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The handling of timescales in assessing post-closure safety of deep geological repositories

Geological repositories are sited, designed and operated to protect humans and the environment from the hazards associated with radioactive waste. Most challengingly, they are required to provide protection after their closure and over timescales that are considerably in excess of those commonly considered in most engineering projects, often up to several thousand or even a million years. This requirement is laid down in international guidance and in many national regulations.

Protection is achieved by locating repositories deep underground, thus isolating the waste from the human environment. In addition, sites and designs are chosen that provide highly effective passive barriers to the release and migration of radioactivity, the aim being to ensure that any releases of radioactivity to the human environment are very low.

The accepted approach for arriving at an adequate site and design is one of constrained optimisation.[1] Regulations set the process to achieve protection in terms of design optimisation and application of sound management and engineering practices, as well as maximum acceptable radiological consequences in terms of dose or risk criteria for hypothetical individuals living in the future. Siting, design and implementation proceed in a step-by-step process. At each step a case for safety needs to be made that is adequate to support the decision in hand and to support any licence application required.

Various processes and events could affect the evolution of a repository and its environment, and hence the containment and possible release of radioactivity from the repository and its migration to the surface. These processes and events are characterised by timescales ranging from a few tens or hundreds of years for transient processes associated with, for example, the resaturation of the repository and its immediate surroundings following closure, to perhaps millions of years for changes in the geological environment. The figure shows an example of the division of future time into a number of phases, or time frames, for safety assessment purposes. The figure shows how, in each time frame, different phenomena or "safety functions" are emphasised in the safety case. In this example, a "latent function" is one that only operates if other safety functions (unexpectedly) fail to operate. A "reserve function" is one that may well enhance the level of safety, but uncertainties are such that it cannot be relied upon with confidence within a given time frame.

Safety assessments must also consider whether any releases of radioactivity lead to consequences greater than those targets set by regulation. In order to evaluate compliance with dose or risk criteria, assumptions must be made regarding the habits of

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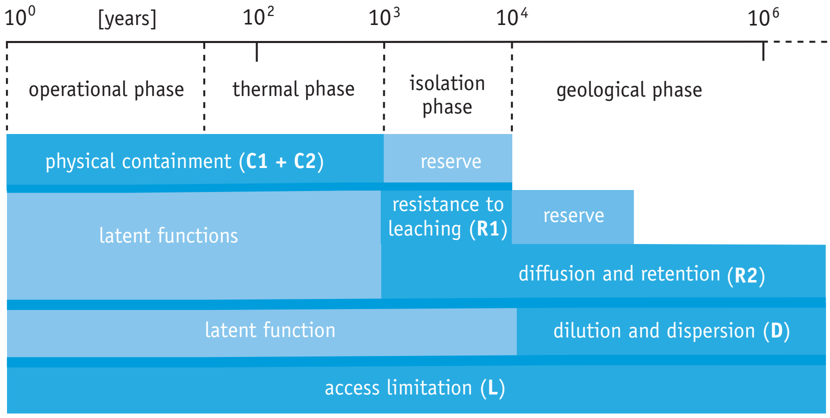

An example from ONDRAF of the four phases of the normal evolution of a repository for high-level waste and the corresponding long-term safety functions. The first two safety functions can each be subdivided into two sub-functions. For the "physical confinement" function, which aims to prevent any release of activity from the waste matrix, the two sub-functions are "water tightness" (C1) and "slow water infiltration" (C2).

potentially exposed groups (e.g. diet, lifestyle and land use), and these may change over timescales of just a few years.

The need to deal with such a wide range of timescales gives rise to a range of issues related to the methods and presentation of safety assessments. In particular:

- Is it really necessary to argue a case for safety over timescales of a million years or more?
- If so, how predictable is the evolution of the repository and its environment over these timescales?
- What types of arguments are available that take account of the inevitable changes and uncertainties associated with long timescales?
- How can public concerns affect the emphasis given to different types of argument at different times?

These issues are of concern to all national programmes and provided the motivation for the IGSC (Integration Group for the Safety Case, set up by the OECD Nuclear Energy Agency) to support and organise a workshop entitled "Handling of timescales in assessing post-closure safety". The workshop was held in Paris on 16-18 April 2002 and was hosted by the French Institute for Radiological Protection and Nuclear Safety (IRSN). The NEA prepared a synthesis of the workshop, which was published in the proceedings.[2] The main findings may be summarised as follows.

- **The timescale over which a safety case needs to be made**

It is an ethical principle that the same or better level of protection for humans and the environment applicable today should also be provided in the future. This implies that the safety implications of a repository need to be assessed for as long as the waste presents a potential hazard. There are no scientific or ethical arguments that justify imposing a definite limit to the period considered by safety assessments. The long timescales addressed in practice in safety assessments arise from the finite, though sometimes long, half-lives of some of the isotopes in the waste and the high degree of effectiveness with which deep geological disposal facilities are expected to contain radioactivity – safety studies for deep geological repositories tend to focus on the distant times when releases eventually occur.

- **Intrinsic quality of the site and the design and limits to predictability**

An important line of argument in safety assessments relates to the intrinsic quality of the site and the design. The safety of any repository depends primarily on the favourable characteristics of the engineered materials and the geological environment – including their predictability over prolonged periods – and these characteristics need to be stressed in safety cases. As regards the geological environment, evidence for stability and other favourable characteristics often comes from *in situ* observations and measurements. More generally, thermodynamic, kinetic, mass balance and palaeohydrogeological arguments can play a role. Arguments for the feasibility, in principle, of safe geological disposal can also be made based on the existence of natural analogues and, in particular, natural uranium deposits.

Another aspect of the intrinsic quality of the site and the design for most repositories is the fact that multiple barriers or processes contribute to safety. This is termed the "multi-barrier" and/or "multi-function" concept. As conditions in the repository and its environment evolve over the course of time, some components can cease to perform certain functions and new functions come into operation.

Nevertheless, in order to maintain credibility within the scientific community as well as with other stakeholders, it is important to acknowledge the limits of predictability of the repository and its environment in both regulations and in safety cases.

- **Arguments for safety in different time frames**

Multiple lines of argument, with an emphasis on different types of argument and different indicators of performance and safety in different time frames, some of which are more qualitative in nature, are useful for building a convincing safety case. Safety assessments are increasingly taking into account the full range of arguments for safety that is available, as well as the safety and performance indicators that can be used to complement dose and risk; regulations are increasingly providing guidance regarding their use.

As discussed above, well-supported statements regarding the radiological consequences can be made that cover a prolonged period provided a repository is well designed and a suitable, geologically stable site is selected. A less rigorous assessment of radiological consequences is likely to be adequate at times when the stability of the geological environment can no longer be assured, on account of the strongly decreased radiological toxicity of the waste that is expected at these times.

- **Stylised approaches**

Given that changes in human society, technology and the surface environment are likely, and are largely unpredictable over the time period of interest in safety assessments, there is international consensus that radiological doses and risks calculated for hypothetical human groups dwelling in the future, but with habits and technology similar to that of the present day, are appropriate as indicators of repository safety. More generally, "stylised approaches" are commonly applied as a means of addressing the evolution of the surface environment and the nature of future human actions. Such approaches involve defining a range of alternative "credible illustrations" or "stylised situations", including, for example, different possible future climate states, agricultural practices and exposure pathways, and analysing the resultant dose or risk for hypothetical critical groups. This avoids open-ended speculation on issues that in any case should not impact unduly on the decisions taken on repository development.

- **Complementary safety and performance indicators**

The use of dose and risk as primary safety indicators does not preclude the use of other additional indicators of safety or performance. The use of safety and performance indicators other than dose and risk can help circumvent both the limited predictability of the surface environment and, on a far longer timescale, the limited predictability of the geological environment. They provide useful complementary arguments for safety if accepted reference values or criteria for comparison can be agreed upon. Natural systems may often provide the basis for such reference values or criteria.

Arguments based on complementary indicators can sometimes be more accessible to a non-specialist audience than those based primarily on dose or risk calculations. Furthermore, even for a technical audience, the presentation of dose or risk as a function of time is not, on its own, an effective way to convey the message that deep geological repositories provide an appropriate level of safety. For example, they tend to focus attention on the small releases that may eventually occur, rather than on the fact that most radioactivity is isolated and contained within the repository and its immediate surroundings, where it decays. It can thus be useful to complement graphs of dose or risk as functions of time with additional graphs or tables giving indicators that more directly illustrate the performance of the different repository barriers and combinations of barriers.

- **Addressing public concerns**

Irrespective of timescale, documents aimed at the public should highlight arguments that the public might find persuasive. The presentation of safety cases for the period of a few hundred years following emplacement of the waste may, however, deserve particular attention, with greater emphasis on the fact that, for most repository concepts, zero release of radioactivity is expected in this period. Monitoring during the operational and immediate post-closure period may potentially contribute to public confidence. ■

Notes

1. ICRP, *Radiation Protection Recommendations as Applied to the Disposal of Long-lived Solid Radioactive Waste*, ICRP Publication No. 81. Pergamon Press: Oxford and New York, 2000.
2. NEA, *The Handling of Timescales in Assessing Post-closure Safety of Deep Geological Repositories. Workshop Proceedings, Paris, France, 16-18 April 2002.* OECD: Paris, 2002.