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International co-operation regarding site characterisation and site evaluation for geological repository systems for long-life radioactive waste

Hosszú élettartamú radioaktív hulladékok földtani tárolórendszereinek telephely-jellemzésére és értékelésére vonatkozó nemzetközi együttműködés

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Abstract

This general paper is principally aimed at providing examples of OECD Nuclear Energy Agency initiatives in the field of the characterisation and evaluation of potential sites for the geological disposal of long-life radioactive waste. The examples focus on the geoscientific aspects of geological disposal and the added value of addressing them in an international context. Most of the initiatives chosen have resulted, or will soon result, in open publications. Following introductory information on the OECD Nuclear Energy Agency, the paper also presents an overview of some of the key challenges that are, or will have to be, faced in the implementation of the geological disposal of long-life waste.

Összefoglalás

Ez a cikk alapvetően az OECD Atomenergia Ügynökség példáit kívánja segítségül hívni a hosszú élettartamú radioaktív hulladékok földtani elhelyezése, a lehetséges telephelyek jellemzése és értékelése témában. A példák a földtani elhelyezés földtudományos oldalára összpontosítanak, amihez jelentős pluszt ad az a tény, hogy a problémák nemzetközi összefüggésben kerülnek terítékre. A választott példák többsége már megjelent, vagy a közeljövőben jelenik meg publikációként. Az OECD Atomenergia Ügynökségről szóló bevezető után a cikk egy áttekintést is közöl azokról a legfontosabb problémákról, amikkel a hosszú élettartamú hulladékok földtani elhelyezése kapcsán szembesülhetünk.

Radioactive waste management at the NEA

The Nuclear Energy Agency (NEA) is a semi-autonomous body which was established in 1958 within the framework of the Organisation for Economic Co-operation and Development (OECD). NEA membership today consists of 27 countries and represents 85% of the world's installed nuclear capacity.

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The primary objective of the NEA is to promote co-operation among the governments of its member countries in furthering the development of nuclear power as a safe, environmentally acceptable and economical energy source. This is achieved notably by:

– encouraging harmonisation of national regulatory policies and practices (with particular reference to the safety of nuclear installations) protection of human against ionising radiation, the preservation of the environment, radioactive waste management, and nuclear third party liability and insurance;

– assessing the contribution of nuclear power to overall energy supply;

– developing exchanges of scientific and technical information, particularly through participation in common services;

– setting up international research and development programmes and joint undertakings.

In these and related tasks, the NEA works in close collaboration with the European Commission (EC) and the International Atomic Energy Agency (IAEA).

The work of the NEA in the area of waste is guided by the Radioactive Waste Management Committee (RWMC), a forum of senior representatives from implementing agencies, regulatory authorities, policy-makers and relevant R&D institutions. The cross-party representation of industry, safety authorities, and governmental policy bodies, and the wide range of expertise it musters amongst the NEA Members countries, make the RWMC a uniquely placed international forum for addressing issues in radioactive waste management. The Committee assists Member countries by providing objective guidance on the solution of radioactive waste problems, and promotes safety in the short- and long-term management of radioactive waste. The focus of the RWMC effort is on the identification and pursuit of issues in which there is pan-national interest and which are important for developing sufficient confidence in the safety and social acceptability of waste management options.

In recent years, the programmes under auspicies of the RWMC have focused on both technical and non-technical aspects of the deep geological disposal of long-life radioactive waste. The rationale for this focus is multiple:

– considerable experience exists in the handling, treatment, transportation and storage of all types of waste,

– disposal facilities for short-life waste are already in operation in many countries, at surface level such (as at the El Cabril and the Centre de l'Aube facilities in Spain and France respectively), or in shallow underground facilities (such as in Forsmark, Sweden (SFR) and at Olkiluoto (VLJ) and Loviisa in Finland),

– geological disposal of high-level, long-life waste has not been implemented yet, apart from one notable exception: the Waste Isolation Pilot Plant (WIPP) located in New Mexico (United States), where transuranic waste has been disposed of since March 1999 in bedded salt at a depth of 650 m; and

– the technical confidence in the long-term safety and feasibility of geological disposal is not always shared by other stakeholders, in particular the general public.

Key challenges related to the geological disposal of high-level, long-life waste

This paper does not intend to detail all actual and potential, technical and non-technical challenges that are, or will have to be, faced in the various decision-making and implementing steps of geological disposal. However, in order to put the specific geoscientific aspects of disposal into perspective, it is worthwhile summarising some of these key challenges.

In recent years, waste management programmes have focused on the technical aspects of deep underground disposal of long-life radioactive waste. Today, a consensus exists between experts in various countries which accepts that that sites can be properly identified and characterised, that geological repositories can be designed so that no short-term detriment to populations will result from the waste disposal, and that an acceptable level of safety is provided for times far into the future (OECD/NEA 1991, 1999a). There also exists a consensus, among the experts, that the current generation, which has benefited from the nuclear energy produced, should provide future generations with the means to dispose of the waste permanently (OECD/NEA 1995). Recent setbacks in disposal programmes have not been based on technical arguments, but rather political and societal aspects. The waste management community must therefore find new ways to address the concerns of all stakeholders in the repository development process. Among the general strategic challenges linked with the above consideration are the following:

- the establishment of, and confidence-building in the entire step-wise process of decision-making; this should take into account technical aspects of repository development and more qualitative arguments, as well as consider the active involvement of all stakeholders, including the general public;
- the assessment of the place of waste disposal within the broader debate on environmental and sustainability issues, including the demonstration that safe and environmentally acceptable strategies can be applied;
- the comparison of the principles of radioactive and non-radioactive waste management and of the evaluation of their impacts; and
- the evaluation of the impact of financial pressures on waste management programmes – e.g. due to deregulation of electricity markets – as well as the impact of waste management on the continued economic sustainability of nuclear power.

From a more technical point of view, some of the key challenges could be synthesised as follows:

- the establishment of technical confidence in long-term safety assessment in the presence of uncertainties inherent in natural systems and very long time-scales;
- the adequate consideration of the interfaces between the various natural and man-made components of the repository system; and
- the appropriate consideration of site-specific geoscientific information in the preparation of a safety case; this includes (i) the avoidance of over-conservatism which may lead to the effective disregard of the geosphere as a barrier, and also

to bias in the sensitivity analysis, and (ii) the use of large amounts of „soft" information*.

NEA initiatives regarding site characterisation and evaluation

Introduction

A large propotion of NEA initiatives regarding geological disposal site characterisation and evaluation has been conducted under the auspices of the Co-ordinating Group on Site Evaluation and Design of Experiments for Radioactive Waste Disposal (SEDE); this operates under RWMC guidance. The main aim of SEDE work could be summarised as the promotion of actions that enhance confidence in the process of site characterisation, leading to site evaluation and the determination of site suitability. This is in the general framework of the assessment of the long-term safety of deep repository systems for radioactive waste. Most SEDE activities are closely linked with those of the NEA Performance Assessment Advisory Group (PAAG).

As most national programmes are shifting from a research phase to a development and demonstration phase for potentially suitable sites, at the SEDE level the following needs have arisen:

- to emphasise the development of relevant activities to the end-use of site characterisation – i.e. site evaluation and performance assessment – therefore, to foster co-operation between site characterisation and safety-analysis specialists on the basis of site-specific geoscientific information;
- to integrate design and construction issues, given that site characterisation data are vital to the detailed design of the repository concept and of the engineered barrier system; and
- to consider the interfaces between the various components of the repository system and their interactions with the geosphere.

In order to reflect the needs and questions detailed above, the SEDE concentrates its priorities and initiatives on three specific areas:

- underground testing;
- roles of the geosphere in safety assessment; and
- interface between the geosphere and the engineered barrier system.

Furthermore, a specific application of the above working areas has been developed in the field of argillaceous media under the auspices of the SEDE Working Group on Measurement and Physical Understanding of Groundwater Flow Through Argillaceous Media (informally named the „Clay Club").

* „Hard" data are quantitative measurements that have a clear relationship to disposal safety-relevant features and processes represented in assessment models (e.g. hydrogeological data from the testing in boreholes and tunnels). „Soft" data include both qualitative information (such as expert judgement and geological experience) and also quantitative information that is either weakly correlated to the attributes of interest in assessment models (e.g. geophysical and geochemical data), or describes the attribute of interest through constitutive equations (e.g. hydraulic heads to hydraulic conductivity).

Underground testing

The main aims of the activities related to underground testing for geological disposal are to build confidence in *in-situ* characterisation methodologies, and to lend further technical support to testing programmes.

International Stripa Project

One of the most significant activities developed in this area under NEA auspices was the International Stripa Project, which ran from 1976 to 1992. Nine countries co-operated on this underground research laboratory project. The latter was established in the former iron mine of Stripa, located in Sweden at depths between 360 and 410 m, in granitic settings. Among the project outcomes were (OCD/NEA & SKB 1993):

- the development of characterisation techniques (e.g. borehole radar and seismics);
- the underscoring of the importance of matrix diffusion for radionuclide retardation and of groundwater flow channelling;
- the performance of single fracture and 3D tracer tests; and
- the development of sealing systems for disposal holes and galleries.

The NEA is not currently carrying out an underground research project. However, the NEA „Clay Club" served, through expert networking and exchange of information, as a launching platform for the Mont Terri project, an international rock laboratory located in the Opalinus Clay, a Mesozoic shale formation in Switzerland (THURY & BOSSART 1999).

Justification of further testing

Considering the wide range of objectives that are assigned to existing and planned underground testing facilities, a recent initiative consists in a rationalisation and justification of further underground characterisation, testing and demonstration from an international perspective. The report, which is planned for 2000, will aim to help technical decision makers when planning and evaluating the best uses of existing and/or future underground facilities.

Roles of the geosphere barrier in safety assessment

The objective here is to build confidence in the geosphere as a barrier. Most of the activities described below have been developed in co-operation with the PAAG.

Geosphere as a barrier to radionuclide transport

To help member countries develop specific tools for the assessment of the geosphere barrier, the NEA set up, between 1987 and 1993, the INTRAVAL Project ,aimed at conceptualising and developing groundwater flow and radionuclide transport models (OECD/NEA & SKI 1996). The project consisted of a series of

test cases (*in-situ* or in laboratory) in various geological environments and with different spatial and temporal scales. Among the main issues encountered were:

– the characterisation of the geological variability in the field;

– the theoretical and computational analysis of the impact of variability on the prediction of flow and transport for the space- and time-scales of relevance in disposal performance assessment; and

– the evaluation of the use of simplification in performance-assessment models (e.g. 1–D streamtubes with averaged and constant transport properties, linear sorption equilibrium concept, time-independence).

On the basis of the INTRAVAL outcomes, the GEOTRAP Project on Radionuclide Migration in Geological, Heterogeneous Media was set up in 1996. GEOTRAP is devoted to current approaches to acquiring field data, and testing and modelling flow and transport of radionuclides in actual (and therefore heterogeneous) geological formations for the purpose of site characterisation and safety assessment of deep repository systems of long-life radioactive waste. The project is articulated in a series of structured, forum-style workshops whereby national waste management agencies, regulatory authorities and scientists are able to interact and contribute to the advancement of the state of the art in these areas. The topics addressed so far have related to the:

– roles of field tracer experiments in the prediction of radionuclide migration (OECD/NEA & EC 1997);

– modelling of the effects of spatial (natural) variability (OECD/NEA 1998);

– characterisation and representation of water-conducting features (OECD/NEA, 1999b); and

– confidence in models of radionuclide transport for site-specific performance assessment (OECD/NEA in prep).

Overall, the GEOTRAP workshops confirmed (LALIEUX et al. 1999) that a multidisciplinary approach is necessary in order to address more fully the issues relevant to transport modelling in a heterogeneous geological medium, in which coupled and, possibly, non-linear processes operate. Effective communication between the different groups involved is therefore essential. Despite the difference in the host rock, in concepts and terminology, the GEOTRAP workshop series has been successful in developing a constructive dialogue between experimental scientists and modellers. In addition, both implementers and regulators have participated actively in the project. The project is thus helping to bridge the gap between data acquired *in-situ* and their uses for performance and safety assessment purposes.

The workshops have highlighted significant advances in the achievement of a depth of understanding in relation to geosphere heterogeneity and, in particular, water-conducting features. This understanding is required for performance-assessment modelling and for the compilation of a repository safety case that can be defended and which is credible. A depth of understanding implies the use of wide-ranging information to support the decisions that underlie transport-model calculations, even if not all this information is incorporated directly in the models. Specific advances have, for example, been noted in the integration of methods used to characterise heterogeneity over a wide range of scales, in the

incorporation of a wide range of qualitative data to constrain uncertainties in characterisation, and in building an overall geological understanding of a site. Furthermore, external peer review, at all stages of a project, has an important role to play in this matter.

In spite of the efforts to achieve a wide-ranging debate encompassing all aspects of geosphere transport, discussions at the GEOTRAP workshops have centred predominantly on the characterisation of hydraulic properties and on their representation in flow models. It can be concluded that this reflects the weighting of current work internationally, and the relative maturity of hydraulic-characterisation techniques and flow models; nevertheless, it may not always adequately reflect the needs of performance assessments.

To further support detailed models of radionuclide retardation on natural materials (e.g. surface complexation models), the NEA also sponsored a special project called ASARR -Analogue Studies in the Alligator Rivers Region – from 1987 to 1997. It consisted of a field study on the mobilisation and migration of uranium in groundwater in the weathered zone surrounding the Koongarra ore body in the Northern Territories of Australia. The project was of notable help development investigation techniques and understanding of geochemical processes (ANSTO 1997).

Matching the results of various site-characterisation methodologies

Matching the results of the various geoscientific methods used in site characterisation, and communicating the rationale and implications of this matching, as well as associated uncertainties and limitations, are important. This is especially true with respect to confidence-building in the data, concepts and models which are used for the description, understanding and assessment of current and future performance of the geological barrier.

In this framework, a workshop was organised in 1997 to help assess the potential of groundwater chemistry as a method for testing site-specific, time-dependent groundwater flow models (OECD/NEA 1998b). The workshop illustrated significant progress in the integration of flow and chemistry, and helped to acknowledge the inherent limitations of, and difficulties in this integration. The progress has, however, not been communicated enough outside the hydrogeochemistry community. In current national disposal programmes, hydrogeochemistry is used more as a tool for „site understanding" than for direct testing of flow models. The main workshop conclusion is that hydro-geochemistry could be used both in developing conceptual flow models and in testing flow models; however a better formalisation is required to help provide a consistent and transparent picture of the site and to help communicate the confidence gained.

Interfaces between the geosphere and the engineered barrier system

The main objectives of the initiatives below are to assess the perturbation induced in the geosphere by the repository and to promote the understanding of the interactions with the geosphere when defining repository components.

In underground repositories for radioactive waste, significant quantities of gases may be generated as a result of several processes – notably the interaction of groundwaters and brines with waste and engineered materials placed in disposal systems. The gases may migrate through the engineered barrier system and the natural geological barrier. The potential impact of gas generation, accumulation and migration on the long-term safety of a repository will be dependent upon the waste types, the repository concept, the host geological environment and the scenarios for the long-term evolution of the system. It is recommended that the potential impact of gas accumulation and migration on the performance of the various barriers should be addressed and assessed in the development of safety cases for radioactive waste repositories.

Significant efforts have been, and continue to be, expended in numerous national and international programmes in analysing the potential impacts of gas in underground repositories. In light of these efforts, and in order to help focus further work, the European Commission and the NEA have jointly undertaken a review of the knowledge gained so far in order to establish the current status of the basic understanding of the topics concerned (RODWELL et al. 1999). The review report covers most underground repository concepts presently being considered. Amongst the repository concepts that are reviewed in the report, that for the Yucca Mountain is unique in that disposal is envisaged in unsaturated rock in an arid region. The consequence for this concept is that two-phase flow issues are absolutely central to repository performance analysis, and have therefore commanded more resources and attention than gas migration in repository concepts developed for saturated locations. For other repository concepts – i.e. those involving emplacement in saturated rocks – the scenarios involving substantive gas migration issues vary in line with the repository concept.

Argillaceous media

The initiatives mentioned below are aimed at building confidence in the characterisation and understanding of natural argillaceous media and at assessing their barrier performances. They are being carried out under the auspices of the „Clay Club".

Comparison of clay characteristics

A whole range of argillaceous media are currently being considered as potential host rocks for geological disposal, i.e. from soft, potentially plastic clays with relatively high water content (e.g. Boom Clay in Belgium), to hard, potentially fractured mudrocks with low to very low water content (e.g. Opalinus Clay in Switzerland, Boda Siltstone Formation in Hungary). Most of the

initiatives set up under the Clay Club auspices help to assess the commonalities and differences between various argillaceous formations; therefore, they facilitate the transferability of the information gained – notably in underground testing facilities – and foster international and multilateral co-operation.

Among these initiative is the elaboration of a catalogue of Features, Events and Processes specific to argillaceous media (FEPCAT Project). The catalogue, which is planned for the end of 2000, will provide, for each post-closure FEP, an up-to-date, critical overview of conclusions and key references related to current understanding and potential impact on the long-term performance of the geosphere barrier, and also information on ongoing and planned work. In addition to systematically exploring the commonalities and differences among argillaceous media, it should help provide a sound, realistic and defensible international basis for further long-term safety assessments.

Regulation of water chemistry

The determination of the natural processes that regulate water chemistry and the assessment of the hydrochemical changes induced by the repository are essential aspects of the understanding of transport barrier capacities of the geosphere. Given this, obtaining representative *in-situ* geochemical porewater compositions is one of the key difficulties in tight media with low water content. Therefore, the Clay Club is reviewing (i) the advantages and limitations of existing extraction methods, (ii) the current basic understanding of the perturbations induced while extracting porewater, and (iii) the approaches to interpretation of the results (e.g. geochemical modelling). The report summarising this review process (SACCHI et al. 2000 in prep.) also identifies key challenges and ways to tackle them.

Basic processes of water, gas and solute movement

The Clay Club fosters multidisciplinary understanding of the basic processes of water, gas and solute movement through argillaceous media. The main initiative in this field has been the elaboration of a state-of-the-art report that synthesises the available information, identifies key concepts and mechanisms and their coupling, makes the appropriate links between basic microscopic phenomena and their macroscopic responses, and highlights, wherever possible, unresolved issues (HORSEMAN et al. 1996).

In this framework, special emphasis has been put on the role of sedimentary and structural heterogeneities and discontinuities (OECD/NEA 1998c) and on the conditions and processes for the self-healing of faults and fractures at repository depths. To help a multidisciplinary coverage of these topics, the Clay Club is also promoting exchange of ideas from other sectors – in particular, the academic community and the oil and gas industry.

Conclusions

It can be concluded from the above examples that, concerning the geoscientific aspects of confidence building in the long-term safety of geological disposal, the NEA has contributed to:

- the fostering of common understanding with respect to important site characterisation and evaluation issues, and the sharing of resources therein;
- the provision, comparison and testing of the technical and scientific bases for site characterisation, understanding and evaluation in order to build a coherent picture of the site/processes that is adequate for safety assessment;
- helping devise an appropriate consideration of the geosphere barrier in the overall safety case; and
- the comparison of the state of the art in the waste disposal community with that in other geoscientific disciplines.

Overall, the above examples also demonstrate that the NEA promotes a constant evaluation and understanding of the commonalities and differences between national disposal programmes, facilitates dialogue across professional sectors, and helps build confidence in the soundness and completeness of individual national programmes.

As a concluding remark, it is fundamental to acknowledge the very high quality of the technical work carried out at national and multilateral levels which constitute the basis for all NEA initiatives.

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