

KEY ASPECTS OF THE SECOND PROGRESS REPORT IN THE JAPANESE R&D PROGRAMME FOR HLW DISPOSAL

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ABSTRACT

The Japan Nuclear Cycle Development Institute (JNC), successor to the Power Reactor and Nuclear Fuel Development Corporation (PNC) as of 1st October 1998, is currently preparing a second progress report (tentatively entitled H12) on research and development for geological disposal of high-level waste (HLW) in Japan. The H12, which documents progress made since the publication of the first progress report (H3) in 1992, will be presented to the Japanese Government for assessment by the year 2000. The purpose of the work was specified in a report published in April 1997 by the Advisory Committee on Nuclear Fuel Cycle Backend Policy of the Atomic Energy Commission (AEC) entitled "Guidelines on Research and Development Relating to Geological Disposal of High-Level Radioactive Waste in Japan" (hereafter the AEC Guidelines). The primary objective of the H12, as specified in the AEC Guidelines, is to present an outline of "the technical reliability of geological disposal in Japan". It should also provide input for the siting and regulatory processes, which will be set in motion after the year 2000.

INTRODUCTION

In Japan, as outlined in the overall HLW management programme defined by the Atomic Energy Commission (AEC) of Japan (1), the HLW separated from spent nuclear fuel at reprocessing plants will be immobilised in a glass matrix and stored for a period of 30 to 50 years to allow cooling; it will then be disposed of in a deep geological formation (geological disposal). Pursuant to the overall HLW management programme, an organisation with responsibility for implementing HLW disposal will be established around the year 2000. This will be followed by site selection and characterisation, demonstration of disposal technology, establishment of the necessary legal infrastructure, relevant licensing applications and repository construction, with the objective of starting repository operation by the 2030s and no later than the mid 2040s.

The HLW disposal programme is currently in the research and development (R&D) phase and the Japan Nuclear Cycle Development Institute (JNC) has been assigned as the leading organisation responsible for R&D activities. The aim of the R&D activities at the current stage is to provide a scientific and technical basis for the geological disposal of HLW in Japan, which in turn promotes understanding of the safety concept not only in the scientific and technical community but also by the general public. As one of the features of R&D programmes, its progress is documented at appropriate intervals, with a view to clearly determining the level of achievement of these programmes and promoting the understanding and acceptance of the geological disposal strategy by the general public. At a major milestone, PNC (now JNC) submitted a first progress report, referred to as H3, in September 1992 (2). H3 summarised the results of R&D activities up to March 1992 and identified priority issues for further study. The second progress report (tentatively entitled H12), scheduled to be submitted around 2000, and should demonstrate more rigorously and transparently the feasibility of the specified disposal concept. It should also provide input for the siting and regulatory processes, which will be set in motion after the year 2000.

PNC (now JNC) issued the first draft of the H12 report (First Draft) in September 1998, which summarises the results of R&D activities up to July 1998 (3). The aim of the First Draft is to confirm, through a series of discussions with experts in various fields related to geological disposal, whether current R&D activities have been carried out in accordance with the AEC Guidelines. The First Draft also contributes to the overall goal of the H12 by integrating the results of R&D activities; this is necessary because most R&D activities address specific scientific and technical issues identified in the Guidelines. This paper introduces the key findings of the First Draft of JNC's H12.

DEVELOPMENT OF GEOLOGICAL DISPOSAL CONCEPT IN JAPAN

In 1976, the AEC of Japan presented a plan for high-level waste management (4). It was decided at that time that the focus should be on geological disposal and strategies for required research and development were formulated. Relevant organisations, such as JNC, subsequently developed R&D programmes in accordance with these strategies. The AEC then outlined a disposal concept which utilises a multibarrier system to provide a basis for geological disposal in Japan; this concept is described in the report of the AEC's Advisory Committee on Radioactive Waste Management (ACRWM) published in 1980 (5). In 1984, the ACRWM published a report which stated that R&D activities should be promoted from a broad viewpoint with regard to the rock types being considered as potential host rocks for geological disposal (6). In the revised "Long-Term Program for Development and Utilization of Nuclear Power", published in 1987, the basic policy for HLW disposal was presented (7). According to the Long-Term Program, HLW resulting from reprocessing of spent fuel should first be vitrified in order to provide a stable waste form. It should then be stored for 30 to 50 years in order to allow cooling and then be subjected to deep geological disposal.

In 1989, the ACRWM established a set of guidelines entitled "Major Targets and Methods of Implementation in Research and Development for the Geological Disposal of High-level Radioactive Waste" (8). These guidelines specified that predictive assessment of the long-term performance of geological disposal based on a multibarrier system was a major issue to be addressed by research and development activities. It was also stated that the feasibility of constructing a multibarrier system which would be appropriate for a range of geological conditions throughout Japan should be clarified. In addition, the guidelines estimated that it would take more than 10 years to attain the required progress in research and development and therefore recommended that past achievements and future prospects should be summarised in the form of an intermediate report in order to inform a general audience of the steady progress in R&D activities, with a view to promoting public understanding and support.

PNC (now JNC) published a comprehensive report (the first progress report; H3) in 1992, based on the results of past research and development activities supporting geological disposal in Japan. The report described the concept for safe geological disposal as follows.

The concept of geological disposal in Japan is similar to that in other countries, being based on a multibarrier system which combines the natural geological environment with engineered barriers. The approach to repository concept development has targeted neither a particular type of rock nor a particular area. Particular consideration is given to the long-term stability of the geological

environment, taking into account the fact that Japan is located in a technically active zone. The wide range of geological environments throughout Japan is also considered and, within this context and due to Japan's complex geology, a design for an engineered barrier system (EBS) with sufficient margins in its isolation functions to accommodate such geological environments has been assessed. The major component of overall barrier performance of the disposal system is borne by the near-field, while the remainder of the geosphere serves to reinforce and complement the performance of the EBS. This massive EBS was introduced to ensure long-term performance of the disposal system for a wide range of geological environments. To summarise, the basic concept in Japan is to construct an engineered barrier system, with sufficient margins for long-term isolation of the waste, in a stable geological environment (9). The reference layout of the EBS involves either axial, horizontal emplacement in the tunnel or vertical emplacement in the pit of vitrified waste encapsulated in a thick steel overpack which are surrounded by highly compacted bentonite. In this paper, the axial, horizontal emplacement is discussed as the reference EBS layout.

Within the context of this disposal concept, it is important for R&D activities to focus on the natural system attributes which optimise the EBS performance. These attributes include relative tectonic stability, low groundwater flux, favourable geochemistry and a low risk of disruptive events. The safety concept assumes that disruptive events can be avoided by site selection. The remaining geological environments identified as having favourable characteristics for the disposal system provide the basis for repository design. Finally, the performance assessment is conducted for a reference repository design, consisting of the massive EBS combined with a favourable geological environment, taking alternative future evolutions of the system into account.

If safety functions of the geological disposal system are assured, minor amounts of radioactivity released from the engineered barrier system will further decay and concentrations will be reduced by dilution during the long migration period in the geosphere. HLW disposal can thus be realised in such a way that no significant detrimental influence is exerted on either man or his environment.

The ACRWM published an evaluation of PNC's (now JNC's) first progress report in July 1993, stating that the report had demonstrated the technical feasibility and safety of geological disposal in Japan (10). At the same time, the ACRWM recommended policies for future research and development efforts.

R&D ACTIVITIES FOR SECOND PROGRESS REPORT (H12)

In the AEC Guidelines entitled "Guidelines on Research and Development Relating to Geological Disposal of High-Level Radioactive Waste in Japan", which was published in April 1997 (11), the technical reliability of geological disposal in Japan was required to demonstrate in the context of H12. The Guidelines also specified the major issues to be dealt with in the H12 in order to provide a technical basis for the selection of potential disposal sites and for the formulation of safety standards, both of which are required for implementation of a geological disposal project. The final issue was the identification of the research and development activities which would be required after the year 2000. The AEC Guidelines also considered the approach to R&D to be performed by PNC (now JNC) in cooperation with other agencies and organisations, and how to evaluate research results objectively and transparently in the H12.

Building on the basis provided by H3, and taking into account the provisions of the AEC Guidelines, JNC has tackled the problem of demonstrating the technical feasibility and reliability of the geological disposal concept in the H12 report. The report will also provide key input for site selection procedures and development of a regulatory framework.

In order to demonstrate the technical reliability and safety of HLW disposal, the H12 report is required to show that the safety framework provided by a multibarrier system constructed in a suitable host rock formation is capable of functioning as designed, given the characteristics of the geological environment in Japan. The R&D requirements for the H12 can therefore, be defined as follows:

- The characteristics of the geological environment that are important for adequate geological disposal must be specified and it must be shown that suitable rock formations with these conditions exist in Japan. Information on host rock properties required to ensure the long-term safety of HLW disposal should be compiled via appropriate investigations.
- The design criteria for the EBS and other repository components must be specified and the feasibility of constructing a repository to fulfilling these criteria demonstrated.
- The performance of the disposal system, given the specific characteristics of the geological environment of Japan, must be evaluated with a high degree of reliability.

In order to meet the above requirements, current R&D work focuses on development of detailed and realistic near-field models and on improving the understanding of key processes and corresponding databases, taking into account a wide range of geological conditions. In JNC's R&D programme, three major areas of research have been conducted taking into account comprehensive information accumulated through geoscientific studies. These are: 1) evaluation of the geological environment, 2) repository design and engineering technology and 3) performance assessment.

KEY FINDINGS IN THE FIRST DRAFT OF H12 (3)

Evaluation of Geological Environment

The geological environment has two main functions in terms of ensuring the safety of geological disposal. One relates to the fundamental long-term stability of the site and the other to the properties of the host rock formations and groundwaters which facilitate the emplacement of the engineered barrier system and act as a natural barrier. In this connection, the feasibility of selecting a geological environment in Japan which is appropriate for geological disposal was discussed, based on findings obtained from case studies and field measurements.

First of all, important natural phenomena which can degrade the long-term stability of the geological environment were identified. These include earthquake and fault activity, volcanic activity, uplift, subsidence and denudation and climatic and sea-level changes. The occurrence of these natural phenomena and the extent of changes in the geological environment caused by them were investigated, focusing on the potential effects on the performance of the geological disposal system.

Case studies were carried out in regions where the natural phenomena mentioned above could be

easily observed. The locations and regularity of their occurrence and the extent of any changes were investigated over timescales of several hundred thousand years or more. This work was constrained by variability in the quantity and accuracy of the information, depending on the type of phenomena and the regions involved. The location of localised phenomena, such as volcanic activity and major fault movements, can be well specified and the effects of these phenomena can thus be avoided by selecting an appropriate disposal site. On the other hand, gradual phenomena such as uplift, subsidence, denudation and climatic and sea-level changes are more ubiquitous. It is, nevertheless, possible to estimate future trends and their potential effects by extrapolating data obtained on the current rate and the extent of such processes. In this way, it is possible to select a sufficiently stable environment for geological disposal.

For example, there is little possibility that the locations of volcanic activity will change to a significant degree unless there is a major change in the plate tectonic situation. The results of tracing the history of volcanic activity in the Quaternary (i.e. from approximately one million seven hundred thousand years ago to the present) show that the locations in which volcanic activity occurs are limited to distinct regions and that there is little change in these locations (Fig. 1.). In addition, the direct effects of volcanic activity are expected to be restricted to within several tens of kilometers from the activity center. Significant effects from this source can thus be avoided by selecting disposal sites distant from currently active volcanoes.

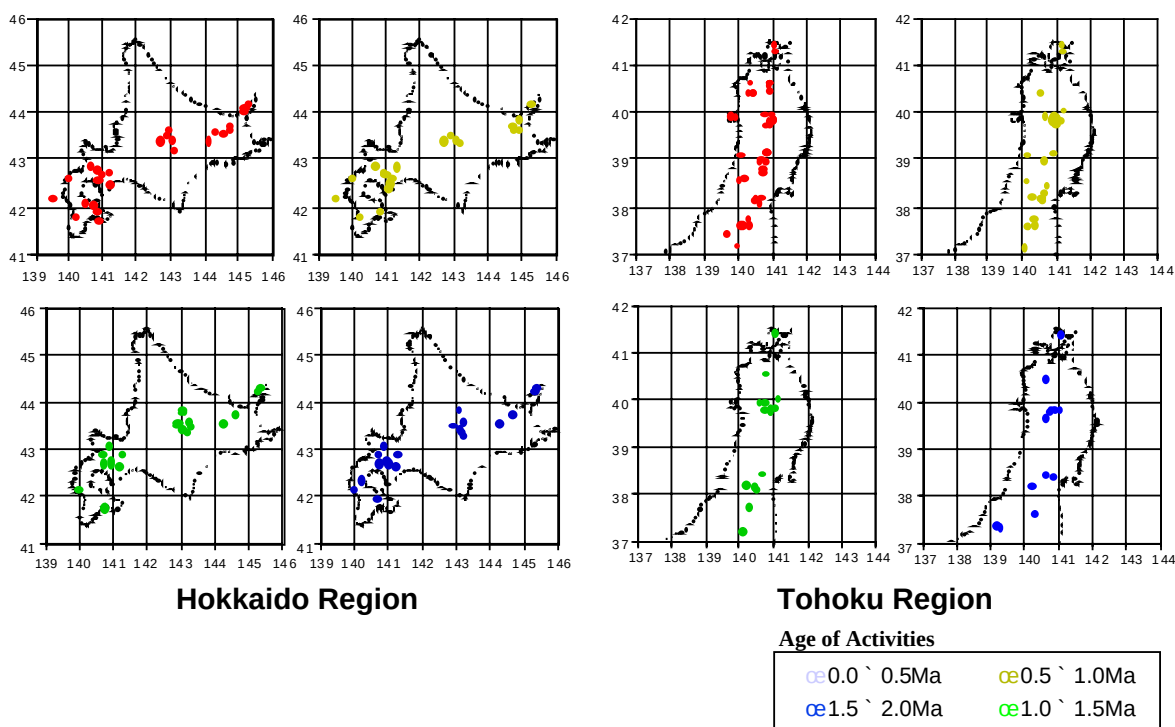


Fig. 1. Quaternary Volcanism in Northeastern Japan

The characteristics of the geological environment which are important in terms of its second (barrier) function mentioned above include groundwater flow, the geochemical characteristics of groundwater, the thermal and mechanical properties of rock formations and solute transport phenomena. A great deal of data have been obtained on these characteristics, particularly from geoscientific studies carried out in the Tono area and the Kamaishi mine.

Groundwater flow analyses and measurements taken from two 1,000m deep boreholes in the Tono area show that the hydraulic gradient deep underground is less influenced by topography, being approximately half of that near the ground surface where the gradient is strongly governed by topographic conditions.

Data in the published literature, taken mainly from the civil engineering field, were compiled in order to investigate the permeability of different rock types. At the same time, these data were compared with measurements taken at several hundred points in the Tono area and Kamaishi mine. It was concluded that permeabilities obtained from the literature data were more than an order of magnitude greater than the measurements taken in the Tono area and Kamaishi mine. Excluding fracture zones and fault crush zones, the measured permeability of deep rock formations ranged between 10^{-12} and 10^{-6} m/s, with average values in the order of 10^{-9} - 10^{-8} m/s.

Measurements of low mineralised groundwaters in the Tono area and Kamaishi mine show that water chemistry becomes strongly reducing deep underground. This phenomenon can be explained by reactions between the groundwater and the major minerals which constitute the rock, clay minerals, microorganisms and organic substances.

Measurements were carried out as part of the geoscientific studies in the Tono area and Kamaishi mine in order to confirm the initial stress state of the rock. It was found that the ratio between the vertical stress and internal horizontal stress was almost equivalent to 1. It was also found that changes in rock properties caused by tunnel excavation extended to approximately 1 meter from the tunnel wall.

Pore structures observed in numerous mines and tunnels were investigated in order to clarify the mechanisms of underground solute transport. Observations and test results from the Kamaishi mine and Tono area showed that fracture networks developed in crystalline rocks and old sedimentary rocks provide the major transport pathways. On the other hand, interparticular pores and microfractures provide the major transport pathways in recent sedimentary rocks. It was also confirmed that clay minerals and ferrous minerals, such as mica and pyrite, display generally higher radionuclide sorption than quartz and feldspar.

The above findings led to the conclusion that the deep geological environment can maintain the integrity of the engineered barrier system for a long period of time and that the strata themselves can function as a natural barrier.

Repository Design and Engineering Technology

The design requirements for the EBS and the disposal facility in general were clarified based on currently available technologies, taking account of the wide range of geological environments throughout Japan. Realistic and reliable data and analysis techniques were used in order to derive an example of specifications for the engineered barrier system and disposal facility, which also took economic aspects into consideration.

Since the publication of the first progress report, more reliable supporting data have been obtained from demonstration tests on both a laboratory and an engineering scale. The demonstration tests were carried out as part of studies performed at JNC's ENTRY facility (12),

geoscientific studies in the Tono area and Kamaishi mine, international joint research activities at underground research laboratories abroad and studies at research facilities both in Japan and abroad (13). The design requirements have been reviewed, analysis techniques which provide tools for the design have been improved and the database for the design has been developed.

Data collected mainly from the published literature were compared with the findings obtained from the in situ studies carried out in the Tono area and Kamaishi mine. The practical feasibility of designing and emplacing the engineered barrier system and the disposal facility was clarified for a wide range of physical rock properties. This has provided a basis for designing and constructing the engineered barrier system and disposal facility which can be tailored to the specific characteristics of a potential disposal site in the future.

Aspects of the engineered barrier system specifications, such as the materials and the thickness of the overpack and buffer materials, were investigated and the results of preliminary calculations were presented based on the design requirements (Fig. 1.). According to the calculations, the thickness of both the overpack and buffer materials could be reduced by approximately 30% compared with the specifications indicated in the first progress report. Bentonite mixed with quartz sand was selected as the buffer material, which would bring about a reduction in costs while maintaining the required level of performance.

The mechanical stability of tunnels was investigated based on data obtained from relevant geological environments and rough estimates were then made of the depth range in which construction of the disposal facility is feasible. In addition, a design concept for efficient emplacement of the vitrified waste and layout of the tunnels was developed based on thermal analyses. It was shown that the specifications of this engineered barrier system will allow construction of the disposal system, emplacement of the waste forms (i.e. operation of the facility) and backfilling of the tunnels (i.e. closure of the facility) using currently available technologies or technological advances which are expected in the near future. Development of more reliable technologies is ongoing and it is also expected that the applicability of the engineering technologies will be further confirmed in a planned deep underground research facility.

Performance Assessment

An assessment method which allows reliable evaluation of the safety functions of the geological disposal system was developed and an integrated analysis of the above concept was carried out using this method.

A systematic scenario analysis procedure was developed. Based on this, models which simulate relevant phenomena in detail, together with associated databases, were established in order to quantify selected scenarios. Firstly, a comprehensive list of FEPs (features, events and processes) was prepared. The FEPs were reviewed for relevance and grouped into scenarios. A reference scenario (the groundwater scenario) was taken as a standard case. In this reference case, the geological disposal system is characterised by realistic data from the geological environment and the specifications of the engineered barrier system which represent the design parameters (Fig. 2.).

Models which can simulate the evolution of the engineered barrier system and subsequent radionuclide migration in the rock surrounding the buffer material were developed based on the reference case. More detailed and realistic modelling was aimed using improved understanding of key processes and corresponding databases than in the H3 case.

The model used in EBS performance analysis are based on one-dimensional, diffusive transport with linear, reversible and instantaneous sorption. Shared solubility and precipitation of each radionuclide are also considered for migration process through the buffer. The first order reaction, hydration and Si diffusion are imposed as glass dissolution at the waste glass-bentonite interface. Radionuclide is assumed to be congruently dissolved with glass and limited solubility at the glass surface. The radionuclides released from the EBS are assumed to be instantaneously mixed within the excavation disturbed zone (EDZ) and distributed among fracture pathways in proportion to each pathway's individual water-flux.

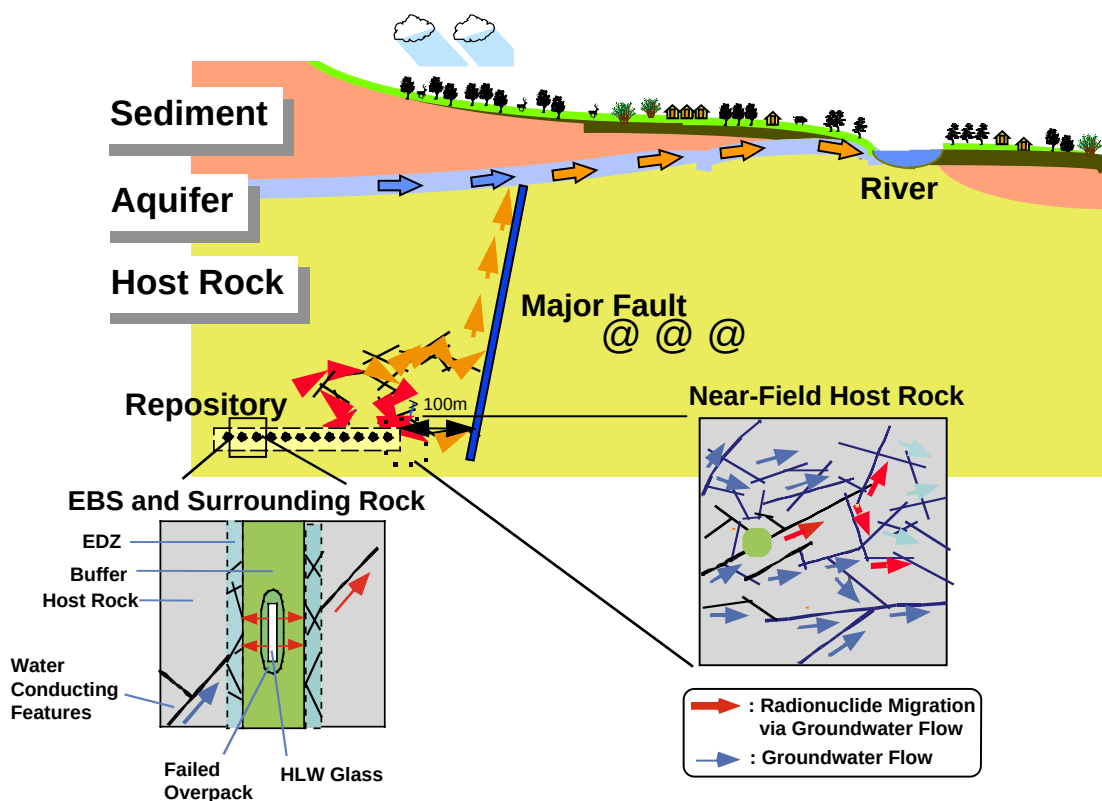


Fig. 2. Groundwater Scenario Reference Case and Conceptual Models for Radionuclide Migration

In assessing geosphere performance in a host rock, three-dimensional heterogeneous channel network models are constructed for this purpose using a stochastic discrete fracture network (DFN) models by linking the fracture intersections on each fracture plane. The radionuclide flux released from the EBS was applied along a 100m section of source drift in the middle of the block-scale region in order to avoid the effect of lateral boundaries on transverse mechanical dispersion. Radionuclide migration which takes into account advection-dispersion in a fracture

network, matrix diffusion, sorption in a rock matrix and radioactive chain decay is then solved in the channel network using the Laplace transform Galerkin method. Preliminary radionuclide-migration analysis in a 200m cubic block region of hypothetical granitic rock was made in order to better understand the impact of radionuclide migration processes in fractured rock (Figure 3). The processes considered include dispersion due to the network system and variability of velocity as well as the effects of matrix diffusion and sorption on retarding radionuclide migration. Total radionuclide release from a whole repository is evaluated by integrating the results of the fifty realizations of the stochastic block-scale model under the hypothesis of ergodicity. A simplification of the complex three-dimensional DFN model using a one-dimensional parallel-plate model, needed for extensive Monte Carlo simulations and sensitivity studies in order to evaluate the effects of parameter uncertainty as well as parameter variation on radionuclide migration, was also discussed.

Calculated radionuclide flux at the 100m distance from the repository is assumed to directly enter to a fault zone and then to a river of $10^8 \text{ m}^3/\text{y}$ flow rate through an aquifer. The retardation effect and traveling time are conservatively neglected in the fault zone and the aquifer. Radionuclides released in the river is dispersed in the surface environment, which is modelled by using a reference biosphere methodology.

These developed models were linked with one another in a safety assessment model chain, which allows the performance of the entire geological disposal system to be assessed. This includes a biosphere module which uses dose as a performance indicator. A reference case for a single package of vitrified waste was analysed using this model chain. In addition, the results were compared with results obtained using analysis codes developed by other organisations in order to confirm that the safety assessment methodology can correctly perform its function.

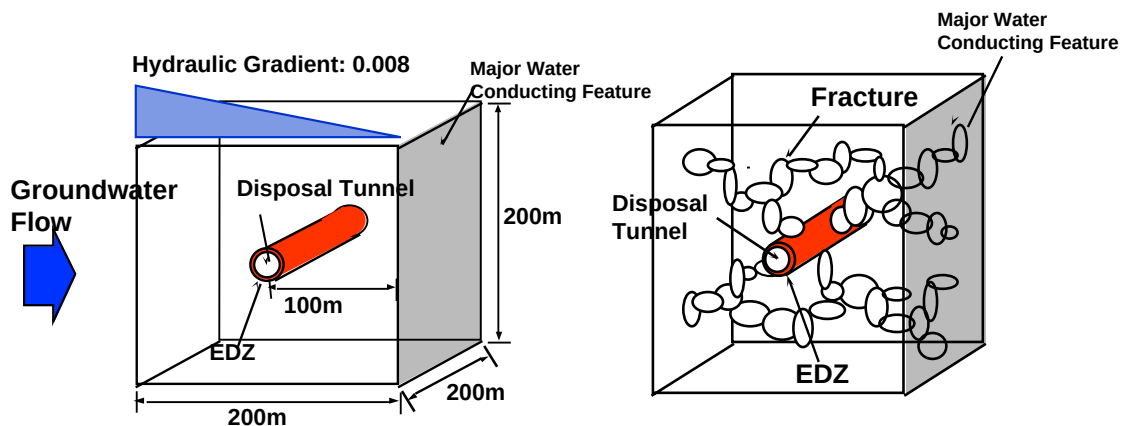


Fig. 3. Schematic View of Block Region for Geosphere Radionuclide Migration Analysis

The basic model chain mentioned above performs calculations for one package of vitrified waste (Fig. 4). When considering the overall safety of geological disposal, it is necessary to apply the model chain in a realistic way by taking groundwater flow within the entire repository into consideration. At the same time, it is necessary to take account of the fact that the leaching and migration of radionuclides are limited by interactions between packages. Further, the migration path lengths from the engineered barrier system to fault crush zones are different for individual

vitrified waste units, being longer for those located upstream. This may result in a larger barrier effect being attributable to the rock. A more realistic analytical framework, which allows assessment of the overall performance of the geological disposal system taking account of the conditions mentioned above, will be provided. For a repository containing 40,000 packages of vitrified waste, the calculated result for one package was multiplied by a factor of 40,000. Even such an extremely conservative calculation results in a maximum annual dose of much less than dose limitations of international recommendations and foreign standards currently in force.

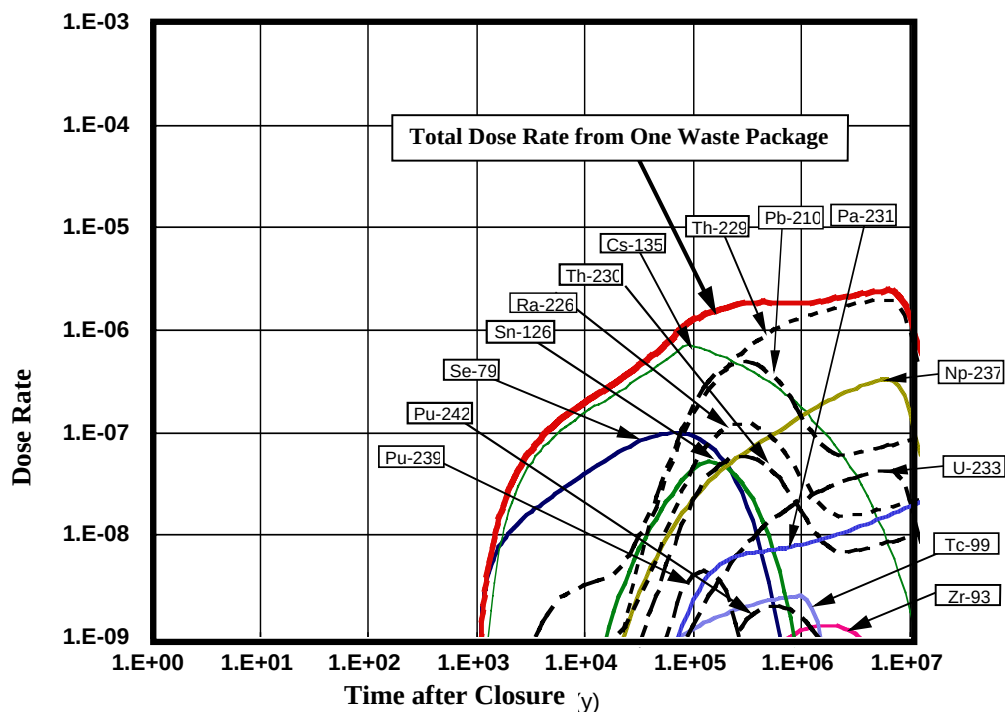


Fig. 4. Example of dose evaluation for one package of vitrified waste (Overpack is assumed to lose its integrity at 1,000 years after disposal and distance from the EBS to fault zone is conservatively fixed 100m.)

CONCLUSION

The major results of these studies to date can be summarized as follows:

- The location and scale of natural phenomena, such as volcanic activity, faulting and crustal movement have been traced over approximately the past several hundred thousand years by conducting appropriate case studies and analysing the latest information available through scientific literature and conferences. The fact that the level and accuracy of information vary somewhat for different types of phenomena and geographical regions is taken into account. Based on the results of these studies, it can be shown that it is possible to select a sufficiently stable geological environment in Japan such that a repository will not be influenced by the disruptive natural phenomena for around the next hundred thousand years. Databases on the properties of rock formations and deep groundwaters have been extended to include the latest scientific information available in the literature. Data from measurements in the Tono region and in the Kamaishi Mine have also been included to refine understanding of processes and

enhance the credibility of the databases. Based on these revised databases, it can be confirmed that the deep geological environment is generally suitable as a natural barrier and as an environment for construction, thus supporting the long-term performance of the EBS.

- In order to reduce the degree of conservatism in designing the EBS and the disposal facility as a whole, which takes into account a wide range of geological environments, detailed models and databases have been developed. Using these models and databases, the volume of EBS material has been reduced by up to 50% when compared with similar designs in the H3 report. Fabrication tests, engineering-scale tests and in-situ testing have shown that it is possible to construct the EBS and the repository with a reasonable investment of effort and cost using conventional engineering technologies.
- To ensure the long-term safety of the disposal system, consisting of a suitable geological environment and an appropriately designed EBS, a methodology for safety assessment has been developed which focuses on the performance of the near field. This methodology consists of developing relevant scenarios and realistic models, along with assimilating data with a view to evaluating the overall safety of the system. Using these models and databases, a performance assessment has been conducted for the groundwater scenario reference case, which takes into account the requirements set down by the AEC Guidelines. The results show that the risks at the time of maximum influence on man are considerably below the levels of foreign standards currently in force.

Outputs from these various R&D activities are being integrated as part of developing a safety case that demonstrates the technical reliability and safety of the geological disposal concept. These studies are also expected to provide a technical and scientific basis for both the site selection process and developing a regulatory framework.

The First Draft of the H12 provides a generalised summary of the second progress report and provides its context as an intermediate or provisional report, and includes some parts, which may not be sufficient to respond to the scientific and technical issues identified in the AEC Guidelines. It has been opened for comments from technical experts and these comments will be reflected to complete H12 for its goal defined by the AEC Guidelines.

REFERENCES

1. ATOMIC ENERGY COMMISSION OF JAPAN, Long-Term Program for Research, Development and Utilization of Nuclear Energy, (1994).
2. PNC, Research and Development on Geological Disposal of High-level Radioactive Waste, First Progress Report - H3, PNC TN1410 93-059, (1992).
3. PNC, Research and Development on Geological Disposal of High-level Radioactive Waste, First Draft of the Second Progress Report - H12, PNC TN1412 98-013, (in Japanese), (1998).
4. THE ATOMIC ENERGY COMMISSION OF JAPAN, R&D Program on Measures for Radioactive Waste, in Japanese, (1976).
5. THE ADVISORY COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT, THE ATOMIC ENERGY COMMISSION OF JAPAN, Promotion of R&D on Radioactive Waste Processing and Disposal, in Japanese, (1980).
6. THE ADVISORY COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT, THE

ATOMIC ENERGY COMMISSION OF JAPAN, Radioactive Waste Processing and Disposal Measures, in Japanese, (1984).

7. ATOMIC ENERGY COMMISSION OF JAPAN, Long-Term Program for Research, Development and Utilization of Nuclear Energy, (1987).
8. THE ADVISORY COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT, THE ATOMIC ENERGY COMMISSION OF JAPAN, Major Targets and Methods of Implementation in Research and Development for the Geological Disposal of High Level Radioactive Waste, in Japanese, (1989).
9. S. MASUDA, M. YAMAKAWA, H. UMEKI, K. MIYAHARA, and M. NAITO, High-level Radioactive Waste Disposal in Japan: Research and Development Programme, Proc. Waste Management'98, Tucson, (1998).
10. THE ADVISORY COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT, THE ATOMIC ENERGY COMMISSION OF JAPAN, On the Progress of R&D on High-Level Radioactive Waste Geological Disposal, in Japanese, (1993).
11. THE ADVISORY COMMITTEE ON NUCLEAR FUEL CYCLE BACKEND POLICY, THE ATOMIC ENERGY COMMISSION OF JAPAN, Guidelines on Research and Development Relating to Geological Disposal of High-level Radioactive Waste in Japan, (1997).
12. S. MASUDA, K. ISHIGURO, M. YUI, and T. MANO, Core Message from PNC/H-3 and Key Issues for the Next Milestone, Proc. The Fifth Ann. Int. Conf. High Level Radioactive Waste Management, Las Vegas, (1994).
13. S. MASUDA, M. YAMAKAWA, and H. UMEKI, Role of International Collaboration in PNC's R&D Programme for HLW Disposal, Proc. SPECTRUM'96, Seattle, (1996).