Assessing Long-term Safety of Deep Disposal in Belgium: The SAFIR 2-Report

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INTRODUCTION

ONDRAF/NIRAS – the Belgian radioactive waste management agency – is currently aiming at establishing if it is feasible, both technically and financially, to design and build on the Belgian territory a deep disposal facility for high-level and/or long-lived radioactive waste that is safe, while not prejudging the site where such a solution would actually be implemented. Practically, the ONDRAF/NIRAS methodological R&D programme is intended to develop the methods and to gather the knowledge needed to undertake an in-depth assessment of the safety and feasibility of a repository in poorly-indurated clays. It mainly concerns the Boom Clay, a silty-clay formation of Rupelian age, which is present between ~290 and 190 m beneath the Mol–Dessel nuclear zone (NE Belgium). This zone is also the location of the Nuclear Energy Research Centre (SCK•CEN) which was the initiator of the Belgian deep disposal programme in the mid-70's and still is the main scientific contributor to the programme.

Considered HLW includes vitrified waste arising from the reprocessing of spent fuels as well as spent fuels as such. The HLW originates from 7 nuclear power plants (PWR) representing a total of 5.7 installed GWe. For a 40-year lifetime of the plants the total UO_2 fuel consumption is estimated to be around 4860 tHM.

In publishing the SAFIR 2 report – *Safety Assessment and Feasibility Interim Report 2* – [1 and 2 – both released in July 2002], ONDRAF/NIRAS has provided its supervising authorities and the various parties involved with a state-of-the-art document that will enable them to assess the progress made during the period 1990–2000 with regard to the feasibility and safety of a Belgian disposal solution.

Because the issues raised by the long-term management of radioactive waste have to be addressed within a broad context, wider than the strictly technical and scientific aspects, societal and economic dimensions will have to be included in the future programme of ONDRAF/NIRAS in order to support a decision-making process in this matter. To address this, ONDRAF/NIRAS intends to start in the very near future a broad-base societal dialogue [3] aimed at considering alternative long-term management options and analysing all of the environmental effects of the proposed solution. In this respect, ONDRAF/NIRAS proposes to establish a document of the type *Strategic Environmental Impact Assessment* [4].

SOME GENERAL RESULTS ON LONG-TERM SAFETY

At present, none of the research findings indicates any prohibitive issue surrounding HLW disposal into the Boom Clay. This reinforces confidence in the studied solution and confirms that for the waste considered in the SAFIR 2 report, disposal within poorly-indurated clay remains a viable option.

Up to now the methodological research and development work has helped establish a significant level of confidence in the methodology used to assess long-term radiological safety.

In general terms, the work presented in SAFIR 2 confirms the favourable results of assessments, especially regarding the key contribution to long-term safety made by the host formation. Hence the importance of understanding the radionuclide migration processes in the Boom Clay and the importance of knowing and controlling the disturbances that are induced in the clay and that may potentially affect its barrier properties. These disturbances may be generated by the construction and operation of the repository (e.g. EDZ, oxidation) and by the presence of the waste and other repository materials (e.g. thermal impacts, radiolysis, migration of an alkaline plume from the degradation of concrete lining or backfill etc.). It also confirms the primary role in the radiological impact of the moderately-retarded or non-retarded radionuclides (^{129}I, ^{36}Cl, ^{79}Se, ^{126}Sn, ^{14}C). The knowledge of the migration properties of these radionuclides in the clay can be regarded as generally adequate, even though the chemistry of tin and selenium needs to be refined.

In SAFIR 2 two major ways of evaluating the long-term safety have been developed and elaborated: safety assessment calculations and an evaluation of the fulfilment of the main long-term safety functions.

SAFETY ASSESSMENT RESULTS

The safety assessment methodology comprises the usual steps: FEP- and scenario analysis, development of conceptual and calculational models, stochastic and deterministic calculations (including uncertainty and sensitivity calculations) and interpretation of results.

Some of the more important results are illustrated below.

In the case of the vitrified waste (4860tHM equivalent), only a very small portion of the initial activity reaches the Neogene aquifer, situated above the Boom Clay, due to a few very long-lived activation and fission products such as ^{129}I, ^{107}Pd , ^{79}Se and ^{99}Tc, or actinides (U isotopes and daughters):

- about $2 \cdot 10^{10}$ Bq of activation and fission products for a total initial activity of $7 \cdot 10^{19}$ Bq;
- about 10^{7} Bq of actinides (i.e., the mean concentration of actinides in 0.2 m^3 of low-level radioactive waste) for a total initial activity of around $5 \cdot 10^{17}$ Bq.

This is illustrated in Figure 1.

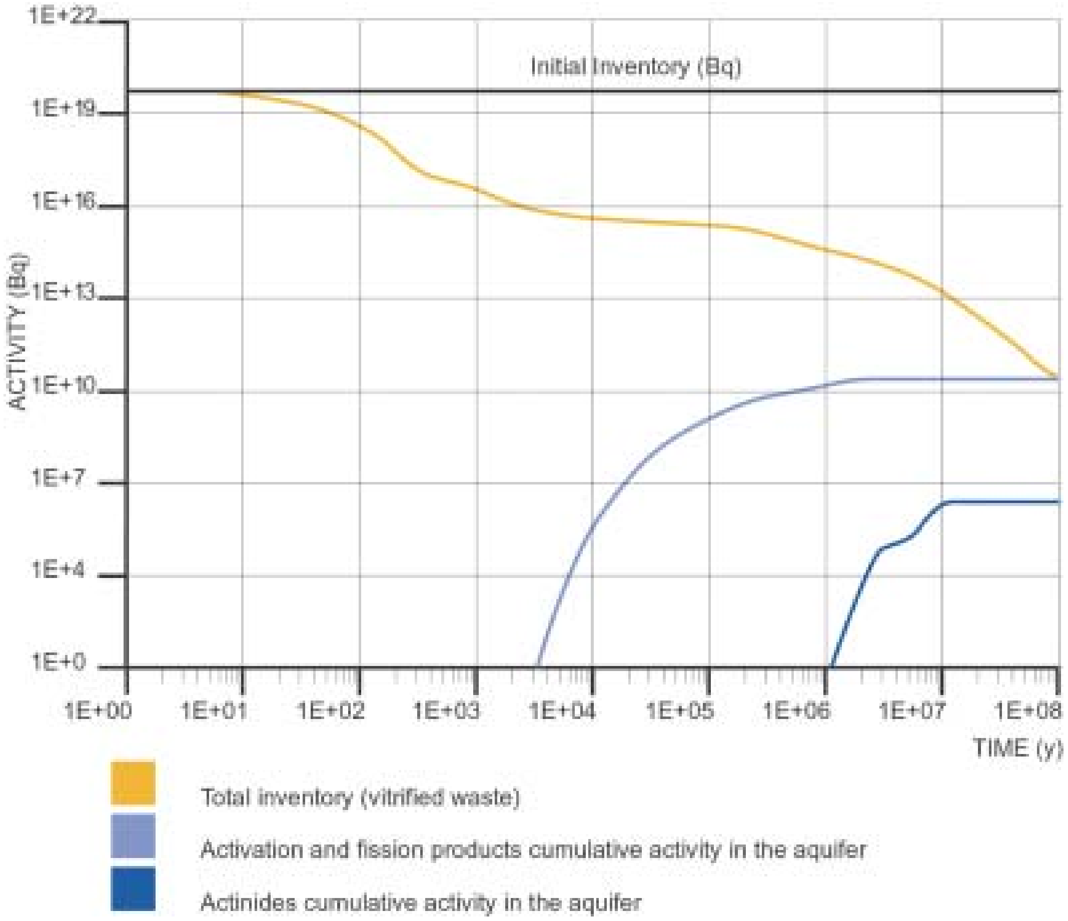

Figure 1: Cumulative activity reaching the Neogene Aquifer in case of disposal of vitrified waste (4860 tHM equivalent)

Thus the disposal system acts as an extremely efficient containment system, with the major portion of the activity initially placed in the repository disappearing before it can reach the aquifer. The containment factor (the ratio of disposed activity to cumulative released activity in the aquifer) is $4 \cdot 10^9$ for the activation and fission products and $5 \cdot 10^{10}$ for the actinides.

The maximum activity flux for the vitrified waste, spent fuel, and hulls and endpieces at the interface between the Boom Clay and the Neogene Aquifer is approximately $2 \cdot 10^7$ Bq per year. This is less than 100 $\mathrm{Bq \cdot m^{-2}}$ per year, given that the area of the considered repository is 0.224 $\mathrm{km^2}$ to accommodate the vitrified waste and 1.17 $\mathrm{km^2}$ to accommodate the spent fuel.

This maximum annual flux is very small, since it is equivalent to the alpha activity of the uranium, thorium, and radium naturally occurring in a layer of Boom Clay of around 0.1 mm thick. (The mean activity of these isotopes in the clay is approximately 360 $\mathrm{Bq \cdot kg^{-1}}$, or $7 \cdot 10^5$ $\mathrm{Bq \cdot m^{-3}}$.) In addition, the flux of radionuclides that leaves the Boom Clay and reaches the Neogene Aquifer only adds 0.0008 % per year to the natural activity already present in the Berchem Sands, a sub-layer of the Neogene Aquifer approximately 20 metres thick and situated just above the Boom Clay. (The natural activity of uranium, thorium, and radium in this layer is approximately 400 $\mathrm{Bq \cdot kg^{-1}}$, or $6 \cdot 10^5$ $\mathrm{Bq \cdot m^{-3}}$.) Finally, the cumulative total activity due to the vitrified waste that reaches the Neogene Aquifer, integrated over a period of 100 million years (Figure 1), can be compared to the alpha activity naturally present in the Berchem Sands. For the released activation and fission products, this corresponds to the alpha activity present in an approximately 10-cm-thick layer of the Berchem Sands and, for the actinides, it corresponds to the alpha activity in a layer approximately 0.1 mm thick.

As exemplified by Figure 2, which shows the cumulative releases of ^{126}Sn – a moderately retarded radionuclide – over time in the case of direct disposal of spent fuel (1980 tHM of UOX fuel with a 55

GWd.tU^{-1} burn-up), the Boom Clay clearly represents the most dominant barrier and contributor to long-term safety. It should be noted that one of the basic hypotheses of the safety approach is that a perfect containment of the waste is ensured during the thermal phase of the repository (i.e. several hundreds years for vitrified waste or several thousands years for spent fuels) by an austenitic stainless steel overpack. This containment avoids considering numerous phenomena linked with waste matrix degradation and radionuclide migration under a strong thermal gradient. Confidence is such a containment still needs to be further enhanced.

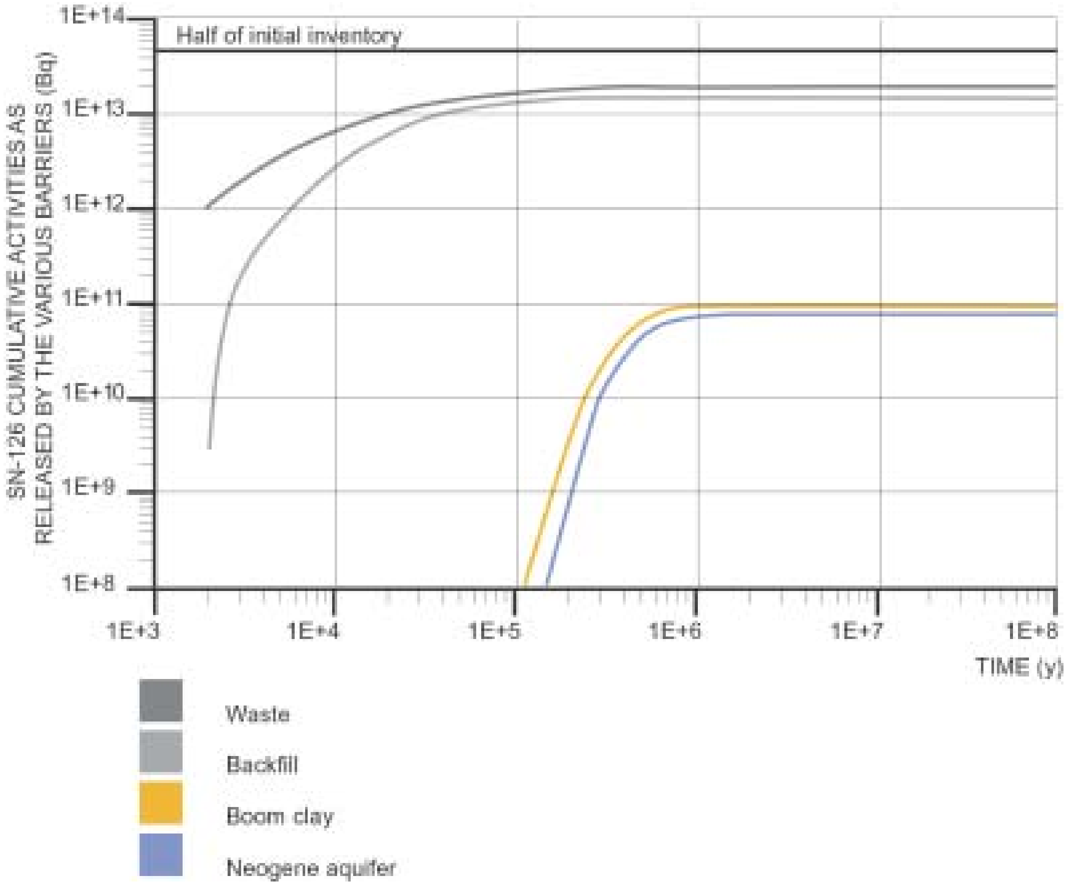

Figure 2: Cumulative quantities of ^{126}Sn released by the different barriers of the disposal system and by its environment for the disposal of 1 980 tUOX–55 (normal evolution scenario).

THE LONG-TERM SAFETY FUNCTIONS

In general terms the basic long-term safety functions of a disposal system (i.e. the engineered barrier system, including the waste forms 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 the disposal system are "physical containment" (C), "delaying and spreading the release" (R), "limitation of access" (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 containment" function, which aims to prevent any release of activity from the waste matrix the two sub-functions are "water tightness" (C1) and "limit the water infiltration" (C2). The "water tightness" function must prevent any contact between infiltrating water and the waste matrix; the "limit the water infiltration" function must delay the moment that water can come into contact with the waste matrix without guaranteeing water-tightness.

The "delaying and spreading the release" function takes over when physical containment 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. Slow diffusion-controlled migration, sorption on the solid (immobile) phase and precipitation/co-precipitation (low solubility limits) are the main underlying processes.

The safety function "limitation of access" 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 SAFIR 2 four characteristic periods or phases were identified for the normal evolution of the disposal system in time, during repository operation and after repository closure. The contributions of the long-term safety functions in each of the four phases are given in Figure 3. 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.

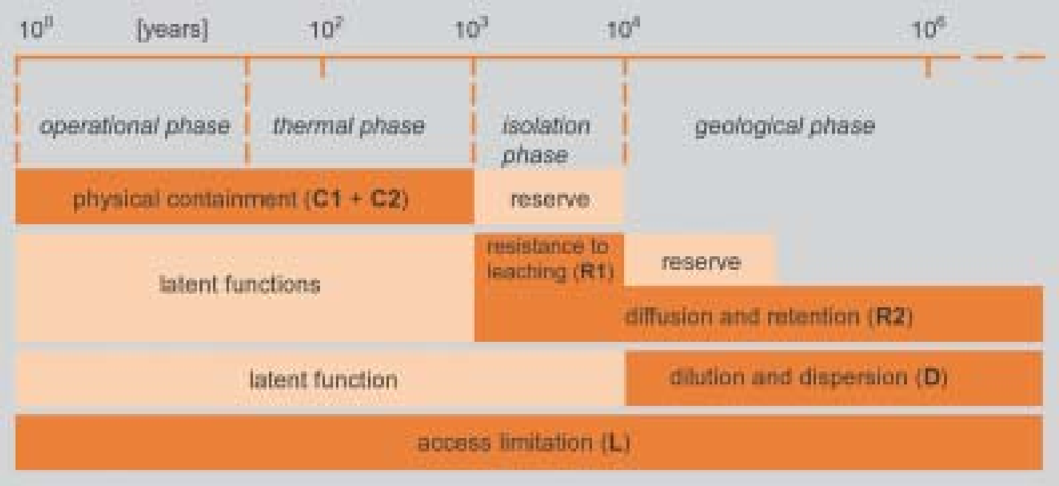

Figure 3. The four phases of the normal evolution of the disposal system (high level waste) and the corresponding long-term safety functions.

This Figure 3 also shows that the "delaying and spreading the release" and "dilution and dispersion" functions are latent functions during the physical containment, because even in case of a premature failure of the physical containment the latent functions will perform partially or totally. These latent functions have to be evaluated in the altered evolution scenario of a premature failure of the physical containment, in order to assess if this early failure could have unacceptable radiological consequences. The performance of the "delaying and spreading the release" function in the case of this premature failure of containment can be affected by the higher temperature in the disposal system, resulting in a more rapid degradation of the vitrified waste matrix and an accelerated migration in a thermal gradient. This analysis of the latent functions still has to be done

This SAFIR 2 analysis has focussed on the normal evolution scenarios for which the safety functions are defined in the first place. The purpose of the altered evolution scenarios in a safety assessment is to evaluate or test if important disturbances of the system or unexpected failures of system components can significantly increase the radiological consequences compared to the consequences of the normal evolution scenario.

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.

REFERENCES

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[4] EC, Directive on the Assessment of the Effects of Certain Plnas and Programmes on the Environment, Directive 2001/42/EC of 27th June 2001, Official Journal of the European Communities, L 197, July 2001