Appendix A

REPORTS OF THE WORKING GROUPS

In the working group discussions, three broad topics were addressed by four working groups (A-D), with each working group assigned two topics. The participants in each working group and the topics assigned are shown in Table A-1.

Table A-1. **The participants in each working group and the topics assigned**

Working Group A – Topics 1 and 2

Participants		**Affiliation**
NORRIS, Simon	(Chair)	NDA, United Kingdom
RÖHLIG, Klaus-Jürgen	(Rapporteur)	Technical University, Clausthal, Germany
ALTORFER, Felix		HSK, Switzerland
BRUNO, Jordi		Amphos XXI Consulting SL, Spain
DE CRAEN, Mieke		SCK•CEN, Belgium
DUPLESSY, Jean-Claude		CNE, France
FEDOR Ferenc		MECSEKÉRC, Hungary
JENSEN, Mark		OPG, Canada
NIIZATO, Tadafumi		JAEA Horonobe, Japan
SCHELKES, Klaus		BGR, Germany

Working Group B – Topics 1 and 3

Participants		**Affiliation**
MAZUREK, Martin	(Chair)	University of Bern, Switzerland
ANDERSSON, Johan	(Rapporteur)	JA Streamflow AB, Sweden
BARRACLOUGH, Ian		Environment Agency, United Kingdom
BEAUHEIM, Richard		Sandia National Laboratories, USA
CAPOUET, Manuel		ONDRAF/NIRAS, Belgium
GEIER, Joel		Clearwater Hardrock Consulting, USA
KURIKAMI, Hiroshi		NUMO, Japan
LEBON Patrick		Andra, France
PELLEGRINI, Delphine		IRSN, France
SAEGUSA, Hiromitsu		JAEA, Japan
WIKSTRÖM, Liisa		Posiva Oy, Finland
WOLLRATH, Jürgen		BfS, Germany

Table A-1. **The participants in each working group and the topics assigned** (Cont'd)

Working Group C – Topics 2 and 3

Participants		Affiliation
SERRES, Christophe	(Chair)	IRSN, France
VAN GEET, Maarten	(Rapporteur)	ONDRAF/NIRAS, Belgium
MOHANTY, Sitakanta		CNWRA, USA
HELLMUTH, Karl-Heinz		STUK, Finland
NAGY, Zoltan		PURAM, Hungary
WOLF, Jens		GRS-Braunschweig, Germany
STOMBERG, Bo		SKI, Sweden
RAHN, Meinhert		HSK, Switzerland
PESCATORE, Claudio		OECD/NEA
VOINIS, Sylvie		Andra, France
HELLÄ, Pirjo		Pöyry, Finland

Working Group D – Topics 1 and 2

Participants		Affiliation
FRANK, Erik	(Chair)	HSK, Switzerland
Griffault, Lise	(Rapporteur)	Andra, France
De Hoyos, Amelie		IRSN, France
Falck, W. Eberhard		JRC, European Commission
Hatanaka, Koichiro		JAEA, Japan
Larue, Peter Jürgen		GRS, Germany
Linden, Ronald		Golder, USA
Munier, Raymond		SKB, Sweden
Rocher, Muriel		IRSN, France
Szücs, Istvan		MECSEKÉRC, Hungary

To encourage "cross-fertilisation" of ideas and a better synthesis of views, a number of "observers" were nominated who were not assigned to one specific group. Rather, they were asked to move between the groups, providing insights from one group to another and conveying opinions that had been expressed. The observers were Betsy Forinash (OECD/NEA), Paul Smith (SAM, United Kingdom) and Jan-Olof Selroos (SKB, Sweden).

Topic 1: What are the processes by which information from site characterisation is selected and applied in safety assessment (i.e. scenario development and modelling)?

Topic 2: How are the uncertainties in geological data and scaling issues dealt with in repository design and the safety case? (i.e. modelling)

Topic 3: How does (and to what extent) the development of the repository design and of the safety case influence site characterisation and R&D priorities? (Information flow back from the safety case)

Topic 1: What are the processes by which information from site characterisation is selected and applied in safety assessment (i.e. scenario development and modelling)?

This topic was addressed by Working Groups A, B and D. The working groups were asked to consider the following aspects:

- Identification of most relevant processes.
- Simplification and abstraction.
- Probability of events.

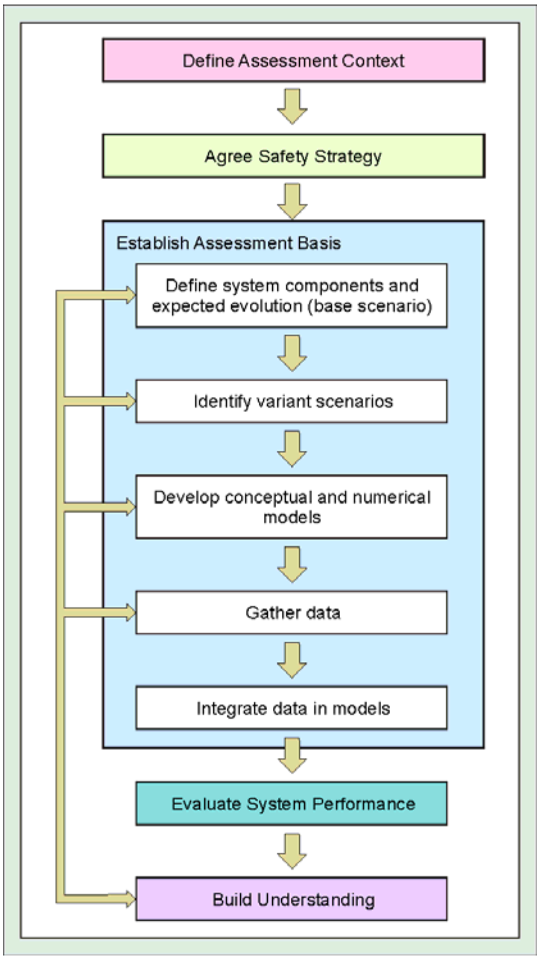
- Propagation of uncertainties.
- Traceability.

Report of Working Group A

Background

To address the issues raised in Topic 1, it is initially valuable to consider the general process for conducting a safety assessment as input to the safety case. An illustration of the safety assessment process is given in Figure 8. Safety assessment involves developing an understanding of how, and under what circumstances, radionuclides might be released from a repository, how likely such releases are, and what the radiological consequences of such releases could be to people and the environment.

Figure 8. **Illustration of the safety assessment process** (after Nirex 2005)



Safety assessment therefore involves: collating data; developing models both of components of the repository and its environment and the overall repository system; and performing safety analyses. In addition to numerical calculations, safety cases now include a broad range of evidence and arguments that complement and support the reliability of the quantitative analyses.

The key stages in the safety assessment process are:

- Definition of assessment context.

- Agreement of safety strategy.
- Establishment of assessment basis.
- Evaluation of system performance.
- The building of understanding.

A safety assessment also needs to address:

- Management of uncertainty: uncertainty causes many of the challenges inherent in conducting a safety assessment; therefore appropriate handling of uncertainty is a central issue. There will inevitably be more uncertainties at the early stages of developing a disposal facility. A consistent strategy for managing uncertainty needs to show how uncertainty will be reduced and addressed throughout the facility development programme, so that by the implementation stage at the latest, any remaining uncertainty is shown to be acceptable. The treatment of uncertainty forms the basis of Topic 2, and Working Group A's deliberations on this subject are noted later in this report.
- Safety arguments: the safety case does not rely solely on quantitative modelling. Programmes generally aim for a multi-faceted safety case that uses a variety of lines of argument, reasoning and results to build confidence in the long-term safety of a geological disposal facility.

Identification of most relevant processes

The identification of the most relevant processes is based on the inter-related FEPs, conceptual models and safety functions specific to a particular site and disposal concept, and the evaluation of system performance.

Identification of relevant processes is a key function undertaken in the establishment of the assessment basis. Establishing the assessment basis requires a clear description of the disposal system and its expected evolution. This provides a definition for a reference case, or base scenario. Factors that could potentially affect the safety of the system but which are not part of the definition of the base scenario may be dealt with by considering separate variant scenarios.

A relevant example of an international FEP database is the Features, Events and Processes Catalogue for argillaceous media – FEPCAT – developed by the NEA Working Group on the Characterisation, the Understanding and the Performance of Argillaceous Rocks as Repository Host Formations (known as "Clay Club") (NEA, 2003). FEPCAT is particularly useful (for clays) as it relates site-specific geoscience attributes that influence far-field performance and their relative importance with respect to assessment of mass transport and long-term barrier integrity (erosion, palaeohydrogeology, mineral diagenesis, fault sealing etc).

Typically at the outset of a programme, there is a comprehensive and systematic effort to identify all features, events and processes (FEPs) that have the potential to affect the long-term safety of a geological repository. This stage involves a wide range of experts and can also be open to non-technical stakeholders to ensure that all issues and concerns are identified and taken into consideration from the first stage of the assessment process. Expansive, lateral thinking is encouraged, with all FEPs of potential relevance being included at this stage, without regard to their relative importance. The aim is to achieve a comprehensive database of FEPs. This is facilitated by a systematic and structured elicitation process, leading to the development of a structured FEP diagram. It is also valuable to compare the national FEP database with similar databases developed by overseas radioactive waste disposal agencies, for example using the OECD/NEA international FEP database. This provides a cross-check that no potentially relevant FEPs have been omitted.

There is a need to acknowledge that site characterisation in the strict sense of the word is focused on collating information about the site's state prior to repository construction (including a description of its evolution from past to present day), while the needs of safety assessments clearly go beyond that in considering the evolution of a site in the future and in the presence of a repository. There is also the need to account for the site's potential evolution in response to site investigation. Knowledge from palaeogeology, paleohydrogeology, and paleohydrogeochemistry can serve as a basis for extrapolation in time. There are examples where it is possible to determine potential reactions of a geological environment to disturbances caused by the repository, by using information about disturbances that occurred in the past. As an example: basaltic intrusions at the Gorleben salt dome demonstrate that temperatures of up to 1 150°C caused alterations in sodium-rich rock salt to a distance of only a few centimetres from the basalt intrusions.

Certain observations made at a repository site or at another comparable location ("site analogues"[1]) can be used to understand the present situation and history of a site, and also to indicate that processes that will or may happen during the evolution of a repository. Such observations are an increasingly important element of safety cases. Examples that can readily be cited are: the diffusion-dominated regime in the Opalinus clay addressed in the CLAYTRAC project; salinity profiles at Gorleben confirming the diffusion-dominated regime in the overburden of the salt dome. Knowledge about the past evolution can also be used for testing or calibrating models utilised in safety assessments.

A stepwise approach is important to pinpoint important processes. With increasing maturity of a disposal programme, with the attendant increase in site data and understanding, the priorities and key issues affecting a safety assessment might evolve or change. The issue of bias in the safety assessment must be rigorously addressed, and a bias audit is a key component of the process of developing a safety case. The iteration with the regulator and regulatory review play a key role in this approach (examples: WIPP re-certification, HSK review of Opalinus clay case), even if there is no legal requirement for this interplay.

When developing a disposal programme and acquiring the necessary information, it is important to keep the balance between investigation needs on one hand and the need to keep the site as undisturbed as possible in order to maintain its safety functions on the other.

Simplification and abstraction

It is essential that the justification for simplification and abstraction of models are documented and discussed with a range of internal and external stakeholders, to ensure there is "buy-in" to the decisions being proposed.

Any simplification and abstraction must be based on a knowledge of system performance, and therefore will be linked to the inter-related FEPs, conceptual models and safety functions specific to a particular site, and to the evaluation of system performance. Simplification and abstraction is guided by the question about what conditions are needed to maintain the safety functions. Safety assessment procedures lead to a hierarchy of functions and effects, guide discussions, help substantiating statements and the identification of research priorities (examples of such practice include: ONDRAF/NIRAS and SCK•CEN procedures leading, via a "tree" structure, to statements about the degree of importance of processes for safety functions; SKB function indicators; Andra PARS sequence of quasi-equilibrium states addressing evolution and change of importance with time).

1. As described in the main text, a distinction can be drawn between "process analogues", which support arguments for which direct evidence may not be available at a site (e.g. uranium deposits giving evidence for the limited mobility of uranium under certain conditions), and "site analogues", which closely resemble a site in that they share most or all of its relevant properties.

Simplification and abstraction in safety assessments needs to be communicated both within the project team and to wider audiences. Communicating them within the project team is essential in order to develop a consistent assessment which is based on input from, and supported by, the whole range of expertise represented in the team. It is important to:

- Document and communicate modelling assumptions (including implicit ones) and conservatisms in a way that is understandable to the whole team.
- Use a common technical language, possibly based on a glossary.
- Utilise data in a sensible and consistent way.

An iterative approach (from simplistic models, via the identification of knowledge gaps, to more sophisticated ones), as agreed between technical groups with differing core disciplines, helps in cases where experts are not fully satisfied with model simplifications. Such an approach, in which models are refined progressive throughout the repository programme, acknowledges that at early stages of a repository programme, the data and knowledge to support more sophisticated models is not necessarily always readily available.

Communicating safety assessments to wider audiences including the general public is challenging since the credibility of assessments in general is often questioned. Site analogues and natural analogues are often helpful when communicating the general conceptualisation rather than a mathematical or assessment model. Visualisation and animation are valuable tools to make the concepts underlying geologic disposal understandable. There is a tendency to accept anthropogenic analogues more readily than natural analogues since the associated timescale is better understandable. There is a necessity to address “negative analogues” (e.g. the Nevada test site), and to discuss their relevance or irrelevance.

Having identified all relevant FEPs, the next stage involves building understanding of the interactions between FEPs and defining scenarios that are relevant to the evolution of the disposal facility and its surrounding, as well as developing conceptual models to represent those scenarios. This may involve, for example, the generation of a series of matrix diagrams which systematically examine the potential pair-wise interactions between different FEPs and groups of FEPs (Nirex, 2003). A review of the FEPs may identify that some can be screened out at this stage, for example if they have little or no significance to safety when reviewed alongside other FEPs.

All screening decisions should be taken by appropriately qualified experts and fully documented and justified. Stakeholder input is very helpful at this stage to ensure that wider issues (particularly those that may affect social acceptability of the disposal facility) are not neglected. Note that the relevant importance of FEPs may change over the timescales considered in a safety case as the repository environment, including the geosphere and biosphere, evolves over various timescales in response to e.g. climate change; this needs to be accounted for in the analysis of the inter-relationship of FEPs, conceptual models and safety functions specific to a particular site, and the evaluation of system performance.

On the basis of the stages described above, the translation of the conceptual models into mathematical models can then progress. A mathematical model is a representation of the features of the system, the impacts of events and a description of the processes operating and their interactions in terms of parameters and algebraic equations. Mathematical models are constructed for different components and sub-components of the disposal system.

The mathematical models provide the technical specification for the development of the software for use in the performance assessment. In many cases, the mathematical models may be used to demonstrate that existing software provides an adequate representation of the processes. In other cases the mathematical models may be used to design new models of sub-models for use with existing software tools (Locke and Bailey, 1998a). The advantage of following this systematic approach is that the software used in the safety assessment can be traced back to the FEP analysis and an audit trail is established demonstrating how all relevant FEPs are treated in the safety assessment.

The final confidence-building stage occurs in parallel with all four preceding stages in the assessment model development process. The aim is to build confidence in each stage through expert review and involvement of a wide range of stakeholders. Confidence is also built through the iterative development of subsequent assessment cycles. It is important to be able to show how the safety assessments presented for authorisation purposes at the implementation stage have evolved from those presented at the earlier stages, for example to support the decisions on the siting of the disposal facility.

Probability of events

The probability of processes or disruptive events will naturally be considered as part of the safety strategy discussed above. Note that some stakeholders may focus on low probability "what if?" scenarios, and it is important that these are adequately addressed in the assessment basis, which is itself based on the inter-related FEPs, conceptual models and safety functions specific to a particular site, and the evaluation of system performance. Since disruptive events with low probability and potential high consequences seem to be a focus of public interest, the communication of their handling in assessments is challenging but can also be seen as a chance to communicate the philosophy and reasoning of safety assessments.

Scenarios for the potential evolution of the disposal system are identified by considering which FEPs are likely to be present or active for the majority of the time and which may only be triggered in certain circumstances, for example in the event of an earthquake, or someone drilling into the disposal facility. The majority of FEPs are included within the base scenario. This defines our best understanding of the expected evolution of the disposal facility (Locke and Bailey, 1998b). Those FEPs that are less likely to occur, but whose occurrence could lead to a different evolution of the disposal system, are used to define variant scenarios. When assessing the overall performance of the disposal system, particular attention needs to be paid to those variant scenarios that have the potential to lead to greater risks than are represented by the base scenario. If the risks from a variant scenario are less than those from the base scenario at all times, then it is likely that the variant scenario can be subsumed (i.e. considered as encompassed) within the base scenario. The process for identifying and characterising scenarios is discussed in detail within (Billinton and Bailey, 1998).

Propagation of uncertainties

The treatment of uncertainty forms the basis of Topic 2, and Working Group A's deliberations on this subject are noted later in this report.

Traceability

Given the very long duration of a repository development project, the maintenance of adequate records (appropriate to the relevant QA regime in place) and the use of an appropriate data clearance system are of significant importance in order to make uncertainties visible and traceable. This holds[2] for data uncertainties associated with the fact that data were collected at different times, by different teams or individuals, and possibly for different purposes. An appropriate records management system, e.g. a meta database, together with procedures for data clearance (cf. e.g. Nagra clearance procedures presented at the 2nd AMIGO workshop, NEA, 2007) will ensure future personnel engaged in the project are able to understand fully the work that has been undertaken previously, thus ensuring an efficient process that avoids "re-inventing the wheel" and conducting activities that essentially repeat earlier work (of which, were records not adequately maintained, surviving knowledge may be poor to non-existent), and ensuring appropriate use of data in assessments.

Changes in information technology over the duration of a programme are another challenge to be considered. It might be sensible to develop an "encyclopedia of radioactive waste management" in order to maintain the knowledge acquired and make it accessible for future times and to other programmes. As there will most likely be a number of iterations in developing a safety case, it is to be expected that priorities/key issues will evolve as the specific programme progresses; records management and information traceability are a key aspect of a repository development programme.

References

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Report of Working Group B

General observations

Past experience in a number of national programmes illustrate some problem areas related to the use of site characterisation data in safety assessment:

- Safety assessment and FEPs analysis were usually performed by the safety assessment team only (SKB, WIPP, others).
- Safety assessors asked for numbers, but geoscientists were reluctant to go beyond qualitative descriptions (Nagra).
- Geoscientists had their own interpretation and application of conservatism, without knowing how the data would be used in safety assessment. Recurrent stages of "conservative" margins were added to parameter values by different teams (BfS).
- Because the focus in safety assessment was "hard" output, such as dose curves, the integration of other important data and evidence in the framework of a safety case did not always happen.
- Site characterisation programmes sometimes tended to be driven by the managerial and practical aspects of accomplishing field operations; sometimes forgetting about the safety

assessment needs (this may still be true today). (At Andra, the management of site characterisation is shared between the field-operations and the data-analysis teams in order to prevent such a situation.)

At the present day, the need for integration of site characterisation and safety assessment is recognised and addressed in most disposal programmes. Site syntheses (in the form of a site-descriptive model (SDM or a geosynthesis) are important steps linking site characterisation and performance assessment. The interface between site characterisation and safety assessment has been recognised as a key element and is managed using various strategies:

- A designated working group (comprising both site characterisation and safety assessment experts) produces the geosynthesis, including a geo-data set that is used directly in safety assessment (e.g. Nagra).
- A specific Integration Group (geosciences, radionuclide transport, modelling and computing) is responsible for production of both phenomenological models and data sets for safety assessment (Andra).
- Input to safety assessment is provided by geosynthesis experts (from a "site descriptive model" report); final recommendation of data is assessed by safety assessment team (e.g. SKB Data reports).
- Structured evaluation of support for *"safety statements"* and implications on safety importance (ONDRAF/NIRAS). Interdisciplinary working groups are organised around the safety statements.
- The same experts (hydrogeologists, rock mechanics,...) do both the evaluation and the safety assessment modelling (e.g. WIPP, SKB and Posiva).
- A limited part of the safety assessment team integrates the results of the specific modelling.

Practical challenges to integration remain, notably how to maintain a focused process and efficient meetings or information exchanges with (usually) a larger and more inter-disciplinary group of experts (internal and sometimes external) interacting and coordinating with one another.

Identification of most relevant processes

This is an iterative process, generally starting with hypotheses suggested by safety assessment. Site characterisation experts then provide confirmation or, if needed, propose adaptations of these hypotheses and conceptual models. Documentation of all stages of this process is essential (e.g. SKB Process reports, ONDRAF/NIRAS Safety Statements). Some non-exhaustive examples include:

- Confirmation of diffusion-dominated migration.
- Evidence that off-diagonal Onsager effects are unimportant.
- Quantifying uplift and erosion.
- Influence of climate perturbation on ground-water flow.
- Impact of earthquakes.

In the course of site characterisation, new findings may emerge that may lead to the consideration of new processes, e.g.:

- High sulphide concentrations at a specific depth level at Olkiluoto, Finland.
- Explanation of overpressures at Bure, France and Benken, Switzerland.

The degree to which the underlying processes need to be understood depends on their relevance for safety.

Some potentially relevant processes in the geosphere are linked to interactions with the engineered barrier system, e.g.:

- Interaction of clay with steel.
- Spatial distribution of water-conducting fractures in crystalline rock to understand the issue of buffer erosion in a crystalline environment.

Lastly, changes in regulations (e.g. the extension of the time scale to be considered) may lead to the consideration of new processes.

Simplification and abstraction

Simplifications are inevitably necessary but need to be *justified in relation to the application*, and the simplification process also needs to be properly *documented*, including all explicit and implicit assumptions. The degree of simplification depends on the process considered. Integration groups are an important way for making and justifying simplifications. The uncertainty introduced by simplification can sometimes be quantified by comparing the model results with those of more detailed and more realistic models (that require less simplification). An example of this is numerical modelling of the thermal impact of heat-emitting waste in the near field by considering various degrees of simplification and averaging of the thermal rock properties. Experience also suggests that when a very good and justified complex model exists, it may be easier to apply it without simplification, instead of abstracting it into a simpler model.

Probability of events

Probabilities are frequently handled by categorising processes in “normal evolution”, “alternative evolution” and “what-if” scenarios. In some programmes, they need to be quantified, either by the analysis of data or by expert elicitation. Examples of geosphere-related events whose probabilities are under discussion in disposal programmes in crystalline rock are post-glacial faulting and the penetration of glacial water to depth.

Propagation of uncertainties

There are various sources of uncertainties, such as poor accuracy, bias, limited process understanding, ambiguities in conceptual models, representation of heterogeneity, etc. Parameter uncertainties and their propagation on the results of a safety analysis are frequently handled by the safety assessment teams. On the other hand, input from site characterisation is needed to assess conceptual uncertainties, such as alternative (hydro)structural models, boundary conditions or descriptions of heterogeneity. Documentation of the whole chain of assumptions underlying the calculations is essential for tracing the impact of poorly justified assumptions.

Traceability

Typically, a hierarchical methodology is adopted:

- Screening and quality assurance of investigation data.
- Primary evaluation of investigation data (e.g. from hydraulic test to T-value).
- Integrated geoscientific site-descriptive model or geosynthesis.
- Selection/abstraction of input data for safety assessment.

Each of these steps requires proper documentation, justification and cross-referencing. This also includes the selection of investigation methods, borehole locations, and the like. In the case of underground excavations that may become parts of a repository (and therefore a nuclear installation), safeguarding regulations dictate specifically stringent criteria for the traceability of certain data, such as the precise geometry of the excavation.

Information is best organised in quality-assured data bases:

- Controlled procedures are required for how to enter and retrieve data from the different databases.
- A strategy is needed regarding the treatment and use of old electronic records. In certain situations, it may be less expensive to redo the measurement than to update the old information. Such a strategy also pertains to old modelling results that cannot be repeated on current computer platforms, even if the input files are still available.
- Procedures are also needed for qualifying "external data" – e.g. from hydrocarbon wells – whose quality cannot be easily checked.

It is recognised that knowledge management is an issue, in order to make sure that as little as possible knowledge is linked exclusively to specific experts.

Report of Working Group D

Introduction

Before starting the discussion, the group members found that there was some need for clarification of the question:

- The question is understandable if the site or possible area of implementation of the repository is known. Some countries have not yet reached this stage of site characterisation.
- The question is understandable if the general approach to "safety assessment" is known, for example if the safety functions and associated data requirement are defined (link with communication when sharing information and/or experience, JRC).
- There is a need to identify at which stage the waste management programme of geological disposal is at the moment (conceptual and planning stage; area survey stage; site selection stage; site characterisation stage by surface investigations (seismic survey, drillings) and by underground exploration (URL); and site confirmation stage during the construction of the disposal facility).
- Site characterisation is an iterative process which proceeds step by step and which is strongly linked to the safety concept, the repository design and to the safety assessment work.

Bearing that in mind, the following two questions were added and discussed in the working group:

- Has all safety relevant geo-scientific information been integrated and addressed in the safety assessment?
- Has the site been adequately characterised for that purpose?

During the working group sessions the group members presented examples of their practical experiences regarding site characterisation, system identification (FEPs), data synthesis, development of conceptual models and integration into safety assessment. The conclusions of the working group discussion were listed as follows.

Identification of most relevant processes

- The focus is on the most important processes that are identified by a systematic scenario-based analysis of FEPs relevant for safety assessment.
- There is a need to perform sensitivity analysis to show which of the parameters and FEPs are most important for safety.
- There is a distinction between "hard" information – which can be measured and used as input data for the safety assessment – and "soft" information, such as sedimentation facies or paleo-hydrogeological information, which is not directly used in the safety assessment but is important for confidence building.
- Consideration of some specific FEPs may be required by regulation.
- It is important to include the multiple lines of evidence in the safety case. Some site characterisation data are not directly used in the safety assessment but are important for understanding processes, including "qualitative arguments" such as evidence of the old age of pore water or having a plausible reconstruction of the site stability in the past.

The group discussed whether information should be acquired to arrive at a realistic picture of the site for the next million years: a safety assessment is quantification to the dose for a "scenario" (enveloping "realistic scenarios" or so called "what if scenarios"); a safety case may include all the arguments (quantitative and qualitative). FEPs are not considered relevant only for safety issues, but also for the understanding the site evolution (Andra, GRS, SKB, HSK/Nagra).

Simplification and abstraction

- Are necessary but need to be justified.
- Process models can be verified with geo-scientific data.
- The issue of "model validation" was raised. In a strict sense, safety assessment model cannot be validated.
- Abstractions such as K_d – values are necessary but have to be used in an adequate way and must be justified (e.g. enveloping all the mechanistic processes).

From the experience of the "Dossier Argile 2005", Andra summarised their approach in building a conceptual model from the geological data (simplification in order to encompass observed processes, justification using reference knowledge documents) up to a numerical model for safety calculation (Box 1). The overall procedure is called integration. Various examples of integration are given in Plas and Vigneron.

Probability of events

- Examples were given of how to handle seismic and volcanic events (evaluation of the probability, i.e. example from Golder in which the probability of an earthquake was evaluated).
- Examples were discussed for handling less likely events using alternative scenarios or extreme scenarios.
- In some countries, the method for establishing the probability or for prioritising events might be dictated by the regulations (e.g. French regulations require that the reference "scenario" must address the most "probable" events).

Box 1. **Role of the geosphere in safety performance assessment** (Andra, 2005)

Safety Functions of Geosphere

- ✓ No function is allocated to surrounding formations
  - ➷ Even if they participate to dose calculations
- ✓ "Host rocks":
  - To minimise water flow
  - To minimise the release of RN and immobilise them within the repository
  - To delay and to mitigate migration of radionuclides

➷ Geo-synthesis data are analysed through RN transport and chemical properties/processes in time and space

- – Transport processes: ad convection, diffusion, non diagonal processes…
- – Chemical processes: solubility, retention…
  - ⇨ Macroscopic parameters in space and time:
    - D_{app} (apparent diffusion coefficients for anions and cations)
    - n_D (diffusion accessible coefficients for anions and cations)
    - S (Solubility)
    - K_d (Retention)
    - K (Permeability)
    - n_c (Advection accessible coefficients for anions and cations)
- – Transport and chemical boundary conditions in time
- – Geometry and dimensions

⇨ Qualitative and quantitative analysis: calculations are led in order to evaluate processes, associated models and parameters on indicators in bond with the safety functions

Uncertainty propagation

- There was general agreement that uncertainty has to be evaluated correctly by addressing all important sources of uncertainty (parameter uncertainty, uncertainty in conceptual models, uncertainty in scenario development).
- Quantitative sensitivity analyses may be useful to prioritise uncertainties.
- For evaluating uncertainty propagation, the timescales have to be taken into account.
- There is a need to develop rationales to constrain possible variant explosion. A case study in this regard is SKB attempt to quantify uncertainty propagation, which proved to be too complex, voluminous and not practical (variant explosion).

Traceability

- There is general agreement that traceability of data (not only geosciences data) and decisions are necessary and important.
- The requirements and processes for traceability are best handled when planned from the beginning of the project (Golder).
- In terms of geosciences, there is a need to develop a basic understanding of the site that goes beyond simply providing data for safety assessment.
- The importance of quality assurance is agreed.
- A question to be addressed is how long should records be maintained to ensure that the data remain traceable and transparent?
- Traceability requirements are specified in some national regulations (IRSN, French BSR.III.2.f).

Considering that site characterisation is a long and iterative step-by-step process (beginning with area survey and site selection, then site characterisation from the surface, site characterisation from underground by a URL-facility and finally site confirmation during the construction of the repository). Data management and traceability of all information are key aspects in a waste management programme.

Topic 2: How are the uncertainties in geological data and scaling issues dealt with in repository design and the safety case? (i.e. modelling)

This topic was addressed by Working Groups A and D. The working groups were asked to consider the following aspects.

- Probabilistic versus deterministic.
- Stochastic data.
- Transferability from URL to repository scale: temporal and spatial scaling.
- Modelling methodologies.
- Design choices to mitigate uncertainties.

Report of Working Group A

Background

The issues raised in Topic 2 are addressed below. It was considered that the issues surrounding modelling methodologies will, in practice, be an artefact of the safety assessment approach(es) pursued, and as this aspect of Topic 2 has been considered in the responses given to Topic 1 above, it is not addressed further. Furthermore, as it is inevitable that a repository programme and the consideration of site data implicit therein will need to consider stochastic data (the approaches to doing this are complementary to the modelling methodologies employed), this aspect of Topic 2 is also not addressed explicitly further in this section.

A key driver for a deep geological repository as an option for the long-term management of radioactive waste is to remove the large uncertainty associated with leaving the waste accessible to humans at the surface over very long timescales. Geoscience provides an understanding of the evolution and attributes of the selected site that substantiate or justify the ability of the far field to act as a barrier in the repository concept. However, it is also important to recognise that there are substantial uncertainties associated with processes operating in a radioactive waste repository system on a timescale of hundreds of thousands of years, and these uncertainties require appropriate treatment in the stepwise development of a disposal facility and its associated safety case. Management of uncertainties is a pivotal element in this process. In response to the question about which uncertainties are important, it is important to put them into context with regard to the safety functions attributed to various components of the disposal concept system. Regulatory and peer review aid in identifying and managing uncertainties by providing a perspective independent from that of the repository developer or implementer.

Uncertainty management includes:

- Reducing uncertainties by further R&D (cf. the presentation by Cahen and Voinis on programme perspectives in France).
- Avoiding or mitigating them e.g. by appropriate design choices (cf. the SKB/Posiva presentation on acceptance criteria for locations for waste emplacement).
- Analysing their significance by means of safety assessment.

Regarding the latter, there are a number of different areas in which uncertainty may influence assessment studies:

- Uncertainty in data.
- Uncertainty arising from the use of conceptual models (covering how the repository system evolved to its present day state, how that present day state is understood to function, and how the site may evolve in the future).
- Uncertainty arising from mathematical models.
- Uncertainty in future human behaviour.

For a post-closure performance assessment, there may be substantial uncertainty associated with the future of the repository system. Methodologies for addressing this uncertainty in a systematic way, based on the analysis of FEPs and development of scenarios which are then addressed in detail in an assessment, are frequently developed and applied in national programmes.

For a given scenario, strategies for handling uncertainty tend to fall into the following broad categories:

1. Demonstrating that the uncertainty is not important to safety because, for example, safety is dominated by other processes.
2. Addressing the uncertainty explicitly, usually using probabilistic techniques, and showing that the expected situation is acceptable.
3. Bounding the uncertainty and showing that even the bounding case gives acceptable safety.
4. Ruling out the uncertainty, usually on the grounds of very low probability of occurrence, or because other consequences (were the uncertain event to happen) would far outweigh concerns over the repository performance.
5. Agreeing on a stylised approach for handling a specific uncertainty.

Probabilistic versus deterministic

Working Group A considered the "versus" to be unnecessary; both probabilistic and deterministic modelling have a role in a safety case.

A dialogue – between the regulator and waste management organisation and other stakeholders – at the outset of, and throughout, a geological disposal programme is important for defining the broad principles for the evaluation of long-term safety. Thus, establishing a common understanding of the basis for determining whether a performance target (or limit) is achieved, including the role of probabilistic and deterministic modelling, in a specific national repository programme will be a key discussion point from the programme's inception.

Table 1 below summarises the different approaches to handling parameter uncertainty in deterministic and probabilistic modelling approaches and lists potential advantages and potential disadvantages of each approach (the relevance of these potential advantages and disadvantages will vary from national programme to national programme, dependent on preferred approaches to the development of the safety case).

Different safety assessments use either or both deterministic and probabilistic modelling techniques. The choice can sometimes reflect national regulatory guidance and preferences (for example United Kingdom and the United States regulations tend to favour probabilistic approaches, whereas other assessments are primarily deterministic).

In order to construct appropriate and meaningful probability distribution functions (PDFs) for probabilistic calculations, more data and understanding are required regarding the various components of the repository system, the processes operating and their interactions. This level of data and understanding may not be available for generic repository concepts, particularly for the natural (geological) component. Hence most of the early stage assessments prefer to focus on deterministic calculations, usually supported by a wide range of sensitivity studies to explore the impacts of uncertainty in important parameters. However, it can also be beneficial to use probabilistic safety assessment calculations with defined PDFs to analyse parameter sensitivity (for example, this was done in the Nirex Generic Performance Assessment (GPA) (Norris *et al.*, 2003) to represent the characteristics of a generic geological setting). Depending on the context, such an analysis can be used to identify favourable characteristics for a repository location or to determine where "real" knowledge of parameter values is most crucial as an input to research or site investigation programmes.

Table 1. **Deterministic and probabilistic modelling**

Deterministic	Probabilistic
Approach • A single value is defined for each model parameter. • Calculations may be repeated using different values. For example, this could be done with the "best estimate" value, or a "robust, cautious" value or a "worst case" value.	**Approach** • A range of values is elicited for uncertain parameters, in the form of a probability density function (PDF). • A large number of realisations are performed, sampling different parameter values for each. • The assessment "result" is usually presented in terms of some key statistics, e.g. mean, percentiles, confidence limits (the mean often being especially important in certain regulatory environments), derived from all these realisations.
Potential advantages • Coupled with sensitivity studies, allows transparent treatment of different types of uncertainty • Easier to understand and communicate • May be able to use more detailed models, as fewer calculations required.	**Potential advantages** • Explicit representation of parameter uncertainty enables wide coverage of combinations of uncertainty. • Facilitates derivation of a single risk estimate for the whole system. • Allows analysis of parameter sensitivity.
Potential disadvantages • Difficult to demonstrate that adequate coverage has been given to combinations of uncertainty. • May be difficult to explain why variants have been selected, i.e. need stronger justification for the parameters used, for example to defend a 'best estimate' or "worst case" calculation. • May be difficult to produce a total risk estimate (would need to consider appropriate weights for each deterministic case).	**Potential disadvantages** • Need to obtain appropriately detailed probability distribution functions (PDFs) for uncertain parameters, sometimes difficult to justify PDFs and probabilities. • Need to avoid parameter combinations that are physically impossible (i.e. may need quantitative descriptions of correlations between non-independent sampled parameters). • Difficult to demonstrate appropriate handling of low-probability, high-consequence "tails". • Assumptions and results may be difficult to communicate.

It may also be easier to explain the results of deterministic calculations to non-technical audiences. The results of probabilistic calculations are usually presented as the mean, or average, of a set of realisations. If a sufficient number of realisations has been performed, such that the mean is converged (i.e. performing another realisation and re-calculating the mean value does not lead to a different answer), then this mean value gives an accurate result for the expectation value. However, there is some debate over what such a value actually represents in the context of a repository safety assessment and whether it is the right quantity for comparison with a risk target. In particular, there is the potential for risk dilution when averaging over realisations derived from PDFs that represent uncertainties arising from a lack of knowledge, without having a statistical basis (for a more detailed discussion of these points and the presentation of numerical risk estimates, see Environment Agency 2001).

Development of the safety case requires the assembly of a range of geoscience arguments; the treatment of geologic uncertainty is considered as part of the related safety assessment but may also be treated through separate geoscience modelling. Such modelling examines, for example:

- The influence of spatial variability in permeability fields on groundwater flow and solute migration.
- Rock mass permeabilities at formation scales based on preservation of anomalously (either elevated or under-pressured) hydraulic head conditions.
- Anisotropic far-field properties based on inclusion of discrete fracture networks and sedimentary bedrock structures.
- The influence of variably dense or saline groundwater on flow and transport, etc.

Such focused calculations speak to the bounding of uncertainties that ultimately underpin the safety assessment and provide alternative scientific reasoning to communicate confidence (or not) in site properties and attributes as they affect repository performance.

There are roles for both deterministic and probabilistic calculations in most safety assessments. The important thing is to develop an overall approach that demonstrates understanding of the behaviour of the repository system and the relative influences of the various uncertainties on that behaviour. Probabilistic calculations are likely to be most appropriate when the uncertainty can be quantified and the basis for the underlying PDFs justified. For other uncertainties, where there may be no coherent statistical basis for developing and interpreting PDFs, a series of deterministic "what if?" calculations is likely to be more appropriate.

Transferability from URL to repository scale: temporal and spatial scaling

Handling time-dependence issues

A further complexity to be addressed within a safety assessment is the fact that it needs to represent a natural system evolving over very long timescales. Time-dependent processes occur throughout the repository system and decisions need to be made about how best to represent these in performance assessment calculations. Not all time-dependent processes are significant in terms of the overall impact on repository behaviour and, in many cases, it may be appropriate to adopt a simple conservative treatment of the process, rather than to model the time dependence explicitly.

However, when a time-dependent process has a significant impact on the overall performance of a repository system and a single conservative value is so overly pessimistic that it gives an unacceptable result or makes the models insensitive to other variables, it will be appropriate to address the time dependence in some way.

Broadly, there are three ways of representing time-dependent effects in a safety assessment:

- Time-independent modelling, in which variability of parameters with time is treated by carrying out sets of calculations in each of which the parameters are set to different, but constant, values, spanning the expected ranges of variation; either a deterministic approach can be adopted, using conservative parameter values supplemented with sensitivity studies, or a probabilistic approach can be used, in which parameters are sampled from the expected ranges of variation, expressed as probability density functions.

- Simulating changes over time with a continuous modelling approach that includes time-varying parameters.
- Dividing the assessment period into a number of timeframes, each of which can be assessed using different modelling assumptions and even different modelling approaches, some of which may be time-dependent.

Quantitative analyses, undertaken as part of a safety case, will be necessary at least over the time period required for regulatory compliance. The results from detailed safety assessment models are liable to be more uncertain at longer times into the future.

At such times other arguments may be used to illustrate safety, for example, based on natural safety indicators. Their use helps to demonstrate appropriate consideration of near-field and geosphere processes and potential future effects. To build confidence in our understanding of the behaviour of components of the geological disposal facility over very long timescales, it is common to look for analogues in nature or archaeology. When presenting such related safety arguments it is important to be aware of their limitations. For example, the conditions under which the artefacts have survived may not be identical to those in a geological disposal facility. Nevertheless, comparisons with natural and archaeological systems can provide powerful support to the safety case.

Internationally, the use of natural safety indicators is being progressed in several radioactive waste management programmes. Examples of natural safety indicators used to justify and strengthen certain aspects of a safety case are considered in NEA (2004), including the following:

- Natural safety indicators for a long groundwater travel time could draw on information from:
  - Groundwater age and travel times through the geosphere to the biosphere.
  - Spatial distribution of hydraulic properties such as over- and under-pressurisation, location of recharge and discharge areas, and hydraulic gradients.
  - Spatial distribution of groundwater composition, including variations in total dissolved solids and the presence of main and trace ionic species and isotopes.
- Natural safety indicators for radionuclide migration in the geosphere could draw on information from:
  - Groundwater composition and isotope signatures.
  - Rock/water interactions and their influence on, for example groundwater composition, isotope signatures and fracture infill.
  - Rates of release of natural radionuclides from geological formations to the biosphere.
  - Natural analogue studies.
- Natural safety indicators for geochemical stability in the host rock could draw on information from:
  - Palaeohydrogeology, providing information on natural fluxes and fracture infill.
  - Fracture infill.
  - Buffer capacity, providing information on, for example, groundwater composition.
  - Additionally, radioactive and chemically toxic species are present in the natural environment. Measuring the concentrations of naturally occurring radioactive and toxic species and the fluxes of those species in groundwater can provide natural safety measures of repository safety, allowing a comparison to be made with calculated values of disposal facility-derived contaminant fluxes and concentrations (here “contaminant” is taken to mean radionuclide or chemotoxic species).

Working Group A felt that site-specific multiple lines of evidence are powerful tools to build confidence in and demonstrate understanding of the performance of the site over timeframes relevant to geological disposal.

Handling spatial variability issues

Many components of a repository system exhibit spatial variability, or heterogeneity. For example, the rocks of the geological setting will have spatially varying properties. Likewise, in the near field, depending on the waste form, waste packages may vary in their contents. If waste containers corrode and groundwater accesses the wastes, there is the potential for regions of different chemical properties within the near field. (Near-field heterogeneity is more likely to be an issue for repositories dealing with ILW and LLW, as these tend to be far more heterogeneous waste forms than HLW or spent fuel; and HLW and spent fuel are generally disposed in very high integrity containers so near-field chemistry is less of an issue.) Representing such spatial heterogeneity is a challenge for performance assessments. Even if sufficient data were available, in most situations it would be computationally infeasible to represent the full extent of spatial heterogeneity in a repository system. Fortunately, it is not necessary to do so – spatial heterogeneity only needs to be represented to the extent that it is important in understanding the performance of a repository system.

Spatial heterogeneity is also an important issue when modelling the geosphere, particularly in site-specific assessments, where variability in the geomechanical and fluid flow properties of rock are of particular relevance to PA. In the Nirex 97 assessment of the Sellafield site (Nirex, 1997), much attention was paid to representing hydrogeological spatial variability on various length-scales. At that time, Nirex commissioned an independent peer review of the treatment of spatial heterogeneity in rock properties based on its investigations at Sellafield (Knight, 2003). One of the conclusions from this review was that there is no general consensus in the academic community on the most appropriate approach for the treatment of geological spatial heterogeneity. It requires a multi-disciplinary approach, to develop conceptual, mathematical and computer models and despite the considerable growth in computer power, some finely detailed spatial heterogeneity models remain intractable to numerical modelling. This in turn requires some form of upscaling that may involve further expert judgement.

However, for generic, non-site-specific performance assessments it may be more appropriate to adopt a simple approach to representing the geosphere, for example, using an estimate of effective properties, whilst recognising that for a detailed assessment of a facility at a real site spatial heterogeneity would need to be addressed at an appropriate level. This could mean justifying the parameter values used to define the effective properties in more detail, and/or developing heterogeneous models.

Design choices to mitigate uncertainties

Based on the inter-related FEPs, conceptual models and safety functions specific to a particular site and particular repository design, it will be tractable to undertake an analysis of how changes to repository design affect the operational and post-closure phases of a deep geological disposal facility. This analysis may be undertaken in part to address regulatory concerns regarding design and operational optimisation, bearing in mind that various aspects of a repository and its infrastructures will need to be demonstrably optimised for the various phases of a repository's lifetime. The significance of design choices in mitigating uncertainties will vary from disposal concept to disposal concept, dependent on the specific interactions of e.g. the waste, the near field concept and its anticipated performance, the geosphere barrier and its anticipated performance, and the potential time-dependent evolution of the site. Examples mentioned in the working group session were:

- Emplacement acceptance criteria (SKB/Posiva presentation).

- Specific implementation aspects of vertical and horizontal waste emplacement in the KBS-3 concept.
- The interaction of the backfill, buffer, and canister material with the geology in various disposal concepts.
- Design adaptations to handle overpressures caused by gas production.
- The impact of construction choices on EDZ (e.g. blasting vs. drilling).

Where one barrier at a specific site and for a given disposal concept, e.g. the geosphere, is determined likely to have a "poor" performance, it may be necessary to enhance the performance, through engineering and design, of other barriers in the multiple barrier system in order to achieve the necessary overall performance required of the multiple barriers functioning together. Such flexibility may be necessary in nation-specific implementations of a deep geological disposal concept, as the geological environment for which repository construction and waste emplacement is planned may have been chosen based on a variety of social and technical considerations (i.e. not geosphere properties alone).

Specific responses are not given to the topics of "stochastic data" and "modelling methodologies", as the responses to the other topics provide input from Working Group A on these issues.

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Report of Working Group C

As a starting point of this discussion, it was emphasised that the passive safety of repositories relies, in many countries, mainly on the geosphere performances. Nevertheless, the multibarrier/multifunction principle is applied in all countries, meaning that other components also take up safety functions. (Example: US regulations require at least two barriers: one natural, one engineered.)

Because of the importance of the geosphere, a good understanding of its initial state and evolution is needed. With respect to the evolution of the geosphere, it should be mentioned that both, natural evolution and perturbations due to waste emplacement need to be considered. [An example illustrating this statement is the recent review of the Finnish safety case, after which the regulatory agency informed the implementer that there should be a better balance between EBS and geosphere in terms of fulfilling safety functions (STUK)].

Because of the inherent complexity of several aspects of the geosphere, the existence and persistence of uncertainties is unavoidable. In the models, these uncertainties are represented by data variations or by different processes and features. The characterisation of structural heterogeneities is a well known issue for crystalline host rocks (e.g. fractured host rocks in Sweden, Finland; see also contribution Rahn *et al.* concerning the crystalline rocks in northern Switzerland), but appears also to be a topic of discussion regarding clayey host rocks (refer to the presentation and paper of IRSN on the possible existence of fractures in Callovo-Oxfordian Clay, Rocher *et al.*). Another origin of uncertainties is related to the very long time frames considered (10^6 years). The question was raised whether it would be useful to split up the repository's evolution into smaller time periods as a way of addressing the changing significance and likelihood of different processes and events that need to be considered. An example cited during this discussion was related to the frequency of earthquakes. It is known that the likelihood of the occurrence of strong earthquakes rises as the time period under consideration is extended. However, it was immediately remarked in the discussion that the likelihood is indeed increasing with time, but that the timing of occurrence still remains uncertain and that there might be a link with other processes presenting uncertainties in time – e.g. earthquakes related to deglaciation and the formation of tectonic features and potential flow paths – and also that the impact of many small earthquakes needs to be considered. This led to the conclusion that the proposed strategy cannot be applied on the example of earthquakes. However, the conclusion on whether such division into time frames is really applicable is probably not a general rule, but rather must be judged on a case-by-case basis. A final source of uncertainties is related to the limitations of existing characterization methods.

From a practical point of view in the framework of a safety case preparation, the uncertainties can be identified as follows:

- Methodological uncertainty: leading to data and parametric analysis.
- Process uncertainty: leading to alternative models and scenarios.
- Event uncertainty with low probability and high consequences.

In this context of the uncertainty treatment, the work group discussed the possibilities of using probabilistic versus deterministic approaches. First of all, there was a consensus that both approaches are not contradictory, but should be rather used complementary or in parallel. (Z. Nagy from Hungary noted that for the safety assessment of their geological low-level disposal, both methods had to be applied in parallel, allowing the regulator to compare the results.) Moreover, there was also a strong discussion on the meaning of both, illustrating that clear definitions are needed. Especially the European definition of a probabilistic approach seems to differ from the United States definition. In the United States, it is common to use the probabilistic approach, including the probability of scenarios and thus leading to a quantitative risk analysis. In the European context, it is more common to rely on consequence analysis including uncertainty propagation from parameters to results (e.g. indicators as concentration, molar flow or dose) and the probabilistic approach is not used for the scenarios themselves. The French representatives indicated that event uncertainties are evaluated case by case, mainly from a qualitative point of view. Their treatment is assessed regarding the ability of the operator to clearly explain how its overall safety approach deals with their causalities.

In the frame of this discussion, it was believed that the nature of the safety assessment calculation should depend on the progress of the geological repository programme. In the first steps of the programme, when acquisition of knowledge is limited to a general description of FEPs or to generic data, the deterministic approach, associated with conservative assumptions and parameters, seems to be the most relevant. Nevertheless, this approach does not exclude the use of a probabilistic analysis to treat parameter variation ("Dossier 2005" of Andra as an example). It was suggested that this approach might also be used to assess the robustness of the system. But, at this preliminary step, one limitation underscored by the Working Group relies on the possibility of masking the influence of parameter variation due to the use of conservatism. For a more evolved stage of the programme, when knowledge improves (and allows iterative safety assessment between main phases of the programme (generic studies, siting, construction phase, operation, closure…), it was suggested that a more realistic PA might be strived for. Combined with more data and knowledge on relevant processes, the probabilistic approach appeared more promising. But it was underscored that the intensive use of probability density functions should rely on sufficient data collection.

As uncertainties are an important input for scenario selection, some discussion on the definition of scenarios was held as well. The working group acknowledged that site investigation helps to define consistent scenarios, while in more generic programmes it might be more difficult to focus on relevant FEPs. Functional analysis, safety statements or safety criteria are useful tools to communicate and justify the scenarios. (In this respect, refer to Smith *et al.* discussing the use of safety statements in scenario derivation for the Belgian programme.)

The use and relevance of so-called "what-if" scenarios was also discussed. The members of the working group agreed on the fact that the use of such scenarios should be limited and cannot overcome or be used to compensate for a lack of knowledge that is realistically obtainable. Evaluating such scenarios may, however, be useful as a first approach to illustrate the potential impact of processes or events that are poorly understood or difficult to characterise, or where there is significant divergence in the opinions of experts regarding their occurrence or quantification. For example, participants from the Nordic countries mentioned that unlikely processes related to glaciations, such as e.g. meltwater intrusion and postglacial earthquakes can be best treated, in part, by "what-if" analyses. A further relevant example was the use by IRSN of a "what-if" scenario to assess the influence of possible fracturing in the Callovo-Oxfordian clay formation. As such fractures were not observed, characteristics were derived from hydraulic structures detected in the clay formation in the Tournemire site investigated by IRSN. IRSN considered this scenario to be a useful mechanism to foster dialogue and encourage the implementer to address the issue, on the basis of the scenario consequences, by either design adaptation or further site investigations and characterisation. This example illustrates a key challenge with "what-if" scenarios, namely the difficulty of selecting parameters for such scenario, when the phenomena in question cannot be observed – and thus not directly parameterised. With respect to "what-if" scenarios, it can also be a challenge to explain the rationale (and ultimately, the meaning of the results) for such scenarios to an audience who is not directly involved in technical discussions, although a clear structure and justification from the start should help avoid such problems.

A final item of discussion was the choice of design in order to mitigate some uncertainties. It was acknowledged that the uncertainty in the geosphere may certainly influence the design. An example given was that groundwater flow in fractured crystalline rocks might influence the swelling and erosion of the buffer material and, as a consequence, must be considered in technical specification to ensure that components fulfil their assigned safety functions. In the course of discussion, a strong consensus arose that a change in design might solve one problem, but can at the same time induce new questions or problems to be dealt with. This was true, for example, of the United States decision to introduce a new alloy serving as a drip shield; in Finland, the use of low pH grout to avoid degradation of bentonite has raised questions on plasticisers. Therefore, in case of design modification, it is advised to systematically assess the impact on the overall safety and clearly communicate the changes and the related assessment.

The question whether design choices are needed to mitigate uncertainties in the geosphere is viewed as an issue to be addressed as part of the strategy chosen by the implementer. In fact, it is the implementer's responsibility to decide whether an adaptation of the design is valuable, or if additional more detailed scientific investigations are necessary (see IRSN/Andra example above). It was argued that, for implementers, it would be best to maintain some flexibility in repository design for as long as possible. Everyone agreed on this statement, but immediately the question was raised of how long such flexibility could be maintained. The French situation provides a useful example: the repository construction is planned to take about 100 years and it seems reasonable to assume that flexibility remains during this period and the 10-year updates of the license application can provide a mechanism to take into account the possible changes. The aim is to make improvements in terms of cost, robustness, etc. over the course of repository operation. For the regulatory review of a license application, the safety basis and related design options must be frozen but possible design adaptations should remain possible using approaches such as that in described above.

Report of Working Group D

Introduction

The working group discussion started with a short introductory presentation by HSK on stochastic modelling of depositional facies and hydraulic conductivity patterns in the Lower Freshwater Molasse (lacustrine and fluvial sediments consisting of interbedded marls, silt- and sandstones), a potential host rock discussed in Switzerland. The characterisation of this heterogeneous sedimentary unit was much improved by the development of the concept of facies element architecture and hierarchy of scales providing the base for quantitative assessment of the rock properties. Field data, well log analyses and laboratory data allowed the recognition of five basic architectural elements, each differentiated by their geometry, dimensions and depositional facies. Following a request by HSK, a generic study was performed by A. Hölker (ProSeis AG, Zürich) in 2006 for providing a 3-D-stochastic hydraulic conductivity model for a Lower Freshwater Molasse rock volume of 5 km^3. Two types of stochastic simulation methods were applied: (a) stochastic simulation of depositional facies patterns based on statistical description of the different facies elements and (b) stochastic modelling of hydraulic conductivity patterns within each facies element based on the frequency distribution of K-values which were determined from borehole packer test results, permeability measurements on core samples and estimates of spatial correlation lengths of K. The results were then subsequently used for modelling fluid dynamics for a hypothetical repository in the Lower Freshwater Molasse for estimating vertical global fluxes for safety performance assessment.

For providing answers to Topic 2, the working group members shared their experience and presented various examples to all aspects listed above. The conclusions from the discussions are summarised in the following paragraphs. Note that each item of Topic 2 was addressed with respect to the issues raised in the main question i.e. effect "on repository design" and "uncertainty in geological data". The item "design choices to mitigate uncertainties" was discussed with some examples illustrating how uncertainties in geological data have been addressed.

Deterministic versus probabilistic

- Both approaches are needed (complementary rather than versus).
- A probabilistic step can be used for a deterministic evaluation.
- Probabilistic approach may be a tool for evaluating safety behaviour (ex: distribution of values or scenario development).
- Expert judgements such as peer reviews are sometimes needed to reduce uncertainties.

The group discussion first focused on what kind of data can be addressed by a deterministic or by a probabilistic approach. It was acknowledged that probabilistic approach was an interesting tool for distribution of values (i.e. some specific parameters, K-values in the case of Andra…) even though if in a lot of cases the end value is deterministic (i.e. dose).

GRS and SKB gave examples of the role of scenarios, in which a probabilistic approach might be required, as well as risk is to be evaluated. SKB indicated that two cases may be considered relative to the effect of glaciations (one considering the glaciations effects and one not). The French regulations (BRS.III.2.f) give recommendations for scenario treatments (for example, "likely" events are to be included in a reference scenario, the so-called normal evolution scenario).

Stochastic data

- Stochastic approach might be important for site selection and characterisation.
- The approach is rock and site specific (e.g. needed for fracture network modelling for crystalline rocks or stochastic facies simulations as shown for the Lower Freshwater Molasse).

The presentation of HSK illustrates that such an approach may be helpful for repository layout (to choose the appropriate geological layer, or to choose some design options for the engineered/technical barrier system such as the use of bentonite). In site selection, it would require more work to be done, but may help to build confidence relative to a homogeneous rock-system such as "Opalinus Clay".

SKB pointed out that one issue to be considered in choosing one or the other modelling approach is that of scale (i.e. deterministic regional model providing boundary conditions to a site-scale stochastic groundwater flow model). There is no contradiction between probabilistic and stochastic methods when dealing with uncertainties. A good stochastic model may help in understanding the fracture pattern and finding migration pathways but requires a lot of data (an attempt to quantify uncertainties for tunnel selection was given by SKB). It was acknowledged that some constraint may be linked to the geology of the country (i.e. the availability of host rock formations and the degree of heterogeneity and spatial variability in rock properties).

Transferability from URL to repository scale: temporal and spatial scaling

- Temporal scale is a critical issue regarding long term safety.
- Spatial scaling was not regarded as critical but still required to be demonstrated (for example, experiment in underground research laboratory (URL) to extrapolate on repository scale).
- Field experiments may have limitations due to the short term.
- Boundary conditions are not the same (extrapolation to performance assessment conditions are difficult).
- Some geological observations can be extrapolated to long term.
- Transferability is linked to variability and heterogeneity.

Main examples of transferability from URL to repository scale were given by Andra and Golder:

- The change of scale of investigation to gain geological information (when compared to borehole) was acknowledged not only by Andra and Golder but also by other members of the group. HSK referred to the Mont Terri Underground Research Laboratory with diffusion experiments on different scales (migration tests in boreholes versus natural tracer profiles along the tunnel).

- A URL may help in deciding between the two options "shaft entry" or "ramp entry" (Golder), also because the laboratory is about the same size as the foreseen repository.

- A URL may help to capture information on features of the rock media (Golder).

- A URL is a tool to get and support knowledge in rock characteristics (Andra, Golder), and may help in that case to support a transposition area (Andra). For SKB, transferability depends on variability. If variability is high, transferability is low, in which case quantification may be required (and must be justified) and then extrapolation. Temporal scaling seems to be harder to address. It can be approached by increasing knowledge, but significant uncertainties may still remain on long time scales.

Modelling methodologies

- Performance assessment models are used to demonstrate safety, not necessarily to make a prediction of a specific future of the site.
- A distinction should be made between "process models" and "performance assessment models." In any case, care should be taken to establish clearly the interpretation of the word "conservative."
- In some cases, additional and more complex models are used including coupled processes (e.g. TMH).
- Different levels of detail may be needed for different timescales (based on e.g. regulations, safety functions, THMC phases).

The group acknowledged a strong link between the probabilistic and stochastic approaches discussed previously. Modelling methodologies have been discussed essentially in terms of:

- Modelling for integration of geological data (to link with the items of probabilistic and stochastic approaches).
- "Process models" and "performance assessment models" (see examples of Andra).
- Conceptual model development for safety assessment (a simplified abstraction of reality that aims to identify those key processes relevant for safety (Andra, GRS). In the case of Andra, the acquired knowledge is used to derive conceptual models constituting a simplified but robust approach that takes into account the determining factors. Conceptual models represent the repository components evolution in time and space with parameter values. They can help in making decisions regarding possible simplifications such as neglecting one phenomenon in favour of another dominant one. On this basis, the repository system is then completely represented within the scope of a "safety assessment model", which reflects the scenario under consideration.
- Short-term and long-term modelling, "short-term" being more precise which is sometimes requested from regulations (SKB).
- Alternative models to manage uncertainties (if it is not known if a process could occur or not, SKB).
- Coupled or non-coupled phenomena such as THMC (HSK, GRS, Andra).

When it came to address how uncertainties on geological data are dealt with, a question was raised: Should we use conservative values?

- It was agreed one should be cautious. Conservatism can apply to some parameters (judgement). One objective of the evaluation is an overestimation, not an underestimation. But the combination of some conservative values of parameters may not be conservative at the end (JRC).
- Communication/vocabulary about the term "conservative": Some organisations defined it (Andra, SKB, HSK), but it appeared that a coherent and sound use of such a word is to be

considered in the future. Andra gave the example that when using data, it can be expert judgment (conservatism) or statistical approach but when building conceptual model for safety evaluation, you have to be on the safe side (i.e. enveloping processes or scenarios). It is linked to a sound understanding of the system.

Design choices to mitigate uncertainties

- Geological data influence the design of the repository (example: emphasise on EBS).
- Design option can be defined to minimise uncertainties on the natural system.
- On the other hand some geological data may make it possible to optimise design.
- Some geological FEPs may force design changes.

The group tried to give an example in which geological uncertainties would directly be addressed by design. Three types of examples were given:

Design option: uncertainties may imply a greater reliance upon the engineered barrier system relative to the rock barrier system (SKB). Uncertainties may lead to the selection of some technical barriers such as the use of bentonite, mainly for rock mechanical stability reasons in the Swiss Opalinus Clay case (HSK), or, at the stage of the "Dossier 2005 Argile" (Andra), grouping the access shaft and having various seal plugs to avoid water circulation in the repository system.

Design changes: uncertainties can drive design decisions and changes. In the case of SKB, fracture uncertainties have partly been dealt with by repository design. For example, large fractures that are most likely to undergo significant shear movements in the event of an earthquake are, as far as possible, identified and avoided when deciding on positions for emplacing canisters. In the case of the Swiss project, Crystalline-I HAA-waste canisters are surrounded by large quantities of bentonite backfill (140 cm thick) for maintaining the stability of the chemical and physical properties of the engineered barrier system and for reducing uncertainties of seismic effects (HSK).

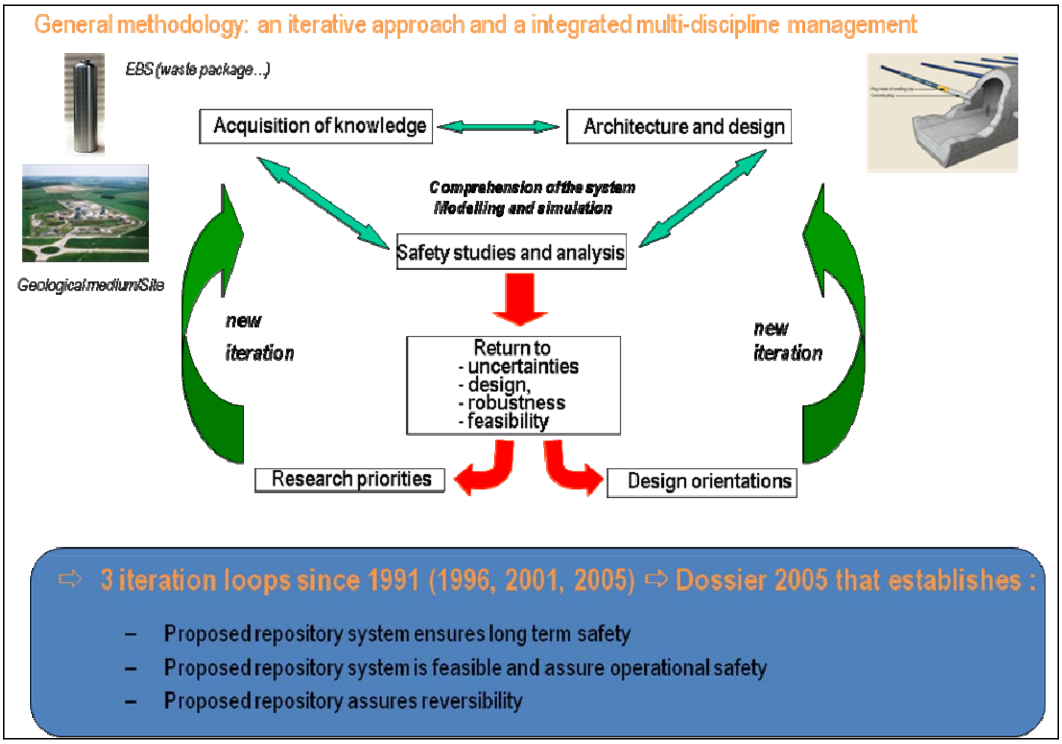
Design optimisation: gaining knowledge and improving understanding of the system may help in design "optimisation". Andra is currently considering some optimisation of the concept presented at the stage of the "Dossier 2005 Argile", for instance, in terms of operational safety and security considerations without degrading long-term safety.

A new feature relative to the list of item was discussed: What are the repository induced effects on the natural system, and what are the effects of the technical barriers on the host rock?

Most of the organisations agreed that design aims at trying to minimise perturbation (Andra, HSK) or reduce the use of foreign material (JRC). Discussing questions on fracture uncertainties, Andra and IRSN gave the example of inclined boreholes to gain better knowledge, but in limited number, in order to preserve the barrier characteristic of the host rock. Another example was given with the emplacement of steel container and limited temperature in the disposal cell to preserve the Callovo-Oxfordian (Andra).

Furthermore, the group discussed how, after an area survey stage, a site is selected based on a pre-screening process linked to site characterisation. From the experience of the French Project "Dossier Argile 2005", Andra presented a short summary of their approach addressing the iterative approach (see e.g. Box 2) and the safety functions of the geosphere and associated data requirement for safety performance assessment.

Box 2. **General methodology used by Andra**



A final observation of the working group was that site characterisation includes several iterate loops between data sampling, system identification (FEPs), model conceptualisation, code development and overall safety performance assessment including design choices for the repository. It is important that there is a strong interdisciplinary dialogue between geoscientists, engineers and safety assessors.

Topic 3: How does (and to what extent) the development of the repository design and of the safety case influence site characterisation and R&D priorities? (Information flow back from the safety case)

This topic was addressed by Working Groups B and C. The working groups were asked to consider the following aspects:

- Emerging technologies.
- Confirmation of required rock or site characteristics (at various scales).
- Reduction of uncertainties by further investigation.

Report of Working Group B

General observations

The ongoing development of a safety case does affect the site-characterisation programme. At the beginning of a programme, the communication between the safety assessment and site characterisation teams is generally initiated by the formulation of a “wish list” of data needs by the safety assessment group and a “toolbox” of available techniques and data feasibility by the site characterisation group. Both wish list and toolbox are adapted during the development of the programme.

The needs from safety assessment can be oriented around safety functions that are attributed to the geosphere, and these are site- and design-specific. Frequently, the following safety functions are applied:

- Isolation of the waste from the human environment.
- Provision of suitable geochemical and geomechanical conditions for the engineered barrier system.
- Attenuation of radionuclide releases to the biosphere.

In addition to fulfilling the specific needs for safety assessment, a general qualitative and quantitative site understanding (main features and processes) is also an important component of a safety case.

The development of a safety case is a staged procedure, typically including the following elements over time:

- Generic studies to identify key safety features.
- Development of a basic level of site understanding.
- Feedback from safety assessment and design on which specific issues are important, and on what scale.
- Findings from site characterisation may alter focus of safety case.

There is a continued need for internal and external reviews at all stages of repository development.

Keeping in mind the need to demonstrate a high degree of site understanding, it is nevertheless necessary to focus site characterisation activities due to the finite availability of manpower and financial resources. Safety functions, as well as environmental and design issues, are instrumental means in the prioritisation and in the communication between interdisciplinary teams. While site-characterisation efforts in support of safety-assessment calculations (finally resulting in radionuclide fluxes or dose curves) can be largely focused on the rock units that provide the confinement, a broader view (and therefore a need to extend site characterisation to the whole system) is needed for the safety case. The degrees to which the whole geological environment is characterised, over and above the direct needs of safety assessment, varies between programmes, often reflecting the differences in explicit or implicit regulations.

Specific examples of how safety assessment and design criteria can affect site characterisation

Feedback from safety assessment:

- Studies of gas-transport mechanisms in the Callovo-Oxfordian at Bure (France) were initiated in response to the needs of operational and long-term safety after having taken into account reversibility requirements (Andra).

- More emphasis is placed on understanding redox conditions and salinity evolution in the crystalline host rock because safety assessment shows these processes to be key to safety; strong focus on palaeo-hydrogeological evolution is used to help demonstrate this understanding (SKB/Posiva).

- Further work to better characterise flow in the near field was undertaken after potentially detrimental processes to EBS were identified by safety assessment (SKB/Posiva).

- Better characterisation was required of the clay layer overlying the salt host rock to quantify subrosion. The safety assessment assumption that this layer is continuous and homogeneous was shown not to be true (BfS).

- The development of arguments supporting the hypothesis that transport in the clay-rich host rock is dominated by diffusion (modelling of tracer profiles) requires proper and continuous sampling of pore waters in the whole low-permeability sequence (Nagra).

Feedback from repository design:

- Very generally, changes in design frequently change the focus of site characterisation, e.g. the consideration of disposal in horizontal instead of vertical deposition tunnels (KBS3H/KBS3V; SKB, Posiva).
- The design requirement of retrievability led to the need to use steel linings, which in turn called for studies of the possible geochemical interactions with the host rock (Andra).
- The disposal of higher burn-up fuels (only reprocessed waste was originally considered) leads to a higher thermal impact in the near field and so to further characterisation needs (Nagra).
- Repository design requires certain areas not to be penetrated by boreholes, and this restricts site characterisation in such areas to non-destructive techniques, such as geophysical methods. Further restrictions on drilling locations are related to the need to avoid intersections with existing or planned underground excavations (Posiva, SKB).
- The control of environmental impacts, such as the need to inject grout in excavations in order to prevent drawdowns of the ground-water table, places limits on the feasibility of certain site-characterisation techniques and measurements (JAEA).
- In NUMO dry-run safety study targeted at the design of repository panels in a hypothetical repository in Japan, it becomes evident that tools and methods to better predict the location of faults and to measure the stress system more accurately are necessary.

There are also cases where safety assessment or design changes have no or limited consequences for site characterisation:

- The use of more cementitious materials in the new Belgian design did not greatly affect the needs from the site characterisation programme (ONDRAF/NIRAS).
- In situations where human intrusion is the only relevant scenario that could lead to radionuclide release, other needs related to conditions in the filled repository (e.g. waste shear strength) may be equally as important as geoscience needs (WIPP).

Emerging technologies

From a viewpoint of data evaluation and modelling, major advances have been made in recent years. This includes mainly the establishment, within many organisations, of integration groups consisting of both site characterisation and safety assessment experts. Enhanced numerical modelling capabilities allow more complexity to be introduced in process and safety assessment models. Examples of topics that have received much attention recently include palaeo-hydrogeological modelling approaches and the understanding of gas-migration mechanisms.

With respect to advances in measurement techniques, the following examples are mentioned (though this is not an exhaustive list):

- Extensive use of 3-D seismics in crystalline environments to locate discontinuities.
- High-resolution borehole logs and geostatistical post-processing allowing the identification of past climate cycles and possible gaps in the sedimentary record.

- New isotope techniques (B, Li, noble gases) potentially allowing further assessment of the origin of water or rock.
- Nano-technologies, such as microscopic imaging techniques (FIB, etc.) and molecular modelling.
- Lidar technology for detailed surface characterisation.
- Detailed scale cross-hole charge-potential measurements.
- Ground penetrating radar, for e.g. EDZ studies in crystalline rocks.
- Monitoring technologies.

Reduction of uncertainties by further investigations

Further investigations can contribute to reducing uncertainties. However, the return on investment needs to be carefully explored, as many uncertainties may remain in spite of recurrent characterisation efforts. New questions may arise in the course of in-depth site-characterisation efforts. The decision to go underground is not based on the status of site characterisation alone but depends on several other aspects. Some detailed points regarding uncertainties:

- Prediction-outcome studies during tunnel construction provide information on uncertainties in qualitative and, partially, in quantitative terms (Posiva).
- Mechanistic studies, e.g. of the interactions between radionuclides and clay, will provide better understanding but possibly not greatly affect safety assessment (ONDRAF/NIRAS).
- Sensitivity analyses can be performed by probabilistic modelling tools. However, the amount (or lack) of available data must be considered, and care must be taken to account for bias in sampling and measurement techniques (Andra).

Report of Working Group C

As an introduction to this topic, it was acknowledged that the iterative cycle of safety case development and reviews is aimed at ensuring consistency between safety strategy, design, and site characterization and is an efficient way of focusing R&D studies on priorities. This cycle is primarily the responsibility of the implementer but is also based on periodic reviews and on interactions between implementers and regulators. The presentation by the United States – CNWRA, for example, puts forward a model in which there is ongoing dialogue regarding the implementer's methodology to inform a common understanding, move towards agreement on approaches, and ensure that implementer provides sufficient information in a license application for review. The working group agreed that review cycles and R&D programmes should be adapted to the different stages of repository development (feasibility; construction; operation; closure…), with the view to structuring the communication of the scientific understanding between the different parties. The dialogue between the implementer and the regulatory or technical support organizations is supported and improved when the regulatory bodies are able to develop their own scientific knowledge and skills. In particular, the development of independent experimental and modelling capabilities by the regulator supports the establishment of requirements as well as a rigorous assessment of the approaches and R&D programme proposed by the implementers. (See again the presentation by the United States CNWRA). Sometimes the public more easily accepts technical results produced by the regulator, as has been observed by SKI in the Swedish programme. This observation may apply particularly to the geosphere and site characterisation, which are – especially in the Swedish programme, but also in other programmes to varying degrees – more complex compared to the EBS.

In order to illustrate how safety assessment and related scientific studies may guide further site investigation, at various scales, two examples were discussed from the assessment by IRSN of the Andra “Dossier 2005”. The first one deals with the existence of hydraulic structures in the Callovo-Oxfordian formation (cited above). Because it was recognised that seismic investigation from the surface could have limitations, it was recommended to drill inclined boreholes to check the presence/absence of fractures at the location where seismic indices were observed. The additional and complementary investigations allowed ruling out the presence of hydraulic structures in this area and thus reducing uncertainty about the homogeneity of the rock.

A second example (see poster presented by IRSN, A. Dehoyos *et al.*) concerned the improvement of the groundwater model developed by IRSN for which, after several years of development and data fitting, it was concluded that salinity should be accounted for in the model. This led to the gathering of additional data related to salinity concentrations in the Parisian Basin with the view to improving the relevance of the processes modelled and the data approximation.

Finally, the working group discussed the use of an underground research laboratory, identifying two main types. In the first, the URL is planned eventually to serve as part of the final repository (e.g. Finland); in the second type, the URL is used for characteristics confirmation, but the repository will be located outside the URL (although perhaps nearby or in the same geological formation (e.g. France). In the first case, where scientific investigations are performed in parallel with the construction, there might be constraints on the construction techniques used in order to avoid any perturbations between scientific studies and investigations and the construction (timing, etc). In the second case, the homogeneity of the rock is used to transfer information over a wider zone but will probably imply additional investigations to confirm the homogeneity at larger scale (see IRSN example above).