn Monitoring Workflow, and the comments from the breakout group indicated that the presentation of the workflow needed improvement.

Michael Jobmann noted that the importance of a clear plan for responding to unexpected monitoring results had been reiterated by this breakout group.

An external partner suggested that it was not clear from the MoDeRn Monitoring Workflow whether the safety case should drive the monitoring programme, or whether the monitoring programme drives the development of the safety case. Matt White suggested that a repository safety case would be developed iteratively, and monitoring is one of the inputs supporting updates to the safety case.

# 4. Monitoring Technologies

## 4.1 Introduction to Technology Theme

Brendan Breen introduced the objectives and scope of breakout group discussions on monitoring technologies, which were held during the afternoon of 5 May 2011.

Breakout groups were organised to consider the following three topics:

1) How to get representative monitoring information across a repository (Breakout Group Topic 4).

2) Confidence in monitoring results (Breakout Group Topic 5).

3) Monitoring techniques/technologies (Breakout Group Topic 6).

As with the process-themed breakout groups discussed in Section 3, a series of questions was presented to help guide discussion within each breakout group. However, Brendan Breen noted that participants should feel free to discuss issues that they felt were of particular importance, and should not feel constrained to only focus on these questions.

## 4.2 Breakout Group Topic 4: How to get representative monitoring information across a repository

The following questions related to this topic were posed to help guide discussion:

- How to deal with spatial aspects (what distribution of monitoring can be considered as representative for the whole repository)?

- How to deal with time-scale issues (for all those processes important to long-term safety evolving very slowly and/or not materialising until long after repository closure)?

- What are the corresponding (and/or other) limitations of added value that can reasonably be expected from monitoring? Are these acceptable? How to communicate them?

The group was chaired by William Turner, who also provided feedback to the plenary group. Brendan Breen provided information to this group on behalf of the MoDeRn Partners. The group scribe was Matt White. The group discussed each of the questions above in turn. Associated discussion is recorded below.

***Ensuring monitoring is spatially representative***

The breakout group suggested that the same monitoring systems would not necessarily be applied right across a repository. They noted that the geological environment of a repository will exert controls on the design of a monitoring programme, the selection of appropriate monitoring techniques, and the extent to which spatial variations in behaviour are expected. Geostatistical techniques are available for the characterisation of heterogeneous rock masses, and consideration of these techniques could influence the distribution of monitoring sensors.

The breakout group also observed that different waste inventories may have different monitoring requirements, due for example to differences in the engineered barriers that may be employed, the different levels of heat/gas output from different wastes and other national factors, such as

the need to ensure fissile materials are safeguarded. It could be appropriate to carry out monitoring to confirm that detrimental interactions between different waste types do not occur if they are co-located in the same repository.

***Suggestions for addressing the long timescales associated with a repository***

Timescales required for monitoring at all stages of the disposal process will vary from country to country and there is no clear definition of what constitutes a "long" period for monitoring purposes. At present, the period during which a repository will be under institutional control has not been defined in most disposal programmes, and monitoring timescales may be strongly linked to this timeframe. The breakout group commented that significant societal changes can occur over relatively short timeframes, and could potentially occur during the period of institutional control. The breakout group recognised that there had to be a good reason for monitoring to be maintained by society; the example of the church being maintained as a living institution over centuries was discussed, and it was agreed that the church had survived because of a continued belief in religion within society.

The breakout group noted that processes that are important for long-term safety may occur so slowly that no evolution in behaviour may be seen over feasible monitoring timescales. It is therefore crucial to have confidence that if no change is recorded, this corresponds to the true behaviour of the disposal system, and not to failure of monitoring equipment.

The breakout group recognised that it was not necessarily the role of monitoring to provide all of the information on the rate of processes that would be applied in the safety case. Natural system information can be used to show the rate of processes occurring at a site. For example, oxygen isotopes had been used to determine the rate of diffusion through the Opalinus Clay in Switzerland. The breakout group recognised that understanding of fundamental geological processes was important to understanding the evolution of a system. The group suggested that processes such as local dissolution and re-precipitation need to be accounted for in the feature, event and process (FEP) databases that underpin safety assessment.

Over time, monitoring the disposal system would lead to an increased understanding of the behaviour of the disposal system. The reduction in uncertainty may make it practical to develop predictive models against which monitoring results could be compared. An analogy was drawn with the oil and gas industry in the North Sea. In the early stages of production of oil and gas, estimates of reserves were highly uncertain and numerical models of multi-phase flow were not able to predict future production rates. However, following decades of production, a closer match could be achieved owing to the greater understanding of the system.

Monitoring data would feed into the periodic updating of safety cases. In time, the amount of monitoring undertaken would probably reduce as uncertainties in the disposal system were reduced. The breakout group recognised that safety assessment models would continue to be conservative, although more realistic models needed to be used as a basis for assessing monitoring data. This could present a challenge to the integration of monitoring results into a safety assessment.

There was also a requirement that monitoring data should inform the initial state of the post-closure safety assessment.

***Other limitations on monitoring***

The breakout group commented that not all of the processes that are fundamental to repository performance are amenable to being monitored directly. Certain types of behaviour would need to be inferred through indirect monitoring. Nevertheless, it can be useful to constrain possible behaviour of one variable through the monitoring of other variables. This would allow the development of confidence in understanding of repository performance.

The breakout group commented that a monitoring programme with built-in redundancies and sharing of data, particularly with other similar disposal programmes, would help to improve the robustness and confidence in the monitoring programme. Establishing the baseline conditions of a potential repository site and ensuring that the natural behaviour of the system is understood are particularly important to help plan a representative monitoring programme. The breakout group suggested that there may be value in monitoring some parameters away from the repository, if it aids an evaluation of site characteristics. Modelling can be used to refine the understanding of site characteristics, particular where parameters are strongly coupled.

The breakout group suggested that the approach to manage monitoring data so that it is useable, including data analysis, together with the strategy for responding to unexpected monitoring results, are as important as undertaking the monitoring itself.

The breakout group noted the potential value of sharing available information between repository development projects, particularly those having similar disposal concepts, and thereby consolidating evidence for repository behaviour.

The breakout group concluded by emphasising that the repository must be passively safe. Monitoring should not be used to ensure this – it should be integral to the disposal system design. Monitoring should be carried out primarily for confirmation and reassurance.

***Associated plenary discussion***

Matt White suggested that periodic review and update of the safety case could be a key driver for management of monitoring data and development of the monitoring programme. He suggested that the volume of monitoring data would build up through this iterative process.

## 4.3 Breakout Group Topic 5: Confidence in monitoring results

The following questions related to this topic were posed to help guide discussion:

- What is the basis for judging monitoring results?
- How should boundaries (e.g. trigger values) be defined?
- Should bounding values be related to the conservative assumptions of models to predict evolutions?
- How should the implementer deal with unexpected results (i.e. results outside initially identified bounds, calling for further analysis and possibly further actions)? Will they call for different types of actions whether they relate to pre-closure performance as opposed to the basis for long-term safety?

The group was chaired by Jean Pierre Wouters, who also provided feedback to the plenary group. Michael Jobmann provided information to this group on behalf of the MoDeRn Partners. The group scribe was Alastair Clark.

This group held general discussions relating to approaches to build confidence in monitoring results, rather than addressing each of the questions in order. Key suggestions made by the breakout group members during the discussion are recorded below.

A clear action (response) plan is needed, with trigger values imposed that would stimulate certain responses to unexpected monitoring results. A graduated series of possible responses was recommended, based on the nature of the unexpected results.

A monitoring programme needs to incorporate redundancy (e.g. in the spatial distribution of monitoring, frequency of monitoring or use of several different sensor types/monitoring techniques), in order to give confidence that monitoring data truly reflect the behaviour of the disposal system.

Proven, established monitoring techniques should be used where possible – new technologies may behave unexpectedly. If new technologies are used, steps should be taken to ensure that there can be confidence in the associated monitoring results, for example by carrying out the same monitoring using a more established technology.

Monitoring should be clearly linked to the safety functions of the disposal system and the associated criteria for each function. Monitoring should also focus on any safety-critical parameters where the safety case identifies that there is uncertainty in expected behaviour. This would give confidence that the monitoring programme focuses on aspects of repository performance that are key to pre-closure and long-term safety.

Transparency in the activities of the implementer, the regulator and other expert stakeholders is crucial to build lay stakeholder confidence.

The use of an independent body to oversee monitoring, and to interpret monitoring data should be considered. This would give confidence that all monitoring data is made available and analysed, and that appropriate responses will be implemented and followed up if necessary. Monitoring during the early periods of repository development should be used as a tool to build confidence in performance of the system.

There may be a link between existing monitoring programmes at nuclear power stations and monitoring a repository. However, the link is not currently clear, because of the different monitoring timescales that could be involved, and because there is variation in monitoring approaches adopted in different countries and at different nuclear sites.

There should be a clear strategy from the outset on when and how to communicate with lay stakeholders on monitoring. This would help to avoid ambiguity in the approach followed, which might otherwise detract from peoples' confidence. The approach to communicate monitoring data with lay stakeholders will depend on the local/national context for monitoring.

***Associated plenary discussion***

An external participant agreed with the findings of the breakout group, noting that the amount of monitoring data to be made available to lay stakeholders would depend on the local, national and

international context. Jan Verstricht suggested that there might be security issues associated with making large volumes of monitoring data available in the public domain. Another external stakeholder suggested that it was more important to ensure that the repository is managed effectively and any anomalous monitoring results are responded to appropriately, and at the earliest opportunity, than it is to ensure that monitoring data are immediately made available to the public. This might delay or limit the release of source data from monitoring. Lou Areias agreed and suggested that it might not be appropriate for monitoring data to be available on a live, real-time basis. He also noted that in some cases, it might not be appropriate to wait for feedback from lay stakeholders on monitoring results before taking some action in response to anomalous monitoring – a quick response might be more important. Brendan Breen agreed and suggested that there should be a clear distinction between timescales for making monitoring data available, and the timescale for any responses to monitoring by the implementer. He also suggested that making large volumes of raw data available would not necessarily contribute to confidence building, since such data would require significant amounts of processing to rationalise it and identify any patterns in the data. An external participant commented that it was important to explain the implications of what is measured to lay stakeholders. Another external participant agreed and suggested that raw monitoring data should not be made available to the public without providing the context necessary to understand it.

Jan Verstricht commented that uncertainties about the significance of a pattern observed in monitoring data could persist even after collecting data for relatively long periods of time. He cited patterns in climate change data as an example, noting that there was still disagreement over the causes of observed increases in temperature and greenhouse gases.

### 4.4 Breakout Group Topic 6: Monitoring techniques/technologies

The following questions related to this topic were posed to help guide discussion:

- Is our approach to concentrate on non-invasive technology appropriate?
- Can you recommend other techniques for monitoring?
- Should additional techniques be developed?
- How should we deal with further development of the state-of-the-art? What might be the influence of new technologies on monitoring approaches? When should we stop incorporating new techniques into the monitoring programme?

The group was chaired by Frederic Bernier, who also provided feedback to the plenary group. Jan Verstricht provided information to this group on behalf of the MoDeRn Partners. The group scribe was Liz Harvey. The breakout group consider each of the questions in turn.

***Focus on non-invasive (non-intrusive) monitoring technology***

There was a short initial discussion to clarify what monitoring techniques are being considered within the MoDeRn Project. It was noted that the state-of-the-art report would consider both intrusive and non-intrusive monitoring technologies, with discussion structured according to the location of the monitoring equipment (e.g. repository-based, borehole-based, surface-based and air-based). This approach is taken so that a judgement on what constitutes intrusive/non-intrusive monitoring can be formed by the reader, rather than imposed by the MoDeRn Project.

Experimental and demonstration work within the MoDeRn Project focuses on several non-intrusive monitoring and data transmission techniques. The report of the Troyes Monitoring Technologies Workshop (EC, 2010) provides a valuable source of information on currently available monitoring techniques, including techniques used by the civil engineering, waste storage, mining, carbon capture and oil and gas industries. It will be a key input to the state-of-the-art report to be prepared under the MoDeRn Project.

The breakout group suggested that non-intrusive monitoring provides many benefits during all periods of a repository lifetime and suggested that it was appropriate for the MoDeRn Project to focus on developing and demonstrating such techniques. However, it was recognised that there were weaknesses associated with currently available non-intrusive monitoring technologies (for example sensor lifetime and prevalence of point measurement techniques). The breakout group suggested that the limitations of non-intrusive monitoring equipment should be clearly defined at the outset of planning a monitoring programme. The group also suggested that where possible (without affecting the passive safety of a repository), conventional monitoring techniques should be used to build up a clear, reliable picture of the behaviour of the disposal system. Wired monitoring could also be combined with wireless data transmission across key barrier components of the repository, in order to utilise the benefits of two complementary approaches.

Some breakout group participants felt that borehole-based monitoring could not be considered to be non-intrusive, because boreholes would need to be drilled in relatively close proximity to disposal tunnels, and would potentially intrude into the near field.

Other participants noted that the term "non-intrusive" is used to denote all techniques where wires do not provide a potential pathway for rapid transport of radionuclides. Given this definition, non-intrusive techniques would include wireless techniques and remote monitoring techniques. However, wireless monitoring typically employs *in situ* sensors in conjunction with wireless data transmission. Breakout group participants suggested that the sensors could affect local conditions within the repository, creating minor perturbations, and therefore, such monitoring approaches might not be considered truly non-intrusive.

***Recommendations of other techniques for monitoring***

The breakout group noted that various additional non-intrusive monitoring techniques were available that were not being investigated as part of the MoDeRn Project. These include acoustic emission/micro-seismic techniques, satellite interferometry and other airborne techniques. The breakout group suggested that magnetic imaging techniques are also available, and could potentially be used to monitor changes in the oxidation state (and hence, corrosion) of some materials, which can be challenging to monitor directly by other means. It was suggested that the state-of-the-art report should consider all available monitoring techniques, not just those investigated in detail within the MoDeRn Project.

The importance of visual inspection as a monitoring technique, particularly during the early periods of the repository lifetime was also noted. It was also noted that monitoring in support of long-term safety need not be limited to the repository location – it could begin with package monitoring during processing and interim storage.

A breakout group participant noted that the report of the Troyes Monitoring Technologies Workshop (EC, 2010) provides a good overview of available monitoring technologies, but noted that the parameters that could be monitoring by applying each technique were not discussed.

The participant suggested that this was an important link to make, to facilitate planning of a monitoring programme.

***Suggestions on additional techniques to develop***

The breakout group recommended that R&D efforts should focus on improving the reliability, robustness and lifetime of equipment used for non-intrusive monitoring, and should combine these assets with miniaturisation of equipment, to minimise any perturbations on the repository environment.

A participant suggested that developing techniques for remote monitoring of waste packages in a repository would also be beneficial for monitoring during storage on the surface, since this would reduce the need to physically retrieve individual packages in order to monitor them.

The value of Pilot Facilities for carrying out monitoring was reiterated, although it was suggested that a decision to utilise such facilities was strategic, rather than technology focused.

The breakout group noted that it would be important to consider how monitoring equipment (particularly that within the repository or within boreholes), would be dismantled, once no longer needed, so that stakeholders could be confident that barriers would remain intact, and such dismantling would not affect the passive safety of the repository over the long term.

***Incorporating further developments in the state-of-the-art***

The breakout group supported the need to build relationships and draw experience from outside the nuclear industry, although participants cautioned that "off-the-shelf" technologies might not always be transferable to repository monitoring. It was suggested that the aircraft industry might also have experience of monitoring relevant parameters such as metal fatigue using miniature devices under extreme conditions.

Monitoring programmes should consider the current state-of-the-art to select the best available technique for a particular purpose. Participants were confident that there will be significant technological developments in the field of monitoring over the coming years. However, it was noted that although newer technologies offer advances in size, resolution and robustness, they are not always sufficiently reliable, or well understood, to be employed for repository monitoring. In some cases, it is preferable to employ established, well-understood techniques with a proven track record.

A breakout group participant suggested that new techniques could be used in conjunction with more established techniques for repository monitoring, until there is confidence that the new technique is fully understood, at which point, a complete switch to the new technique could be made. If such an approach were used, it would be possible to continually update and adapt the techniques and equipment used for repository monitoring.

Capturing developments in the state-of-the-art should be achieved by ensuring that a monitoring approach is flexible and adaptable to future monitoring requirements and developments in technologies.

***Associated plenary discussion***

Jan Verstricht reiterated the need to strike a balance between incorporating state-of-the-art techniques in a monitoring programme, and being confident in the reliability of a new technique. He also noted the benefit of monitoring waste packages during storage as a contributor to confidence building. An external participant agreed, noting that store monitoring also provided an opportunity to test monitoring techniques in a high radiation environment. The external participant supported the use of remote monitoring techniques where possible.

An external participant noted the importance of developing monitoring techniques in the context of a monitoring strategy, i.e. to fulfil requirements to monitor certain processes or parameters.

# 5. Workshop Closing Remarks

Stefan Mayer thanked the NDA for hosting the MoDeRn Expert Stakeholder Workshop. He noted that participants had engaged fully in discussion and thanked everyone for providing valuable feedback, despite the challenge of having only a short timescale to familiarise themselves with repository monitoring and the MoDeRn Project. Stefan Mayer highlighted some of the common issues reiterated by different groups and individuals throughout the workshop (these points are included in Section 6 of this report).

Stefan Mayer noted that feedback received during the MoDeRn Expert Stakeholder Workshop would be used to improve activities within the MoDeRn Project. He observed that expert stakeholders were supportive of the work being undertaken in the project, and that constructive suggestions had been made for ensuring that MoDeRn activities capture the issues associated with repository monitoring in greater detail.

Stefan Mayer reminded participants that published project deliverables are placed on the MoDeRn website at http://www.modern-fp7.eu/ He noted that (apart from the planned engagement with lay stakeholders) the next MoDeRn outreach activity would be an international conference on repository monitoring, to be held in 2013. This conference has a broad target audience including participants at the MoDeRn Expert Stakeholder Workshop, as well as those involved in the Troyes Monitoring Technologies Workshop (EC, 2010).

# 6. Summary of Key Recommendations Raised in Discussion

This section provides a summary of key recommendations identified through discussion at the MoDeRn Expert Stakeholders Workshop. In particular, it records key conclusions that were reiterated by a number of different participants or groups.

- There is a need to clearly explain the relationship of the monitoring programme to the overall repository development programme, especially the safety case and to engineering design. Links to the safety case could be added to the MoDeRn Monitoring Workflow. Describing the links to the safety case would help to communicate why we assume that monitoring is undertaken to confirm expected behaviour, rather than to check that the system is performing adequately. There is a sound basis for this approach, but if not explained properly, it could be perceived as arrogant and over-confident.

- The MoDeRn Monitoring Workflow provides a valuable overview of what must be considered when developing a monitoring programme.

- It is important to define acceptable ranges (tolerances) for monitoring results, and to have a clear plan in place to respond to any results collected that fall outside these ranges.

- There may be benefit in considering the issue of post-closure monitoring further within the MoDeRn Project.

- There is a need for monitoring programmes to be flexible to support the future requirements of decision making within a repository development programme, and so that they take account of future developments in the state-of-the-art. However, there is still a need to provide today's view of what can be done, particularly with respect to post-closure monitoring.

- Some stakeholders feel that there is a need for independent scrutiny of monitoring programmes, and monitoring results in particular, in order to build the trust of the general public. Stakeholders also feel it is important to have a clear strategy in place from the outset of implementing a monitoring programme, on when and how the results of the monitoring programme will be published and communicated.

# 7. References

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ONDRAF/NIRAS (2009). Long-Term Testing and Monitoring Strategy, SFC1 level 5 report: Final report, NIROND-TR 2011-29 E, December 2009.

# 8. Appendix A: Workshop Programme

| Wed 4 May | Item | Lead |
|---|---|---|
| 14.30 – 15.00 | Coffee and Registration | NDA |
| 15.00 – 15.10 | Welcome | NDA |
| 15.10 – 15.40 | Project Overview | Andra |
| 15.40 – 16.10 | IAEA, Safety Standards for Monitoring | IAEA |
| 16.10 – 16.40 | Process (WP1, WP4) | DBE/UA/GSL |
| 16.40 – 17.10 | Technology (WP2, WP3) | NDA/Aitemin |
| 17.10 – 17.40 | Day 2 Programme & Discussion | Andra/NDA |
| 18.30 – 19.15 | Reception | |
| 19.15 – 22.00 | Dinner | |

| Thu 5 May | Item | Lead | |
|---|---|---|---|
| 08.30 – 08.45 | Introduction to Theme: *Process* | Andra | |
| 08.45 – 10.30 | *Process* Theme Group Session: (3 parallel Topics)<br>**Topic 1**: Expectations and requirements of a monitoring programme (with distinction of aspects pertaining to pre-closure management and to support basis for long term safety).<br>**Topic 2**: Relationship between monitoring programme and managing the disposal process.<br>**Topic 3**: A structured approach to developing a generic monitoring roadmap | Information | Scribe |
| | | **1** - Andra | NDA |
| | | **2** – NDA | GSL |
| | | **3** - DBE | GSL |
| 10.30 – 11.00 | Coffee | | |
| 11.00 – 12.00 | *Process* Plenary feedback & discussion | Nagra | |
| 12.00 – 13.00 | Lunch | | |
| 13.00 – 13.15 | Introduction to Theme: *Technology* | NDA | |
| 13.15 – 14.30 | *Technology* Theme Group Session: (3 parallel Topics)<br>**Topic 4**: How to get representative monitoring information across the facility?<br>**Topic 5**: Confidence in monitoring results<br>**Topic 6**: Monitoring techniques/technologies | Information | Scribe |
| | | **4** - NDA | GSL |
| | | **5** - DBE | NDA |
| | | **6** - EURIDICE | GSL |
| 14.30 – 14.45 | Coffee | | |
| 14.45 – 15.45 | *Technology* Plenary feedback & discussion | Aitemin | |
| 15.45 – 16.00 | Conclusions and closing remarks | Andra | |

# 9. Appendix B: Workshop Participants and Affiliations

| Name | Organisation / Affiliation | Status |
|---|---|---|
| Fergus Gibb | CoRWM | External Participant |
| Simon Harley | CoRWM | External Participant |
| Erik Frank | ENSI | External Participant |
| Doug Ilett | Environment Agency | External Participant |
| Florian Amann | ETH | External Participant |
| Frederic Bernier | FANC | External Participant |
| Jean Pierre Wouters | FANC | External Participant |
| Wakasugi Keiichiro | NEA | External Participant |
| William Turner | NII | External Participant |
| Christophe Depaus | Ondraf/Niras | External Participant |
| Eckhard Kruse | Pfarramt Gartow | External Participant |
| Rainer Laaksonen | STUK | External Participant |
| Jose-Louis Garcia Sineriz | Aitemin | MoDeRn Partner |
| Samira Ouchhi | Andra | MoDeRn Partner |
| Stefan Mayer | Andra | MoDeRn Partner |
| Stephane Buschaert | Andra | MoDeRn Partner |
| Michael Jobmann | DBE | MoDeRn Partner |
| Jan Verstricht | Euridice | MoDeRn Partner |
| Lou Areias | Euridice | MoDeRn Partner |
| Liz Harvey | GSL | MoDeRn Partner |
| Matt White | GSL | MoDeRn Partner |
| Bernd Frieg | Nagra | MoDeRn Partner |
| Alastair Clark | NDA | MoDeRn Partner |
| Brendan Breen | NDA | MoDeRn Partner |
| Steve Reece | NDA | MoDeRn Partner |
| Benno Haverkate | NRG | MoDeRn Partner |
| Martina Ligaunova | RAWRA | MoDeRn Partner |
| Kei Suzuki | RWMC | MoDeRn Partner |
| Assen Simeonov | SKB | MoDeRn Partner |
| Susanna Andren | SKB | MoDeRn Partner |
| Anne Bergmans | UA | MoDeRn Partner |

# 10. Appendix C: MoDeRn Expert Stakeholder Workshop Brief



## Expert stakeholder workshop
## Workshop Brief

| | |
|---|---|
| Grant Agreement number: | 232598 |
| Author: | NDA |
| Date of preparation: | 23 March 2011 |
| Version status: | 2 |
| Draft update status | 0 |
| Comments on Draft | |

**An International Workshop for Expert Stakeholders on Geological Repository Monitoring**

**Venue: Oxford Spires Four Pillars Hotel, Oxford, UK, May 4th-5th 2011**

**Organised by the UK Nuclear Decommissioning Authority (NDA)**

This brief provides information for attendees of the Expert Stakeholders Workshop, organized by MoDeRn (Monitoring Developments for safe repository Operations and Staged Closure), an EC co-sponsored FP7 project. This information has been provided to inform the invited experts of the scope of the work programme and the content of the workshop.

## SUMMARY OF MODERN WORK PROGRAMME

The objective of the collaborative project MoDeRn is to take the state-of-the-art of broadly accepted, main monitoring objectives, to develop these to a level of description that is closer to the **actual implementation of monitoring** during the staged approach of the disposal process.

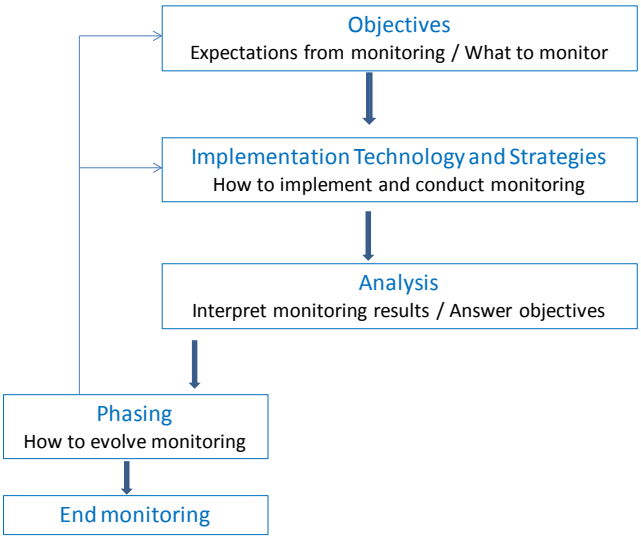
It is intended to verify whether such implementation is able to address **expert and lay stakeholder expectations**, to provide an understanding of **monitoring activities** and **available technologies** that can be implemented in a **repository context**, and to provide recommendations for related, future stakeholder engagement activities.

As a core part of its proposed activities, MoDeRn will provide a clear description of monitoring objectives and strategies, taking into account a variety of physical and societal contexts, available monitoring technology, and feedback from both expert and non-expert stakeholder interactions. In relation to this, the project has defined the technical requirements of monitoring activities and has begun to assess the latest relevant technology. A technical workshop involving other monitoring Research and Technology Development (RTD) projects was hosted to identify RTD techniques that enhance our ability to monitor deep geological repositories. In particular, innovative monitoring approaches specific to repository design requirements are being tested within underground research laboratories. In addition, a case study was initiated to illustrate the process of mapping objectives and strategies onto the processes and parameters that need to be monitored in a given context, with a further aim to illustrate the potential design of corresponding monitoring systems and possible approaches to prevent and detect measurement errors. The case study will also show how unexpected repository evolutions may be handled.

Collectively, these activities will form the basis for a 'roadmap for repository monitoring' which should enable radioactive waste management organisations to further progress towards implementing deep geological repositories that are safe and acceptable for all.

It should be noted that the MoDeRn project recognizes the diversity of monitoring activities that will be required in a repository, in particular related to operational safety and environmental impact assessment. **The projects emphasis, however, is on the main monitoring objective of verifying/confirming expected repository system evolutions** (i.e. natural environment and engineered system evolutions) during a progressive construction, operation and closure phase that may last on the order of a century, to the extent these would be related e.g. to the basis of the safety case and/or to evolutions that may be of interest to evaluate disposal process management options.

The flowchart below provides an overview of key steps to consider when developing a monitoring program.




These have been developed to a greater level of detail (see the Preliminary MoDeRn Monitoring Workflow on next page) and will be presented and discussed during the workshop.

All project work programmes are progressing and the following documents have been published and are accessible on the MoDeRn website (http://www.modern-fp7.eu/):

- Project Presentation
- National Monitoring Contexts – Summary Report
- National Monitoring Contexts – Country Annexes
- Technical Requirements Report
- Monitoring Technologies Workshop Report (and the workshop presentations)
- Site plans and monitoring programmes report (for monitoring demonstrators)

Interaction with stakeholders is at the heart of the MoDeRn project. Workshops (such as this one) and conferences will provide opportunities to report and discuss results with the research community, experts (e.g. from technical safety organisations) and non-experts (e.g. from civil society) and to collect feedback. Note that the topic *International Performance Confirmation Strategies for Geologic Repositories* was recently introduced to the planning of the **WM2012** conference. It will provide further opportunity to present and discuss progress on repository monitoring. Also note that the project will organize and host an **International conference on repository monitoring**, scheduled for early to mid-2013, providing a broad platform for presentations and discussions as well as a further opportunity to present MoDeRn project results.

# A Preliminary MoDeRn Monitoring Workflow

Matt White (Galson Sciences), Brendan Breen (NDA) and Stefan Mayer (Andra)

Monitoring Developments for safe Repository operation and staged closure

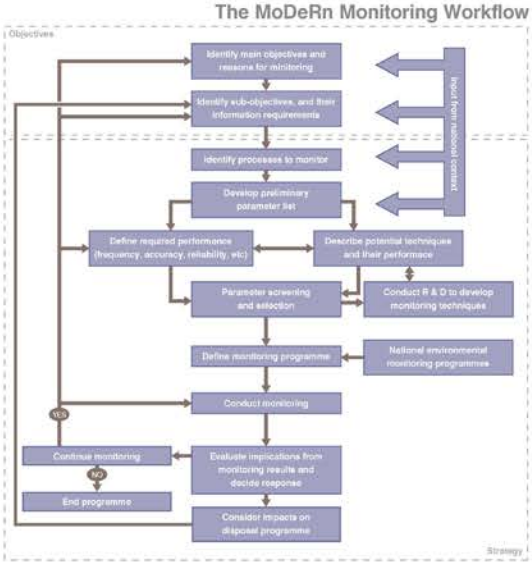
## Background

Early work in the MoDeRn Project has included preliminary development of a generic structured approach – the MoDeRn Monitoring Workflow, which provides a methodology for developing and implementing a monitoring programme under specific national boundary conditions. This poster presents the preliminary MoDeRn Monitoring Workflow and illustrates how the workflow relates to work being undertaken in the project.

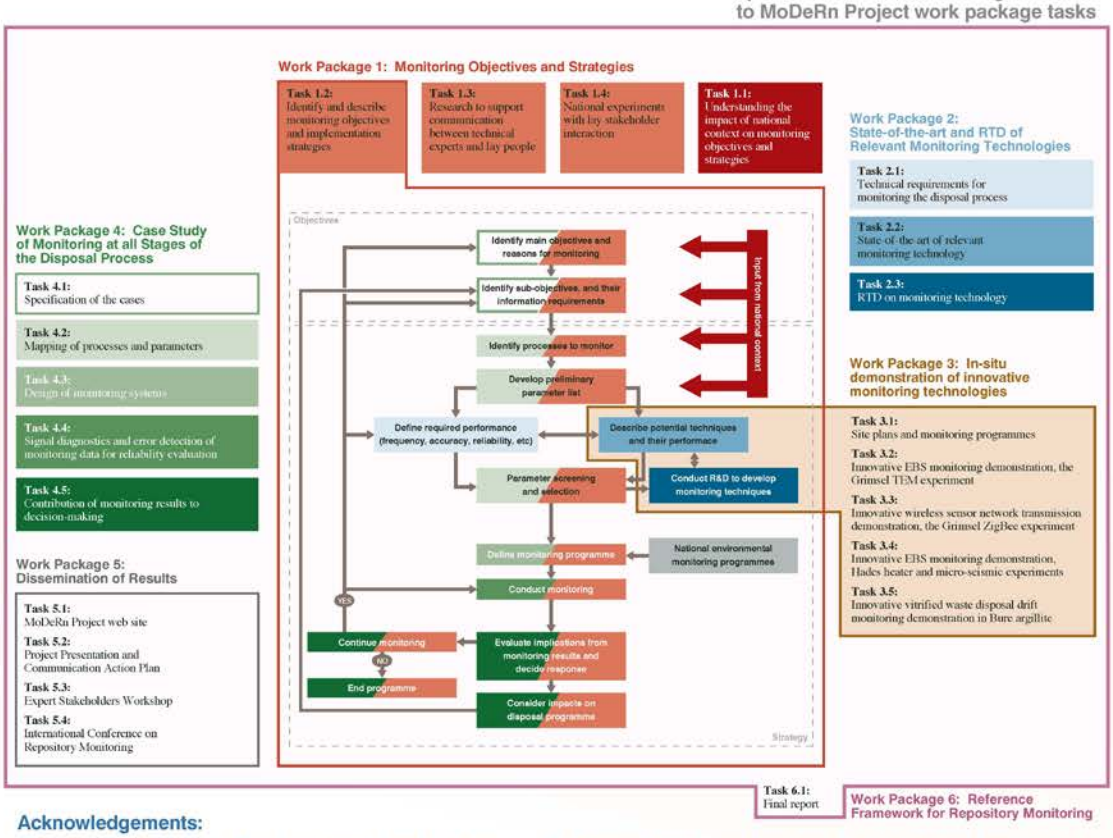
## Further Development

Development of the MoDeRn Monitoring Workflow will continue throughout the project. The workflow will be tested by the detailed work in each work package task, and will be revised based on the outcomes. It is anticipated that the MoDeRn Monitoring Workflow will provide a reference framework against which specific monitoring programmes can be developed with due consideration of the appropriate boundary conditions (i.e. the national context).

## The MoDeRn Monitoring Workflow




## Relationship of the MoDeRn Monitoring Workflow to MoDeRn Project work package tasks




**Acknowledgements:**

The preliminary MoDeRn Monitoring Workflow has been developed through discussions at MoDeRn Project workshops, to which all project partners have contributed.

*The research leading to these results has received funding from the European Atomic Energy Community's Seventh Framework Programme (FP7/2007-2011) under grant agreement 232598*

**Lead author contact details:**

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E-mail: mjw@galson-sciences.co.uk

## AIMS OF THE WORKSHOP

The partners in this EC MoDeRn Project have invested in this work programme with the aim of providing a generic monitoring roadmap for use in national programmes; to develop a better understanding of the state-of-the-art for monitoring through research into available technologies and our own programme of development and demonstration of leading-edge monitoring technology.

This workshop forms part of our programme of engagement in the MoDeRn programme. Our aim from this workshop is to present to our expert stakeholders the programme content; where we are now; and some of our thoughts and developments with a view to seeking discussion, feedback, challenge and advice to aid the direction we take in completing this work programme. After presenting work done so far in defining an approach to developing repository monitoring programmes as well as progress on associated technological aspects of monitoring, the workshop aims at engaging and facilitating expert stakeholders' discussions on these two overarching issues to incorporate workshop results and feedback into the remainder of the programme.

The output from the workshop will be produced as a report of the workshop proceedings. We would aim to produce this within 1 month of completion and circulate to attendees for comment prior to publication.

We would also value any further feedback and comment after the event and we plan to provide attendees with the means for providing such feedback.

## GENERAL ORGANISATION

The workshop will be organised and hosted by the NDA (UK), and is one of three key outreach events of the MoDeRn project. The workshop duration is one-and-a-half days. The workshop will provide for a mix of plenary presentation and discussion sessions, and breakout group discussions.

Enclosed are details of how to get to the venue with details of transport (bus and rail) from London and Heathrow Airport.

A copy of the workshop agenda is appended. The first afternoon will include brief summary presentations of the work programme as a basis for informing invited experts on the programme content, as well as providing an overview of related IAEA Safety Standards, with opportunities for questions and discussions. The second day will provide an opportunity for the invited experts through breakout groups to consider two key themes of the programme: "Process" (a.m.) and "Technology" (p.m.). For each of these themes, three working groups will be formed with a chairperson nominated by the group members to lead discussions on a specific topic. The working groups are viewed as an opportunity for the invited experts to provide their views on monitoring; MoDeRn partners will assist the work of the breakout group by acting as rapporteurs for each chairperson and by providing, as requested, information relating to the project programme. The chairperson will nominate a member from each group to present their findings to the other groups. **Invited experts are asked to advise Dr Alastair Clark (alastair.clark@nda.gov.uk) of their first and second preferences for specific topics for both thematic sessions.** We will aim to organise groups to meet your preferences while ensuring balanced group sizes and appropriate spread of representatives from each country.

## A-1. Detailed Agenda and Breakout Group Topics

**Draft Agenda**

| Wed 4 May | Item | Lead |
|---|---|---|
| 14.30 – 15.00 | Coffee and Registration | NDA |
| 15.00 – 15.10 | Welcome | NDA |
| 15.10 – 15.40 | Project Overview | Andra |
| 15.40 – 16.10 | IAEA, Safety Standards for Monitoring | IAEA |
| 16.10 – 16.40 | Process (WP1, WP4) | DBE/UA/GSL |
| 16.40 – 17.10 | Technology (WP2, WP3) | NDA/Aitemin |
| 17.10 – 17.40 | Day 2 Programme & Discussion | Andra/NDA |
| 18.30 – 19.15 | Reception | |
| 19.15 – 22.00 | Dinner | |

| Thu 5 May | Item | Lead | |
|---|---|---|---|
| 08.30 – 08.45 | Introduction to Theme: *Process* | Andra | |
| 08.45 – 10.30 | *Process* Theme Group Session: (3 parallel Topics)<br>**Topic 1**: Expectations and requirements of a monitoring programme (with distinction of aspects pertaining to pre-closure management and to support basis for long term safety).<br>**Topic 2**: Relationship between monitoring programme and managing the disposal process.<br>**Topic 3**: A structured approach to developing a generic monitoring roadmap | Information | Scribe |
| | | **1** - Andra | NDA |
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| 10.30 – 11.00 | Coffee | | |
| 11.00 – 12.00 | *Process* Plenary feedback & discussion | Nagra | |
| 12.00 – 13.00 | Lunch | | |
| 13.00 – 13.15 | Introduction to Theme: *Technology* | NDA | |
| 13.15 – 14.30 | *Technology* Theme Group Session: (3 parallel Topics)<br>**Topic 4**: How to get representative monitoring information across the facility?<br>**Topic 5**: Confidence in monitoring results<br>**Topic 6**: Monitoring techniques/technologies | Information | Scribe |
| | | **4** - NDA | GSL |
| | | **5** - DBE | NDA |
| | | **6** - EURIDICE | GSL |
| 14.30 – 14.45 | Coffee | | |
| 14.45 – 15.45 | *Technology* Plenary feedback & discussion | Aitemin | |
| 15.45 – 16.00 | Conclusions and closing remarks | Andra | |

# Breakout sessions - Themes and Topics

## THEME: PROCESS

### Topic 1: Expectations and requirements of a monitoring programme (with distinction of aspects pertaining to pre-closure management and to support basis for long term safety).

Open questions related to this topic:

- Do you agree with the projects main objectives?
- Would you use monitoring differently than the implementer?
- What are your priorities for monitoring?
- What do you see as others' priorities?
- What level of flexibility should there be in defining the monitoring programme now for future stages? Could monitoring be reduced or augmented over time?

### Topic 2: Relationship between monitoring programme and managing the disposal process.

Open questions related to this topic:

- What is the relative importance of monitoring to you?
- How do you view monitoring and what do you require for your own confidence building, i.e. in order to authorize further progress in the disposal implementation?
- How do you view monitoring in the context of others' (e.g. general public) confidence building?
- What type of decisions should be supported by monitoring information?
- What type of decisions do not require support by monitoring information?
- What are the key stages of repository implementation requiring monitoring input for your decision making? In particular, does monitoring play a key role in allowing a decision to close? Do we know enough to completely define what will be required for closure? Can we or do we have to decide today on post-closure monitoring, if any?
- What are the responsibilities of the different actors (implementer, regulator, other stakeholders) in the monitoring programme (expectations, development, implementation, use...)?
- What advice would you give us in communicating our programme to lay stakeholders?
- What do you think is your role in communicating on monitoring to the lay stakeholders?

### Topic 3: A structured approach to developing a generic monitoring roadmap

Open questions related to this topic:

- How useful is the monitoring workflow diagram?
- Does the workflow represent a structured approach for monitoring developments?
- What steps in the workflow need clarification?
- Will the approach provide a basis for development of a generic monitoring roadmap?
- What would you do differently – could you suggest items to improve the workflow?
- Is the workflow complete as presented or should something be added?
- Is the monitoring workflow applicable (truly generic) to your national context?

## THEME: TECHNOLOGY

### Topic 4: How to get representative monitoring information across the facility?

Open questions

- How to deal with spatial aspects (what distribution of monitoring can be considered as representative for the whole repository)?
- How to deal with time-scale issues (for all those processes important to long term safety evolving very slowly and/or not materializing until long after repository closure)?
- What are corresponding (and/or other) limitations of added value that can reasonably be expected from monitoring? Are these acceptable? How to communicate on them?

### Topic 5: Confidence in monitoring results

Open questions

- What is basis for judging monitoring results?
- How should boundaries (e.g. trigger values) be defined?
- Should bounding values be related to the conservative assumptions of models to predict evolutions?
- How should the implementer deal with unexpected results (i.e. results outside initially identified bounds, calling for careful analysis and possibly further actions)? Will they call for different type of actions whether they relate to pre-closure performances as opposed to the basis for long term safety?

### Topic 6: Monitoring techniques/technologies

Open questions

- Is our approach to concentrate on non-invasive technology appropriate?
- Can you recommend other techniques for monitoring?
- Should additional techniques be developed?
- How should we deal with further development of state of art? What might be the influence of new technologies on monitoring approaches? When should we stop incorporating new techniques into the monitoring programme?