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Master Plan

of

Mizunami Underground Research Laboratory

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Tono Geoscience Center

Japan Nuclear Cycle Development Institute

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1 INTRODUCTION

In June 1994, the Atomic Energy Commission of Japan reformulated the Long-Term Programme for Research, Development and Utilisation of Nuclear Energy (LTP). The LTP (item 7, chapter 3) sets out the guidelines which apply to promoting scientific studies of the deep geological environment, with a view to providing a sound basis for research and development programmes for geological disposal projects. The Japan Nuclear Cycle Development Institute (JNC) has been conducting scientific studies of the deep geological environment as part of its Geoscientific Research Programme. The LTP also emphasised the importance of deep underground research facilities in the following terms:

- Deep underground research facilities play an important role in research relating to geological disposal. They allow the characteristics and features of the geological environment, which require to be considered in performance assessment of disposal systems, to be investigated *in situ* and the reliability of the models used for evaluating system performance to be developed and refined. They also provide opportunities for carrying out comprehensive research that will contribute to an improved overall understanding of Japan's deep geological environment.

- It is recommended that more than one facility should be constructed, considering the range of characteristics and features of Japan's geology and other relevant factors.

- It is important to plan underground research facilities on the basis of results obtained from research and development work already carried out, particularly the results of scientific studies of the deep geological environment. Such a plan for underground research facilities should be clearly separated from the development of an actual repository.

JNC's Mizunami underground research laboratory (MIU) Project will be a deep underground research facility as foreseen by the above provisions of the LTP.

2 JNC'S GEOSCIENTIFIC RESEARCH PROGRAMME

Within the framework of its Geoscientific Research Programme, JNC's Tono Geoscience Center has been studying the characteristics of the deep geological environment at the Tono mine and its surroundings in Gifu Prefecture and has completed a study at the Kamaishi mine in Iwate Prefecture. These studies, which were planned on the basis of existing knowledge of the geological and hydrogeological characteristics of rocks in Japan, cover both sedimentary and crystalline rocks.

Studies on groundwater flow and hydrogeochemical characteristics, mass transport and disturbance caused by shaft/drift excavation have been carried out in the sedimentary rocks overlying the crystalline basement at the Tono mine. The No. 2 shaft, which is 6 metres in diameter and 150 metres in depth, was sunk in 1989 to investigate the excavation disturbance. Relevant properties of the deep geological environment were observed continuously before, during and after the shaft excavation and changes in these properties were predicted and evaluated. Based on a comparison between predicted results and actual observed data, methods for analysis and evaluation were developed and iteratively improved. A regional hydrogeological study has now been conducted to investigate the mechanisms of groundwater flow and to develop techniques for characterising the groundwater flow regime around the Tono mine. The area covered by the study is approximately 10 km by 10 km, to a depth of about 1 km, which includes both the sedimentary cover and basement rocks. The planning of the MIU Project can draw on the results of the excavation disturbance experiment and the regional hydrogeological study.

Studies on geological structure, groundwater flow, hydrogeochemical characteristics, excavation disturbance and earthquake activity, *etc* were carried out in granitic rocks at the Kamaishi mine. The programme was divided into two phases (Phase 1: FY1988 - FY1992 and Phase 2: FY1993 - FY1997). The Phase 2 includes studies on geological properties, excavation disturbance, mass transport, engineering technologies and earthquake activity.

The comprehensive investigations carried out to date in the Tono and Kamaishi mines have provided a wealth of relevant data and experience. Key data on the deep geological environment have been obtained and methodologies for investigation and analysis have been developed. On the other hand, from a geoscientific viewpoint, it is important to develop an understanding of the natural (*ie* undisturbed by human activity) state of the deep geological environment and the evolution with time of changes caused by excavation. In this respect, there are limitations to the studies in the existing underground facilities, as explained below:

1. Disturbance due to existing shafts and drifts

   As it is a long time since the existing shafts and drifts were excavated, it has to be assumed that lithostatic pressure, groundwater flow patterns and hydrogeochemical characteristics were disturbed on a regional scale. It is impossible to fully reconstruct the undisturbed state of the geological environment.

2. Limits of the study area

   Access to significant geological features such as lithostratigraphical boundaries and fault zones is restricted because the study area is limited to the vicinity of the existing drifts which were, in fact, designed for mining purposes.

The MIU investigations will commence prior to construction of the underground facility and will proceed stepwise during and after the construction. Such an approach, with systematic studies starting in a previously undisturbed area, will be realised for the first time in Japan by the MIU Project. Prediction and verification of deep geological characteristics will be carried out iteratively in each phase and then evaluation of the effects of the construction will be made. Changes in the deep geological environment, including the response after partial backfilling of the shaft and/or drifts, can thus be characterised.

3 OUTLINE OF THE MIU PROJECT

Against the background provided by the Japanese governmental policy and the content of the Geoscientific Research Programme, JNC plans to construct an underground research laboratory at the Shobasama-bora site in Akeyo-cho, Mizunami City, Gifu Prefecture. The MIU studies will focus mainly on granitic rocks, which are widely distributed throughout Japan. The MIU Project is planned as an expansion of the existing Geoscientific Research Programme (*eg* regional hydrogeological study, shaft excavation disturbance experiment, *etc*) which has been carried out in recent years in and around the Tono mine. In addition, the results from the regional hydrogeological study will be valuable for the MIU studies as the MIU site is located within the area covered by the regional hydrogeological study.

A wide range of geoscientific research and development activities of the MIU Project is planned in three phases (*ie* before, during and after the construction of the underground facility) over the next 20 years:

- First phase: surface-based investigation
- Second phase: construction
- Third phase: operations

3.1 Goals of the MIU Project

As discussed in section 2, the MIU studies will start with the characterisation of the natural (*ie* undisturbed by human activity) state of the deep geological environment. This is complemented by investigation of the effects of the perturbations caused by excavation and operation of the facility for precise understanding of processes in the deep geological environment. It will thus be possible to precisely plan and extensively execute the development of technology and methodology for the characterisation and the investigation.

The project objectives are divided into main goals, which are relevant for the project as a whole, and phase-specific goals, which are specific to each of the three investigation phases. In each phase, predictions are made regarding the characteristics of the geological environment which will be encountered in the next phase and, based on the assessment criteria established previously, the predictions made in the previous phase are verified.

3.1.1 Main goals

1. To establish comprehensive techniques for investigating the geological environment

   The first goal is to systematically combine the fundamental methodologies developed and improved in the Geoscientific Research Programme and to provide comprehensive and integrated investigation strategies. The aim is to demonstrate the effectiveness of a series of techniques for reliably investigating, predicting and modelling the characteristics of the deep geological environment and verifying the models of the geological environment. The reliability of the investigation techniques used and resultant data quality will be studied. It is planned that the techniques developed during the project will provide the technical means for reliably investigating a range of geological environments.

2. To acquire data on the deep geological environment

   The second goal is to acquire high-quality data on the deep geological environment. These data, which will be backed up with results of geoscientific studies both in Japan and abroad, will be used to improve the reliability of conceptual models of the deep geological environment in Japan. They will also be used to evaluate engineering methods and equipment for later phases of underground construction and operations. The integrated dataset produced, which will include relevant results of geoscientific research performed abroad, will provide a basis for other parts of the R&D programme for geological disposal in Japan.

3. To develop a range of engineering techniques for deep underground application

   The third goal is to evaluate techniques for design and construction of large-scale underground facilities and to clarify the potential long-term effects of these techniques on the geological environment (*eg* possible interactions between construction materials and groundwater/bedrock, *etc*). Studies will also be carried out on infrastructures for managing safety and the operating environment in such underground facilities.

3.1.2 Phase-specific goals

Surface-based investigation (phase 1)

1. To acquire data on the undisturbed geological environment with surface-based investigation methods and to predict the characteristics of the geological environment and the effects of construction of underground facilities

   These data will be used to construct geological, hydrogeological and hydrogeochemical models for predicting both the geological properties which will be encountered and the effects of construction in the next phases.

2. To establish methodologies for evaluating predictions

   Criteria and detailed methodologies will be specified for checking the plausibility of model predictions made in this phase by comparison with the data obtained in the subsequent construction phase.

3. To formulate detailed design concepts for underground facilities and to establish detailed plans of the construction phase

   Based on the data obtained in this phase, as well as on modelling results, a detailed design concept for the underground facilities will be formulated and detailed investigation plans will be established for the construction phase.

Construction (phase 2)

1. To acquire data on the geological environment by investigations from shafts and drifts and to predict the characteristics of the geological environment around the drifts

   Data on the geological environment will be acquired by investigations performed from shafts and drifts during shaft sinking. The geological, hydrogeological and hydrogeochemical models which have been formulated in phase 1 will be refined using these data and then used to predict the geological conditions which will be encountered in phase 3.

2. To verify predictions made in phase 1

   Based on the criteria and methodologies previously established, specific predictions made during the surface-based investigation phase regarding deep geological characteristics and the changes caused by the construction of underground facilities will be evaluated. The degree to which the geological, hydrogeological and hydrogeochemical models are appropriate and the degree to which the surface-based investigation methodologies are effective will be evaluated. If significant differences between predictions and observations are noted, relevant studies may be repeated or models may be refined.

3. To evaluate the effectiveness of engineering techniques used for design and construction of underground facilities

   The effectiveness of engineering techniques selected in phase 1 will be assessed. In cases where problems are identified, recommendations for improvements will be made, which may be transferable to a later stage of the project.

4. To establish plans for the operations phase

   Based on the integrated dataset derived in this phase and on model analyses, detailed plans will be developed for the operations phase.

Operations (phase 3)

1. To acquire detailed data on the geological environment via investigations in drifts

   Additional detailed data on various deep underground characteristics and phenomena will be acquired through investigations in the drifts.

2. To verify predictions made in phase 2

   Based on the criteria and methodologies previously established, the results of predictions made in the construction phase regarding the deep geological environment, as well as of the changes caused by the construction of the underground facilities, will be evaluated. The degree to which geological, hydrogeological, hydrogeochemical and rock mechanical models are appropriate and the degree to which the investigation techniques employed are effective will finally be evaluated. If significant differences between predictions and observations are noted, relevant studies may be repeated or models may be refined.

3. Demonstration of engineering techniques for deep underground utilisation

   Techniques for ensuring the safety of the working environment, for performing thermo-hydro-mechanical coupled experiments in the near field and for restoring the excavation disturbance will be evaluated. The ability of current engineering techniques to minimise the perturbing effects on the geological environment of the construction of underground facilities will also be investigated.

3.2 Outline of the facilities

The laboratory will consist of both surface and underground facilities. A conceptual overview of the laboratory layout is shown in Figure 1. The surface facilities consist of an office, a core storage facility, a workshop for manufacture, maintenance and repair of equipment and instrumentation and support facilities for underground construction. The underground facilities consist of a main shaft, a system of drifts and a ventilation shaft.

The diameter of the main shaft has provisionally been set at 6 metres and the proposed depth is 1,000 metres. Details of the geometry and depth of specific underground facilities, including the main shaft, the ventilation shaft and the drifts, will be defined using data on the geological environment obtained during the surface-based investigation phase, assuming no surprises during phase 2.

3.3 Description of the location

The laboratory will be constructed at the Shobasama-bora site in Akeyo-cho, Mizunami City, Gifu Prefecture. In the region of Mizunami and Toki cities, the area in which the laboratory will be constructed is located close to the boundary between the Ryoke Belt (Cretaceous igneous-metamorphic complex) and the Mino Terrane (Meso-Palaeozoic sedimentary complex). The main components of the MIU underground facilities will be constructed in crystalline basement, the Toki Granite, which is distributed throughout this area (Figure 2).

The area offers a number of advantages for carrying out such research programmes:

- A commonly encountered geological setting in Japan (*ie* granitic basement overlain by sedimentary sequences)
- The presence of groundwater, faults and the largest uranium ore mineralisation in Japan, all of which are interesting subjects of JNC's geoscientific research
- An easily accessible location in the central region of Japan
- A local infrastructure which includes the Tono Frontier Science Research City Plan

In addition to these advantages, JNC has, over the last 30 years, accumulated wide-ranging experience and information at the Tono Geoscience Center through uranium exploration activities. Usable research facilities and instrumentation are thus already available.

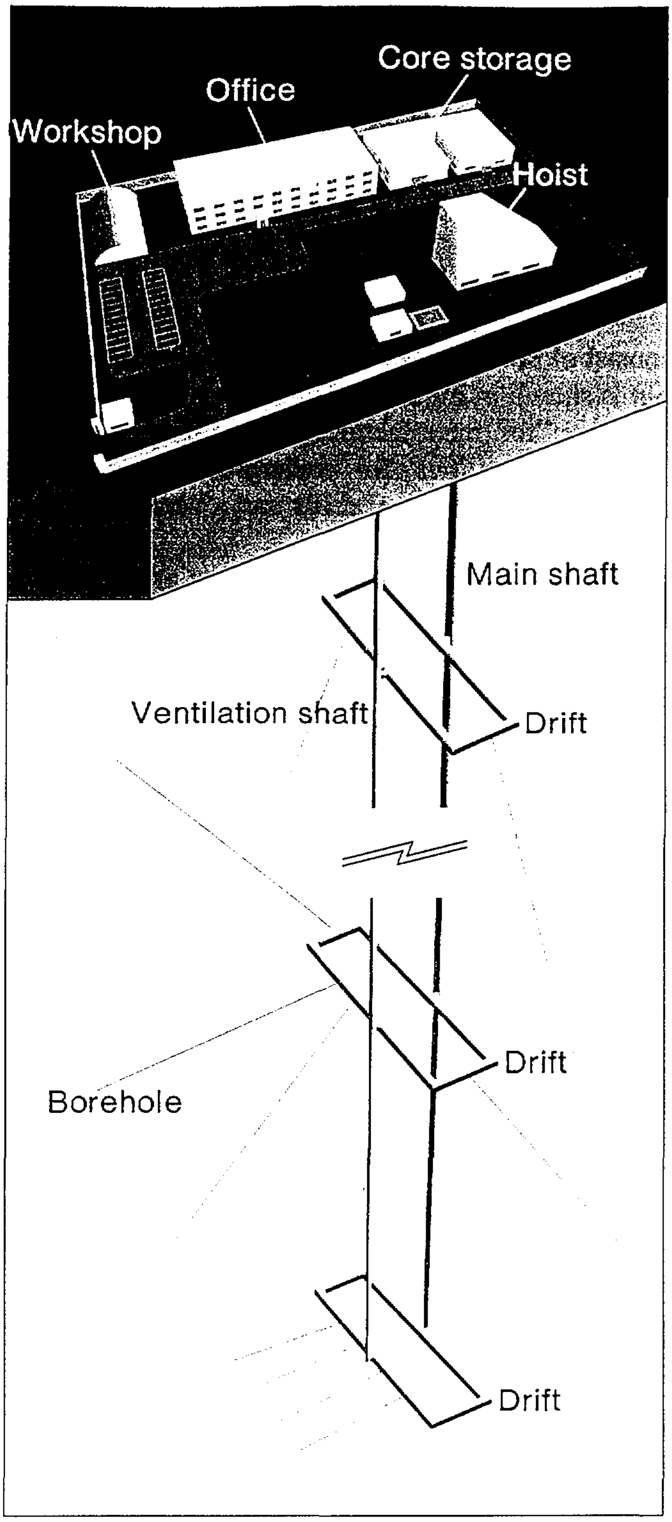


Figure 1 Conceptual view of laboratory layout

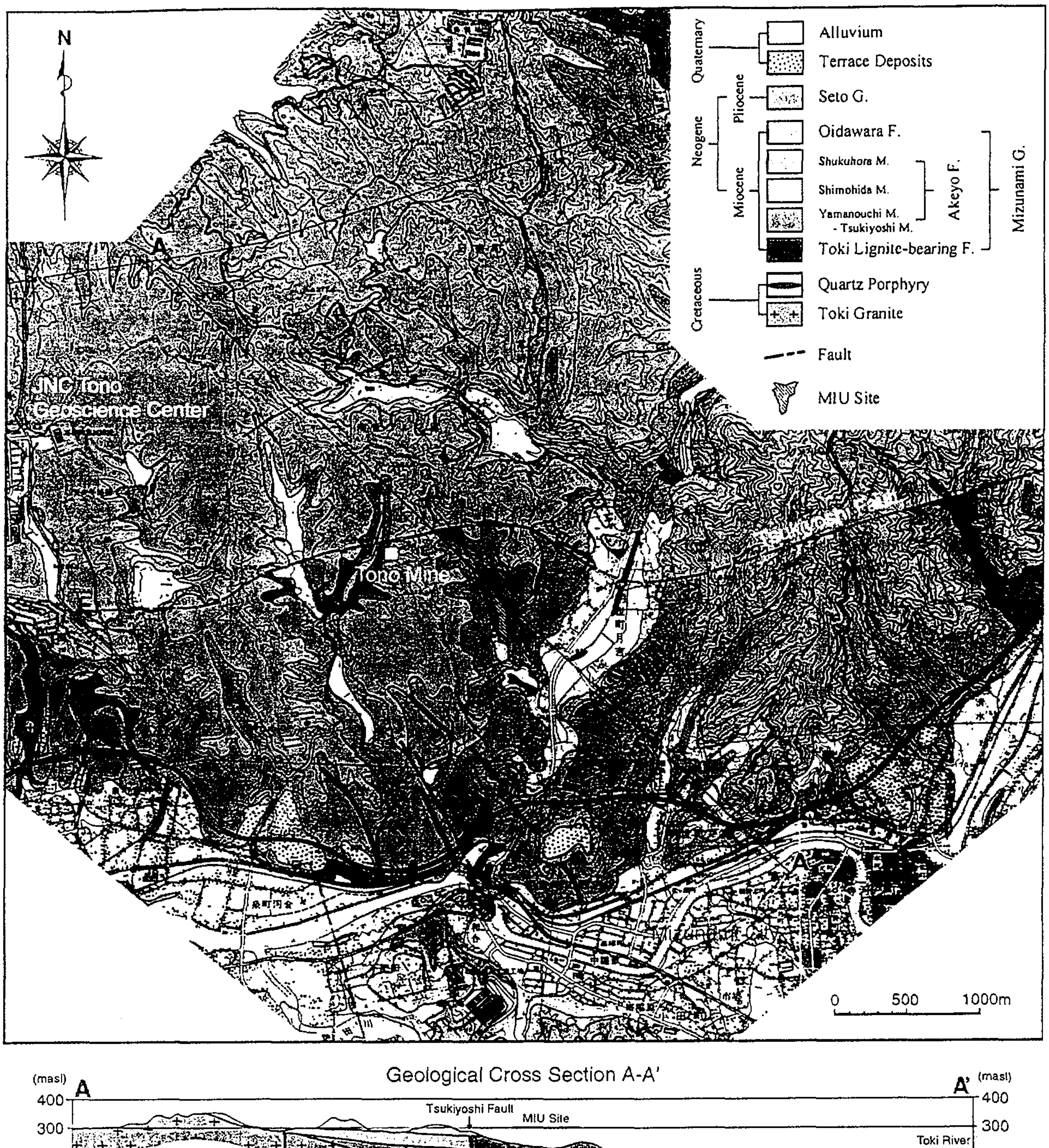


Figure 2 Geological map around the MIU site

3.4 Organisation of the MIU Project

It is necessary that the organisation of the MIU Project should be established separately for each of the three phases. Working groups on geological structure, hydrogeology, hydrogeochemistry, *etc* will provide a core of expertise for the surface-based investigation phase. Working groups on mass transport, rock mechanics, engineering techniques, *etc* will be set up as necessary in the second and third phases.

The geoscience planning and management group of the Tono Geoscience Center is responsible for overall management and co-ordination of the project, and will promote smooth running of the work programmes. In order to develop the scientific and engineering skills required for efficient performance of the work programmes, planning strategies and investigation results will be reviewed by experts outside JNC, who provide advice and input for the revision of plans. The waste isolation research division of the Tokai Works provides technical collaboration in transferring the results from the MIU Project as the scientific and technological basis for the R&D programmes relating to geological disposal projects.

The organisational infrastructure for conducting work, meetings of experts (including outside experts) and meetings on the progress of construction has been established. A committee that will decide on the utilisation of the underground laboratory once JNC's programme has been completed has already been set up at the request of the local communities. Plans are already underway for establishing a committee that will be organised by the administrative, JNC and local people and which will consider safety issues of the MIU Project.

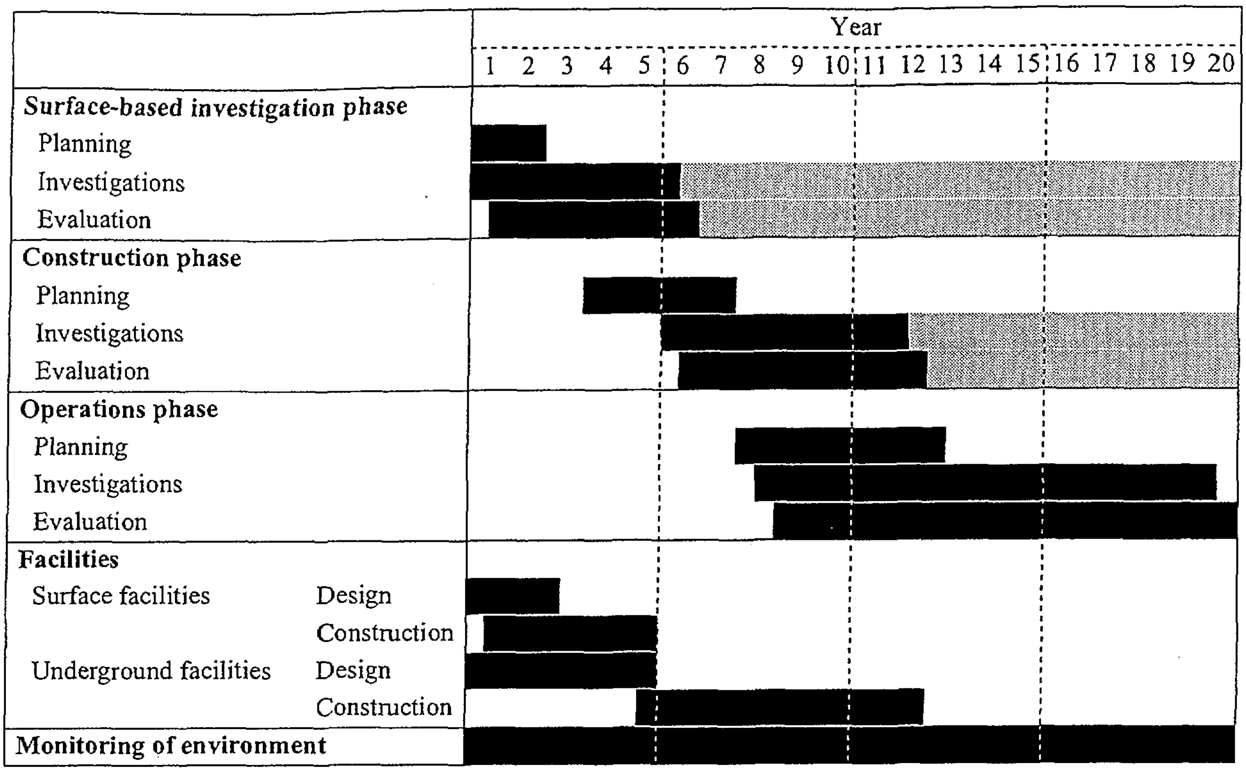
The MIU Project programmes foresee scientific research and development activities in the fields of geology, hydrogeology, hydrogeochemistry, mass transport, rock mechanics, engineering techniques, *etc* utilising a wide range of advanced civil engineering and investigation techniques. JNC therefore intends to collaborate with organisations and universities with relevant experience both in Japan and abroad. As the deep geological environment is being considered world-wide for the storage of materials, the laboratory will be used not only for JNC's research purposes but is also offered as a study site for other researchers from Japan and abroad. It is JNC's intention that the facility should become an internationally leading centre of excellence in earth sciences.

3.5 Schedule

A wide range of geoscientific research and development activities are planned in the three phases (*ie* surface-based investigation phase, construction phase and operations phase) which will extend over the next 20 years (Table 1). JNC has been participating for many years in relevant programmes world-wide, for example the URL in Canada and the HRL in Sweden, and the experience and know-how obtained from this involvement in foreign programmes will be utilised in the MIU Project.

As the volume of knowledge on the geological environment increases, it will be necessary to reconsider this plan.

Table 1 MIU Project timetable



4 GEOSCIENTIFIC STUDIES OF THE MIU PROJECT

4.1 Knowledge to date and future tasks

4.1.1 Geology

As part of the Geoscientific Research Programme, JNC has been developing drilling techniques and methods for analysis of remote sensing data, as well as improving equipment for geophysical surveys. For example, reflection seismic surveys have been carried out and the application tested of the RAMAC system that was developed as part of an international co-operative study organised by the OECD/NEA (with JNC participation). The applicability of both methods has been confirmed. A methodology for classifying fractures in crystalline rocks from the viewpoint of mass transport has also been established and *in situ* investigations have been conducted at the Kamaishi mine with a view to generalising the methodology. Furthermore, a new understanding of the heterogeneity of the Toki Granite has been obtained by borehole investigations conducted as part of the Geoscientific Research Programme.

The objectives of the MIU Project include the development of systematic investigation methodologies applicable to crystalline rocks in Japan. During the surface-based investigation phase, existing techniques and installations will be evaluated individually. Based on results obtained and on relevant studies carried out previously in Sweden, Canada and elsewhere, the key task will then be to establish an effective integrated investigation strategy by the optimum combination of these techniques and by comparing results obtained with data and observations from later phases.

4.1.2 Hydrogeology

At Tono, JNC has been conducting hydrogeological investigations of the shallow sub-surface at a hillside location and in boreholes in order to analyse groundwater flow regimes within the regional hydrogeological system. Data have been acquired on the distribution of hydraulic conductivities and topographically controlled hydraulic head, water fluxes in surface channels, recharge rates, *etc.*

In the case of the investigations of the shallow sub-surface, meteorological parameters, soil moisture contents, discharge rates, water table levels, *etc* have been observed. This database was used to study the disturbance in and around the Tono mine caused by sinking the No. 2 shaft. The average recharge rate measured in this area is 0.57 mm/day.

In the borehole investigation programme, long-term observations have been carried out using the multiple piezometer system (MP system) developed in Canada. Hydraulic packer tests have been made to depths of 500 metres and potentially water-conducting features have been characterised. The equipment used for these investigations has been tested extensively. Equipment for hydraulic packer tests, which can be applied to low permeability rocks down to depths of 1,000 to 2,000 metres, has already been developed abroad. In 1994, JNC also developed equipment for hydraulic packer tests down to depths of 1,000 metres under geological conditions in Japan.

Various computer codes have been developed in Europe and the USA for the simulation of groundwater flow. For regional groundwater flow analysis, three-dimensional finite element codes (MOTIF, FELOW, NAMMU, *etc*) are used for porous media and special codes (FracMan/MAFIC, TRINET, NAPSAC, *etc*) have been developed for fractured media. JNC has introduced the TAGSAC code, developed by Saitama University, which can handle steady-state and non-steady-state flow under both saturated and unsaturated conditions in porous media. This code was used for predictive analysis of the hydraulic perturbation caused by the excavation of the No. 2 shaft in the Tono mine. For fractured media, the FracMan/MAFIC code has been introduced and the Don-Chan model was developed in collaboration with Saitama University. The applicability of these two codes to fractured media was confirmed by the simulation of tracer tests conducted in the Kamaishi mine. A geostatistical approach has been applied in Sweden and other countries to determine the spatial distribution of hydraulic conductivities. JNC has confirmed the effectiveness of this methodology, complementing measured hydraulic conductivities/transmissivities with logging data and applying geostatistical and fractal models to specific host rocks.

JNC is currently applying newly developed equipment to measure hydraulic conductivity/transmissivity at depths of more than 500 metres. The depth dependency of hydraulic conductivity/transmissivity is being studied. Natural hydraulic gradients are also measured and the hydrogeological properties of major water-conducting features which are considered to have a significant influence on groundwater flow are being investigated. It is necessary to develop methodologies for simulating groundwater flow and estimating the spatial distribution of hydraulic conductivities/transmissivities in fractured crystalline rocks, where permeability is controlled by the distribution of water-conducting features.

4.1.3 Hydrogeochemistry

Data on the pH and chemical composition of groundwater have been acquired to a depth of 180 metres around the Tono mine. Isotopic data for hydrogen, oxygen and carbon have allowed the origin and residence time of the groundwater to be estimated. In the Kamaishi mine, the chemical and isotopic compositions of groundwater in the granite body to a maximum depth of 800 metres have been determined. For groundwater sampling and analysis, two different hose systems have been used for the first time to measure physico-chemical parameters and to sample groundwater in a 1,000 metre deep borehole. The groundwater sampling equipment developed by JNC for use to a depth of 1,000 metres has been employed in the Geoscientific Research Programme in the Tono area and the Kamaishi mine.

Chemical classification of groundwater by multivariate analysis and theoretical analyses of its evolution using water-rock interaction codes (PHREEQE, EQ3/6) have been conducted in Sweden and elsewhere to investigate the evolution of groundwater and to develop hydrogeochemical models. JNC has been conducting relevant studies, drawing on experience from abroad. Based on isotopic data, the groundwater in the sedimentary rocks at the Tono mine was determined to be of meteoric origin; the deepest groundwater in the mine is estimated to be about 10,000 years old. It has been established that calcite dissolution and ion exchange reactions between clay minerals and groundwater are dominant water-rock interactions occurring. This is based on field data, water-rock interaction experiments and chemical thermodynamic analyses. In the Kamaishi mine, groundwater is classified by multivariate analysis of its chemical components. The vertical distribution of tritium concentration of the groundwater indicates that groundwater flow may have been affected by the existing drift system. The value of the combined application of multivariate analysis of hydrochemical data and modelling of water-rock interactions is confirmed by these studies.

Perturbation of hydrogeochemical characteristics by the existing drift system is indicated in both the Tono and Kamaishi mines (*eg* by the drawdown of hydraulic head and the detection of tritium). In the surface-based investigation phase, it will therefore be important to acquire groundwater data, particularly on physico-chemical parameters such as Eh, from the surface to a depth of about 1,000 metres.

4.1.4 Investigation techniques and equipment

JNC has been developing techniques and equipment for investigating the characteristics of the undisturbed geological environment. In the surface-based investigation phase, it is planned to utilise the existing investigation techniques and equipment. It is important to clearly specify investigation aims and to tailor the characterisation programme to efficiently cover all areas of interest. The following investigation techniques and equipment will be mainly developed.

Drilling techniques

Drilling using water without drilling mud has been carried out in several countries in order to minimise disturbance of the groundwater chemistry. JNC plans to drill boreholes without any chemicals/additives in the drilling water. The wireline drilling technique widely used in the fields of metal mining and prospecting is used. However, the integrity of the borehole wall is more difficult to be maintained when drilling with fresh water as compared to mud-bearing fluids. Since a technique needs to be developed for partially reinforcing the borehole wall in order to prevent collapse, JNC is currently developing a partial borehole reamer. At a later stage, techniques for grouting weak zones and for the installation of casing pipes with filters will be developed. These techniques will be applied for drilling boreholes in the MIU Project.

Improvement of hydraulic packer tests and groundwater sampling equipment for use down to 1,000 metres

The maximum temperature limit of the current hydraulic packer tests and groundwater sampling equipment is 50°C. It is planned to improve this equipment for use at 70°C and, at the same time, its operation and maintenance aspects.

Development of long-term pumping test equipment

It is necessary to develop equipment to handle the large volumes of groundwater involved in carrying out the planned large-scale, long-term pumping test which is intended to simulate the drawdown of hydraulic head by the actual shaft construction.

Development of the long-term downhole monitoring system

Porewater pressures in the deep geological environment can be monitored using the MP system. In the vicinity of a shaft, it is necessary for the equipment to function under the high differential pressure environment caused by the drawdown of hydraulic head.

Development of database and data visualisation systems

It is necessary that database and data visualisation systems should be developed in order to maximise the utilisation of data obtained. The systems include a component for unified management of data from various investigations and laboratory construction in the surface-based investigation phase and also for management of the schedule of investigations and laboratory construction.

4.2 Studies in the surface-based investigation phase

Outline

The studies in phase 1 will focus mainly on geological structure, hydrogeology and hydrochemistry and will be conducted primarily in deep boreholes. Data obtained during the course of phase 1 will be used to model geological structure and to develop reliable hydrogeological and hydrogeochemical models. The design of the underground facilities and the numerical simulation of groundwater flow will be based on these models. A computing system capable of efficiently managing and handling large volumes of data will be set up.

Properties of the deep geological environment, changes in the flow regime and chemical composition of groundwater during the construction of underground facilities will be predicted on the basis of the data acquired in phase 1. At the same time, criteria and methodologies will be established for verifying the predicted results. The information will also be used to prepare a detailed design concept for the underground facilities, which includes, for example, detailed specifications of shafts and the depth and dimensions of drifts, and to assist in planning the construction phase study.

The goals of the surface-based investigation phase are:

1. To acquire data on the geological environment and to predict the changes caused by the construction of underground facilities,
2. To establish methodologies for evaluating predicted results and
3. To formulate a detailed design concept for the underground facilities and to plan the construction phase study.

4.2.1 Geology

The flow characteristics and hydrochemical properties of deep groundwater are influenced to a large extent by lithostratigraphical features, distribution of water-conducting features and geological heterogeneity. The main goal of the study of geological structure is to obtain a detailed understanding of geological structure and to construct a model which describes the three-dimensional distribution of lithofacies and major water-conducting features as realistically as possible.

It is planned to drill up to 10 deep boreholes in the vicinity of the main shaft. Information obtained on geological structures and rock mechanical properties will be used to construct the 3-D geological model of the area under investigation and to provide input for designing the underground facilities. The results of the geological investigations can also provide continuous input for hydrogeological and hydrogeochemical studies.

Model predictions of geological structure will be verified by comparison with data obtained in the subsequent construction phase. The resulting database will then be used to design the layout of experiments on mass transport, rock mechanics, *etc* in the underground facilities.

4.2.2 Hydrogeology

For a comprehensive determination of chemical characteristics of groundwater, it is important to obtain data on groundwater flowpaths (*ie* water-conducting features) and residence times. These data include information on the distribution of hydraulic conductivities/transmissivities and the influence of topography on groundwater flow rates and flowpaths. It is also necessary to measure the groundwater recharge rate as this parameter is used as a boundary condition in the numerical simulation of groundwater flow. Techniques for acquisition of this information have been tested in the regional hydrogeological study conducted as part of the Geoscientific Research Programme.

In connection with groundwater flow, specific parameters still to be investigated include the depth dependency of hydraulic conductivity and the hydrogeological characteristics of fracture zones, which are considered to represent major hydrogeological features. In particular, the hydrogeological properties of water-conducting features encountered in the Japanese geological environment are assumed to be different from those of water-conducting features in the stable geological blocks being investigated in other countries and a targeted investigation programme is necessary in this respect. Techniques for analysing groundwater flow in fractured media and for estimating the three-dimensional distribution of hydraulic conductivity/transmissivity also need to be evaluated.

In the MIU Project, a hydrogeological model will be constructed using data obtained from the boreholes drilled in the vicinity of the planned shaft and this model will be used to simulate groundwater flow. This simulation is used to predict the extent and scale of hydrogeological perturbations caused by the construction of the underground facilities and the discharge rate of groundwater into the facility. A long-term pumping test will be carried out after completion of all borehole investigations and the results will be used to identify groundwater flowpaths and to refine the hydrogeological model. The results of geological and hydrochemical investigations will also provide input for the hydrogeological model, as will the regional hydrogeological study carried out also as part of the Geoscientific Research Programme.

The resulting hydrogeological model will be verified by comparing the predicted and measured values for porewater pressure before, during and after the long-term pumping test. Predictions of the hydrogeological effects caused by excavation and the discharge rate of groundwater into the shafts and drifts will be verified by comparing them with the values measured during the construction phase.

4.2.3 Hydrogeochemistry

The Geoscientific Research Programme carried out in and around the Tono mine has revealed that there are differences in the hydrogeochemical characteristics of sedimentary and granitic rocks. The differences are presumed to result from variations in groundwater residence times, the types of rocks and soils and the distribution and connectivity of groundwater flow channels (*ie* water-conducting features). To obtain an accurate understanding of hydrogeochemical characteristics, it is therefore important to consider data on geological structure and groundwater flow from the point of view of water-rock interaction processes.

Borehole investigations will be carried out to determine hydrogeochemical characteristics before the geological environment is disturbed by the construction of the underground facilities and will be used to predict the changes caused by such construction. A series of investigations and predictive analyses will be carried out in order to construct a hydrogeochemical model which simulates the distribution of groundwater chemical parameters and the main directions of groundwater flow.

These investigations and analyses will then be extended in order to modify the hydrogeochemical model and to predict the effects of underground construction. The predictions will be verified by comparison with the data obtained during the construction phase.

4.2.4 Engineering techniques

The detailed design of the underground facilities will be based on the results of the surface-based investigations. However, when construction is commenced, it cannot be ruled out that unexpected geological conditions will be encountered. It is therefore essential to maintain a sufficient element of flexibility in the design concept to allow it to be adapted to take account of conditions encountered underground.

The design study has numerous components, for example selecting an appropriate layout for the underground facilities and suitable construction methods, establishing a plan for restoring the undisturbed geological environment to the maximum extent possible and long-term studies on the safety and management of the underground facilities.

4.2.5 Investigation techniques and equipment

JNC has developed a range of data acquisition techniques and equipment, such as remote sensing, geophysical prospecting, hydraulic testing and groundwater sampling to a maximum depth of 1,000 metres.

In the first phase, it is important to obtain a sound understanding of the characteristics of the geological environment. Investigations in this phase will be carried out using the existing techniques and equipment. However, in the event that it proves impossible to attain objectives using only the existing techniques, any necessary improvements and developments will be carried out. Investigation techniques and equipment which will be used in the construction phase will also be developed.

It is important to clearly specify investigation aims and to tailor the characterisation programme to efficiently cover all areas of interest.

4.3 Studies in the construction phase

Outline

The studies during the construction phase will include studies on rock mechanics as well as studies on geology, hydrogeology and hydrogeochemistry. A series of measurements will be carried out in parallel with the construction of the underground facilities, using equipment set up in the first phase. The horizontal or inclined drifts constructed from the shaft will allow investigation of important geological features such as fracture zones and lithofacies boundaries in three dimensions. It is also important to study the properties of the geological environment immediately surrounding the drifts. The results predicted in the first phase will be verified on the basis of the geological environment observations during the construction of the underground facilities and the geological environment which will be encountered in the third phase will be predicted. In the event that there are significant differences between predictions and observations, relevant studies will be repeated or models will be improved.

The number, extent and layout of the drifts will be determined on the basis of data obtained in the first phase. Drift construction will be divided into several stages. As the volume of data on the geological environment increases with the progress of construction of the underground facilities, it will be necessary to reconsider the study programme.

Along with the construction of the planned underground facility, the goals of the studies to be carried out during this phase are as follows:

1. To acquire data on the geological environment via studies in the drifts and to predict the geological environment surrounding the drifts.
2. To verify predictions made in the surface-based investigation phase.
3. To estimate the applicability of the techniques for designing and constructing the underground facilities.
4. To establish the plan for the operations phase.

4.3.1 Geology

The geological structure predicted on the basis of the information obtained during the first phase will be compared with that actually observed during the construction of the underground facilities and the degree to which the applied investigation methodologies are appropriate will be confirmed. Any discrepancies may lead to further studies or to model refinement. Predictions will be made regarding the geological profiles in the next phase. The three-dimensional geological structural investigation provides fundamental information for many other studies, for example, the chemical composition of the rock types encountered in the drifts and the distribution of fractures that represent potential migration pathways.

4.3.2 Hydrogeology

The main tasks of the hydrogeological study in this phase will be to evaluate the investigation methodology by verifying the hydrogeological model developed in the first phase and the prediction of the changes in groundwater flow caused by excavation. Data on the hydrogeological characteristics in the rock surrounding the drifts are also important for planning the study programme of the next phase. The existing hydrogeological model and groundwater flow analyses will be improved using the data obtained during this phase. The hydrogeological characteristics which will be encountered and the changes in groundwater flow in the next phase will be predicted.

Predictions of the changes in hydraulic pressure and the discharge rate of groundwater into the drifts at each stage will be tested by comparison with the observed values during this phase. The degree to which the hydrogeological model and methodologies for the hydrogeological investigation and analysis are appropriate will be evaluated and the results will then be used to improve the hydrogeological model and/or the characterisation methodology.

One of the tasks of the hydrogeological study in this phase is to estimate the extent of changes in hydrogeological characteristics of the excavation disturbed zone (EDZ) induced by shaft/drift excavation.

4.3.3 Hydrogeochemistry

Hydrogeochemical data will be obtained via investigations in the drifts and the model constructed in the first phase will be verified. Changes in hydrogeochemical characteristics caused by shaft/drift excavation will be also studied.

Hydrogeochemical data obtained from groundwater and rocks sampled in drifts and boreholes will be used to determine the changes in hydrogeochemical characteristics caused by excavation. The predictions in the first phase will be verified by comparison with the actual measured data. The predicted changes in groundwater chemistry and redox condition will be compared with the data obtained in the long-term hydrochemical monitoring.

4.3.4 Rock mechanics

During the construction phase, the mechanical behaviour of the rock mass surrounding the shafts and drifts will be studied in parallel with the excavation work. This study is important in terms of providing basic input data for the excavation disturbance experiment and the thermo-hydro-mechanical coupled experiments planned in the next phase. It also provides information on the physical stability of the underground facilities in the rock mass.

The mechanical response of the rock mass surrounding the shafts and drifts to the excavation work will be measured and compared with the predictions made in the first phase. Mechanical models and input parameter values will be improved so that the mechanical properties of the host rock can be predicted.

4.3.5 Engineering techniques

Verification of the techniques used for underground facility design and construction and further studies on a safety and support infrastructure for the underground facilities will be carried out in parallel with construction. In case the geological conditions predicted in the first phase do not match with the actual observations, the design concept initially formulated is flexible enough to allow appropriate modification. Design methodologies and required construction materials and techniques will be also further developed.

Underground temperature increases with depth and it is therefore important to regulate the environment in the shafts and drifts to ensure the safety and health of workers. It is also important to consider the aspects of long-term safety in the stability of underground facilities as the shafts and drifts will be utilised over long timescales. Relevant technical developments will therefore be planned in the fields of safety and environmental control.

4.3.6 Investigation techniques and equipment

The studies in this phase will be focused on the relatively small scale and detailed geological environment immediately surrounding the drifts. High precision and stability of equipment should be required in the restricted working environment. It is important to improve the existing equipment and/or to develop new techniques and instrumentation as the need arises, which will ultimately lead to rationalisation and systematisation of investigation strategies.

4.4 Studies in the operations phase

Outline

Studies in this phase will focus mainly on mass transport, rock mechanics, engineering techniques and earthquake activity aspects. The scale of the geological environment investigated in this phase will be similar to that in the construction phase. The excavation disturbed zone (EDZ) around the drifts will be studied in detail to provide an understanding of the phenomena which have occurred in this zone and to evaluate strategies for restoring the EDZ if necessary. The layout of the drifts and the components of the study programme for this phase are determined on the basis of the data obtained up to the end of the construction phase. A preliminary study programme for the operations phase is outlined in the following.

The goals of the studies to be arrived at during this phase are as follows:

1. To acquire more detailed data of the deep geological environment.
2. To verify the predictions made in the construction phase.
3. To estimate the applicability of engineering techniques to design, construct and maintain deep underground excavation.

4.4.1 Geology

From a geoscientific viewpoint, the drifts will be excavated at depths which are appropriate for studying key geological features in detail. Geological structures around the drifts will be investigated and the predictions made in the construction phase will be verified.

4.4.2 Hydrogeology

Predictions made in the construction phase will be verified and a detailed hydrogeological model will be constructed based on the geological environment surrounding the drifts revealed in this stage. One of the main issues to be studied in this phase is the resaturation process after backfilling the drifts.

4.4.3 Hydrogeochemistry

Studies will be carried out on long-term chemical changes in the groundwater, the redox conditions in the EDZ and the redox buffering capacity of the rock surrounding the drifts. The investigations provide background for mass transport studies and allow the prediction of chemical conditions after groundwater resaturation.

4.4.4 Mass transport

The mass transport study is one of the most important tasks in this phase. Characterisation of potential migration pathways will be supported by a programme of laboratory investigations but the main aspect of the study will be migration experiments carried out in the deep geological environment surrounding the drifts. A model of mass transport will be developed and tested using the results of *in situ* experiments performed.

4.4.5 Rock mechanics

The main experiments carried out will be aimed at identifying excavation effects. Investigations of undisturbed rock properties and installation of measurement equipment will be carried out before drift excavation. Vibration effects, displacement phenomena and change in rock stresses will be measured during excavation. Predictions of the effects of excavation and the extent of the EDZ will be also verified by the measurements made after excavation.

4.4.6 Engineering techniques

Techniques should be developed for ensuring that a safe and controlled environment is established in the drifts, for performing thermo-hydro-mechanical coupled experiments in the rock mass around the drift and for restoring the EDZ. Appropriate methodologies for measuring and analysing thermo-hydro-mechanical responses, for developing construction materials and techniques and for ensuring safety in drift stability will be evaluated experimentally. Furthermore, it is important to investigate groundwater resaturation behaviour, as the data on this phenomenon are relatively sparse, and to clarify the effects on the surrounding geological environment of controlling the environment in the drifts over long time periods.

4.4.7 Earthquake activity

Earthquake vibrations deep underground and any resulting changes in the geological environment will be monitored and the effects of seismic activity on the stability of the underground facilities will also be evaluated. Japan is a country with frequent earthquake activity and the results of these studies will be relevant for foreign research programmes. Discharge rate meters and seismographs will be installed at different depths in the underground facilities to measure changes in geological environment characteristics due to earthquake activity.

5 CONCLUSIONS

The Mizunami underground research laboratory project (MIU Project) planned by JNC in Mizunami City in Gifu Prefecture is a deep underground research facility as foreseen by the Japanese governmental policy embodied in the Long-Term Programme for Research, Development and Utilisation of Nuclear Energy (LTP). The MIU Project will expand the Geoscientific Research Programme conducted by JNC to date.

JNC plans to adopt a flexible approach in deciding the content of the MIU Project, which will allow rapid, targeted responses to requests from the various groups which will utilise the research results. Both the results of the study programmes and the underground facilities themselves will be open to the public. In addition to providing input for JNC's Geoscientific Research Programme, the underground research laboratory will also provide opportunities for other organisations, both in Japan and abroad, to conduct research in different technical and scientific fields. For example, advanced seismic studies and micro-gravity experiments are already being considered by relevant research organisations and will continue even after JNC's programme will be completed.