
NEA Perspectives on Timescales and Criteria in Post-Closure Safety of Geological Disposal

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Abstract

A key challenge in the development of safety cases for geological repositories is associated with the long periods of time over which radioactive wastes that are disposed of in repositories remain hazardous. The OECD Nuclear Energy Agency (NEA) has recently examined issues related to timescales in the context of two projects under the auspices of the Radioactive Waste Management Committee (RWMC): the Timescales Initiative and the Long-Term Safety Criteria (LTSC) Initiative. These projects examine, respectively, the treatment of timescales in actual safety cases and in the development of radiological protection criteria for geological disposal. They treat different aspects of timescales but have some overlap and have shown some convergence of the results achieved to date. Based on these projects, this paper examines general considerations in the handling of timescales, including ethical principles, evolution of the hazards of radioactive waste over time, and uncertainty in the evolution of repository systems (including geological features). The implications of these considerations are examined in terms of repository siting; levels of protection in regulations; planning for pre-closure and post-closure actions; and development and presentation of safety cases. A comparison is made with previous NEA work related to timescales, in order to show evolutions in current understanding.

1 BACKGROUND

The long periods of time over which radioactive wastes remain hazardous is a key challenge in illustrating and assessing the safety of geological disposal systems. Over such periods, a wide range of events and processes characterised by many different timescales acts on a repository and its environment. These events and processes, their attendant uncertainties, and their possible impacts on repository evolution and performance must be identified, evaluated and communicated in a safety case. The handling of issues related to timescales was discussed at an OECD/NEA⁴ workshop held in Paris in 2002 and a short report providing an account of the lessons learnt and issues raised at the workshop, was published in 2004 (NEA 2004). There is, however, an evolving understanding regarding the nature of the issues related to timescales and how they should be addressed.

The NEA has recently conducted a survey of its member organisations regarding the treatment of timescales in safety cases and is in the process of producing a report discussing the results. Responses to the survey questionnaire were provided by twenty-four organisations, representing both implementers and regulators from thirteen OECD member countries, and discussed at a series of meeting throughout 2005. The aims of the survey and report are:

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- to review the current status and ongoing discussions on the handling of issues related to timescales in the deep geological disposal of long-lived radioactive waste;
- to highlight areas of consensus and points of difference between national programmes; and
- to determine if there is room for further improvement in methodologies to handle these issues in safety assessment and in building and presenting safety cases.

This paper describes the issues identified and the preliminary conclusions reached in the course of the project to date. Many of the issues are subject to various interpretations, and remain under discussion within national programmes, as well as internationally, so the findings should not be viewed as conclusive, but rather as a contribution in moving ahead the debate and understanding the differences among approaches.

The handling of timescales in safety cases is affected by a number of general considerations, which are described first. Three broad areas in the regulation and practice of repository planning and implementation affected by timescales issues are then discussed:

- repository siting and design and the levels of protection required in regulation;
- the planning of pre- and post-closure actions; and
- developing and presenting a safety case

Finally, the conclusions are drawn, including a review of the statements made in the 2004 "lessons learnt" report in light of the more recent discussions.

2 GENERAL CONSIDERATIONS IN THE HANDLING OF ISSUES OF TIMESCALES

2.1 Ethical principles

Given the long timescales over which radioactive waste presents a hazard, decisions taken by humans now and in the near future regarding management of the waste can have implications for the risks to which generations in the far future may be exposed. There are thus ethical issues to be considered concerning, for example, our duty of care to future generations and the levels of protection that should be provided. Decisions regarding phased planning and implementation of repositories, particularly whether to close a repository at the earliest practical time or to plan for an extended open period, also have an ethical dimension. This is because they affect the flexibility allowed to future generations in their own decision-making as well as the burden of responsibility passed to these generations. Relevant ethical principles, such as intergenerational and intragenerational equity and sustainability, are open to different interpretations and can sometimes compete. The interpretations made and balance struck between competing principles is a matter of judgement and may vary between different countries and stakeholder groups, and remain matters of discussion internationally, e.g. in the Long-term Safety Criteria (LTSC) Task group of the RWMC.

2.2 Evolution of hazard

The hazard associated with radioactive waste results primarily from the external and internal radiation doses that could arise in the absence of adequate isolation (including shielding) and containment of the waste. Although the radioactivity of the waste declines significantly with time, the presence of very long-lived radionuclides means that the waste may remain

hazardous almost indefinitely.

2.3 Uncertainty in the evolution of the repository system

Geological repositories are sited and designed to provide protection of man and the environment from the hazard associated with long-lived radioactive waste by containing and isolating the waste. Though the sites and engineered barrier designs are generally chosen for their long-term stability and predictability, repository evolution is nonetheless subject to unavoidable uncertainties that generally increase with time. Furthermore, radiological exposure modes, which are closely related to individual human habits, can be predicted with confidence only in the very short term. The decreasing demands on system performance as a result of the decreasing hazard of the waste partly offset the increasing demands that uncertainties place on safety assessment. Nevertheless, while some hazard may remain almost indefinitely, increasing uncertainties mean that there are practical limitations as to how long anything meaningful can be said about the protection provided by any system against the hazard. These limitations should be acknowledged in safety cases.

2.4 Stability and predictability of the geological environment

Repository sites are chosen for their geological stability and broad predictability. Although predictions of the evolution of even the most stable sites become uncertain over long enough timescales, many national programmes have identified sites that are believed to be stable and sufficiently predictable over timescales of millions of years or more, based on an understanding of their geological histories over still longer timescales. Others plan to search for such sites. For example, in Germany, any new site selection process is likely to follow the procedure set out by an interdisciplinary expert group (*Arbeitskreis Auswahlverfahren Endlagerstandorte - AkEnd*), which requires the identification of a site having an "isolating rock zone" that will remain intact for at least a million years, based on the normal evolution of the site.

3 REPOSITORY SITING AND DESIGN AND THE LEVELS OF PROTECTION REQUIRED IN REGULATION

In repository siting and in designing complementary engineered barriers, the robustness of the system is a key consideration. Thus, events and processes that could be detrimental to isolation and containment, as well as sources of uncertainty that would hamper the evaluation of repository evolution and performance over relevant timescales, are, as far as reasonably possible, avoided or reduced in magnitude, likelihood or impact.

The isolation of the waste from humans is regarded as an essential role of the geological environment, and must be considered at all times addressed in a safety case. On the other hand, both the geological environment and the engineered barriers can contribute to ensuring that radionuclides are substantially contained, and the roles of the different system components in this regard can vary as a function of time. Most programmes aim for containment of the major part of the radionuclide inventory at least within a few metres from the emplacement horizon and certainly containment in the geological stratum or immediate rock mass where the repository is located, although, in some disposal concepts, more mobile radionuclides, such as ^{36}Cl and ^{129}I , are expected to migrate relatively rapidly (in terms of geological timescales) if released from the repository. The consequences of these and any other releases need to be evaluated.

Regulations specify what needs to be shown, and in some cases over what time frames, in order that a proposed site and design can be considered to offer acceptable levels of

protection from this hazard.

The minimum levels of radiological protection required in the regulation of nuclear facilities are usually expressed in terms of quantitative dose or risk criteria. In the case of geological repositories, quantitative criteria apply over time frames of at least 1 000 or 10 000 years and sometimes without time limit. It is, however, recognised in regulations and safety cases that the actual levels of dose and risk, if any, to which future generations are exposed cannot be forecast with certainty over such time frames. Models are used that include certain stylised assumptions, e.g., regarding the biosphere and human lifestyle or actions. Additionally, the “dose” that is being calculated is what radio-protectionists refer to as “potential dose”. Hence, the calculated values are to be regarded not as predictions but rather as indicators that are used to test the capability of the system to provide isolation of the waste and containment of radionuclides.

The concept of “constrained optimisation” put forth by the International Commission for Radiological Protection (ICRP) in ICRP-81 is also often a requirement; it is reflected in various terminology but encompasses the concepts in ICRP-81 that a series of technical and managerial principles, such as sound engineering practice and a comprehensive quality assurance programme are key elements to enhance confidence in long-term safety. For geological repositories, optimisation is generally considered satisfied if all design and implementation decisions have been taken with a view to ensuring robust safety both during operations and after repository closure and if provisions to reduce the possibility and impact from human intrusion have been implemented. In some regulations, alternative or complementary lines of evidence for protection and other more qualitative considerations are required or given more weight beyond 1 000 or 10 000 years, in recognition of the fact that increasing uncertainties may make calculated dose or risk less meaningful.

Generally, although the measures of protection specified in regulations may vary with time, this does not necessarily reflect a view that it is acceptable to expose future generations to levels of dose or risk different to (and higher than) those that are acceptable today. Rather, it reflects practical and technical limitations: in particular, regarding the weight that can be given to results of calculations over such long time frames and the meaning of dose estimates at times when even human evolutionary changes are possible.

There is ongoing discussion on the issue of how to define and judge criteria for protection in the furthest future, as a basis for decision-making today. The NEA is furthering such discussions through a related initiative under the RWMC's Long-Term Safety Criteria (LTSC) task group. That initiative deals with aspects of the demonstration of safety that differ from those covered in the Timescales Project, but there is considerable overlap and convergence of the results achieved to date. The LTSC has undertaken a review and comparison of long-term radiological protection criteria for disposal of long-lived waste. The goal of the review was not to achieve harmonisation of criteria (which, after all, are expected to vary in order to reflect national cultures, values, and technical differences among programmes), but rather to understand the basis for similarities and differences in their derivation and in the principles they represent.

The review of criteria found significant numerical differences among national criteria, ranging over roughly two orders of magnitude. Because criteria in all countries are well below levels at which actual effects or radiological exposure can be observed, either directly or statistically, this variability in the regulatory criteria does not translate to meaningful differences in the level of radiological impacts. The differences appear to reflect differences in the ways numerical criteria are applied, different expectations regarding the desired level of confidence in safety, and differing cultural attitudes towards the questions of establishing

and interpreting safety-related criteria and margins of safety (NEA 2006). One of the key outstanding issues is the development of a common understanding of the obligations to future generations with respect to long-lived wastes, and how to translate these obligations into safety regulations. This issue has also been elaborated in the Timescales Project (as discussed in preceding sections of this paper). A seminar is planned by the NEA in 2006 to explore the issues raised by the LTSC and Timescales projects.

4 NATIONAL POLICIES IN THE PLANNING OF PRE- AND POST-CLOSURE ACTIONS

Current national programmes vary considerably in the degree to which an extended open period prior to the complete backfilling and closure of a repository is foreseen. The ethical principle that future generations should be allowed flexibility in their decision-making favours assigning to future generations the decisions regarding backfilling and closure. Early backfilling and closure may, on the other hand, be seen as more consistent with the ethical principle that undue burdens should not be passed on to future generations, and also guards against the possibility of future societal changes, which could lead to lapses in the necessary maintenance and security. Another concern, particularly for repositories in saturated environments, is that detrimental changes to the system may occur or events take place during the open period, and that the severity of these changes or events will increase with the duration of the open period. In such cases, it may be prudent to work towards closure soon after completion of waste disposal. It is, however, recognised that such technical considerations need to be balanced against other factors, such as policies on monitoring and retrievability, which may require a more prolonged open period, or the views of the local community. In any case, it is widely agreed that flexibility regarding the open period should not extend so long as to jeopardise long-term safety.

Monitoring of a wide range of parameters within and around a repository is likely to be carried out prior to repository closure, and some monitoring may take place in the post-closure period. Other post-closure requirements may include passive measures such as record keeping, and active measures such as restricting access to a site. A key consideration in planning such measures is that they should not jeopardise the isolation of the waste and the containment of radionuclides. The planned duration of active measures, including monitoring, varies between programmes, as does the period during which either active or passive measures can be relied upon in a safety case, in particular to deter human intrusion. A cautious approach is generally applied in which no credit is taken for such measures in averting or reducing the likelihood of human intrusion beyond around a few hundred years. This is because of the potential for societal changes and our inability to predict the priorities of future generations. The *target* time frame for active measures may be longer than this, however, for example to improve societal acceptance and confidence. Furthermore, measures that are more passive, such as durable markers or record keeping, may in reality inform future generations about the existence and nature of a repository over periods well in excess of a few hundred years.

5 DEVELOPING AND PRESENTING SAFETY CASES

In the interests of gaining, sharing and showing understanding of a system as it evolves over long timescales, it is useful to both define and develop means to address various time frames in a scientific and logical manner.

How to deal with generally increasing uncertainties in repository evolution and performance is a key problem to be addressed in developing a safety case. Quantitative safety

assessment modelling tends to focus on potential radionuclide releases from a repository to the biosphere. The uncertainties affecting these models can generally be quantified or bounded and dealt with in safety assessment using, for example, conservatism or evaluating multiple cases spanning the ranges of uncertainty.

Where the consequence of calculated releases are expressed in terms of dose or risk, the biosphere must also be modelled. The biosphere is affected by human activities and relatively fast or unpredictable surface processes, and there is consensus that it is appropriate to carry out biosphere modelling on the basis of "stylised biospheres". That is, representations of the biosphere can be based on assumptions that are acknowledged to be simplified and not necessarily realistic, but are agreed and accepted internationally as valid for modelling studies.

Where regulations do not explicitly specify the time frames over which protection needs to be considered, the implementer has the challenge of deciding on the level and style of assessment to be carried over different time frames, which will then be subject to review by the regulator. Calculations of releases cannot, however, extend indefinitely into the future. Factors to be considered when deciding the time at which to terminate calculations of radionuclide releases include:

- uncertainties in system evolution which generally increase with time;
- the declining radiological toxicity of the waste - as noted above, spent fuel and some other long-lived wastes remain hazardous almost indefinitely;
- the time of occurrence of peak calculated doses or risk;
- the need for adequate coverage of very slow long-term processes and infrequent events; and
- the need to address the concerns of stakeholders.

Truncating calculations too early may run the risk of losing information that could, for example, guide possible improvements to the system. Importantly, if the assumptions underlying the models are questionable in a given time frame, then qualifying statements must be made when presenting the results, so that they may be properly interpreted. The time frames covered by modelling in recent safety assessments range from 10 000 years to one hundred million years, although a million years seems to be emerging as a commonly accepted time frame in recent safety assessments.

In considering safety beyond the time frame covered by calculations of release, some programmes have developed arguments based on comparing the radiological toxicity of waste on ingestion with that of natural phenomena (e.g. uranium ore bodies; although the limitations of such arguments are acknowledged). Other lines of argument refer to the geological stability of a well-chosen site, which can provide evidence, for example, that uplift and erosion will not lead to exposure of the waste at the surface over timescales of millions of years or more. In practice, a number of different arguments may be presented, and different arguments may provide the most confidence in safety over different timescales, and to different audiences.

In the interests of communicating effectively with stakeholders and to build stakeholder confidence, safety cases need to be presented in a manner that communicates clearly how safety is provided in different time frames. This includes relatively early time frames when substantially complete containment of radionuclides is expected, as well as later times, where some limited releases may occur. Non-specialist audiences are often (though not

universally) most concerned about safety at early times - a time frame of the order of a few hundred years after emplacement. Especially when presenting safety cases to such audiences, it can be useful to emphasise the strong arguments for safety in this time frame. It may also be useful to devote a specific section of a safety report to explain the handling of different time frames, how uncertainties are treated (and how this varies with time), how multiple safety and performance indicators are used, and how to interpret the results as a function of time.

6 REFINEMENT OF UNDERSTANDING OF KEY ISSUES RELATED TO TIMESCALES COMING FROM THIS WORK

The NEA timescales project has revisited the various issues discussed in the earlier "lessons learnt" report of 2004, and discussed additional areas such as the planning of pre- and post-closure actions. For some issues, current understanding is unchanged compared to the 2004 document, whereas for others, some differences can be identified.

6.1 The timescales over which the safety case needs to be made

The 2004 document argued that ethical considerations imply that the safety implications of a repository need to be assessed for as long as the waste presents a hazard. The present report recognises that there are different and sometimes competing ethical principles that need to be balanced. It seems that the discussion of how to come to a balanced and socially acceptable view is still at an early stage in many nations and internationally. In addition, this discussion should be informed by inputs from a wide range of stakeholders, which is beyond the remit of the current project.

6.2 The limits to the predictability of the repository and its environment

Both the 2004 document and the present report reflect a view that the limits to the predictability of the repository and its environment need to be acknowledged in safety cases.

6.3 Arguments for safety in different time frames

Both the 2004 document and the present study note that the types of argument and indicators of performance and safety used or emphasised may vary between time frames. The current study has identified ongoing developments in the approaches to partition future time into discrete time periods and developments in phenomenological and functional analysis in different time frames.

The 2004 document observes that regulations are increasingly providing guidance on the use of lines of argument that are complementary to dose and risk. This observation is supported by recent regulations and draft regulations in Sweden and the US. The current work emphasises that complementary lines of argument are required, not only to compensate for increasing uncertainties affecting calculated releases at distant times, but also to address other aspects of safety, especially continuing isolation, even at times beyond when quantitative safety assessments can be supported. Complementary arguments might be based, for example, on the absence of resources that could attract inadvertent human intrusion and on the geological stability of the site, with low rates of uplift and erosion. The argumentation for safety in the very long term is, however, an issue of ongoing discussion that is likely to require a consideration of ethical principles, since it relates to our ability and responsibility to protect the environment in the very remote future.

6.4 Interpretation of dose and risk calculated in long-term safety assessments

Both the 2004 document and the current study note international consensus that doses and risks evaluated in safety assessments are to be interpreted as illustrations of potential impact to stylised, hypothetical individuals based on agreed sets of assumptions. The assumptions are site-specific. Their basis, derivation, and level of conservatism can vary significantly; for this reason, the calculated results from safety cases should be carefully analysed if they are compared among national programmes.

6.5 Complementary safety and performance indicators

The 2004 document states that the use of complementary indicators, their weighting in different time frames, as well as reference values for comparison, are issues that may well deserve further regulatory guidance. Recent regulatory guidance cited in the present report shows that safety indicators and requirements are not only quantitative, but can include more qualitative concepts such as best available technique (BAT) and optimisation. This issue of how to evaluate compliance with requirements expressed in terms of qualitative indicators may, however, require further consideration, as may the interpretation of optimisation of protection when dealing with impacts across different timescales.

6.6 Addressing public concerns

Both documents note that the period of a few hundred years following emplacement of the waste may deserve particular attention in documents aimed at the public. The present document makes a number of other specific recommendations regarding the communication of how safety is provided in different time frames

7 CONCLUSION

In conclusion, the range of timescales that needs to be addressed within our safety cases presents considerable challenges. The decreasing demands on system performance as a result of the decreasing hazard associated with the waste with time partly offset the demands that increasing uncertainty (and decreasing predictability) place on safety assessment. Nevertheless, while some hazard may remain almost indefinitely, increasing uncertainties mean that there are practical limitations as to how long anything meaningful can be said about the protection provided by any system against these hazards. Thus, time and level of protection—and assurance of safety—are linked to one another. These practical limitations need to be acknowledged in safety cases.

There are a range of approaches available now that can be called upon for developing and presenting safety cases. Furthermore, there is room to develop these approaches, for example, taking account of experience gained from stakeholder interactions to develop presentations suited to the needs of less technical audiences.

A general observation from the timescales questionnaire responses is that, in many programmes, a significant part of the final responsibility for the handling of timescales issues in safety cases is assigned to the implementer. Apart from setting safety criteria (that may or may not vary over time), the regulator's task is generally to review and point out any difficulties in the approaches to the handling of timescales issues adopted by the implementer. Wherever the final responsibility lies, a dialogue between the implementer, regulator and other stakeholders is valuable in resolving the issues in a manner that is widely accepted and such dialogue is ongoing in many programmes.

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