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Integration Group for the Safety Case (IGSC)

Workshop on Handling of Time Scales Assessing Post-Closure Safety

Compilation of Abstracts

A workshop organized by the OECD Nuclear Energy Agency and hosted by the French Institute for Radiological Protection and Nuclear Safety - IRSN

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IRSN

Workshop on
Handling of Time Scales in Assessing
POST-CLOSURE SAFETY

Paris, France
16-18 April 2002

A workshop organised by
the OECD Nuclear Energy Agency

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1. GENERAL CONTEXT

The closure of a repository represents a transition from active management of the facility to passive safety. A convincing **Safety Case**¹ addressing post-closure safety is required to support positive decision to move on the next step in the stepwise process of the planning and developing underground repositories for the disposal of radioactive waste. The Safety Case must provide evidence for safety at all relevant times subsequent to closure. Relevant times may extend into the future, in some cases for as long the radiotoxicity associated with the repository represents a hazard to human health and the environment. Dependent on the half-life and activities of the radionuclides under consideration, the Safety Case may thus need to address very long periods of time.

Time is also an important consideration in the analysis of potentially disruptive human actions. The time when institutional control of the repository can no longer be guaranteed and the time when human intrusions need to be incorporated in a safety assessment must be considered.

Post-closure safety is typically provided by a system of multiple barriers, providing a range of safety functions. The barriers generally include an engineered barrier system and the geological setting (the natural barrier or barriers). The significance to system performance of particular barriers, the safety functions that they provide, and uncertainties and perturbing phenomena that affect them, vary over the time period of concern in a safety case. Uncertainties arise, for example, from:

- The relatively complex phenomena that may occur during an initial, transient phase subsequent to closure (e.g. resaturation phenomena and chemical reactions);
- The long-term evolution of the near field components and of the geological setting which may result in significant changes (e.g. uplift/erosion, tectonics, changes in geochemistry);
- The limited predictability, even in the short term, of societal evolution and future human activities (e.g. deep drilling, biosphere changes, human habits).

Thus, some phenomena and uncertainties may be significant between certain time intervals and be of relatively little concern at other times; the issue of how to handle phenomena and uncertainties that are characterised by widely different **time scales** is of concern to all national programmes. The most appropriate ways of quantifying performance or safety may also vary with time (the most common performance indicators are dose and risk, but these may be complemented by a number of other possible indicators). Thus, it may be convenient to divide the post-closure period into a number of intervals (**time frames**), that are characterised by particular types of phenomena or uncertainties, and for which particular types of performance or safety indicators are most suitable. This approach might also help with communicating and discussing the Safety Case with a wide range of audiences.

¹. The term is defined in the NEA report on the “Confidence in the Long term safety of Deep Geological Repositories: its development and communication” 1999. In this report, a Safety Case is defined as a collection of arguments, at a given stage of repository development, in support of the long-term safety of the repository. It comprises the findings of a safety assessment and a statement of confidence in these findings. It should acknowledge the existence of any unresolved issues and provide guidance for work to resolve these issues in future development stages”.

2. AIM OF THE WORKSHOP

The various issues presented in the previous section provides the motivation for the proposed Workshop, the title of which is:

“Handling of Time Scales in Assessing Post Closure Safety”.

The overall aim of the Workshop is to identify and discuss approaches related to and work done on the times scales issue within national waste management programmes, and in the context of assessing post-closure safety of deep repositories. The Workshop is intended to provide a platform both for regulators and implementers. The outcome of both presentations and working group discussions will aim at identifying a common basis or common elements for handling time scales in future safety cases.

The **main issues** of the Workshop will be:

- The ways in which the time scales, including both strategic approaches from regulators and implementers and practical work, have been taken into account in the deep disposal programmes.
- The development of ideas on future work or on exchanges needed on an international level in order to improve the way in which time scales are addressed in a Safety Case.

3. SCOPE OF THE DOCUMENT

This document provides a compilation of the abstracts of each presentation that will be presented during the workshop on 16-18 April 2002 on the " Handling of Time scales in assessing post closure safety". It will allow participants to have a preliminary overview of the presentations before going to the workshop as well as of the issues that could be discussed during the workshop.

The compilation and in particular the order of the abstracts follow the schedule of the workshop within the plenary and working group sessions.

PLENARY SESSION

SOME QUESTIONS ON THE USE OF LONG TIME SCALES FOR RADIOACTIVE WASTE DISPOSAL SAFETY ASSESSMENTS

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A safety case for a radioactive waste repository generally requires assessment of the radiological impact, either in terms of dose or risk, on a potentially exposed group at some time in the long-term future. In the UK, the Environment Agencies' "*Guidance on Requirements for Authorisation*" (GRA) includes the requirement that:

"After control is withdrawn, the assessed radiological risk from the facility to a representative member of the potentially exposed group at greatest risk should be consistent with a risk target of 10^{-6} per year (i.e. 1 in a million per year)".

The time scale over which this risk criterion applies is not set in the GRA, although in the UK, it is generally considered to be of the order of 1 million years for a deep repository. Time scales of 10,000 years or more seem to have become broadly accepted internationally although there are significant variations between different national regulations.

The paper will question what is driving the need to address long time scales and what are the benefits of doing so. The rationale underlying the requirement to address long time scales is not entirely clear. There are a number of questions regarding why regulators and developers consider it necessary to address extremely long time scales in safety assessments of repositories. For, example, does the need arise from a concern to demonstrate to the public that radioactive waste disposal facilities can remain safe for "all time"?

Consideration will also be given to interpretation of risk over extremely long time scales and whether the same weight should be applied to risks in the far future compared similar levels of risk in the near future. Where a risk criterion is adopted as the regulatory standard, what weight does a regulator, or developer, place on a radiological risk at, say, 1,000 years and at 1 million years?

Other issues also arise regarding whether the public believes that credible safety cases can be presented based on extremely long time scales and whether the extrapolation of existing knowledge over such time scales might undermine public confidence. Even among experts there is likely to be dissent over the ability to extrapolate existing models and data to extremely long time scales and this might influence the public's perception of a safety case for a repository. The time scales and dose/risk criteria applied in regulations have generally been developed through expert groups or advisory committees; perhaps more understandable, though still rigorous, performance assessment criteria might developed through wider public dialogue.

HANDLING TIMESCALES IN POST-CLOSURE SAFETY ASSESSMENTS: A NIREX PERSPECTIVE

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Previous Nirex assessments have been based on the use of probabilistic safety analysis covering many millions of years. However, Nirex has also published an assessment methodology in which the assessment timescale is divided into a number of discrete periods of time (timeframes). In a planned update to its published generic post-closure performance assessment, Nirex is considering using the methodology based on timeframes.

One approach to defining the timeframes could be based on the evolution of the repository system, with timeframes being distinguished by the occurrence of certain significant FEPs (for example the period of institutional control, expected time of container integrity or the period for which geosphere stability can be assumed). This approach provides a clear link to the system evolution, but needs to acknowledge the uncertainty associated with the timing of certain FEPs and hence with the definition of the timeframes. An alternative approach would be to define timeframes to reflect the periods of interest to stakeholders. This latter approach provides a clear mechanism for stakeholders to make early inputs to the assessment process, but may not always be easy to integrate into the development of a safety assessment seeking to respond to technically-defined regulatory requirements.

Nirex is seeking to integrate the above two approaches into an assessment methodology that incorporates stakeholder concerns into a technically robust representation of the repository system and its evolution. The Nirex FEP analysis approach to safety assessment involves the development of a “base scenario”, that describes the expected or “normal” system evolution; and a range of variant scenarios that each consider alternative system evolutions which could affect safety. Each scenario is defined in a broadbrush manner on the basis of a FEP sequence. Scenario definition provides an opportunity for stakeholders to make an early input to the assessment process by assisting in defining the FEPs and FEP sequences for consideration. Timeframes could then be defined on the basis of these FEP sequences.

Adopting timeframes as part of a safety assessment methodology has a number of implications. The assessment approach for each timeframe may vary. For example, in later timeframes more qualitative methods may be more appropriate. This has the advantage of providing an assessment framework within which qualitative arguments, alternative indicators of consequence and natural analogues could take on a higher profile. Additionally, it could be expected that timeframes would be shorter in the earlier stages following closure, therefore allowing for a more detailed treatment of the evolution of the near-field barriers. Whatever approach is adopted, it will be necessary to ensure consistency with national regulatory requirements.

HANDLING OF TIME SCALES IN SAFETY ASSESSMENTS: THE SWISS PERSPECTIVE

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In Switzerland, as elsewhere, disposal systems for high level radioactive waste are sited and designed to isolate radioactive materials from the human environment for very long times. Such disposal systems are physically separated from the human environment by their deep underground location and are typically sited in locations that are geologically stable and unlikely to be disturbed by geological events, surface phenomena or future human actions. Siting and design should ensure that the majority of radionuclides are retained within the repository and its immediate surroundings for as long as they present a potential hazard, and that any eventual releases of radionuclides to the human environment are not a safety concern.

Safety assessments are carried out to evaluate the adequacy of proposed disposal systems from the point of view of long-term radiological safety. In order to satisfy Swiss regulations, the doses and risks related to a disposal system "shall at no time" exceed specific values set down by the regulator. Evaluations of dose and risk are, however, always subject to uncertainty, and these uncertainties in general increase with the time scale under consideration.

Safety assessments carried out in Switzerland consider a broad range of cases addressing possible paths (or scenarios) for system evolution. The range of possible evolutionary paths for the engineered barrier system (EBS) of a well-sited repository and for a well-chosen host rock can be bounded with reasonable confidence over about one million years into the future, and, over this period, meaningful estimates of radionuclide release rates to the biosphere can be made. In order to evaluate doses and risks, however, assumptions must be made regarding the evolution of the biosphere and the nature of future human behaviour. Rather than attempt the impossible task of predicting biosphere evolution and human behaviour over a one million year period, Swiss safety assessments consider a range of credible illustrations of future biosphere states, as well as hypothetical critical groups chosen to be representative of the individuals or population groups that might be at greatest risk or receive the highest doses for a given biosphere state.

After about one million years, predictions regarding the evolution of the EBS and host rock become more speculative, and the assumptions on which the evaluation of radionuclide releases to the biosphere are based, such as the continued deep underground location of the repository, become less reliable. By this time, however, the radiotoxicity of the waste has declined considerably.

**HANDLING OF TIME SCALES IN SAFETY ASSESSMENTS OF GEOLOGICAL
DISPOSAL: AN IPSN-GRS STANDPOINT ON THE
POSSIBLE ROLE OF REGULATORY GUIDANCE**

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One of the basic objectives of radioactive waste management is the protection of human beings and of the environment now and in the future. This objective means that the waste should be adequately managed for as long as it contains dangerous amounts of radiotoxicity. The potentially powerful argument represented by radioactive decay can be utilised to determine the time-span needed for isolation especially as far as short-lived wastes are concerned. When the question moves to long-lived wastes and geological disposal projects, this however means the necessity to deal with an unlimited future and leads to serious practical difficulties. These difficulties are notably linked to the nearly infinite variety of events and evolutions that turns out to be plausible in a distant future and the lack of adequate knowledge to predict or extrapolate evolution to long time scale. Two types of problems have thus to be dealt with in the safety assessment of geological disposal: first, it is certain that system behaviour changes with time; second, the achievable certainty in the description of some of the system components will decrease with time and justified modelling of their evolution might be reasonably achievable for a limited timeframe only. Both problems eventually lead to the concern that long-term evaluation could become an endless task, which furthermore often leaves room for pointless speculations.

To overcome the difficulties encountered, the regulators have to face the challenge to provide guidance, clarify the objectives or give more achievable ones. This notably concerns the definition of the scope of safety assessments (What to do? What not to do? How far to go?) and the proposal of solutions where specific difficulties are encountered. As technical organisations supporting the national licensing authorities in Germany and France, GRS Köln and IPSN have been both involved in this effort to provide guidance and clarifications. This paper presents their standpoints on the subject.

The question of defining a scope for safety assessment is first addressed. While acknowledging the potential advantages of adopting a time cut-off, IPSN and GRS consider this decision both unnecessary and difficult to justify from a purely scientific standpoint. However they also state that assessments of far future evolutions do not require the same type of treatment as shorter-term evaluations. Adequate characterisation of the site stability (based on history and regional geological context) and a justified definition of its expected duration are thus considered as most valuable and essential information.

Appropriate site selection decisions should preclude changes of such a fundamental nature as major tectonic movements or volcanic events for an expected period of site stability. Beyond this defined time such events and evolutions may become relevant, and then qualitative or semi-quantitative assessments based on stylised situations and a set of safety indicators may be helpful to approach the residual risk. Definition of conventional situations complementing the use of

radiotoxicity and comparison with uranium mines is a potentially interesting topic for future international collaboration.

In a second part, approaches to overcome the specific difficulties associated with the evolution of man, the society and the surface environment are proposed. The aim is here to supplement the lack of scientific grounds for predicting evolution by proposing conventional choices. Main topics thus addressed are: the role of institutional control and the possibility of human intrusion, and the treatment of biosphere. Basis for the proposed approaches are: reliance on control and memory keeping limited to some 10^2 years – intrusion can accordingly be excluded; definition of stylised biosphere conditions derived from current - and eventually past - climate conditions and human habits and techniques.

In a third part, more general and fundamental guidance is given and perspectives with regard to a future decision making process are proposed. It is in particular stated that the aim of safety analyses is not to predict future but rather to demonstrate the isolation potential of a disposal. The importance of the overall process - that goes much beyond the assessment of radiological impact only – is emphasised. The effort taken to ensure sound siting decisions and adequate design choices is thus considered of a fundamental importance to provide the necessary level of confidence over large timeframes. Technical issues related to early transient phases might therefore deserve sufficient attention.

CONSIDERATION OF TIME SCALES IN THE FINNISH SAFETY REGULATIONS FOR SPENT FUEL DISPOSAL

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Spent fuel disposal program in Finland has passed the decision-in-principle process that is crucial to the selection of the disposal site and to obtaining the political acceptance for the disposal plan. The regulator (STUK) participated in the process by reviewing implementer's (Posiva) safety case. The review was based on the general safety regulation issued by the Government in 1999 and STUK's guide for the long-term safety specifying the general safety regulation. These regulations distinguish four time periods for which different safety criteria are defined.

The safety criteria for the operational period of the disposal facility are based on dose constraints for the normal operation, anticipated transients and postulated accidents. In this timeframe, verification by experience of the compliance with the dose constraints is feasible.

The second time period, so-called environmentally predictable future is defined to extend up to several thousands of years. Conservative estimates of human exposure can be done for this time period, despite the environmental changes, and accordingly the safety criteria are based on dose constraints. The geosphere is expected to remain stable or slight, predictable changes may occur. In this timeframe, the engineered barriers are required to provide almost complete containment of the disposed waste. Then one minimises the impacts from waste induced disturbances and preserves the retrievability of waste.

Beyond about 10 000 years, great climatic changes, such as permafrost and glaciation, will occur. It would be meaningless to assess human exposure for this time period and consequently, the radiation protection criteria are based on constraints for release rates of radionuclides from geosphere to biosphere (geo-bio flux constraints). Although the climatic changes affect also the conditions in the geosphere, their ranges are estimable. Thus radionuclide release and transport assessments in the repository and geosphere are realistic.

Beyond about 200 000 years, the activity in spent nuclear fuel becomes less than in the batch of natural uranium wherefrom it was fabricated. In that timeframe, the hazard posed by disposed spent fuel is comparable to that of natural uranium deposits and the repository can be regarded as a part of nature. No rigorous qualitative safety assessments are required for that time period but the judgement of safety can be based on bounding analyses with simplified methods and comparisons with natural analogues.

HANDLING OF TIME SCALES: APPLICATION OF SAFETY INDICATORS

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The safety of a geological disposal system can be assessed using indicators such as risk and dose, which directly quantify radiological impacts on individuals in the future. The quantitative dose calculations can be undertaken until the peak value is obtained, even if this is beyond one million years. For these cases, however, results from any time period should only be presented after careful interpretation and consideration. Since the safety assessment of a geological disposal system covers a very long period of time, there are inherent uncertainties involved in assumptions about future human activities and environmental conditions, which increase the longer the time frame becomes.

Human lifestyles are, realistically, unpredictable over more than a few tens or a hundred of years at most. On the other hand, ecological changes due to the influence of human actions can be predicted up to around tens or hundreds of years. Concerning the surface environment, it can be argued that some major features of the biosphere will probably remain comparable to present day conditions up to around one thousand years, although human behavior may change significantly and major changes in climate could occur. After this, the next glaciation period is expected to occur around 10^4 to 10^5 years from now. Extensive climatic change will have a significant influence on the near surface environment and the hydrogeological system in particular. The engineered barrier system (EBS) and the geosphere are located at considerable depth and hence will be relatively unaffected by surface changes. It can be shown that there exists a sufficiently stable geological environment such that a repository will not be influenced by disruptive natural phenomena over next a few hundred thousands years. Significant changes to the EBS and geosphere performance are not expected to occur over this time period if a stable geological environment is selected for disposal.

The following measures have been proposed to address these uncertainties associated with safety assessment:

- Use of Reference Biospheres as a tool for assessing the performance of a disposal system in terms of radiation dose (e.g. BIOMASS, 1999);
- Supplementing the assessment results based on dose (or equivalent risk) by other independent indicators, which do not rely on assumptions made in biosphere models (IAEA, 1994).

The former approach has already been adopted in various performance assessments in order to illustrate the impact in the biosphere over time scales of interest. The use of supplementary indicators is also useful as they are more indicative of the isolation capability of a disposal system and the potential risks associated with radioactive waste (Neill *et al.*, 1994; IAEA, 1994; Röthemeyer, *et al.*, 1996); examples of such supplementary indicators include concentration and flux of specific nuclides and radiotoxicity index.

These supplementary indicators have already been studied in some national programs. For example, the flux of natural radionuclides in the vicinity of the Hard Rock Laboratory (HRL) in Sweden has been compared with the established limit for radionuclides assumed to be released from a repository to the biosphere (Miller *et al.*, 1996). In this study, natural radionuclide fluxes resulting from groundwater, denudation by glaciers and weathering have been calculated and the results compared with Swedish safety limits.

As an example of radionuclide concentrations being used as a supplementary safety indicator, Neall *et al.* (1994) made a comparison of predicted releases of radionuclide concentrations from a performance assessment with the concentrations of natural radionuclides occurring in groundwater. This comparison was made to confirm the credibility of the assessment results of the Swiss Kristallin-I study (Nagra, 1994). This study used an approach to the assessment of barrier performance which involves a radiotoxicity index, which can be calculated by dividing the radionuclide flux released from any barrier by the yield of a typical well (to convert flux to concentration) and dividing the result by water intake limits. Implicitly, this focuses on releases into groundwater and takes a well to be a 'worst case' which minimizes the extent of dilution. This approach keeps the assessment results from being affected by changes in human activities that are hard to foresee, but requires the assumption that the average amount of well water drawn will remain unchanged in the future.

In the H12 study (JNC, 1999), which is the project aimed at establishing a technical basis for HLW disposal in Japan, supplementary safety indicators have been applied to increase confidence in the safety assessment. The nuclide concentrations evaluated in the geosphere and biosphere in the H12 repository system were compared with measurements of naturally occurring nuclides. The comparison indicated that the concentration of radionuclides released from the repository would be several orders of magnitude lower than that of natural radionuclides. This suggests that application of supplementary safety indicators could increase the reliability of long-term safety by more rigorous measurements of concentrations of naturally occurring radionuclides in the characterisation phase at a specific site, which will be compared with concentrations of relevant nuclides predicted by site-specific performance assessment models. An advantage to making such a comparison is that both technical and non-technical audiences can judge the relative, long-term impact of a deep geological repository.

This paper will discuss the roles of safety indicators for handling of time scales in safety assessment of geological disposal based on the practical examples of application of these indicators.

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HANDLING TIME SCALE AND RELATED SAFETY INDICATORS

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The fundamental objective of a nuclear waste repository is a long-term protection of man and environment. To conduct safety analyses over long period of times, up to the million years, is not a straightforward question. For example, the required demonstration of safety, in respect of the fundamental rule of safety, is out of the scope of any experiment. The safety analyses of a geological disposal system is usually addressed by using qualitative and quantitative approaches. But in any case, the evaluation is made for specific time-span and those have to be carefully chosen and discussed in term of uncertainties, especially for the long term.

At Andra, a tentative time fractionation has been conducted for geological disposal through two types of approaches:

- The first one is based on a “phenomenological” description of a series of situations dependant of the time scale. The tentative time fractionating of the repository have been proposed for the operational and post-closure phases using the thermal, hydraulic, mechanical and chemical (THMC) processes occurring within the system. The safety case can then be based on a series of simulations which objectives are to assess the level of safety which can be reached to various internal defects or external events (see paper from G. Ouzounian on Phenomenology Dependant Time Scale).
- The second one, purpose of this paper, proposes to handle time scale using supplementary “safety indicators”. Quantitative “measure” of safety is generally obtained using “safety indicators” such as the conventional calculation of the “individual dose” (mSv/y) which means a calculation of a direct radiological impact on individuals. This individual dose evaluation is usually preferred to other because it is a direct safety indicator, widely used with a large international consensus and it can be compared with existing standards (ICRP). However, the only dose calculation is not entirely satisfying because it relies upon great uncertainties associated to the assumptions made as regards to critical group, human behavior and climate change. As well, the probability of exposure is not taken into account in the calculation. The risk, number of health effects per year, bears more information than the dose. It also allows comparison with level of risk associated with other industrial activities or natural risks. But, the risk is a complex tool if it is not well explained and underlying problems can arise with the estimation of probabilities.

With an objective of confidence building, Andra is seeking the use of complementary safety indicators within the framework of safety assessment of a geological HLW repository. With regard to the definition of a safety indicator which must provide a measure of safety, directly or indirectly, and can be compared to a judged acceptable value, supplementary safety indicators can be an assess towards a more qualitative approach. Beyond safety issues, safety indicators may also be a valuable contribution to communication, to decision making concerning the repository, to support technological choices relative to concept or to handle time scale.

Safety analyses commonly refers to time, such as transfer time through each barrier, time to reach the biosphere, decay time, time for alteration of waste packages or waste containers, time until the next glacial period, time of geosphere stability...Still, direct link between safety and time is difficult to assess. This paper attempt to put into perspective time scale and safety indicators. The possible use of the supplementary safety indicator, activity, radiotoxicity, radionuclides fluxes and concentrations is presented and discussed.

TIME SCALES IN THE LONG-TERM SAFETY ASSESSMENT OF THE MORSLEBEN REPOSITORY, GERMANY

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The Morsleben repository for radioactive waste (Endlager für radioaktive Abfälle Morsleben, ERAM) has been in operation since 1971 as a repository for short-lived low- and intermediate-level radioactive waste. Until the end of the operational phase in 1998 a waste volume of about 37,000 m³ with a total activity of approx. $4.5 \cdot 10^{14}$ Bq had been disposed of.

The repository is located in the salt structure of the Aller valley zone, formed in the geological formation of Zechstein/Thuringium (upper Permian). The salt formation consists of folded rock salt, potash salt and anhydrite stratifications. The overall thickness of the salt formation is between 350 m and 550 m. The salt formation is overlain by a tight cap rock. The mine extends over a length of 5.5 km in NW-SE direction and 1.4 km at the maximum perpendicular. The 525 m deep Bartensleben shaft connects 4 floors in various levels between 386 m and 596 m. Due to rock salt and potash production, many cavities exist in this former mine with dimensions up to 100 m in length, 30 m in width and in height, amounting to a volume of about $8 \cdot 10^6$ m³ of underground openings. After backfilling during salt production an open volume of more than $5 \cdot 10^6$ m³ remains. The sealing concept provides for an extensive backfill of these underground openings in order to meet the safety goals. Nevertheless, an open space of some $1 \cdot 10^6$ m³ will remain after backfilling.

The examination of the Morsleben site and its surroundings enables a comprehensive determination and assessment of the potential hazards compromising the natural barriers of the repository through geological processes and water inflow from surrounding geological units. Most important for the safety of the repository is the limitation of water inflow into the salt structure by the tight cap rock.

Despite the fact that no subdivisions into different time frames are provided for in the German regulations, in the scenario analyses a number of time frames were identified which influence the further behaviour of the repository system:

- As long as the cap rock keeps its present behaviour the amount of water inflow is limited to some 100 m³/yr at maximum if an inflow occurs at early times. In conjunction with the amount of open space remaining in the mine and the creep behaviour of the salt which tends to reduce this openings the limited water inflow leads to a time frame of some 1 000 years which is needed to fill the mine before brine could be squeezed out of the salt structure.
- Due to tectonic reasons the hydraulic behaviour of the cap rock can change after some 10,000 years by the creation of additional conductivity. Then, the cap rock no longer limits the rate of water inflow into the openings present in the salt structure at that time. This results in a nearly instantaneous flooding of the remaining openings and an immediate begin of water being squeezed out of the salt structure.
- The climatic development leads after some 60,000 years and some 100,000 years to a cooling with the occurrence of permafrost which could modify the groundwater flow regime in the Aller valley zone. The present hydro-geological model loses its validity

after approx. 150,000 years when the hydraulic conductivities of the aquifer system and the corresponding driving forces change substantially.

Another important time frame is related to the development of the hydraulic conductivity of the engineered barriers which divide the locations where waste is disposed of from the remaining parts of the mine. Due to the fact that the material of the engineered barriers could be effected by the brine established in the mine due to possible contact with different salt minerals the initial hydraulic conductivity might be increased depending on the number of exchanges of the pore water in the engineered barriers. Laboratory experiments on the barrier material show that 10 exchanges of the pore water result in an increase in hydraulic conductivity of one order of magnitude. Taking into account the planned dimensions of the engineered barriers these 10 exchanges last 5,000 to 10,000 years.

TECHNICAL TOPIC A:

**THE DIFFERENT TIME SCALES
VERSUS
THE REGULATORY FRAMEWORK
AND PUBLIC ACCEPTANCE**

LONG TIME SCALES, LOW RISKS: BALANCING ETHICS, RESOURCES, FEASIBILITY AND PUBLIC EXPECTATIONS

N. A CHAPMAN
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This paper discusses a range of technical and non-technical factors related to long time scales for deep geological repositories, and is intended to provoke discussion.

The key ethical positions on long-term safety are, to some extent, contradictory. Primarily, we plan to provide the same measure of safety for all future generations (sustainability: no undue burdens). Secondly, opponents of disposal exhort us to do nothing that could cause irreversible harm unless there is some compelling need (precautionary principle). Third, we should use our resources to provide for the needs of immediate generations, putting priority on near-term hazards rather than on hypothetical long-term hazards (chain of obligation principle).

It has been brought forcibly home (to implementors in particular) that we are not solving this problem in isolation: as ‘guardians’ who know best. We are acting on behalf of society, so we also have to ask how society would like to weight these three principles. Individually, each ethical position can easily be met if the impacts of disposal, under all reasonable scenarios, are always negligible. Implementors aim to guarantee doses that are always a minute fraction of a variable natural background: hypothetical doses to hypothetical people, living ten or twenty times further into the future than the Ancient Empire of Egypt existed in the past.

Some factors that should condition our approach to thinking about time scales are:

- **RESOURCES:** Society has no ethical or value-based view (and is seldom asked specific questions) about how to divide and allocate a pool of resources so as to solve multiple ‘future’ problems or to improve future conditions. Consequently, some people assume that there are sufficient resources available to protect all people for all time. Although risk tolerability and ALARP are neat concepts for allocating resources, they are not used by political decision makers or society: ‘risk informed decision making’ for technical matters is still largely an academic concept. Trade-offs between the present benefits of alternative use of resources and the reduction of hypothetical far-future harm are never considered: if they were, we would be spending no money at all on P&T research and a vast amount more on natural hazard prediction or mitigation. Making information more readily interpretable in terms of hypothetical *benefits* (of alternative uses of resources) as a function of time, rather than hypothetical *detriments* might be a way forward.
- **REAL PUBLIC CONCERNS:** Most people are seriously concerned about the safety of future generations no further than their great-grandchildren: about a 100 year time frame. Will the repository next door irradiate them each time they drive past it; will it leak and poison their water; will it contaminate their land for generations? This suggests we should apply much effort to reassuring people about what we (perversely, in the public view) would call ‘short-term’ safety. This is not the same as stipulating a ‘cut-off’: some regulations do not require compliance with ‘early period’ dose/risk targets beyond 10,000 or 100,000 years. If these targets could be exceeded under reasonably likely conditions beyond this period, the cut-off approach is clearly non-sustainable. What is

does imply is some form of discounting of future harm – an issue over which views differ markedly.

- **POOR EXPERIENCE OF PREDICTION:** Experience of scientific prediction is that, within a person's lifetime, things generally work out differently to how we were told they would. People are sceptical about claims to predict the integrity of passive, man-made, engineered systems for more than a few decades into the future, unless constant maintenance is assured. This suggests a rethink to the conventional way that we present safety assessments. Basing core arguments on time scales associated with natural isolation mechanisms may be much more digestible.
- **HUGE AND TINY NUMBERS:** For a properly sited repository, relying on long-term stability of a hydrogeologically non-dynamic, isolated system as the main pillar of safety, we are dealing with unidentifiably low potential impacts, unless someone digs the waste up again. The health impacts we calculate for the far future are stochastic, addressable only by statistical methods. There are widespread misconceptions about the meaning of the risks that are calculated. The numbers themselves are surrounded by a growing dispute over whether such low incremental doses have health significance that should be of any concern to society. Implementors have hoped to make a convincing case to the public by trying to balance huge numbers (hundreds of thousands of years) against tiny numbers (microsieverts) – often on the same diagram. Trying to use this as the main thread of a safety case can present a real burden.
- **PERCEPTION OF TIME:** Some programmes countenance some form of control for around 300 years, possibly even retrievability, presumably managed by national institutions: 300 years ago, about one half of today's European nations did not exist. The whole of recorded human history happened in the last 5000 years: about the time some concepts expect their waste containers to last. Modern human beings appeared perhaps 150,000 years ago: about the time it takes for spent fuel to reach the 'cross-over' to toxicity levels similar to uranium ore. Modern human beings didn't reach Europe until 40,000 years ago: in some deep clay formations, it takes water that long to move one metre. There are mixed messages in these facts: different people will feel reassured or worried by them, emphasising that perceptions of long time scales vary considerably.
- **GEOLOGICAL STABILITY REDUCES THE SIGNIFICANCE OF UNCERTAINTIES:** Uncertainties surround the far-future estimates of many aspects of system behaviour. If a disposal system contains uncertain mechanisms that could lead to releases on short (1000s of years) time scales if they behave in a particular way, then the proponent is in a position of weakness. Cases that rely on favourable interpretations of flow rate distributions, and retardation and dispersion mechanisms in the far-field, will automatically be on the defensive. Nothing kills public confidence faster than reputable and technically indistinguishable experts arguing with conviction. Few disposal systems are so obviously conceptually simple, robust and well-founded that such arguments can be entirely avoided. Those that are so robust are in exceptionally stable, hydrogeologically isolated geological environments. The burden of long-term predictability and confidence is borne by stability of the geological environment, which is conceptually easy to illustrate to people, not engineered barrier performance.
- **ONLY RADIOACTIVE WASTE?:** Should society be alert to long time scales in other endeavours with potential hazards? Global warming has obvious long-term consequences whose impacts are hard to scope, let alone quantify in the form of health risks to future

generations. Toxic chemical wastes, which do not decay like radioactive wastes, have to be disposed of or stored. We overexploit land and aquifers, which will take thousands of years to recover: health impacts on future generations living in these areas are readily conceivable, but difficult to quantify.

- **GRADED IMPACTS & TIMESCALES:** Which approach could provide appropriate levels of protection and also be more readily endorsed by society? A system of '*graded containment objectives*' could be envisaged for deep repositories. Total containment of all activity for 500 years; for 100,000 years, any release through natural mechanisms to give rise to doses (assuming the same biosphere as today) that are less than about 10% of the world-wide variation in normal background radiation (excluding the highly variable radon contribution), which would correspond to what ICRP is currently calling Band 3: Low Concern; after this time, the eventual redistribution of residual radioactivity in the environment by erosion and other natural processes to be indistinguishable from regional variations in concentrations of natural terrestrial radioactivity in near-surface rocks, soils and waters. Clearly, attitudes to leaving what could amount to a rich natural uranium deposit need discussion in this context.

SAFETY IN THE FIRST THOUSAND YEARS

M. JENSEN

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1. Background

The Swedish Radiation Protection Authority, SSI, has promulgated criteria for long-lived waste, "The Swedish Radiation Protection Institute's Regulations concerning the Protection of Human Health and the Environment in Connection with the Final Management of Spent Nuclear Fuel or Nuclear Waste"; decided on September 28, 1998. (SSI SF 1998:1).

The criteria delineate SSI's requirements for any final solution of the waste problem. For a repository, in particular, there are separate post closure requirements for design and construction purposes. The regulations require, inter alia, a risk limit to be met for the most affected group, and protection of the environment.

The regulations also include guidance regarding the treatment of the repository during different time scales after closure. SSI expects a strict treatment to be given for the first thousand years. SSI also expects a description of the repository's protective capability for longer periods, along with a discussion of uncertainties.

2. The Relevance and the Dilemma of the Short Time Scales

Clearly, there is a concern for the public in the municipalities about the time scale when children, grandchildren and coming generations will grow up. It is therefore also in the interest of the implementer to cover this era in its presentations of the safety case.

The short-term view, however, has seldom been in focus either in Swedish or international performance assessments. Part of this problem may stem from the fact that most performance assessments indicate that there will be no significant release during the first thousand years. Consequently, a hypothetical major release during the first hundreds of years has the potential to contradict the confidence in the long-term safety. Also, SSI would not support a license for a repository if significant releases could be foreseen in the near future.

3. A Possible Treatment of the Thousand Year Period

The author would like to offer a suggestion for the description of this period, which amounts to going through a list of possible mechanisms necessary for a significant risk to individuals or detriment to the environment. For each item on the list a description could be made to demonstrate that the scenario has been foreseen, with arguments to show that the scenario can be disregarded. Such an exercise could address both SSI's and the local community's concerns.

TECHNICAL TOPIC B:

**BARRIERS AND SYSTEM PERFORMANCES
WITHIN A SAFETY CASE:**

**THEIR FUNCTIONING AND EVOLUTION
WITH TIME**

FULFILMENT OF THE LONG-TERM SAFETY FUNCTIONS BY THE DIFFERENT BARRIERS DURING THE MAIN TIME FRAMES AFTER REPOSITORY CLOSURE

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In general terms the basic long-term safety functions of a disposal system (i.e. the engineered barrier system and the host rock) are the functions that the system as a whole or its constituents must fulfil in order to assure an adequate level of long-term radiological safety.

The long-term safety functions of a disposal system constitute a generic and methodological tool that can be used in a double sense. In the first place these functions provide an instrument for designing the system: the implementer must ensure that these safety functions are fulfilled by a series of robust system barriers and components. These functions can also be used as a means to describe in general terms the functioning of the system and, so, as a communication tool to different stakeholders who are less familiar with the details of a safety case. In the second case the understanding of the functioning of the system as obtained in the R&D programme is presented as a general description of how the different barriers contribute to the safety functions.

The aim of this paper is to provide such a general description of the system functioning for the Belgian case of deep disposal of high-level waste (mainly spent fuel or vitrified waste from fuel reprocessing) in the Boom Clay. From the detailed safety and performance evaluations the main time frames after repository closure are identified. Each time frame relates to a period during which the successive safety functions play a key role. Also, in each time frame the radiological impact on the environment is distinctly different.

The long-term safety functions of the disposal system are “physical confinement” (C), “retardation & spread release” (R), “limited accessibility” (L); the long-term safety function of the environment of the disposal system is “dispersion & dilution” (D). The first two safety functions can each be subdivided in two sub-functions. For the “physical confinement” function, which aims to prevent any release of activity from the waste matrix the two sub-functions are “water tightness” (C1) and “slow water infiltration” (C2). The “water tightness” function must prevent any contact between infiltrating water and the waste matrix; the “slow water infiltration” function must delay the moment that water can come into contact with the waste matrix without guaranteeing water-tightness.

The “retardation and spread release” function takes over when physical confinement fails; it aims at slowing down radionuclide migration to the biosphere. By doing so, the system will mainly lower and spread the radionuclide releases into the biosphere in time. The two sub-functions are “resistance to leaching” (R1) and “diffusion & retention” (R2). The first sub-function spreads in time the radionuclide releases from the waste matrix; the second one delays the migration of the radionuclides to the biosphere and spreads in time the radionuclide releases into the biosphere.

The safety function “limited accessibility” aims to limit the likelihood and consequences of human intrusion directly into the closed repository. The depth and location of disposal away from natural resources, the resilience of the disposal system to intrusion and the preservation of the memory of disposal are all elements that contribute to this function.

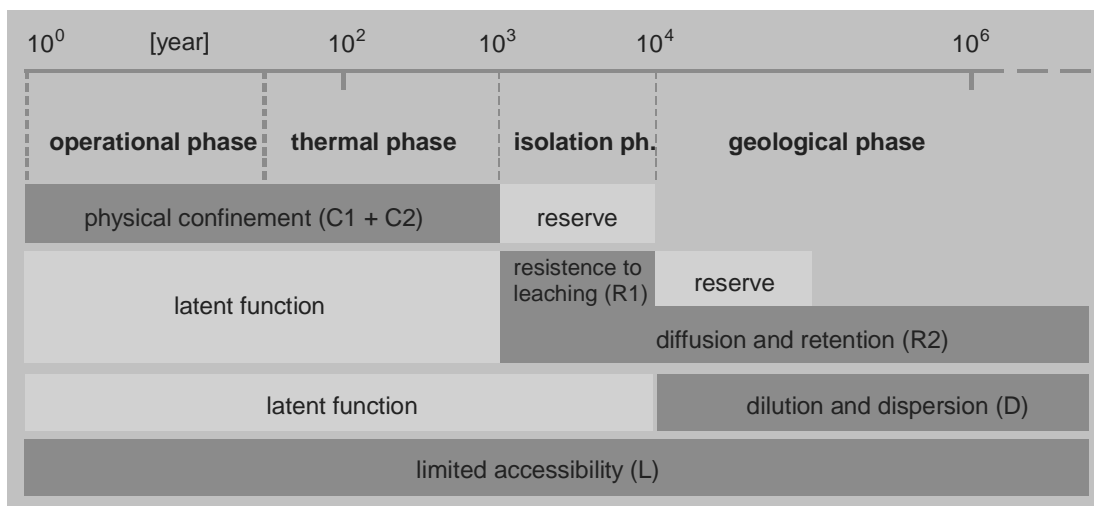
Finally, radionuclide fluxes and concentrations are diluted and dispersed in the environment of the disposal system, i.e. in the aquifers and biosphere.

In a preliminary evaluation of the functioning of the system in time, during repository operation and after repository closure, four characteristic periods or phases were identified, and which will be refined in future evaluations:

- the operational phase: this is the period between waste emplacement and repository closure, and can take several decades;
- the thermal phase: during this phase the heat generating waste significantly increases the temperature in and around the repository; its duration is approximately 300 years for vitrified waste and 2000 years for UO₂ spent fuel;
- the isolation phase: during this phase the radionuclide releases from the disposal system are negligible; in case of deep disposal of high level waste in the Boom Clay this phase is situated between 1 000 and 10 000 years after repository closure;
- the geological phase: here the repository enters the geological timescales (10 000 till million years after closure); the major impact, both due to non-retarded and retarded radionuclides is situated in this phase.

For the normal evolution of the disposal system the contributions of the long-term safety functions in each of the four phases is given in Figure 1. The safety reserves in this figure are based on realistic estimates of container, overpack and waste matrix lifetimes as compared to the conservatively assessed (minimum) lifetimes.

Figure 1. *The four phases of the normal evolution of the disposal system (high level waste) and the corresponding long-term safety functions.*



An next step in the analysis is the identification of the different barriers and components of the disposal system and its environment that contribute to the long-term safety functions in each of the lifetime phases of the closed repository. The result of this analysis is summarised in Table 1. This table enables to analyse and show system redundancies on the functional level and to make visible the safety reserves, i.e. the contributions of system components to the safety functions that are not considered in the safety evaluations.

Future developments of this approach will focus on a refinement of the considered time frames, on the supporting arguments for splitting up in different timeframes, as well as on redundancy and safety reserve evaluations.

Table 1. Components of the disposal system and its environment that contribute to the long-term safety functions during the three main phases after repository closure. The functions that are considered in the safety evaluations are given in bold.

Component	Thermal phase (1000 y)	Isolation phase (< 10000 y)	Geological phase (> 10000 y)
Glass matrix	–	R1	R1
UO₂ matrix	–	R1	R1
Vitrified waste canister	C1	R2	–
Container (spent fuel) or overpack (vitrified waste)	C1	R2	–
Disposal tube	C1	R2	–
Backfill in disposal galleries	C2	R2	R2
Seals	C2	R2	R2
Gallery lining	–	–	–
Shaft lining	–	–	–
Clay host rock	C2	R2	R2
Aquifers	–	D, R2	D, R2
Biosphere	–	D	D

TREATMENT OF BARRIER EVOLUTION: THE SKB PERSPECTIVE

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1. Introduction

This paper serves as a point of departure for the discussions to be held within the Working group of Technical Topic B entitled “Barriers and System Performances within a Safety Case: Their functioning and Evolution with Time”. The paper gives the SKB perspective of the issues to be discussed within the Working Group for this Topic, as they have been described in the Workshop Programme.

The preliminary Workshop Programme presents the following issues to be discussed by the Working Group for Topic B:

- What is the role of each barrier as a function of time or in the different time frames? What is its contribution to the overall system performance or safety as a function of time?
- Which are the main uncertainties on the performance of barriers in the time scales? To what extent should we enhance the robustness of barriers because of the uncertainties of some component behaviour with time?
- What is the requested or required performance versus the expected or realistic or conservative behaviour with time? How are these safety margins used as arguments in a Safety Case?
- What is the issue associated with the geosphere stability for different geological systems?
- How is barriers and system performances as a function of time evaluated (and presented and communicated) in a safety case?
- What kind of measures are used for siting, designing and optimising robust barriers corresponding to situations that can vary with time? Are human actions considered to be relevant?

The following is a brief and preliminary account of SKB’s view of these issues. The time frames for the presentation have been directly adopted from a Workshop presentation by De Preter and Lalieux entitled “Fulfilment of the long-term safety functions by the different barriers during the main time frames after repository closure”. These authors divide the time after waste deposition into four different phases:

- the operational phase between emplacement and repository closure, extending over several decades
- the thermal phase (~1000 yrs) during which heat generated by the waste increases the temperature of the host rock
- the isolation phase (~10,000 yrs) during which releases from the disposal system are negligible and
- the geologic phase (>10,000 yrs) during which the isolating capacity of the engineered barriers is no longer ensured

The KBS 3 concept with spent fuel in copper canisters surrounded by bentonite and deposited in granitic rock is in many respects different from the concept discussed by De Preter and Lalieux with both vitrified waste and spent fuel in steel canisters deposited in Boom clay. Nevertheless, in order to find a common ground for the discussions of time scales, a subdivision into the same phases will be used. The main difference lies in the fact that the KBS 3 system with its copper canisters is designed to isolate the waste over times extending into the geologic phase as defined above. Therefore, these two phases are treated together below. The operational phase will not be treated since this is outside the scope of the Workshop.

When discussing the different time frames, it is also important to bear in mind the evolution of the hazard of the waste, which decreases significantly over the time periods of interest.

2. Role of Barriers

The roles or, rather, the safety functions in the three time phases of the different barriers or system components in the KBS 3 concept are presented in Table 1. In SKB's recent safety assessment, SR 97 [1], it is demonstrated that in the reference case, the copper canisters are expected to keep their isolating capacity intact throughout the time phases discussed above. The role of the other barriers or system components will in the reference case thus be to provide suitable conditions for the canister. SR 97 also treated a scenario with initially defective canisters due to e.g. imperfect sealing. Here, additional safety functions of the different barriers become important, most notably the retarding function of the buffer and the host rock. The safety functions for this scenario are, for the isolation and geologic phases, presented in a separate column in Table 1.

Table 1. *The Safety Functions in the KBS 3 concept assuming intact or defective canisters.*

	Thermal phase 0 – 1000 years	Isolation and Geologic phases; 0 – 10 ⁶ years	
		Intact canisters	Defective canisters
Fuel	As isolation phase	None	<i>Confine matrix embedded nuclides</i>
Canister	As isolation phase	Isolate	<i>Limit release rate from canister interior</i>
Buffer	As isolation phase + Conduct heat	Protect canister (keep canister in position, prevent advective transport, exclude microbes)	<i>Retard</i> <i>Conduct gas (H₂)</i> Filter fuel colloids
Backfill	As isolation phase	Confine buffer	<i>Limit advection in tunnels</i>
Geosphere	As isolation phase	Provide stable chemical and mechanical environment	<i>Retard</i>
Biosphere	As isolation phase	None	<i>(Dilute)</i>

3. Uncertainties

The main uncertainties concerning the barrier performances for the three time phases are presented in Table 2. Additional important uncertainties affecting barrier performance are related to the repository environment on a larger scale, most notably uncertainties related to future climate.

Table 2. Uncertainties KBS 3

	Thermal phase 0 – 1000 years	Isolation and Geologic phases; 0 – 10 ⁶ years	
		Intact canisters	Defective canisters
Fuel			<i>Fuel dissolution rate</i>
Canister (copper shell and iron insert)		Quality of sealing Mechanical strength (isostatic load during glaciation, dynamic load at earthquakes)	<i>Evolution of initial defects</i>
Buffer		Chemical stability	<i>Gas transport properties</i>
Backfill			<i>Hydraulic conductivity, especially under saline conditions</i>
Geosphere		Chemical & mechanical behaviour during glaciation	<i>3D conductivity, transmissivity</i>
Biosphere	Societal structure, human behaviour	Societal structure, human behaviour	<i>Type of ecosystem, radionuclide turn-over, human behaviour</i>

4. Performance evaluation

The performance of the different barriers over time are evaluated with a number of different methods. These include:

- thermodynamic arguments (stability of copper in Swedish deep ground waters)
- kinetic arguments (corrosion rate of iron, fuel dissolution rate)
- mass balance arguments (limited illitisation of bentonite, copper corrosion)
- natural analogues (long term stability of bentonite)
- long-term extrapolation of short term experiments/observations (corrosion processes, radioactive decay)
- complex modelling (groundwater flow, radionuclide transport, earth quakes)

Several of these may be used to evaluate the performance of a barrier for a particular time phase. Table 3 gives an overview of the most important methods currently used by SKB for a selection of key processes.

5. Safety margins

For most safety functions in the KBS 3 concepts, the results of a realistic and also a pessimistic (conservative) evaluation of performance exceeds the required performance, and it is relevant to talk about a safety margin. This is described in the safety report wherever relevant, but there is no systematic way of using the safety margins in the final safety case in SKB's most recent performance assessment.

Table 3. Performance evaluation KBS 3

	Thermal phase 0 – 1000 years	Isolation and Geologic phases; 0 – 10 ⁶ years	
		Intact canisters	Defective canisters
Fuel			<i>Fuel dissolution: Experiments</i>
Canister (copper shell and iron insert)	Peak temperature: Model calculations	Copper corrosion: Thermodynamic & mass balance arguments Sealing: Testing of canister seals Mechanical stability during glaciation: Model calculations based on test results from manufactured canister inserts	<i>Iron corrosion: Experiments</i>
Buffer	(Saturation: Model calculations)	Chemical evolution and stability: TD model calculations, Natural analogues	<i>Gas transport: Experiments</i>
Backfill		See buffer	
Geosphere	(Resaturation: Model calculations)	Chemical & mechanical behaviour during glaciation: Model calculations	<i>Ground water flow: Hydro modelling based on 3D rock map from site investigations RN transport: 1D transport model with input from hydro modelling</i>
Biosphere			<i>RN transport modelling, Exposure pathway analysis</i>

6. Geosphere stability

The meaning of “geosphere stability” is here taken to include both mechanical and chemical stability in relation to what is desirable for a KBS 3 type repository. Two main issues concerning stability of the Swedish granitic bedrock relevant for the KBS 3 concept can be identified. Both regard conditions related to glaciations, which are expected within the next several thousand years in Sweden:

- the maintenance of reducing condition where a particular issue is the possibility of intrusion of oxygenated groundwater during a glaciation; and
- the effects of seismic events during a deglaciation.

7. Measures for siting, designing and optimising

Uncertainties concerning the long-term evolution of the repository system have influenced the siting and design of the repository in several ways.

A fundamental principle behind the design is the multi barrier concept, through which the effects of a possible long-term deterioration of one barrier are mitigated by the presence of the other barriers.

Another principle underlying the design of the repository is the choice of materials which are stable over long time periods. This applies to copper as the canister material and bentonite as the buffer material. Copper is thermodynamically stable under conditions expected in deep groundwaters in Sweden and bentonite is a naturally occurring material which was formed of the order of 10^8 years ago and which has since then mostly been exposed to conditions similar to those expected in deep groundwaters.

The layout of the repository is chosen so that the distances to major fractures/faults, where future seismic events are expected to occur, are chosen so that the risk that these events will cause canister damage is kept low.

A further design consideration is that the distance between neighbouring canisters is chosen so that the maximum temperature on the canister surface is kept well below 100 °C. This is to avoid boiling and accompanying enrichment of salts on the surface which could in turn cause long-term corrosion effects that are difficult to analyse.

Regarding siting, the repository will be located in a portion of the bedrock which does not contain ores of potential interest for future generations.

A more general principle behind the deep repository is to isolate the nuclear waste from man and the surface environment, thereby minimising the effects of uncertain future societal changes.

References

1. Deep repository for spent nuclear fuel; SR 97 – Post-closure safety. Main Report Volumes I and II. Swedish Nuclear Fuel and Waste Management Co., Stockholm 1999.

TECHNICAL TOPIC C:

**THE ROLE AND LIMITATIONS OF
MODELLING IN ASSESSING POST CLOSURE
SAFETY AT DIFFERENT TIMES**

PHENOMENOLOGY DEPENDENT TIME SCALES

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As required by the French act, Dec. .1991, construction projects for disposing of radioactive wastes have to be submitted to the Parliament by 2006. One of the most important points to allow for a decision at this time will be to gain confidence. The major difficulty in such a technical and societal project is to be able to carry out a demonstration of the safety over time scales which are out of the scope of any experiment. Among the arguments involved for the safety case are a series of simulations which objective is to assess the level of safety which can be reached, and its robustness to various internal defects (construction of the drifts, welding of canisters...) or external events (intrusion with deep boreholes, climate change, faulting,...).

Confidence in the simulations can be achieved if they are transparent, based on well understood processes. However, the complexity of the disposal system is such that temptation was great by the past to simplify the models, with a poor level of reporting on justifications, thus leading to what has been described as blackbox models. In the frame of the demonstration to be brought out for 2006, Andra has developed an approach consisting first to describe and analyse all the processes occurring over time and space in the repository. Once this type of information has been gathered in a structured way, then further analyses leading to abstractions, simplifications can be performed in order to facilitate simulations as required for the safety demonstration. The first stage of the approach has been called the phenomenological analysis of the repository situations (PARS). This work gives rise to a reference book in which our knowledge has been reported before being used for the safety demonstration. It also represent a reference for all technical and scientific knowledge based applications, such as digital modeling which is the basis for simulations, the repository design, the reversibility study, including the definition of a monitoring/observation program.

The requirements for the PARS are to fulfill completeness, thus satisfying safety-analysis requirements, and traceability. For this last point, the PARS is capable to evolve in a traceable way according to advances with regard to repository design and further phenomenological knowledge.

The principle of the method relies on a space and time segmentation of the repository evolution, giving rise to "situations", a situation being a phenomenological state of part of the repository or of its environment during a given period of time. For the Meuse/Haute-Marne site to which the PARS has been applied, the space and time segmentation was made possible through:

- The modular design of the repository,
- The layer structure of the geological medium,
- The identification of events triggering new phenomena during operations,
- Differences between the characteristic time scales of phenomena during all the lifetime of the repository.

One of the very important interests of this approach is the possibility to divide the modeling of a repository's phenomenological evolution, and to have simpler models to develop and then to handle for the simulation programme.

The PARS covers the evolution of the repository from the very beginning of the construction up to the appropriate times in relation with the radioactive decay of the waste (1 million years). The analysis of the repository in its environment is performed at a relevant scale in relation with its size and its environmental effects. The considered phenomena are thermics, hydraulics, mechanics, chemistry and radiology.

Input data for the first stage of the PARS are the preliminary designs of the repository, which integrate the state of acquired knowledge on the Meuse/Haute-Marne site and the waste inventory. The spectrum of preliminary designs investigated was selected in order to analyse the entire set of phenomena and factors likely to be involved in the repository evolution. Architectures have been selected for simplification purposes in understanding and modelling phenomena:

- Single-level repository in the middle of the Callovo-Oxfordian clay formation;
- Separation of disposal areas for B waste C vitrified waste, UOX spent fuel and MOX spent fuel , and fragmentation of respective areas into modules;
- An architecture consisting of a nest of “dead-end” cells to limit hydraulic connections;
- Maximum-temperature criteria determining the disposal density of exothermic waste (number of packages/cells, distances between cells).

Spatial fractioning of the repository system has been developed according to the main repository components, surface facilities, shafts, access drifts, 4 disposal areas: B waste, C waste and spent fuels, geological medium and the surface environment. Time fractioning of the repository evolution has been done according to an operational phase and a post-closure phase.

For each situation, the analysis consists in describing the phenomena (THMCR), their couplings and sequences, and identifying the potential radionuclide releases by the waste packages and defining their transfer pathways. Finally, an inventory of existing numerical models applicable to the situation has been proposed, as a first input to modeling and simulation.

It is proposed to introduce the first set of the 83 PARS files, and to illustrate it with a few situations as typical examples, with very explicit views. Conclusions of this first experience are then drawn in 2 ways:

- Management of pending indeterminations on the design and of uncertainties on phenomenological understanding of the situations as well as on data,
- Organisation of the modeling and simulation programme for the 2006 filing and reporting process.

LONG SCALE ASTRONOMICAL VARIATIONS IN OUR SOLAR SYSTEM: CONSEQUENCES FOR CLIMATE

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1. OVERVIEW OF THE AREA

During the last decade a large number of simulations of the planetary system have been reported. Many of these papers have been concerned with the influence of variations in the Earth's orbit on climate (Berger & Loutre 1997, Laskar *et al.* 1993, Quinn *et al.* 1991). As for climate it is generally agreed that changes in the Earth's orbital parameters play an important role in climate forcing, an idea originally brought forward by Milutin Milankovitch. The climatic history of the Earth shows clear evidence of the precession periods (about 19,000 and 23,000 years) and changes in the obliquity (period about 41,000 years).

2. PREVIOUS WORK

Earlier studies usually made comparisons between insolation and SPECMAP ice volume (O-18 measurements in the northern atlantic). The main period in glacial data (around 100,000 years) has been hard to explain in terms of orbital variations. Other mechanisms have been suggested, e.g. changes in the Earth's orbital plane (Muller & MacDonald 1995). Another problem is to understand the time lag between insolation and ice volume of about 5,000 years. The correlation in this type of comparison is also rather poor. Attempts to understand these problems involve a large number of free parameters. In our previous research we instead compared the summer radiation power at high northern latitudes with the *differentiated* ice volume (Edvardsson & Karlsson 2002). In practise, the above mentioned problems then disappear.

3. PRESENT AND FUTURE WORK

3.1 *Analysis of rapid climate transitions*

Our previous work shows that rapid transitions occurring at deglaciations are not well understood and calls for further investigation.

3.2 *Simulations into the future*

Future glacial information is important for practical issues like storage of nuclear waste but is also of high academic interest. We are presently running simulations far into the future. Good correlation between solar activity and short term climate variations was demonstrated (Svensmark & Friis-Christensen 1997). In order to predict future climatic variations, it is of vital importance to explore astrophysical models for the solar activity.

TECHNICAL TOPIC D:

THE RELATIVE VALUE OF SAFETY AND PERFORMANCE INDICATORS AND QUALITATIVE ARGUMENTS IN DIFFERENT TIME SCALES

THE SPIN PROJECT: SAFETY AND PERFORMANCE INDICATORS IN DIFFERENT TIME FRAMES

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SPIN (Testing of Safety and Performance Indicators) is the name of an EC-funded international research project of the fifth EURATOM framework programme 'Nuclear Energy'. The participating organisations come from seven European countries: GRS (Germany), ENRESA (Spain), Nagra/Colenco (Switzerland), NRG (The Netherlands), NRI (Czech Republic), SCK•CEN (Belgium), and VTT (Finland).

Long term safety assessments for final repositories, based on numerical calculations, are normally founded on predictions of the annual dose rate to a future human individual. Due to considerable uncertainties in dose rate predictions over long times, it seems sensible to use additional magnitudes, or indicators, for assessment. The main goal of the SPIN project is to identify and test such indicators. Different indicators can be useful for different time frames.

Within the SPIN project, the following types of indicators are used:

- Safety indicator: A calculable, time-dependent quantity, integrated over all nuclides, which allows a statement on the safety of the total repository system by comparison with suitable, safety-related reference values.
- Performance indicator: A calculable, time-dependent or absolute quantity, nuclide-specific or integrated, which allows a statement on the performance of the total system, a subsystem or a single barrier by comparison between different options or with technical criteria.
- For identification of indicators the open literature is evaluated with regard to indicators which have been proposed or used in certain studies. A more systematic approach is to derive performance from so-called safety functions. These are:
 - physical confinement,
 - retardation / slow release,
 - dispersion / dilution,
 - long term stability.

The identified indicators are calculated for four example repositories in granite. The recent national studies SPA-granite (Germany), ENRESA-2000 (Spain), TILA-99 (Finland), and Kristallin-I (Switzerland) are re-calculated. The resulting curves are presented in a common form and compared. In the last step the calculated safety indicators are compared to safety related reference values, such as regulatory limits or comparative values from natural processes. Such data can be taken, e.g., from the literature. Regulatory limits are, e.g., the release constraints provided by STUK. Another source for reference values may be the IAEA Co-ordinated Research Programme (CRP) on safety indicators which is being carried out at the same time. In this programme, natural contaminant concentrations and fluxes are determined in different countries.

At the end of the project, some indicators will be recommended for use in safety assessments, with regard to different time frames.

**IAEA ACTIVITIES RELATED TO SAFETY INDICATORS,
TIMEFRAMES AND REFERENCE SCENARIOS**

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ABSTRACT

The fundamental principles for safe management of radioactive waste have been internationally agreed and established the basis of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management that entered into force in June 2001. Protection of human and environment and safety of facilities (including radioactive waste disposal facilities) are widely recognized principles to be followed and demonstrated in post closure safety assessment of waste repositories.

Dose and risk are at present the internationally agreed safety criteria, used for judgment of acceptability of this type of facilities. However, there have been a number of activities initiated and coordinated by the International Atomic Energy Agency (IAEA) providing international forum for discussion and reaching consensus on the use safety indicators complementary to dose and risk. The Agency has been working on the definition of other safety indicators, such as flux, time, environmental concentration, etc.; their desirable characteristics, and use of these indicators in different timeframes. The IAEA has focused on safety indicators in the geological disposal to explore their role in the development of a safety case, evaluate the advantages and disadvantages of using other safety indicators and how they complement the dose and risk indicators. The use of these indicators have been discussed also from regulatory prospective and mainly in terms of achieving reasonable assurance and confidence in safety assessment of waste repositories and decision making in the presence of uncertainty in the context of disposal of long-lived waste.

Significant effort has also been placed by the Agency on development and application of principles for defining critical groups and biospheres for deep geological repositories. One of the important and successful IAEA programmes in this field is the BIOSphere Modelling and ASSessment (BIOMASS) project, completed last year, which proposed methodology for development of reference biospheres, in line with suggestions of the International Commission for Radiological Protection 81 (ICRP), and illustrated its application to three example biospheres. At present the Agency is continuing the work on development of reference scenarios for waste disposal in order to assist international agreement on the main principles and concepts for development and use of reference scenarios in development of safety case and decision making of acceptability of waste repositories.