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RESEARCH AND DEVELOPMENT ON GEOLOGICAL DISPOSAL OF HIGH-LEVEL RADIOACTIVE WASTE

First Progress Report

Summary

September, 1992

PNC

Power Reactor and Nuclear Fuel Development Corporation

The "First Progress Report of Research and Development on Geological Disposal of High Level Radioactive Waste", H3 in short, is intended for the Japanese authorities. In accordance with the "Overall Program for High Level Radioactive Waste Management" set forth by Atomic Energy Commission, H3 is designed to clarify the current status of the research and development work performed by Power Reactor and Nuclear Fuel Development Corporation (PNC) up to the year 1991.

H3 presents the updated knowledge on Japan's geological environment, the technology of geological disposal and the performance assessment of the multi-barrier system as a basis for further research and development with the objective of confirming scientific and technical feasibility of the geological disposal concept in Japan. The contents of H3 is summarized in this document.

PREFACE

High-level radioactive waste in Japan refers to the waste resulting from reprocessing of the spent nuclear fuel to recover uranium and plutonium. The volume of waste produced by nuclear power generation is less compared to that of thermal power generation, and above all, the amount of high-level radioactive waste is quite limited. However, since radioactivity of this type of waste is high and long lasting, special attention must be given to ensure the long-term protection of man and his environment when countermeasures are to be considered. The baseline policy of Japan with regard to the treatment and disposal of high-level radioactive waste calls for solidification into a stable form and interim storage for 30 to 50 years for cooling, followed by disposal into geological formations at more than several hundred meters underground to further ensure the long-term safety of man and his environment.

Geological environment in deep underground is considered to be more stable compared to areas near the surface and the waste could be safely isolated for a long period of time. Even if the radionuclides contained in the waste finally released into groundwater, migration of such nuclides will be retarded significantly as they are sorbed by the minerals along the groundwater pathway and so on, the probability of preserving environmental safety is assumed to be sufficient. Based on these advantages, a general concept of geological disposal was introduced as early as in the 1950's. Evaluations made by various countries of possible solutions for isolating high-level radioactive waste concluded, without exception, that geological disposal is the most rational and realistic option at present and research and development work have been carried out. There are countries preceding Japan in conducting research and development in this area, and some of these countries have already worked out the technical feasibility of geological disposal concept. Japan is currently in the stage of assessing technical feasibility of this option to the extent practicable, while referring to the results of research and development work in these countries. Atomic Energy Commission (hereafter called AEC) pointed out, in its reports of the advisory committee on radioactive waste published in December, 1989 and August 1992, that the time has come to put together the results obtained to date. In accordance with AEC policy, H3 presents the current status of research and development work performed by the Power Reactor and Nuclear Fuel Development Corporation (hereafter called PNC), as the core promotional organization.

Research and development work so far conducted in Japan and a number of other countries has revealed that the most important point concerning the safety of geological disposal is to maintain and evaluate safety measures to counteract the possibility of radionuclide affecting man and his environment through groundwater. Principle is to take necessary measures in advance to prevent this from occurring, and further evaluate and confirm that the influence to man and his environment will not be significant in all reasonably foreseeable circumstances. This principle conforms to that of multiple protection for nuclear safety.

The multi-barrier system of geological disposal is being studied as the most favorable system conforms with multiple protection concept. The multi-barrier system is based on the complementary nature of various artificial barriers for waste confinement (engineered barrier) and natural geological environment that have various natural functions favorable to ensure the protection of man and his environment (natural barrier) ***(Fig.1)***. The high-level radioactive waste is melted with a glass material, sealed in a metal canister, and stored in a solid form (vitrified waste). This vitrified waste is then sealed into a container (overpack), and disposed of deep underground. The space between the host rock and the overpack is filled with backfilling material (buffer material) such as clay. This is considered to be the most effective method of disposal at the present time.

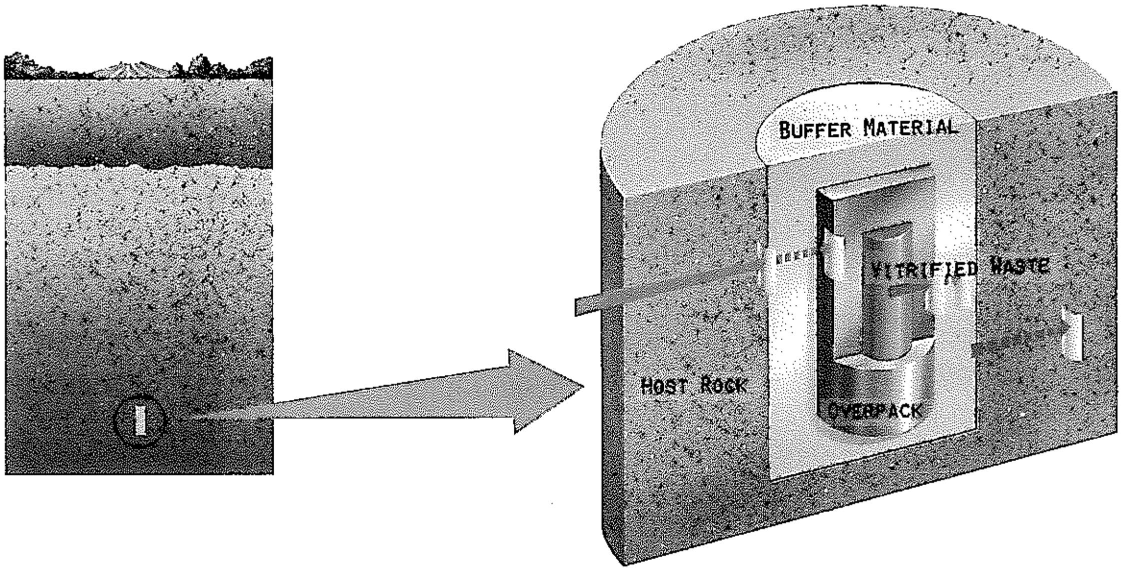


Fig. 1 Multibarrier System for Geological Disposal

In this multi-barrier system, the engineered barrier is constructed of the three components such as vitrified waste, overpack and buffer material. The designed function of the engineered barrier is to prevent groundwater from contacting with the vitrified waste owing to their physical and chemical characteristics. Should groundwater come into contact with the vitrified waste, the engineered barrier reduces the dissolution rate and migration of radionuclides from the waste. In addition, the natural barrier is expected to retain the dissolved radionuclides in the geological environment for a long time by adsorption capacity of the minerals, along with the dispersion and dilution of the radionuclides in the groundwater.

The research on the effectiveness of multi-barrier system has been conducted in various projects in the world, and Japan has participated in some of the research carried out under international framework. While taking the results of these international studies into account, PNC has been studying to assess the technical feasibility of the multi-barrier system in Japan to the extent practicable. Since research and development on geological disposal in Japan is in the stage of promotion without specifying the particular geological environment, it is required to conduct an assessment of the multi-barrier system performance in a generic manner without focusing on particular geological environment. In accordance with this, PNC's research and development program puts its initial emphasis on the study of the engineered barrier, which has less uncertainties as a research object compared with the natural barrier. In the future, when we reach the stage of site specific research and development, it will be important to optimize the design of the multi-barrier systems for the specific conditions of the given sites. In Japan, a country where earthquakes and volcanic activities frequently occur, it is necessary to take these features into consideration in conducting studies on favorable geological environment for geological disposal. However, in principle, detailed quantitative studies on these features should be carried out in the future along with the siting of a repository. At the present stage, from the standpoint of preparing background information and study methods for such future occasions, a systematic acquisition and compilation of fundamental information on geology and geological structure of Japan is deemed necessary.

In its report of December, 1989, AEC's advisory committee on radioactive waste indicated that the research and development for geological disposal should be conducted in three areas: 1) studies of geological environment, 2) research and development of disposal technology, and 3) performance assessment study. H3 is structured according to these three areas.

Studies of geological environment have been conducted to provide generic information concerning the geological environment and its long-term stability in a nation-wide scale as reference materials for the research and development of disposal technology and for the performance assessment study. For the comprehensiveness of the study without focusing on a specific geological environment, systematic research on the information and data accumulated in various academic disciplines have been conducted, and on the other hand, the results of the studies carried out by PNC at presently existing mined galleries as a part of its geoscientific research program were also utilized.

The research and development of disposal technology involves evaluation of technology required for engineered barrier and disposal facilities to ensure feasibility of the geological disposal concept from an engineering standpoint. For this reason, the research first targeted on the essential technology required for the design, manufacture, and construction of the engineered barrier, then focused on the essential technology required for the design, construction, operation and closure of the geological disposal facilities.

The performance assessment study has centered on the effectiveness of the multi-barrier system, as it is essentially important aspect with respect to the safety of geological disposal. The purpose of the performance assessment on the multi-barrier system is to scientifically determine whether a multi-barrier system constructed under suitable geological environment would maintain the desired performance over a long period of time. The assessment study was conducted under a scenario where the radionuclides dissolved from the vitrified waste are transported by the groundwater and reach man and his environment. At first, various phenomena related to this scenario were listed, and a model chain to analyze these phenomena was developed. Subsequently, using this model chain as well as results from study on the geological environment and research and development of disposal technology, the performance of the multi-barrier system was assessed as a series of case studies.

THE GEOLOGICAL ENVIRONMENT

From the viewpoint of geological disposal, the characteristics of the elements consisting geological environment and the long-term stability of geological environment were studied in order to provide reference information for the research and development of disposal technology and the performance assessment study. At first, the information related to Japan's geology and geological structure was reviewed, and the elements composing the geological features of Japan such as rocks, groundwater and resulting materials form alteration were listed. Subsequently, the occurrence of these elements and their mineralogical, geochemical and hydrological characteristics were studied. The occurrence of underground resources was also reviewed with regard to the possibility that they will be taken into consideration within the siting process for a repository. Furthermore, the state of the art of the survey and measurement techniques for obtaining data from deep underground with a quality required for the research and development on geological disposal were reviewed. Seismic activity, fault, upheaval, erosion, igneous activity, climate change and sea level change were listed as major natural phenomena which may have potential influence to the long-term stability of the geological environment, and the occurrence of these phenomena and the extent of their influence on the geological environment in the past and the present were studied.

Japan's Geological Environment

The geology of Japan can be classified into five categories: 1) Paleozoic to Paleogene sedimentary rocks and related regional metamorphic rocks, 2) granitic rocks and rhyolitic rocks, 3) Neogene sedimentary rocks, 4) Quaternary sediments and 5)

Quaternary volcanic rocks from the viewpoint of geological disposal. The rearrangement of geological information according to these categories was then conducted.

The major types of rock composing the Japanese islands were classified into volcanic rock, sedimentary rock, metamorphic rock, pyroclastic material, and pyroclastic rock and their mineralogical and geochemical characteristics as well as their distribution and the occurrence were reviewed. In addition, a literature survey was conducted for information on the physical properties of these rocks, which is required for the research and development of the disposal technology and the performance assessment study of the multi-barrier system.

With regard to groundwater in Japan, the basic characteristics were studied from the standpoint of hydraulics, hydrology and geochemistry. Hydraulic conductivity obtained from a literature survey revealed a tendency for these values to gradually decrease from the surface of the earth to a depth of more than several hundred meters except for the case of the Quaternary sedimentary rocks. Also, geochemical data of groundwater considered to have originated from precipitation indicates, as an overall tendency, that the concentration of dissolved components increases at a depth of more than several hundred meters, the water becomes Na^+-HCO_3^- type, and the pH range of the groundwater is from 5 to 10 except for the samples taken from hot springs. In addition, results obtained from reference measurement showed a redox potential of -300 mV from groundwater taken at a depth of about 165 meters around a boundary between Neogene sedimentary rocks and the granite below.

Concerning the material (minerals) resulting from weathering, diagenesis and hydrothermal metamorphism in Japan, the mineralogical and chemical characteristics as well as their distribution and occurrences were studied to examine the alteration of groundwater geochemistry and sorption properties.

Methods and Instruments

In order to understand the various characteristics of the geological environment with a high degree of accuracy, it is deemed necessary to develop new survey and measurement techniques in addition to making sufficient use of existing techniques. New techniques are especially required for more precise measurement, compared to former underground survey techniques, for measuring the hydrological characteristics in areas of lower permeability and the groundwater geochemistry in sufficiently reduced conditions deep underground.

As a part of geoscientific research program carried out by PNC, various instruments have been developed. These include borehole geophysical system to define geological structures which may carry groundwater, borehole hydraulic system capable of measuring minute flux of groundwater and downhole groundwater sampler for sampling under inactive-confined condition. On the other hand, instruments currently being used in various countries were tested in order to assess their applicability under Japanese geological environment. These include hydraulic measurement and groundwater sampling system for multiple sections within a borehole and groundwater sampling system capable of measuring values of pH, redox potential, pore water pressure and hydraulic conductivity in-situ. These techniques will further be utilized in forthcoming studies of geological environment.

Stability of the Geological Environment

Seismic activities may have potential to influence on the underground openings, however the results of seismic observations at deeper than 150 meters underground clearly indicate that the influence of seismic activity on the geological environment at such depth is less compared to the surface.

Fault activities may affect the geological environment in the adjacent area through the displacement and fracturing of rock. An examination of the recorded activities for faults (active faults) thought to have occurred in the Quaternary period indicated that the average displacement rate of the active faults in Japan ranges from 0.01 to 10m/1,000 years. Faults with large displacement are caused by activities that have occurred several times and the amount of displacement from single occurrence of the faulting activity ranges from 30 centimeters to several meters. It is considered that the possibility of the occurrence of new faults can be examined through detailed surveys of the geological structure and stress conditions of large faults and the occurrence and distribution of faults presently existing around these larger faults.

Upheaval and erosion may have an effect on the stability of the geological environment over a long period of time. The amount of upheaval in the Quaternary period is estimated by geomorphological and geological methods. According to the estimation, the upheaval rate in most of the regions in Japan is 0.5~1 mm/year, although there are mountainous areas where the upheaval rate is more than 1mm/year and plains or basin areas where it is less than 0.5 mm/year. Some major coastal plains are areas of submergence. According to the latest levelling, the amount of vertical displacement in Japan ranges from -10 to +5 mm/year. The current average erosion rate is estimated to be about 0.1~1 mm/year in the mountainous areas and less than that in the plains.

Considering the long-term effects, the amount of upheaval and erosion is only about 1m/1,000 years in most of the regions in the country.

Records on igneous activities such as volcanic eruptions, magmatic intrusion and hydrothermal processes were examined. As a result, for example, locations where volcanic activity took place in Japan have not changed significantly during the last 12 million years and the majority of the volcanoes erupt repeatedly erupted at about the same location.

Climate change and sea level change are generally regarded as the natural phenomena that may influence the groundwater flow system. Sea level changes are global phenomena and transgression and regression have repeated in intervals of about 100,000 years over the past 700,000 years. For a long period of time, it is predicted that the climate will get colder and the sea level will get lower until the next coldest period, which is expected around 100,000 years from present.

In order to further continue the studies of geological environment, it is important to get the latest information from relevant scientific fields and analyze them from the viewpoint of geological disposal, and along with this, to collect data by deep boring and conducting experiments at research facilities deep underground to enable an accurate understanding of the characteristics and phenomena with regard to the geological environment from the earth's surface to deep underground. As to the stability of the geological environment, it is important to clarify the intervals and locations of the occurrence of relevant natural phenomena and the extent and range of their effects.

TECHNOLOGY FOR DISPOSAL

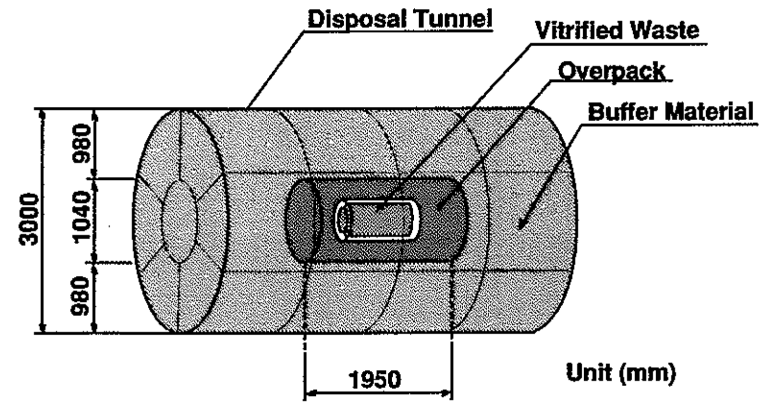
Engineering studies related to essential technology for design, manufacture and construction of the engineered barriers and design, building, operation and closure of the disposal facilities were carried out in order to clarify the technical procedures that would ensure the performance required for the engineered barrier and the functions expected for the disposal facilities.

For the prerequisite conditions, based on the fundamental principles of geological disposal in Japan, vitrified waste is stored for about 30 to 50 years for cooling, prior to the disposal at a depth more than several hundred meters underground. As to the studies of the disposal facilities, geological environment was classified into two broad categories of crystalline rocks and sedimentary rocks for research purposes, from the viewpoint of engineering. As to the studies of the engineered barrier, required performance to prevent groundwater from contacting with the waste and retarding radionuclide migration with groundwater was kept in mind. Methods for manufacturing and constructing the engineered barrier were studied giving due consideration on characteristics and structural strength of potential materials as well as present engineering technology. As to the disposal facilities, mechanical stability of underground openings, thermal loading in the engineered barrier and adjacent rock mass were examined. The relevant technology for construction, operation and closure of the facilities were studied and the extent of applicability of existing technology were assessed. Finally, subjects for future research and development were identified.

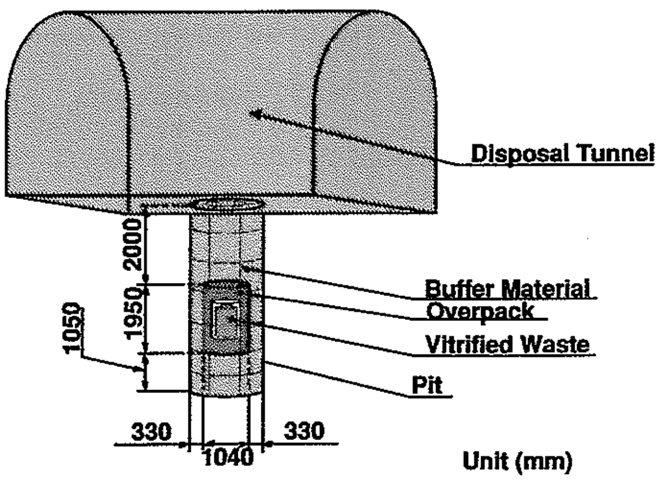
At the present, disposal technology have been examined by focusing on technical studies on the safety aspects of the geological disposal. Detailed studies of the optimization of engineering systems for the engineered barrier and the disposal facilities will be carried out in the future scope of research and development.

Engineered Barrier

Among the structural elements of the engineered barrier, the overpack and the buffer material have been the particular focus of the study *(Fig.2)*.



(a) Tunnel Disposal



(b) Pit Disposal

Fig. 2 Alternative Designs of the Engineered Barrier

With respect to the overpack, comparative studies of corrosion resistance, mechanical strength, and relative simplicity in manufacturing of the potential materials have been made with reference to competent studies in various countries, based on the premise that the longevity of the overpack will be maintained for about 1,000 years until the radionuclides in the vitrified waste are sufficiently decayed. The results indicate that, among others, carbon steel, titanium and copper are considered to be favorable as potential overpack materials. Among these materials, carbon steel was targeted as the first material as its corrosion behavior which is relatively easy to evaluate, as it has sufficient mechanical strength and as it is relatively simple to manufacture. In addition, it is expected to have a buffering effect on reducing the geochemical environment in the waste package (the vitrified waste encapsulated in the overpack) vicinity.

With respect to the corrosion of the carbon steel overpack, the corrosion rate was evaluated considering the geological environment deep underground. The mechanical stress at 1,000 meters underground was assumed conservatively with regard to the sufficient thickness to maintain the integrity of the overpack under such external stress. Based on the results, preliminary assessment of manufacturing techniques was conducted by fabricating a real scale model of carbon steel overpack with a thickness of 30 cm (including an extra 5 cm for corrosion).

The results from these studies indicate that the overpack can be manufactured with existing technology and reasonably foreseeable technology in the near future. Results of calculations on shielding effects of the overpack show that the self-shielding effect of a 30 cm thick carbon steel overpack is sufficient.

Bentonite, which has low permeability, high swelling capability, and high absorption capacity, was examined as the preferred material for the buffer considering required function such as to buffer chemical conditions, to dissipate decay heat, to support overpack, and to buffer external stress over a long period of time. Assessment of the physical and chemical properties of bentonite indicate that compacted bentonite with a suitable density can maintain the performance required for the buffering material as described above. Thermal alteration of bentonite can be neglected in the temperature range under 100°C, and sufficient longevity can be expected. Based on these results, the thickness of the buffer material was examined by considering both cases of the horizontal and vertical disposal option of waste emplacement.

In the future, it will be deemed necessary to improve the reliability of each essential technique, improve the specifications, and also to study the behavior of engineered barrier against the rock stress and earthquakes, etc.

Disposal Facilities

As to the disposal facilities, the intervals of waste deposition in a repository were analyzed considering the thermal loading in the engineered barrier. It was found that the temperature increase in the engineered barrier and surrounding rock caused by heat from the vitrified waste could be controlled by defining the intervals of the waste in a repository. When the maximum permissible temperature with respect to thermal alteration of bentonite is set at about 100°C with reference to the studies of various countries, it was indicated that a required area for one package of waste is approximately 80~100 m^2. The mechanical stability of the deep underground openings were analyzed to define the extent of tunnel lining required both for crystalline and sedimentary rocks. The disposal panel designs were examined considering the working conditions of the construction and the operational phase.

In the future, it will be necessary to conduct more detailed studies of the disposal facilities, incorporating more reliable design methods and including economic considerations.

PERFORMANCE ASSESSMENT OF THE MULTI-BARRIER SYSTEM

In order to assess the performance of the multi-barrier system, it is important to analyze the consequence of the scenario where radionuclides dissolved from the vitrified waste will be transported by the groundwater and enter the human living environment (called the groundwater scenario). For this purpose, models to describe the various phenomena related to the groundwater scenario were developed, so that the performance of the multi-barrier system can be evaluated ***(Fig.3)***. Then, using these models, the regional groundwater flow and geochemical properties of groundwater and the thermal loading, the rock stress, the geochemistry and hydrology of groundwater within and around the engineered barrier, the corrosion behavior of the overpack, the solubility and dissolution rate of the radionuclides from the vitrified waste, and the migration of the radionuclides in the engineered barrier in order to assess the natural barrier have been analyzed in order to assess the performance of the engineered and natural barriers as a case study.

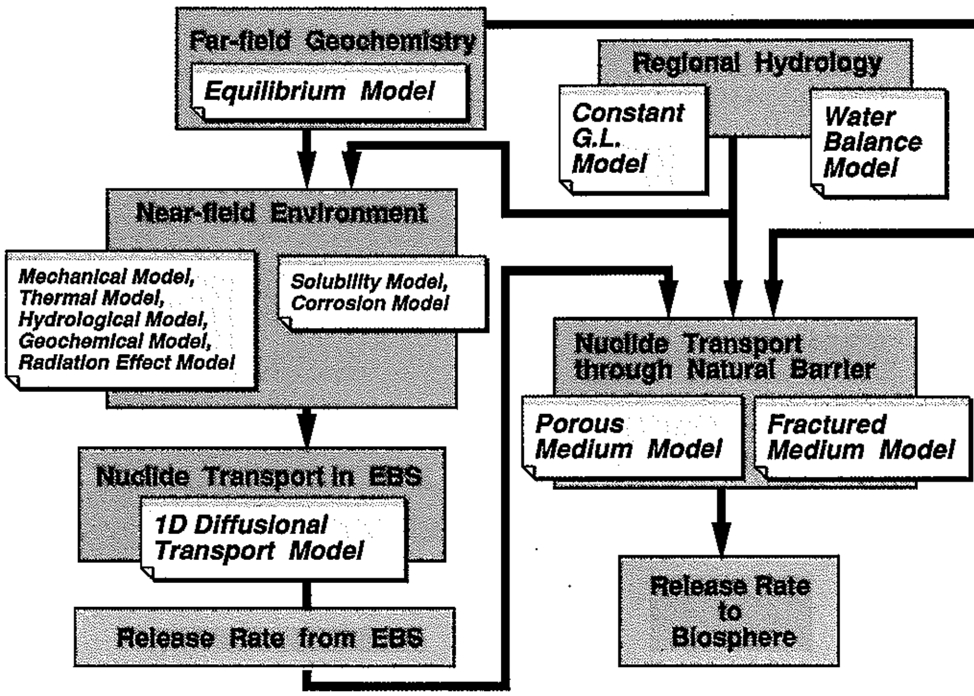


Fig. 3 Model Chain for the Base-case Scenario

Modeling of Geological Environment

The hydrogeological conditions in the vicinity of a repository were obtained by regional study of groundwater flow. In other words, the influence on the hydraulic gradients due to the hydraulic boundary conditions and the existence of faults were studied by considering a hypothetical 2-dimensional topographic cross-section with parameters such as altitude, the slopes, size of the plains and other features based on the topographical data of Japan.

In addition, a 3-dimensional analyses of groundwater flow in actual area in Japan carried out as a part of geoscientific research program, were utilized as a reference. From these results, the hydraulic gradient necessary for analyzing the hydrological conditions of the near field and the migration of radionuclide in the natural barrier were obtained, with an ample margin for safety. Because it is deemed necessary to understand the geochemical conditions for the variety of geological environment in Japan, and considering the fact that geochemical data of deep groundwater is limited, the geochemical evolution of groundwater was modeled by taking major processes influencing the groundwater chemistry into account. The basic properties related to the geochemical conditions of the deep groundwater required for the performance assessment were obtained. Based on the model, the pH, redox potential and major ion activities were calculated by using the geochemical code assuming chemical equilibrium. As a result, the deep groundwater was classified into the 4-types of reducing nature namely: 1) fresh-reducing high-pH, 2) fresh-reducing-low-pH, 3) saline-reducing-high-pH and 4) saline-reducing-low-pH. These 4-types of groundwater model with modeled groundwater geochemistry were given as initial conditions for analyzing the geochemical characteristics of the groundwater in the near field and the nuclide migration in the natural barrier.

Physico/Chemical Conditions in the Engineered Barrier

From the results of analysis of groundwater flow in the near field, it was clarified that the mass transport mechanism in the bentonite buffer is dominated by diffusion due to an extremely low permeability of bentonite.

The processes in which the chemical prerequisite of groundwater as altered due to the reactions with the engineered barrier materials were analyzed to determine the groundwater geochemistry which provides prerequisites for overpack corrosion, dissolution of radionuclides from the vitrified waste and sorption of radionuclides to bentonite. Groundwater which infiltrate the engineered barrier first reacts with bentonite, the material which constitutes the buffer. The oxygen and the carbon dioxide remained in the pores of bentonite are dissolved into the groundwater as it infiltrates, however the result of analysis indicates that these dissolved gas will be consumed in a relatively short time by the minerals in the bentonite. The chemical characteristics of the groundwater which finally reaches the surface of the vitrified waste was calculated by the geochemical code assuming that the groundwater reaches equilibrium with the dominant corrosion products of the overpack after reaction with the minerals in the bentonite. The result indicates that the chemical characteristics of the groundwater changes toward higher pH and lower redox potential compared to these of the groundwater before the reaction with the engineered barrier materials.

Corrosion of the Overpack

Based on the assumption that the oxygen within the bentonite is consumed by the minerals in the bentonite at a relatively early stage, it is considered that the corrosion of the carbon steel overpack occurs slowly. For the purpose of the performance assessment, however, the depth of corrosion was evaluated assuming that all of the oxygen in the bentonite, contributes to the corrosion. Also, the corrosion rate under reducing condition after the oxygen being consumed was estimated based on the results of corrosion test in which the chemical condition of the groundwater was taken into consideration. As to the corrodents other than oxygen, the influence of the reduced sulfides by bacterial activities was studied. By assuming that all of these various forms of corrosion advances, the corrosion rate of the carbon steel overpack was calculated as 32 mm / 1,000 years.

Dissolution of the Vitrified Waste

The long-term dissolution rate and the solubility of important elements for the performance assessment were evaluated with an assumption that the groundwater that has undergone chemical reactions with the engineered barrier materials will come in contact with the waste after the integrity of the overpack is deteriorated. It is believed that the solubility of the insoluble materials is controlled by the altered layer of the vitrified waste surface, and these were calculated by the geochemical code. The results showed that the solubility of these elements is low for 4-types of groundwater chemistry after the reactions with the engineered barrier materials. On the other hand, the dissolution rate of soluble elements were calculated based on the reaction rate of the vitrified waste obtained from the laboratory experiments and the model analysis. The calculated solubility and dissolution rate were used for analyzing radionuclide migration in the engineered barrier.

Radionuclide Migration in the Engineered Barrier

Based on the results of the analyses outlined above, the migration of radionuclides in the engineered barrier was examined. The processes considered in the migration model include mass transport in the buffer caused by diffusion, the sorption / desorption of radionuclides to and from the buffer, dissolution / precipitation reaction, and the radioactive decay. Taking these processes into account, the radionuclide release rate from the engineered barrier to the natural barrier was calculated. The most significant geological parameter which influences the radionuclide release rate is considered to be the chemical properties of the groundwater. Difference between calculated release rates of most of the radionuclides for the 4 types of modeled groundwater chemistry is not significant indicating that the performance of the engineered barrier can be maintained even though the geochemical properties of groundwater change to a certain extent.

Radionuclide Migration in the Natural Barrier

The geological media were roughly divided into two major categories of fractured medium and porous medium considering the characteristics of the groundwater pathway. Fractured medium was modeled assuming that the transport of radionuclides is due to advection and dispersion by the groundwater flow in the major fractures and matrix diffusion into micro pores of the host rock with adsorpted by the minerals along the pathways. On the other hand, porous medium was modeled assuming that the transport of radionuclide is due to advection, dispersion and adsorption considering a relatively homogeneous nature of pore distribution. A sensitivity analysis was carried out to determine the retardation effect on the radionuclide migration of each geological medium considering the range of parameters based on the results of hydrogeological study and field data available. The sensitivity of retardation effect on the migration of the radionuclide in the natural barrier with respect to the parameters such as the hydraulic gradient, the hydraulic conductivity, characteristics of the pore structure, sorption coefficients were calculated and the effective range of parameter values for the retardation effect were determined from the analysis. As a result, assuming that the sufficient performance of the natural barrier is postulated, the safety of the groundwater environment can be assured by the radionuclide retaining capacity of the natural barrier in the vicinity of the engineered barrier ***(Fig.4(a),(b))***. These results suggest the importance of defining the geological environment of host media in the vicinity of the engineered barrier as far as possible.

The future work in the field of performance assessment includes further verification and validation of each model and accumulation of data with required degree of certainty. Important prerequisite for the future work, is on one hand, laboratory experiments under simulated deep geological environment and, on the other hand, in-situ experiments at research facilities deep underground.

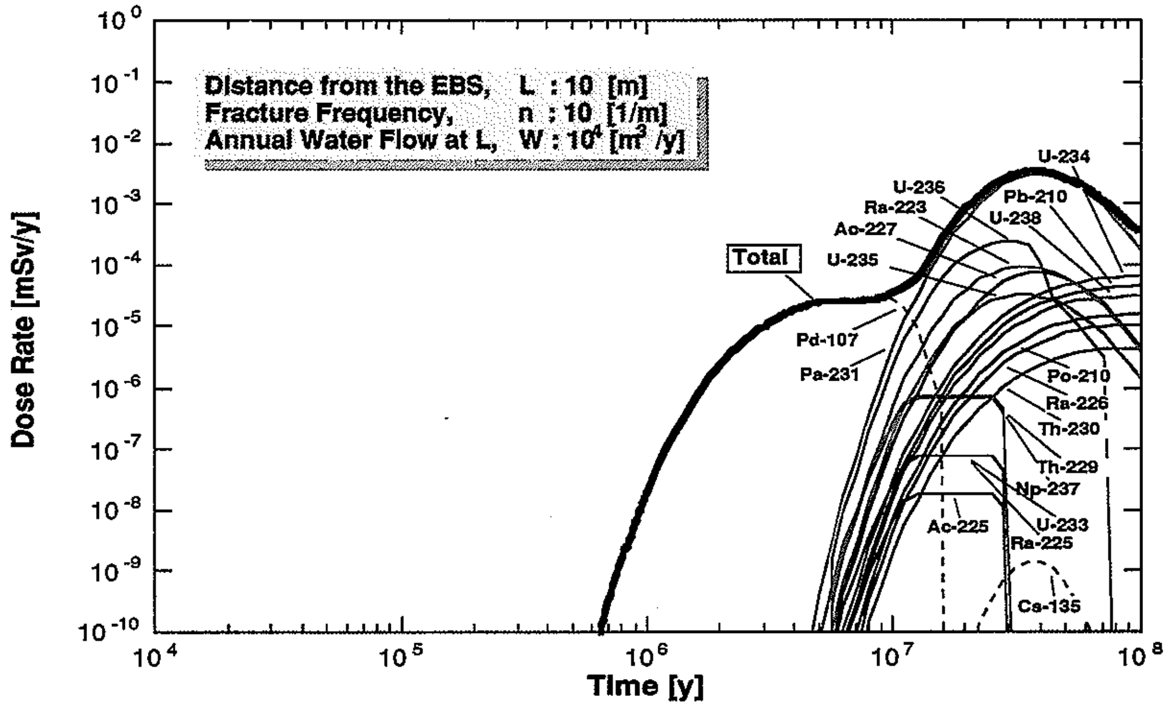


Fig. 4 (a) An Example of Calculated Dose Rate in a Fractured Media

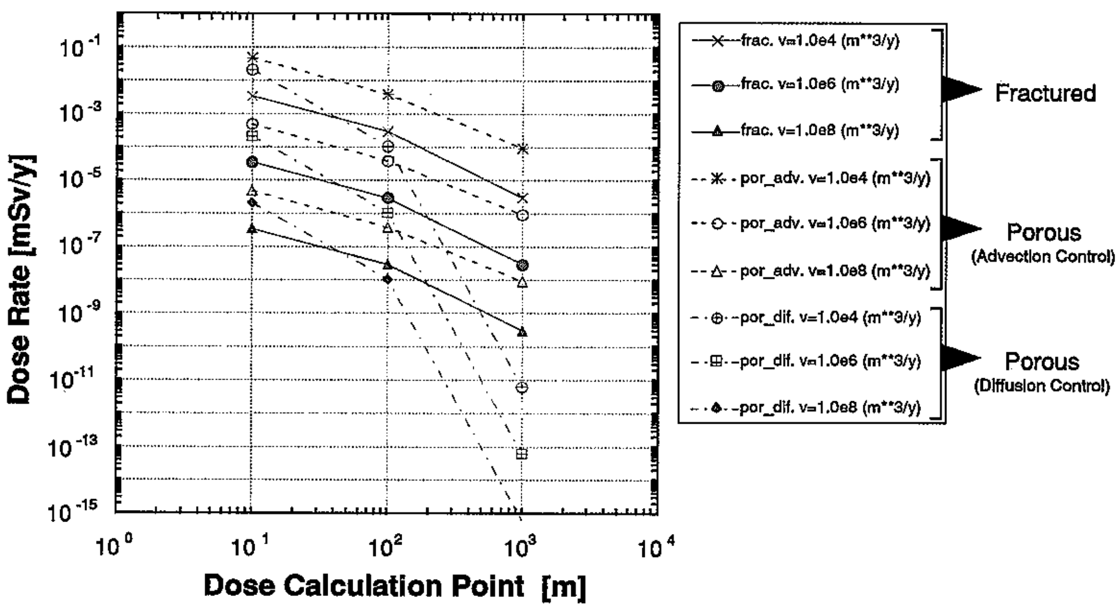


Fig. 4 (b) Calculated Results of Maximum Total Dose Rate

Assuming the repository (40,000 canisters) will lose confinement capability at 1,000 years after emplacement, and distance from the EBS to the calculated point is constant for all canisters.

CONCLUDING REMARKS

Results of research and development work performed up to the end of 1991 by PNC according to the policy set forth by AEC were summarized in this document. The current technical feasibility of the geological disposal concept based on the multi-barrier system was assessed on a generic basis, focusing on the groundwater scenario, which appears to be most important with respect to the long-term safety of geological disposal in Japan.

Work was performed in the three major areas namely, 1) studies of geological environment, 2) research and development of disposal technology, and 3) performance assessment study, and attempt was made to conduct a general assessment with regard to the technical efficiency of geological disposal concept based on the research and development results in each area.

Although it is deemed necessary to study geological environment with more detail, to advance technology as well as to conduct more realistic analysis of the multi-barrier system in the future, it is concluded based on the results to date that 1) existing technology can be applied in principle to design and construct the engineered barrier and the disposal facilities, 2) comprehensive method is available to assess the performance of the multi-barrier system with an emphasis on the assessment method for the performance of the engineered barrier, 3) from a case study performed under geological environment modeled with a certain range of variation, the long-term performance of the geological disposal system can be assured by designing and constructing an appropriate engineered barrier and disposal facilities for a given geological environment.

PNC intends to proceed research and development program in the future with guidance from experts in the relevant fields and understanding and cooperation from the parties involved.

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