Oral Session 17

General strategy: integration and prospective

Chair: Patrick Landais

INTEGRATING GEOLOGICAL INFORMATION INTO SAFETY CASES FOR DEEP DISPOSAL FACILITIES IN CLAY FORMATIONS: EXPERIENCE FROM THE OECD/NEA WITH EXAMPLES FROM BELGIUM, FRANCE AND SWITZERLAND

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THE OECD/NEA AMIGO PROJECT

The description of the geosphere used in developing a safety case generally draws on wide-ranging, site-specific and more generic geological information. This must be integrated in a coherent picture or conceptual model of the current, undisturbed characteristics of the site, as well as past and on going processes and disturbances, including natural processes and those caused by repository construction and operation. The integration of wide ranging information from multi disciplinary sources is a complex undertaking. One challenge for site characterisation is to limit conceptual-model uncertainty through the co-ordinated collection, interpretation and integration of geologic data. This has provided the motivation for establishing an OECD/NEA international project: on “Approaches and Methods for Integrating Geological Information in the Safety Case”, namely AMIGO. This project is structured as a series of bi-annual topical workshops involving site characterisation and safety assessment practitioners with experience in both sedimentary and crystalline rock settings. AMIGO explores and highlights techniques to strengthen the communication and understanding of geosphere performance in the safety case through a series of presentations, working-group discussions and more general discussions.

AMIGO 1: GEOLOGICAL DISPOSAL/BUILDING CONFIDENCE USING MULTIPLE LINES OF EVIDENCE

A first workshop (AMIGO 1) was organised in June 2003, at Yverdon Les Bains, Switzerland (NEA 2004b). The main objective of the workshop was to exchange views on building confidence in analyses and arguments that support the safety case using multiple lines of evidence and integrating the work of geoscientists and safety assessors. The main themes of the workshop were:

- the role of the geosphere in the disposal concept,
- the use of geological information in waste management programmes,
- the synthesis of geological information,
- developing arguments for safety,
- building confidence using multiple lines of evidence, and
- integrating the work of geoscientists and safety assessors.

CLAY-RELATED ISSUES DISCUSSED AT AMIGO 1

The presentations at AMIGO 1 were not restricted to any particular host-rock type, but clay-related issues arose repeatedly at the workshop and covered a number of characteristics that are common to many clay formations and are advantageous from the point of view of safe geological disposal. These include:

Low hydraulic conductivity and groundwater flow in the bulk rock, with diffusion being the dominant transport mechanism, and with sorption retarding the transport of many species.

Self-sealing capacity, meaning that any fractures induced by natural processes or by the presence of the repository (e.g. excavation- or gas-induced fractures, natural fractures) do not form permanent fast-pathways for radionuclide transport.

Explorability, or the ability to characterise the rock at any stage of the project to a degree that is adequate to support a decision on whether or not to proceed to the next stage, is also an advantageous characteristic of clay formations that display tectonically quiet sub-horizontal bedding. Good explorability at an early stage may be key to site selection where several otherwise suitable sites are available.

The past evolution of clay formations (as with other potential host rocks) is relevant to safety studies in that possibilities for the future evolution of the formations and their performance as transport barriers are generally identified based on an understanding of the past. "Natural experiments" cited at the workshop, such as the development of concentration profiles of isotopes and elements in clay pore water, are valuable in that they provide information over long timescales in the past - hundreds of thousands to millions of years - as well as significant spatial scales - hundreds of metres or more.

A key theme of the workshop was "building confidence in analyses and arguments that support the safety case using multiple lines of evidence". Such multiple lines of evidence were cited for key clay characteristics in the workshop presentations. Illustrative examples are given from the safety cases of three national programmes (see boxes 1 – 3) that have recently been peer-reviewed by international review teams under the direction of NEA (NEA 2003a, 2003b, 2004a).

Box 1: Illustrative example from the Belgian program for the disposal of spent fuel and high-level vitrified waste (Ondraf/Niras 2001)

Multiple lines of evidence for diffusion-dominated transport of radionuclides through the Boom Clay formation under the Mol/Dessel nuclear zone:

- very low vertical hydraulic conductivity ($K_v \approx 2\ 10^{-12}\ ms^{-1}$) and natural hydraulic gradient (2 m head of water over 100 m thickness of clay);
- Péclet number (Pe) is less than 1 in all cases in the Boom Clay (e.g. for iodine Pe equals 0.08 at the formation boundary). For Pe < 1, diffusion dominates over advection;
- the low hydraulic conductivity has been confirmed at various scales, ranging from centimeters (laboratory samples) to decameters (using the HADES URL as a macro-permeameter) and kilometers (model calibration);
- 2D high-resolution seismic surveys have excluded the presence of faults under the considered zone;
- both lab experiments and *in-situ* observation have provided evidence of rapid self-sealing capacity of Boom Clay;
- the results of long-term (i.e. >15 years), metre scale, *in-situ* conservative tracer experiments (tritiated water and I) in the HADES URL can be reproduced using a strictly diffusive model and parameter values determined in tests in the surface laboratory;
- a percolation test with ^{134}Cs conducted over 7 years under a very high hydraulic gradient (several orders of magnitudes above the natural gradient) indicates an insignificant percolation effect, demonstrating that Cs migration remains diffusive even under such conditions;
- oxidation of Boom Clay (and in particular of its pyrite content) is rapid; oxidation fronts originating from the fractures in the excavation damaged zone of the URL, however, remain very limited.

Box 2: Illustrative example from the Swiss program for the disposal of spent fuel, high-level vitrified and long-lived intermediate level waste (Nagra 2002 a,b)

Multiple lines of evidence for the very low hydraulic conductivity and diffusion-dominated transport of radionuclides in the Opalinus Clay host roc:

- *in-situ* and laboratory hydraulic testing;
- tests for consistency with the porosity/conductivity relationship for clay formations investigated world-wide;
- the composition of illite/smectite mixed layer minerals in the host rock in comparison with experience from the hydrocarbon industry;
- the existence of hydraulic overpressures, which are interpreted as relics of burial history or as a result of the compressive stress field, but can only be understood if the hydraulic conductivity is even smaller that those derived from hydraulic tests;
- concentration profiles of numerous elements and isotopes in pore water which suggest a diffusion dominated system;
- hydraulic testing of natural faults showing hydraulic conductivities similar to undisturbed rock;
- the absence of anomalies in natural tracer profiles crossing faults; and
- the absence of mineral veins and alterations, suggesting that there was no significant water flow through natural discontinuities in the past.

Box 3: Illustrative example from the French program for the disposal of long-lived intermediate level waste, high-level vitrified waste and spent fuel. (Andra, 2005)

Multiple lines of evidence for the absence of tectonic structures affecting groundwater flow within the Callovo-Oxfordian argillite host rock

- detailed geological mapping and 2D seismic survey showing the lack of major faults in the vicinity of the URL;
- characterization of the regional stress field which indicates the stability of the formation over a period of millions of years;
- 4 km^2 3D seismic survey around the URL highlighting the lack of faults above the brown coal horizon (mid Bathonian);
- coring into the host rock using deviated boreholes which, over a total distance of 1500 metres, crossed just few joints in the upper part of Callovo-Oxfordian;
- hydraulic testing of these joints showing hydraulic conductivities similar to undisturbed argillite;
- sealing of the joints by veins of calcite or celestine;
- the isotopic characterization of the veins which reveals their early origin during diagenesis;
- the concentration profiles of ^{13}C and ^{18}O isotopes in pore water and minerals which suggest a closed system;
- the difference in the halogenide concentrations within the Oxfordian and Bathonian pore water which means that the host rock will provide a diffusion barrier at regional scale.

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INTEGRATED APPROACH FOR DEVELOPING CLAY-BASED ENGINEERED BARRIER SYSTEMS IN GEOLOGICAL REPOSITORIES

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ABSTRACT

Repositories for deep disposal of radioactive waste generally rely on a multi-barrier system to isolate the waste from the biosphere. This multi-barrier system typically comprises the natural geologic barrier provided by the repository host rock and any overlying rock formations, and an engineered barrier system (EBS) constructed within the repository. It therefore creates an overall robustness of the system that enhances confidence that the radionuclides in the waste will be successfully contained.

The EBS represents the man-made, engineered materials placed within a repository, including the waste form, waste containers, and buffer materials, backfill, seals, and plugs.

In 2001, the Integration Group for the Safety Case (IGSC) of the Nuclear Energy Agency (NEA) confirmed its interest in the need for a project to develop a greater understanding of how to achieve the necessary integration for successful design, construction, testing, modelling, and performance assessment of engineered barrier systems, and to clarify the role that an EBS can play in the overall safety case for a repository.

For this purpose, all aspects of EBS performance are considered according to four main perspectives:
- Engineering design perspective, that is: how can a component be (re-)engineered to improve performance or ease of modelling?
- Characterisation and configuration perspective, that is: how can properties of the EBS and the conditions under which it must function be measured or otherwise characterised?
- Process modelling perspective, that is: how well can the relevant processes be modelled?
- Performance assessment perspective, that is: how can the performance of the EBS and/or its components be evaluated under a wide range of conditions?

Taking these perspectives into account, the EBS project was designed to hold a series of four workshops jointly organised by the European Commission and NEA, focusing on the following topics [1]:
- Design requirements and constraints (Workshop 1,Turku, Finland, 2003);
- Process issues (Workshop 2, Las Vegas, USA, 2004);
- Role of performance assessment and process models (Workshop 3, La Coruna, Spain, 2005);
- Design confirmation and demonstration (Workshop 4, Japan, 2006).

This sequence of workshops leads the project through an optimisation cycle for the engineered barrier system.

Recognising the diversity in engineered barrier systems in various national programmes, the project started with understanding the state of the art on knowledge and experience about the integration of EBS functions,

engineering design, characterisation, modelling and performance [2]. Clay-based buffer and backfill are a key component of the EBS in many national programmes, and based on their key functions in relation to the particular waste and site characteristics, key FEPs, such as coupled thermo-hydro-mechanical-chemical (THMC) evolution, re-saturation, swelling, and long-term alteration of buffer, were identified [1]. This provided a basis for subsequent discussions within the context of the optimisation cycle mentioned above, and in particular on design requirements and constraints, and process issues at the first two workshops [3][4].

This paper will outline the integrated approach for developing the EBS that is being analysed in the current NEA project. In this context, clay-based EBS elements will be highlighted as an important example for the discussion held on design requirements and constraints, and on process issues. The future perspective of the project, required to close the optimisation cycle for the EBS, will also be covered.

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