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Master Plan

of the

Mizunami Underground Research Laboratory Project

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Tono Geoscience Center

Japan Nuclear Cycle Development Institute

Preface

In 1994 the Japan Nuclear Cycle Development Institute (JNC) was authorized by the Atomic Energy Commission of Japan (AEC) to construct underground research facilities. JNC plans to construct two facilities ; one is to investigate the properties of crystalline rock, the second to investigate sedimentary rock. The purpose of these underground research facilities was outlined in the AEC's "Long-Term Program for Research, Development and Utilization of Nuclear Energy" (June 1994; revised in 2000 [(1)]; henceforth Long-Term Program). Research at these facilities was intended to promote and support scientific studies of the underground geological environment. In addition, based on these government policy directives, JNC was given a new role of carrying out research and development towards the establishment of technical reliability of geological disposal and of methods for safety assessment, in the Long-Term Program.

JNC has selected and carried out surface-based investigations at two locations: the location for investigation of crystalline rock is in Mizunami City, Gifu Prefecture; the location for investigation of sedimentary rock is at Horonobe, Hokkaido.

This document presents the Master Plan of the facility to be constructed for crystalline rock investigations. The facility is known as the Mizunami Underground Research Laboratory (MIU) and located in Akeyo-cho, Mizunami City. The facility consists of the MIU Construction Site where the underground research Stages will be excavated and the Shobasama Site, a sister site 1.5 km to the west, where an extensive network of deep boreholes were used for initial investigations of the deep geological environment.

The Shobasama Site is located on land owned by JNC. It was selected initially as the site for all investigations and facility construction. An intensive characterization program was carried out and now the site has an extensive borehole network suitable for ongoing research and long-term monitoring. However, due to difficulties in obtaining planning permission to begin construction and excavation at the Shobasama site, JNC concluded a contract on 17th January, 2002 with Mizunami City for the lease of city-owned land at Akeyo-cho, Mizunami City. It was decided that the research galleries and related facilities for an underground research facility should be constructed at this site.

JNC, in order to adjust to the situation, decided to revise the original 1996 Master Plan to reflect the change in activities. Therefore, the 2001 Master Plan, Japanese version, was prepared to include both the new program at the MIU Construction Site in Mizunami City and the continuing activities at the Shobasama site.

Prior to any research for the MIU, surface-based investigations and geoscientific studies at Tono and Kamaishi Mines were effectively utilized for information on the underground geological environment and for development and testing of technology applicable to research on the geological environment. These studies were reported to the Japanese Government in the Second Progress Report on the Research and Development for the Geological Disposal of HLW in Japan, H12 (henceforth the 'JNC's H12 Report').

The Advisory Committee on Nuclear Fuel Cycle Backend Policy of the Atomic Energy Commission of Japan carefully evaluated the JNC's H12 Report. The Committee concluded that; "the second report indicates the technical reliability of geological disposal of HLW in Japan, and also the technical basis is shown regarding the selection of the sites for the repositories and for determining the safety standard". Also the Committee indicated that "the JNC's H12 Report will be the technical basis for execution of geological disposal projects" together with the necessity of future research and development utilizing underground research facilities. Since the submission of the second report the following has occurred:

- the "Specified Radioactive Waste Final Disposal Act (Law 117 of 2000)" was enacted in May 2000.
- The notification in October of 2000 of "Master Plan for Final Disposal of Specified Radioactive Waste" (MITI (Ministry of International Trade and Industry)-Notification No.591).
- Nuclear Waste Management Organization of Japan (NUMO), the implementing agency for geological disposal was established in 2000.
- "The basis for safety Standards of HLW Disposal, first report" was published. The Atomic Energy Commission in November 2000 adopted the new Long-term Program for Research, Development and Utilization of Nuclear Energy.

Thus preparations for the execution of geological disposal are making steady progress in Japan.

Contents

Overview of the Project

Appendix A :

Investigation plan at the "MIU Construction Site" - Phase I (Surface-based Investigation Phase) -

Appendix B :

Investigation plan at the “MIU Construction Site” – Phase II (Construction Phase) -

Appendix C :

Investigation plan at the “MIU Construction Site” – Phase III (Operation Phase) -

Appendix D :

Investigation plan in the Shobasama Site - After 2001FY -

Overview of the Project

1 Background of the Mizunami Underground Research Laboratory (MIU)

1.1 Japanese Government policy position

The steps to be taken and the roles of concerned organizations for the final disposal of high-level-radioactive wastes are described in the Atomic Energy Commission's Long-term Program [(1)]. The Long-term Program required JNC to "steadily carry on research and development activities to verify the reliability of geological disposal technologies and to establish a safety assessment method, using research facilities for deep geological environment". Also that "These research facility for deep geological environments will serve not only as a place for scientific investigation, but also as a place for deepening public understanding of research and development activities related to the geological disposal of waste. Accordingly, this research facility project should be clearly distinguished from the disposal facility."

Further to the requirements of the Long-Term Program, JNC is implementing "scientific studies of the deep geological environment and development of technologies to enhance the reliability of geological disposal technology" (henceforth 'geoscientific research') at the Tono Geoscience Center (TGC). Geoscientific research is the study of the geological aspects of HLW disposal, and will form the basis for the research and development regarding geological disposal.

The MIU is one of the facilities described in the Long-term Program [(1)] and the main location for the research program investigating crystalline rocks (granite).

1.2 Relevant geoscientific research

The Tono Geoscience Center has been carrying out geoscience research on sedimentary and crystalline rocks in the context of understanding the characteristics of the geological environment in Japan. The research has been done at the Tono Mine and its vicinity (since April 1986) and at the Kamaishi Mine (April 1988 to March 1998).

At the Tono Mine and its vicinity, the main research target is the sedimentary rock (Neogene Mizunami Group). Geological, hydrogeological, hydrochemical, rock mechanical and mass transport investigations have been carried out (2). For example, one of the investigations was the 'Shaft Excavation Effect Experiment', carried out during the excavation of the six meter diameter, 150 m deep Shaft No.2. Prior to excavation, TGC staff estimated the change in the geological environment likely to be caused by shaft excavation and subsequently evaluated the accuracy of the predictions. Based on the research results at these mines, development and improvements of methods for investigation, analysis, and assessment of the geological environment were carried out (3). Also methods necessary for investigation, analysis and assessment of geology, groundwater flow characteristics and geochemistry within a 10 km-square and 1 km-deep zone, including the Tono Mine, have been developed in the Regional Hydrogeological Study (RHS) (4).

Investigations and *in situ* tests were also carried out at the Kamaishi Mine using galleries 300 m and 700 m below the surface. To be precise, geology and geological structures, groundwater flow, geochemical and mechanical characteristics of the rock were studied. The mechanical effect of gallery excavation deep underground , and characteristics of mass transport in a crystalline rock (Kurihashi Granodiorite) body were also assessed. The effect of earthquakes on the deep geological environment was clarified, the technology necessary for the above-mentioned tests and studies were developed and improved and their applicability was confirmed (5).

The geoscience research at the Tono Mine and its vicinity and at the Kamaishi Mine was completed with new and existing information and in the existing facilities. From these studies, new information and knowledge on the deep geological environment were acquired, and new techniques developed for investigation, analysis, and evaluation of these environments from both the surface and underground (e.g. (6)) It will be necessary to actively utilize the results for the MIU Project.

In addition to the above, it will also be particularly relevant to use the results of the Regional Hydrogeology Studies Project (RHS) because the RHS study area includes the location of the "MIU Construction Site" in Akeyo-cho, Mizunami City where the research galleries will be excavated and the Shobasama Site. Thus it will be possible to evaluate the applicability of the methods of investigation, analysis, and assessment done on a regional scale to the “MIU Construction Site” scale.

Geoscientific research for the MIU Project will be done in three Phases. Phase I (Surface-based Investigation Phase) will start prior to excavation of the underground research facilities. This research will continue during Phase II (Construction Phase) and Phase III (Operation Phase) [(7)]. Many aspects of the underground geological environment will be predicted by model construction. Evaluation of the accuracy of the predictions will be carried out during each Phase. Phenomena such as disturbance of the groundwater flow system and the rock mass caused by excavation of the shafts and research galleries will be monitored and assessed. These studies, to be carried out concurrently with the construction of the underground facilities, will determine the undisturbed geological conditions and changes to it as a result of construction activities.

1.3 Project site

The underground research facilities and related surface plant will be constructed on land in Akeyo-cho leased from Mizunami City, Gifu Prefecture. The site is about 7.5 ha and located in the Intergarden of Tono Frontier Science Research City. This area lies at the border of plutonic rocks of the Ryoke Belt and Mesozoic sedimentary rock of the Mino Belt. The research galleries of the MIU will be excavated in the Cretaceous Toki Granite, which forms the basement complex in the area (Figure 1). This geological setting is typical of much of Japan; Cretaceous granites occur widely [(2)].

This area has the following characteristics and advantages as the site for the MIU.

- Geological formations and conditions exist with characteristics important as research targets; these include saturated bedrock conditions, abundant structural discontinuities such as fracture zones and faults at various scales and the uranium deposits.
- Direct influence of recent active faulting is small, and thus the area is suited for study of the effect of earthquakes under stable geological conditions.
- It is located in the central part of Honshu Island and access and transport are convenient. Also, the natural and living conditions are excellent.
- The local government is promoting the Tono Frontier Science Research City and its major research theme is the extreme environment.

In addition, expertise and data obtained during the past 30 years of research on uranium resources by JNC (e.g. [(8)]) are available at TGC, with laboratory facilities for research available on site. These geoscientific resources are undoubtedly the greatest advantage for the project.

Furthermore, significant knowledge regarding the geological environment has been acquired in the early Phase I studies at the Shobasama Site. These studies included drilling several boreholes, detailed core logging, borehole geophysical and hydrogeological studies, detailed data analysis and evaluation and modeling activities. Experience in the application of various field methods of investigation and analyses have been applied. It is expected that in the Shobasama Site, investigations methods on the geological environment, including major structural discontinuities (e.g. the Tsukiyoshi Fault), in crystalline rock can be further developed.

1.4 Project plan and execution

Geoscientific research for the MIU Project will be carried out in three Phases and expected to last for 20 years. The three Phases were established considering the construction schedule and the multidisciplinary activities, targets, and scale of research.

Phase I (Surface-based Investigation Phase)
Phase II (Construction Phase)
Phase III (Operation Phase)

The first Phase will commence prior to the construction of any of the underground facilities. This surface-based characterization work will expand on the research carried out in the past at the Tono Mine and its vicinity and at the Kamaishi Mine. As mentioned in Section 1.2, the geoscientific research carried out in the Phases is expected to characterize the undisturbed geological environment and predict changes to the environment during research gallery excavations.

The Phase I will start prior to excavation of the underground research facilities. The geoscientific research will continue during Phase II and Phase III [7]. Many aspects of the underground geological environment will be predicted by model construction. Evaluation of the accuracy of the predictions will be carried out during Phases II and III when direct observation of the underground will be possible. Phenomena such as disturbance of the groundwater flow system and the rock mass caused by excavation of the shafts and research galleries will be monitored and assessed. These studies, to be carried out concurrently with the construction of the underground facilities, will determine the undisturbed geological conditions and changes to it as a result of construction.

The conceptual design of the facility consists of two 1,000 m shafts, the Main and the Ventilation Shafts and two principal research levels, the Main Stage at 1,000 m depth and the Middle Stage at 500 m depth. At these Stages, tunnels will connect the Shafts to the research galleries where the activities will be focused. In addition, smaller research stations (Sub Stages) will be constructed at about 100 m intervals along the Main Shaft. More details are provided in Chapter 4 of the Overview.*

Also the results of the studies carried out prior to the start of construction will provide information for planning the construction and will facilitate determination of the research targets such as the

* The naming convention currently proposed is based on the conceptual designs; following an observational design approach, if the as-built facility is different, the naming can be changed to conform to the actual facility layout.

major structural discontinuities. This integrated and carefully planned research is possible because the MIU Project is starting in an undisturbed geological and hydrogeological environment.

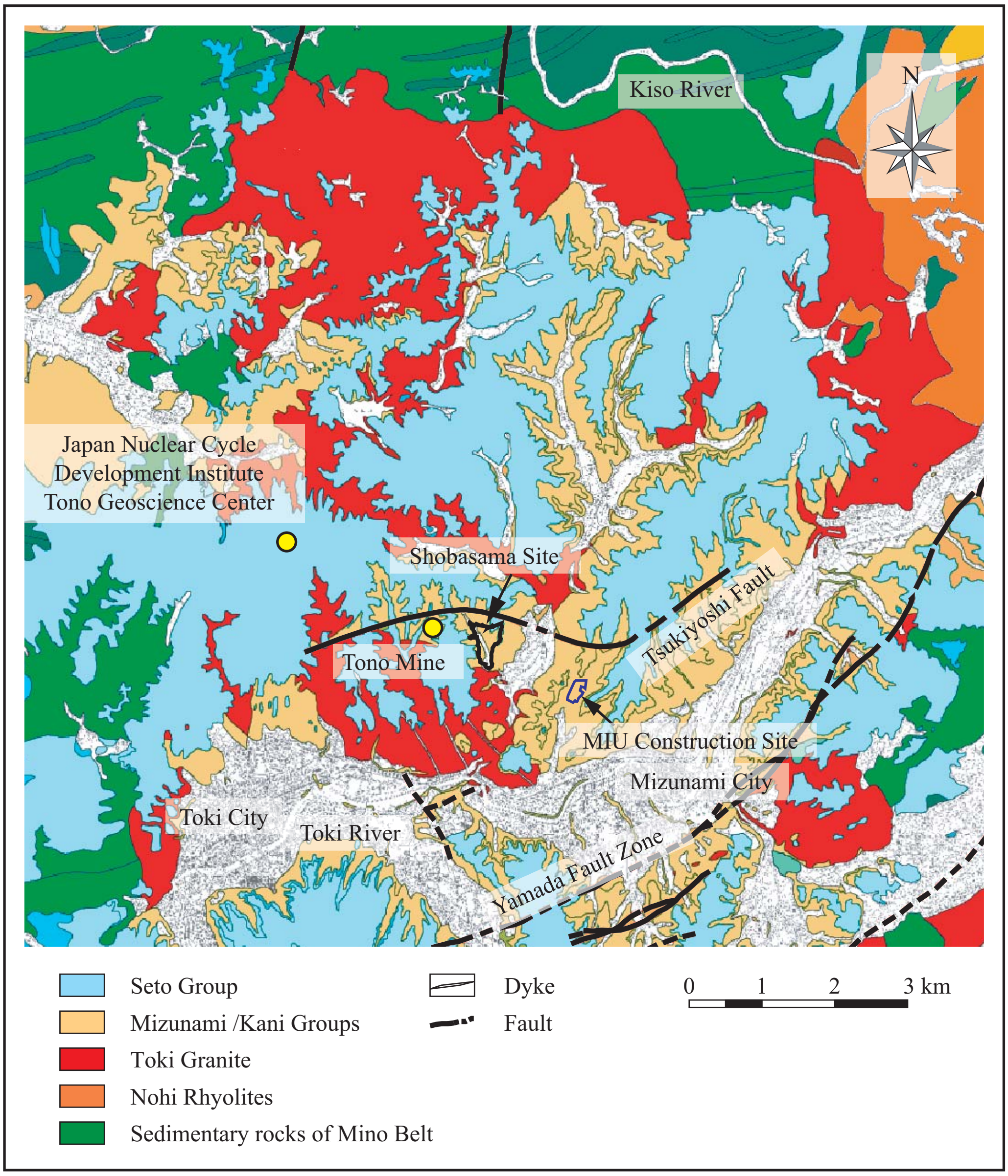


Figure 1 Geology in the vicinity of the MIU

2 Goals of the MIU Project

The goals of the MIU Project are considered in terms of the overall project and the goals specific to each Phase. Goals considered for the entire project are the following:

Project Goals

1. To establish techniques for investigation, analysis and assessment of the deep geological environment
2. To develop a range of engineering for deep underground application

These overall project goals are described in more detail in Section 2.1.

To achieve these overall project goals, goals for each of the Phases have also been developed.

Phase I

1. Construct models of the geological environment from all surface-based investigation results that describe the geological environment prior to excavation and predict excavation response
2. Formulate detailed design concepts and a construction plan for the underground facilities
3. Establish detailed investigation plans for Phase II

Phase II

1. Develop and revise the models of the geological environment using the investigation results obtained during excavation and determine and assess changes in the geological environment in response to excavation
2. Evaluate the effectiveness of engineering techniques used for construction, maintenance and management of underground facilities
3. Establish detailed investigation plans of Phase III

Phase III

1. Revise and improve models of the geological environment using the results of the underground investigations and determine and assess changes in the deep geological environment in response to research gallery extension
2. Evaluate the effectiveness of engineering techniques used for deep underground

These goals are described in more detail in Section 2.2. In achieving these goals the undisturbed geological environment will be described and changes to the environment during research gallery excavations predicted.

2.1 Goals of the entire project

① To establish techniques for investigation, analysis and assessment of the deep geological environment

The establishment of these techniques is important. From JNC's perspective, an important reason is to improve confidence and reliability in geological disposal technology, a requirement of the AEC [(1)]. One way to do this is to demonstrate that the geological environment can be accurately characterized and well understood and therefore, that the understanding shown in models has an acceptable degree of certainty. The MIU provides the opportunity to demonstrate this.

During the MIU Project, the applicability and accuracy of techniques used in each Phase, the data requirements and scope of research needed for characterization will be evaluated as the research proceeds. With improve techniques and data, the accuracy of the models developed can be assessed and improved. Furthermore, the accuracy of the site models describing the geological environment will be evaluated and can be directly confirmed as the research proceeds through the various Phases.

Establishment of the techniques will be done by performing site investigations and research that follow a clearly defined process: (a) develop basic concept to be investigated; problem definition (b) plan the investigations, (c) perform the appropriate investigations using a range of techniques, (d) analysis of data and conceptual modeling and (e) evaluation of the investigations in terms of data requirements, type of investigation and accuracy. The MIU provides a proving ground for the methodology; results from repeated site investigations during the Phases will be analyzed, modeled and predictions assessed. The data and models will then be integrated and used for long-term predictions of performance, which because they are based on proven characterization and modeling techniques, will demonstrate reliability and reduced uncertainty.

The process described above; development of basic concept → planning → investigation → analysis and modeling → evaluation will be repeated with increasing detail in all the MIU Phases and finally lead to improved techniques and understanding of site characterization needs for assessment of the deep geological environment. Therefore, by repetition of this investigation process during the MIU Project, the effectiveness of all the methods can be evaluated, and the technology for investigation, analysis, and assessment established for investigating the deep geological environment.

First, the investigation plan to be followed at the "MIU Construction Site" and the MIU Shobasama Site will be developed based on the understanding of the geological environment developed from available information. This will be followed by systematic acquisition of quality-controlled, integrated information on the geological environment from the surface to the deep underground in accordance with this Master Plan. Knowledge developed during the geoscientific research at the Tono Mine and its vicinity and by international collaboration carried out at other underground facilities such as at Hard Rock Laboratory (HRL) in Sweden, together with newly developed technologies will be systematically integrated. The results from the various geoscientific fields will be analyzed and reported individually and the conformity and consistency of these results will be confirmed through discussions and analyses. Conceptual models of the geological environment and numerical models simulating the environment and various phenomena will be constructed. Assessment of the deep geological environment at the appropriate scale will be carried out using these models and newly developed methods. The accuracy of these results will be evaluated as new information becomes available during excavations.

Repetition of the investigation process described above during each Phase in the Project or at the completion of individual studies will be one method by which to evaluate if the amount of data is sufficient for the desired level of understanding and to assess the uncertainty in the data and analyses (9). It will be important to clarify the importance of the items to be assessed in each Phase by repetition of the above process and by feedback in the research group of the acquired knowledge. Through repetition and feedback, an assessment of (a) the amount of data that can or should be acquired, i.e., the data requirements and (b) the investigations (type, quantity, detail, scope) to be performed can be related to the accuracy of the results needed for analysis and modeling. Through this approach, the effectiveness of the investigation process and methods will be evaluated and the methods for investigation, analysis and evaluation will be improved and established for the geoscientific research. Also the methods being employed will be examined through a comparative study with those applied in other countries. Finally, the methods for an assessment of the deep geological environment are expected to be shown for a given geological environment and scale.

The geological characteristics and information acquired through the above processes are specific to the Toki Granite at the “MIU Construction Site” and the Shobasama Site. Although the Toki Granite is not necessarily representative of all other crystalline rocks in Japan, the methodology developed will demonstrate how integrated investigations from various closely related fields can be used to determine the characteristics of other crystalline rocks, from surface to a depth of more than 1,000 m. It is intended that the above methods will result in the establishment of technology for investigation, analysis, and assessment of the deep geological environment. This knowledge and information will also provide input to development of improved safety assessments methods and for research and development to improve assessment reliability (10).

② **To develop a range of engineering for deep underground application**

The MIU will provide the opportunity to demonstrate the feasibility of safe and reliable construction, maintenance and management of an underground research facility by applying conventional and state-of-the-art engineering technology in a deep geological environment. Also establishment of technology for appropriate analysis and assessment of the long-term effect of construction of research galleries on the geological environment will be an important achievement.

This project calls for the construction of underground research facilities (shafts, stages, research galleries, access tunnels) with minimum disturbance to the geological environment. For this project, current engineering technology will be applied at the “MIU Construction Site”. Also, at the “MIU Construction Site”, the long-term stability of the underground rock mass in terms of the mechanical and seismic stability of the underground development will be analyzed and assessed. The data acquired will enable design and construction planning of the research galleries to withstand possible changes to the geological environment from external events. The effectiveness of the applied engineering technology will be verified by the actual construction, maintenance and management of the research galleries. It will be important to be able to change the plan, or the design to deal flexibly with geological conditions or unexpected phenomena such as large water inflows or rock bursts or to deal with new experiment requirements as understanding of the geological conditions is enhanced during excavations. Thus new technology, construction management system and construction materials will be considered. Within the research galleries, applicable techniques for maintaining and managing the research environment will be evaluated and the best management system will be implemented.

On the other hand, research and development regarding the restoration (reversal) of the effects of shaft and research gallery excavation on the geological environment, assessment of the coupled effects of underground conditions: of heat, moisture, high-pressure water, in situ stress, chemical reaction and the long-term effect of engineering material (particularly cement) are expected to be carried out by international collaboration or at underground research laboratories of other countries. Thus the development of engineering technology will be considered in future.

It is expected to demonstrate that geoscientific studies can be carried out safely in the deep underground in Japan by attaining this goal.

2.2 Goals of Phases I, II and III

The goals of the three Phases are described in this section.

2.2.1 Phase I goals

① **Construct models of the geological environment from all surface-based investigation results that describe the geological environment prior to excavation and predict the excavation response**

In order to construct models that accurately represent the geological environment, detailed characteristics of the deep geological environment need to be determined from surface-based investigations. Models of the subsurface environment (geological, hydrogeological, geochemical and rock mechanical models) will be constructed by interpreting and synthesizing data acquired, at the scale of several hundred meters, the facility-scale. The models will be revised as newly acquired data becomes available. In acquiring site data and developing these models it will be possible to begin assessing the techniques in terms of the data requirements, the types of investigation performed and their applicability. Through this analysis the effectiveness of the methods for investigation, analysis and evaluation will be assessed and improvements made as necessary to meet the overall objective of developing site characterization techniques.

From these investigations and model development, expected changes to the deep geological environment such as changes in the groundwater flow system and its geochemical characteristics and rock mass response to excavation can be estimated using mathematical models developed.

② **Formulate detailed design concepts and a construction plan for the underground facilities**

The detailed layout of the research galleries will be determined on the basis of research plans for Phases II and III. These research plans will be prepared based on knowledge of the subsurface geology and preliminary plans for experimental activities. For this, data obtained in this Phase and the expected changes to the geological environment caused by the research gallery excavation will be considered.

The engineering technology in terms of excavation method and equipment to be used will be selected and the construction plan will be prepared. Also, the construction plan must be such that careful consideration will be given to minimize disturbance of the deep geological environment to the extent possible.

③ **Establish detailed investigation plans for Phase II**

Investigation plans for Phases II and III will be prepared. Guidelines used for preparation of plans may be based on geoscientific research needs identified in the AEC assessment [10] of JNC's H12 Report. As well, knowledge of the deep geological environment and assessment of the predicted changes to the geological environment in response to the excavations will provide insight into what experimental and scientific activities are possible and/or required and that will be of future benefit to (a) understanding the deep geological environment and (b) developing useful technology.

2.2.2 Phase II goals

① **Develop and revise models of the geological environment using the investigation results obtained during excavation and determine and assess changes in the geological environment in response to excavation**

The accuracy of the facility-scale model constructed in Phase I will be evaluated using data acquired during the excavations and the model revised accordingly. Then a new model, several tens of meters square, (the gallery-scale) will be constructed on the basis of the revised facility-scale model and the interpretation of the new data. The gallery-scale model will be revised as geoscientific knowledge accumulates. The process that began in Phase I of assessing the investigations will continue. Assessment of the usefulness and accuracy of the results obtained will be considered in terms of the data requirements and the methods of investigation. Thus, effectiveness of the methods for investigation, analysis and evaluation will be assessed and improvements made as necessary to meet the overall objective of developing site characterization techniques.

The changes in the deep geological environment caused by the excavations will be clarified by analysis of the facility-scale model as well as analysis of data obtained by monitoring carried out simultaneously with excavation.

The research galleries will be expanded during Phase III. The characteristics of the geological environment before extending the galleries will be predicted based on the gallery-scale models for the various disciplines. Changes to the geological environment in response to excavation will also be predicted using mathematical models and the gallery-scale models on which they are based.

② **Evaluate the effectiveness of engineering techniques used for construction, maintenance and management of underground facilities**

The engineering technology for construction, maintenance and management of the research galleries will be assessed, confirmed and refined. Also, it must be confirmed that alteration of the designs and the construction plan to adjust or adapt to unexpected events or geological conditions can be made appropriately by the present engineering technology. Also, technology that ensures human safety during research gallery excavation must be employed.

The construction plan must be such that careful consideration will be given to minimize disturbance of the deep geological environment.

③ **Establish detailed investigation plans for Phase III**

The issues and scientific activities to be considered during Phase III will be reviewed in the light of newly acquired knowledge and the investigation plan for Phase III will be prepared in detail. Guidelines may include requirements from the Implementing Agency, Nuclear Waste Management Organization of Japan (NUMO) and suggestions made by the AEC and those contained within the JNC's H12 Report.

The problems to be solved shown in the second AEC evaluation report [10] will be duly considered together with the investigation results and problems identified during the Tono and Kamaishi Mine investigations.

2.2.3 Phase III goals

① **Develop and revise models of the geological environment using the results of the Phase II underground investigations and determine changes in the deep geological environment due to research gallery extension**

The appropriateness of the facility and gallery-scales models of the geological environment constructed in Phases I and II will be assessed after acquiring and accumulating 3-D data on the geological environment through investigations from the research galleries. The models will be revised as necessary in accordance with the results of the above assessment. By construction and revision of the models, items to be evaluated and their importance will be clarified. The process carried out in Phases I and II of assessing the investigations will continue. Assessment of the usefulness and accuracy of the results obtained will be considered in terms of the amount of data required and the method(s) by which it was acquired. Stated another way, it will be possible to assess the techniques, the actual investigations performed and the details of the studies in terms of the usefulness and accuracy of the results obtained. Thus, effectiveness of the methods for investigation, analysis and evaluation will be assessed and improvements made as necessary to meet the overall objective of developing site characterization techniques.

Also, any changes to the geological environment caused by expansion of the research gallery will be determined. This can be done in some cases by direct observation of rock failure in the research gallery walls. Other excavation induced responses will require monitoring of properties such as hydraulic pressure, strain in wall rocks, in situ stress state, or geophysical surveying to determine changes in permeability or elastic properties. The effectiveness of the analytical methods will be evaluated and refined.

② **Evaluate the effectiveness of engineering techniques used for deep underground**

The applicability of the technology for maintaining the integrity and stability and maintenance of the underground research galleries for a long period of time will be confirmed. Also a management system addressing the engineering procedures and quality control will be established for appropriate maintenance and management of the research environment within the research gallery. Engineering technology with potential to reverse the effects of research gallery excavation on the geological environment will be developed, if necessary.

2.3 Application of the MIU research results

The results of the geoscience research carried out in the MIU Project will be applied as the technological basis for the safety regulations of the government and for the HLW disposal program to be carried out by NUMO. The results will also contribute to the public understanding of scientific studies of the deep geological environment and understanding of research and development regarding geological disposal. Examples of the use of the results regarding the goals of the entire project (Section 2.1) are shown below.

① To establish techniques for investigation, analyses, and assessment of underground geological environment

This goal will be achieved by development and implementation of a process to develop and evaluate the applicability and effectiveness of the investigation methods employed. This process began in Phase I and will continue throughout the MIU Project. It is an iterative process consisting of "develop or revise basic concept → planning → investigation → analysis and modeling → evaluation" for each Phase. Through this process, the following results will be obtained systematically.

- Accumulation of data, knowledge and understanding regarding the deep geological environment in crystalline rock,
- Model construction of the deep geological environment which will contribute to the assessment of deep geological environment; this includes developing expertise in model development, predictive capability and dealing with uncertainty,
- Evaluation of the effectiveness and applicability of the various technical methods employed,
- Illustration of case studies regarding methods for investigation, analysis, and evaluation for assessment of the deep geological environment.

The knowledge and understanding of the deep geological environment developed at the MIU will be needed for understanding the conditions of the geological environment that are the most important for geological disposal. This knowledge and understanding, together with the above-mentioned models will be utilized for development and refinement of safety assessment methods for specific sites and geological environments. Also, these will be vital for the research and development needed for improving the reliability of assessments. The above were outlined by the AEC as problems to be solved [(10)].

In addition, various individual techniques that have proven to be effective, including investigation and monitoring methods for each scientific field and methods for analysis, evaluation and modeling of deep geological environments will also be useful for establishing a system to investigate the various geological environments shown in the JNC's H12 Report (2).

Furthermore, the data and knowledge regarding deep geological environments, together with the results of scientific studies in various geoscience fields, will be applied to understanding underground processes and phenomena (e.g. mass transport, seismicity), improving reliability of models of the geological environment, and examining engineering materials to be used for underground space utilization.

② **To develop a range of engineering for deep underground application**

The effectiveness of the engineering technologies employed for research gallery design, construction planning, safety assessment, excavation, maintenance, management and ensuring operational safety, is expected to be evaluated.

These engineering technologies will be utilized as the basis for developing the most appropriate methods for designing, constructing and operating an eventual waste repository. They will also be vital to verify the possibility of geoscientific studies which will form the basis for future utilization of underground space.

3 Overview of the MIU Project

As stated earlier, Phase I began at the Shobasama Site in 1996. These investigations consisted of a complete range of multi-disciplinary geoscience research activities; more details are provided below in Section 3.1.2. New investigations are being planned for performance at the new site, the Mizunami Construction Site. These are outlined below in Section 3.1.3 and in more detail in Appendix A.

3.1 Phase I (Surface-based Investigation Phase) executed and planned

3.1.1 Goals

The goals of Phase I are as follows (Section 2.2).

① **Construct models of the geological environment from all surface-based investigation results that describe the geological environment prior to excavation and predict excavation response**

② **Formulate detailed design concepts and construction plan for the underground facilities**

③ **Establish detailed investigation plans for Phase II**

The original investigation plan for Phase I (1996 Master Plan) was altered to divide it into two parts, Phase I-a and Phase I-b [(11)]. In Phase I-a (1996 to 1999 FY), technology development and the determination of the geological characteristics of the Shobasama Site were the main focuses of the work. In Phase I-b (2000 to 2002 FY), integration of the multi-disciplinary field investigation results was the major activity. Abundant information was obtained regarding the characteristics of the geological environment in the Shobasama Site (Section 3.1.2). Investigations in Phase I-b carried out for the Shobasama Site were based of the results of the Phase I-a, to address unknown elements and resolve outstanding issues [(12)].

Continuation of Phase I investigations will be carried out at the “MIU Construction Site”, reflecting the knowledge and the expertise developed from the Phase I-a and I-b work at the Shobasama Site. Also, continued technical development will be carried out at the Shobasama Site, utilizing the data accumulated on the geological environment and the borehole infrastructure. The future investigation plan for the Shobasama Site is shown in Section 3.1.4.

During Phase I, various investigations at the “MIU Construction Site” will be carried out from surface prior to start of excavation of shafts and research galleries. Geological and geophysical surveying and subsurface hydrogeological investigations will be carried out from the surface. A deep borehole (> 1,000 m) will be drilled and detailed core logging, geophysical surveying, hydraulic testing, and rock mechanical testing will be carried out. Drill cores and groundwater samples will be studied in the laboratory.

Models of geological environment will be prepared and/or improved for the Shobasama Site and for the larger area of the RHS Project, which encompasses both the “MIU Construction Site” and the

Shobasama Site. These models together with the data obtained by the above mentioned investigations will lead to the construction of facility-scale models for the "MIU Construction Site", namely; the geological, hydrogeological, hydrochemical and rock mechanical models. The conditions expected in the deep geological environment prior to the excavation will be predicted by these models.

Using the data obtained about the deep geological environment during this Phase, detailed investigation plans in Phase II and a rough investigation plan for Phase III will be prepared. Also, detailed layout of the research galleries will be prepared. The construction plan will be decided in detail and engineering methods and equipment to be used will be selected. During the construction of the research galleries, care should be taken to minimize disturbance of the geological environment. Also, monitoring instruments will be deployed in order to effectively determine if any changes to the geological environment are caused by excavation.

3.1.2 Overview of the investigation results obtained from the Shobasama Site

At the Shobasama Site in Phase I-a, the following investigations were carried out.

- Drilling of three 1,000 m-deep boreholes (MIU-1, 2 and 3)
- Detailed core logging and analysis
- Geophysical surveys including electromagnetic and a reflection seismic survey,
- Subsurface hydrogeological investigations included fluid logging and hydraulic testing
- Borehole testing, in situ rock mechanical tests to determine in situ stress and,
- Laboratory testing of rock cores
- Long-term monitoring of pore water pressure using boreholes drilled before the MIU Project.
- Using the above data and data from earlier work, models were constructed for geology, hydrogeology, hydrochemistry and rock mechanics. By using these models, the applicability of survey and analytical methods were evaluated (13,14).

During Phase I-b, synthesis of the results from the various fields of investigation in Phase I-a was attempted. To support this work, one borehole, MIU-4 (790 m long, 60° inclination NE) was drilled with well logging, drill core mapping and analysis, hydraulic testing, water sampling and laboratory testing of drill cores to estimate in situ stress and determine rock mass properties.

In this section, major results of the investigations in various fields acquired at the Shobasama Site are reported. They include construction of geological, hydrogeological and rock mechanical conceptual models, all at facility-scale. The results of MIU-4 borehole investigations are presently being analyzed, and interim results are shown.

(i) Geological investigations

The lack of any exposures of granite at the site prevents the evaluation of fracture style and structural discontinuities in outcrop. Therefore, the first geological structure model was constructed using data on the geological environment obtained from boreholes AN-1 and AN-3, drilled before the MIU Project commenced. Revised geological models were constructed iteratively as data from MIU-1, 2 and 3 boreholes became available.

For the initial geological model based on the existing data (AN series and shallow boreholes for uranium exploration and hydrology studies) sufficient information regarding spatial distribution and continuity of fractures (zones) was limited to the vicinity of the boreholes. Thus the Toki Granite body could only be divided into two simplified parts, namely the upper weathered part and the rest. The second geological model of the Toki Granite distinguished two phases, ‘Biotite granite’ and ‘Felsic granite’ evident from the borehole investigations in Phase I-a. The new geological model represented these two lithofacies as well as the distribution of structural domains based on fracturing, namely the ‘Upper fracture zone’, ‘Moderately fracture zone’ and the ‘Fracture zone along the fault’. The latter was also recognized from seismic surveying at surface and borehole investigations. The fault referred to is the Tsukiyoshi Fault.

The geological structure of the study area, namely the subsurface distribution of the unconsolidated sand and gravel (Seto Group), sedimentary rocks (Mizunami Group), the ‘Biotite granite’ and ‘Felsic granite’ phases of the Toki Granite, was determined by borehole drilling and conceptualized in construction of the geological model during the Phase I-a. Also the distribution of the major geological structures, which are considered to control the groundwater flow and evolution, were included in the conceptualization. The units in the model are; weathered parts of the Toki Granite, ‘Upper fracture zone’, Moderately fracture Zone, Tsukiyoshi Fault and the ‘Fracture zone along the fault’.

The MIU-4 drilling survey carried out in Phase I-b confirmed the locations of the unconformity between the sedimentary rocks and Toki Granite, the weathered part of the Toki Granite, and the Tsukiyoshi Fault. The difference in locations of these units estimated in the conceptual geological model and those confirmed by the MIU-4 borehole investigations were all within 20 m. Also faults, which could not be shown in the first model (existing data only), were included in the new model. Classification of highly permeable fractures (zones) and analysis of fractures including fracture density in all boreholes will continue in the future.

The existence of several highly permeable fracture zones were identified by drill core mapping, borehole geophysics, fluid logging and their permeability was determined by hydraulic testing during the MIU-4 borehole drillings.

(ii) Hydrogeological investigations

Surface hydrological investigations were carried out in the Phase I-a in the region surrounding the Shobasama Site. These investigations comprised observation of meteorological parameters and river flow rate measurements. They were carried out to acquire information for calculating the groundwater recharge rate, needed for the upper boundary condition for groundwater flow simulation, calibration and sensitivity analysis. It was determined from this investigation that groundwater recharge could occur in the range from several percent to slightly more than ten percent of the annual precipitation.

Groundwater hydrogeological investigations were carried out in MIU-series boreholes. Also, head distributions in the study area and the hydrogeological characteristics (permeability, etc) of the geological units: sedimentary cover rocks, weathered zone of granite, Upper fracture zone, Moderately fracture zone and the Tsukiyoshi Fault were investigated. To determine hydrogeological properties and hydraulic continuity of structures, JNC uses a sequence of pressure tests (pulse, slug and pumping) in single borehole investigations and long-term pumping tests in monitored borehole arrays.

Construction of two hydrogeological models and groundwater flow simulations were carried out using the following two data sets: (a) using only existing data before the MIU Project commenced and (b) all data including the Phase I-a results. These analyses were carried out for an area of several kilometers square surrounding the Shobasama Site to understand the groundwater flow of the study area accurately. The results of these analyses were compared with each other. The results of the simulations indicated that irregular, asymmetric drawdown (lowering of hydraulic head) would occur along the trend of permeable fractures intersected during excavation, in particular by the Main Shaft. This simulation reflected the heterogeneity and anisotropy in physical property distributions within the Toki Granite, due to the presence of structural discontinuities such as fractures included in an equivalent continuum model. Also the simulation results were consistent with results expected when the modeling includes the impermeable character of the Tsukiyoshi Fault. Therefore, estimating groundwater flow by the continuum model containing structural discontinuities such as permeable fractures and faults such as the Tsukiyoshi Fault is considered appropriate for an area of several hundred metres square to several kilometers square.

An international study project using different hydrogeological modeling approaches, equivalent porous continuum, discrete fracture and hybrid models, were used to assess the influence of uncertainty due to incomplete geoscientific understanding of the site. Several groundwater flow simulations were performed for each model developed. The results showed that the orientation and location of the structural discontinuities relative to the hydraulic gradient, the main direction of groundwater flow, which is largely controlled by topography, as well as the approach to hydrogeological modeling, exerted a strong influence on the outcome of the simulations (15).

(iii) Hydrochemical investigations

At the Shobasama Site, sampling and chemical analysis of groundwater were only possible in the MIU-4 borehole. The results showed that the groundwater within the Toki Granite, in the hanging wall of the Tsukiyoshi Fault, is weakly alkaline (pH≒9 to 10) and of Na^{+}-HCO_3^{-} type, and that the oxidation-reduction conditions vary independently of depth (Eh: -300 to 0 mV). The depth distribution of Fe^{3+}/Fe^{2+} ratios was determined in rock cores from MIU-1, 2 and 3. The results showed higher ratios down to 300 m depth, ratios less than 1 below 300m depth indicating more reducing conditions at depth and the probability of an oxidation reduction boundary for iron near 300 m depth.

It was also clarified in the RHS Project that the groundwater in the Toki Granite near the Tono Mine is neutral (pH≒7), oxidizing (Eh>0 mV) and Ca^{2+}-Na^{+}-HCO_3 type in the shallow zones (down to 300 m in depth) and changes to weakly alkaline (pH≒9-10), reducing (Eh< -300 mV), and Na^{+}-HCO_3^{-} type in the deeper zones (6). These results are, in general, consistent with the results obtained from the RHS.

(iv) Rock mechanical investigations

The physical properties of the Toki Granite in the Shobasama Site were determined by laboratory tests to have a range in values: uniaxial compressive strength ranges from 100 to 200 MPa and Young's modulus from 30 to 60 GPa. These values are more or less equivalent to average values of other the Japanese granites. The physical properties of the rock mass changes near 300 m and 700 m depth, corresponding to the distribution of fractures. Regarding in situ stress, vertical ground pressure almost coincides with the overburden pressure and the vertical gradient is 0.026~0.027MPa/m. The minimum principal horizontal stress value is about the same as that of the vertical value, and the maximum principal horizontal stress value is 1.5 to 2 times greater than the minimum principal horizontal stress value. The minimum and maximum horizontal principal stress values change abruptly near 300 m and 700 m depth. The maximum horizontal principal stress direction is N-S near surface while it is NW-SE deeper than 300 m. The NW-SE direction is considered more representative of the regional stress. It corresponds to the maximum compressive strain direction in the Tono area obtained by triangulation from the regional, strain monitoring network at surface covering a large part of Japan.

A rock mechanics conceptual model was constructed. The model has been revised several times as research progressed and new data became available. As the knowledge of the rock mechanical characteristics increased, it became evident that the Toki Granite could be divided into three zones –

- Surface to 300/400 m depth,
- 300/400 to 700 m depth and
- 700 to 1,000 m depth.

based on determination of mechanical characteristics (physical properties, mechanical properties, and in situ stress conditions).

(v) Investigation of engineering technology in deep underground

The research activities for Phases II and III were selected in consideration of the previous domestic and foreign research and on the requirements of the Atomic Energy Commission of Japan (16). As well, the procedures for excavation and the method for determining the design specifications of the research galleries were examined (17). The layout of the research galleries was drafted based on the knowledge of the geological environment obtained at the Shobasama Site. The layout should also be based on the scientific objectives of the MIU Project (1). The construction plan of the research galleries was prepared on the basis of this draft layout (18).

3.1.3 Overview of the investigation plan for the "MIU Construction Site"

This section presents an overview of investigations in Phase I at the "MIU Construction Site" in each field and discusses synthesis of the investigation results. The synthesis will be carried out to reach the goals ① and ② of Phase I. More details will be reported in Appendix A.

Investigations in various fields will be carried out from surface in the "MIU Construction Site". Various limitations could be imposed on the site activities such as borehole locations and investigation methods together with restrictions on the number of boreholes, drilling depth and duration of the investigations. Therefore, with such constraints imposed, high accuracy must be targeted and achieved and reasonable and effective implementation of investigations is required.

The research carried out during Phase I will follow the investigation strategy described earlier, that is to continue with the following process:

- Basic concept → Planning → Investigation → Analysis and modeling →Evaluation

In doing so, existing and newly developed analytical and evaluating methods can be applied.

(i) Synthesis of the investigation results

Synthesis of results is important to ensure usefulness and completeness of the data for all end users. The data and knowledge of the geological environment from surface to the deep underground of the “MIU Construction Site” will be summarized for each research discipline. At the same time, conformity and consistency of results will be ensured by discussions, interpretations and feedback across disciplines. Construction of models of the geological environment will be carried out on the basis of the synthesized results; in this way comprehensive understanding of the deep geological environment of the study area will be facilitated.

Individual technologies necessary for investigation from the surface will be improved and their effectiveness will be assessed. Also, the systematic processes for evaluating the deep geological environment will be repeated with resultant acquisition of quality-controlled data and application of useful analytical and assessment methods. During this process, research targets to be investigated at the “MIU Construction Site” will be determined, and the relative importance of these items clarified. And, at the same time, the type of investigations and the level of research detail can be compared and assessed in terms of the usefulness and the accuracy of the results obtained. Thus the methods of investigation, analysis, and evaluation for assessing the deep geological environment will progress.

The investigation plans for Phases II and III and the detailed designing of the research galleries will be a major output of Phase I and provide demonstrated application of the research results from the surface-based investigations. During the surface-based investigations, the following are considered. What data is acquired and is it necessary? If so, are investigation methods for data acquisition and analysis appropriate and will sufficient data be developed? How should inter-disciplinary interpretations and modeling be done? As a result, the extent of the understanding of the geological environment can be assessed and predictions made. One objective is to ensure that (a) investigations methods are appropriate and (b) knowledge passed on to “end-users” is appropriate and sufficient.

(ii) Geological investigations

The geology of the “MIU Construction Site” will be determined by various methods including ground geophysical surveys (reflection seismic survey), borehole investigations using shallow and deep boreholes including core logging and analysis, borehole geophysics, BTV surveying, VSP survey, cross-hole tomography and laboratory tests on drill cores. Of particular importance will be clarification of the distribution and characteristics of the geological units considered to control the flow and chemistry of groundwater such as lithofacies, weathered zones, alteration zones, permeable fractures, faults, and dikes. Also the oxidation-reduction zones will be investigated by laboratory drill core studies and groundwater sampling/analysis. These investigations will start with the construction of the geological model (facility-scale) using existing data on the Toki Granite. The appropriateness of the model will be assessed and the model will be revised repeatedly during the investigation (Figure 2). Finally the 3-D geological model for the "MIU Construction Site" will be constructed.

(iii) Hydrogeological investigations

Hydraulic tests in boreholes (single hole tests and cross-hole pumping tests) and hydrological investigations will be carried out for the development of the hydrogeological model at the facility-scale. This model will be based on the hydraulic continuity and hydrogeologic characteristics of the geological units incorporated in the facility-scale geological model. Also, this hydrogeological model will be used for the prediction of hydrogeological conditions of the "MIU Construction Site" before excavations and as a basis for the mathematical model for groundwater flow simulations. Changes of the groundwater flow caused by the excavations (discharge into the research galleries, changes of groundwater pressure in the vicinity of the research galleries, etc.) will be estimated using this model. The results will be used for detailed design of the research galleries and most importantly, development of the investigation plans for Phases II and III.

(iv) Hydrochemical investigations

The three-dimensional distribution of geochemical characteristics (physicochemical parameters, chemical composition, and isotope composition) of groundwater in Toki Granite at the "MIU Construction Site" will be determined by sampling and chemical analysis of groundwater in existing and new boreholes. Also, major water–rock reactions controlling the water chemistry will be studied by water–rock reaction tests and thermodynamic analysis. Using these results and the results of the sampling and chemical analysis of the groundwater, the present hydrochemical model (water chemistry model, facility-scale) will be assessed. Data on the population of microorganisms which could affect oxidation-reduction state and reactions will be acquired.

(v) Rock mechanical investigations

Mechanical properties of Toki Granite, mechanical characteristics of fractures, and in situ stress conditions of at the "MIU Construction Site" will be determined by laboratory testing of drill cores and mechanical tests in boreholes (e.g. in situ stress measurement by hydraulic fracturing). Also, a 3-D rock mechanical model (facility-scale) of the "MIU Construction Site" will be constructed. The initial, in situ stress state before excavation will be incorporated in this model. Also, rock mass deformation and the changes in the in situ stress conditions in the vicinity of the excavated research galleries, and the range of excavation induced damage in the rock mass will be estimated. The mechanical stability of the research galleries will be assessed and the results will be reflected in the detailed design of the research galleries and in the investigation plans for the subsequent Phases.

(vi) Mass transport investigations

Data concerning pore structure, sorption properties and dispersion, as well as geochemical and mineralogical characteristics of permeable fractures and the rock matrix will be developed by laboratory testing of drill cores (e.g. pore structure study). These data will serve as basic information for clarifying controls on mass transport and the species dependent retardation potential within the Toki Granite. Studies using naturally occurring nuclides will be carried out in order to understand the geologically long-term transport and retardation of materials.

(vii) Investigation techniques and equipment

Investigation techniques and equipment to be used during Phases II and III, will be considered and possibly evaluated. Their applicability and need for improvement and/or development will also be considered. The application of the equipment and the techniques will be considered taking into account the suitability in different geological conditions.

(viii) Investigations on engineering technology in deep underground

The main engineering technology in Phase I concerns the designing and planning the construction of the underground facilities. Multidisciplinary investigations will be carried out during Phases II and III. These investigations will likely have different objectives and experimental requirements and therefore, the research galleries should, unlike conventional underground excavations, be designed so that various investigations can be implemented effectively. Therefore, the construction must be planned accordingly.

During this Phase, investigations considered important and necessary to be carried out during Phases II and III will be determined. These will be selected considering previous work within Japan and abroad. Also, the research gallery layout based on current knowledge of the deep geological environment at the “MIU Construction Site” will be presented. The research gallery layout will become more established as the investigations on the deep geological environment of the “MIU Construction Site” proceed. Finally the details of the research gallery layout will be determined and the construction technology and equipment will be decided. Care will be taken during construction to minimize disturbance of the geological environment.

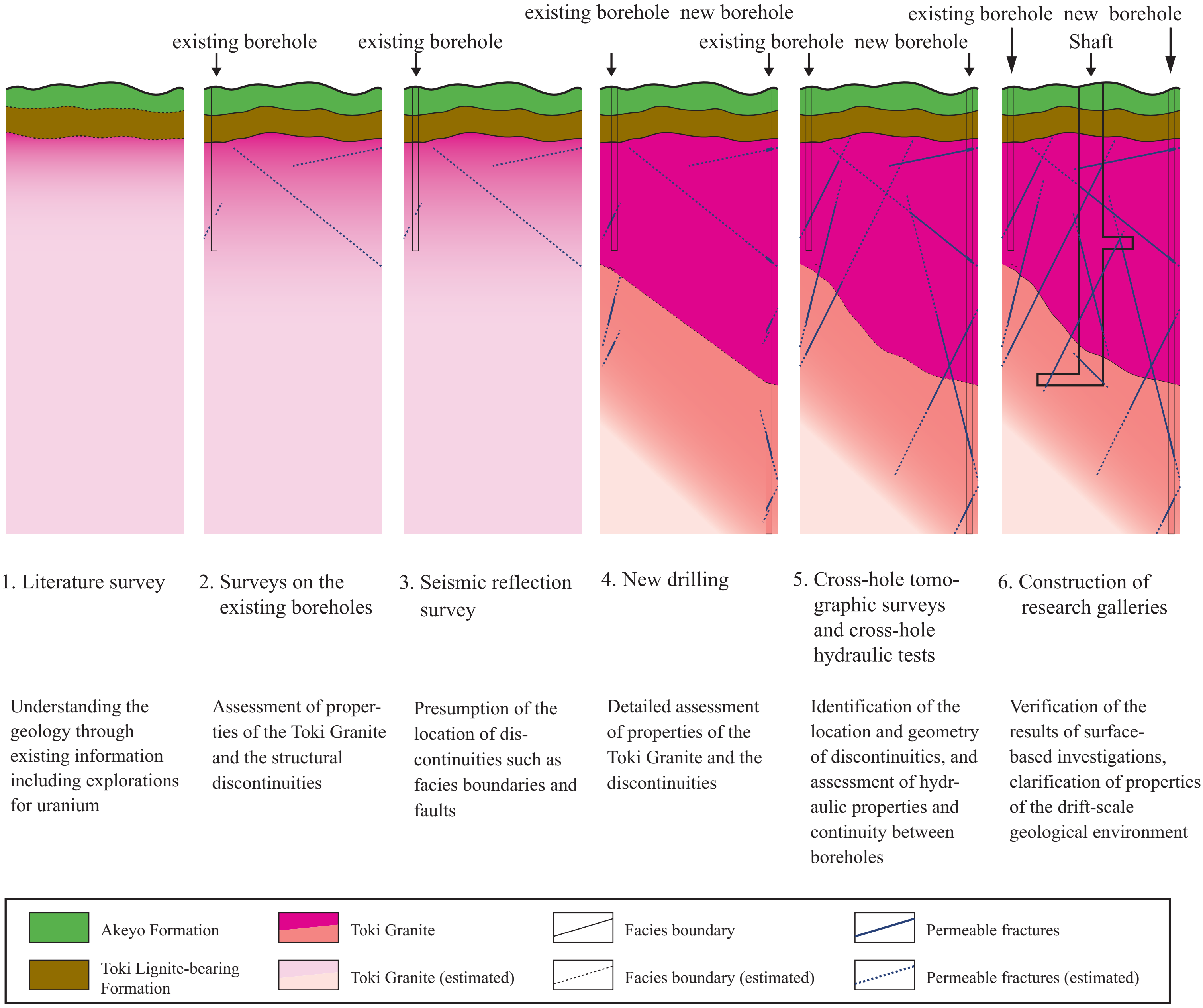


Figure 2 Procedures for research during Phase I at the "MIU Construction Site" (Concept)

3.1.4 Investigation plan in the Shobasama Site

At the Shobasama Site, investigations will be carried out for the improvement of various techniques, methods and equipment complementary to the research at the "MIU Construction Site" (see Appendix D). The purpose is to refine and develop techniques for investigation, analysis and assessment of the deep geological environment, one of the primary goals of the entire project, (Section 2.1). The work will be carried out utilizing research resources such as data on geological environment of the Tsukiyoshi Fault and its vicinity and the abundant borehole database.

Regarding the on going modeling of the geological environment based on surface-based investigations, an assessment of the relationship between the detail and type of investigation and the accuracy and applicability of the results can be done. Thus the models will be improved and the effectiveness of the investigation, analysis, and assessment methods will be verified.

Also, continuous monitoring of hydraulic pressure using existing boreholes will be carried out to assess the effect of shaft excavation at the "MIU Construction Site" on the geological environment.

The objective of investigations in the Shobasama Site will be in part to improve the modeling technology for the geological environment. The following investigations will be carried out:

- Methods for identifying and classifying permeable fractures,
- Techniques for geological model construction,
- Hydrogeological model construction based on long-term pumping tests and long-term groundwater monitoring,
- Hydrochemical model construction based on water sampling using MP system,
- Age dating of groundwater in the Toki Granite,
- Applicability of flow meter logging and
- Assessment methods of water infiltration into rocks.

The details are reported in Appendix D.

3.1.5 Planning the Phases II and III investigation

A detailed investigation plan will be prepared for Phase II, taking the information regarding the deep geological environment obtained in the Phase I and the various models into account. Investigation plans for Phase III will be revised if necessary.

The need and priority of the investigations will be examined. Investigations will be devised to evaluate the accuracy of models of the geological environment. Tasks to be carried out shown in the AEC assessment of the JNC's H12 Report [(10)] will also be considered. New investigation items will also be determined.

3.2 Phase II (Construction Phase)

Investigations and excavations during construction can conveniently be divided into two parts. The first part (Phase II-a) will be investigations carried out at the same time as construction of the Main Shaft and the Ventilation Shaft to the Middle Stage at about 500 m depth and horizontal development of the research galleries at this Stage. The second part, Phase II-b, will include investigations carried out simultaneously with excavation of the Main and Ventilation Shafts from the Middle Stage to the final depth at about 1,000 m. By dividing the investigations into two parts it will be possible to assess progress made in Phase II-a and, if necessary, improve the investigation, analysis, and assessment methods, modify the facility design and the engineering technology implemented by the time that Phase II-b commences. Also it will enable the evaluation of the applicability and effectiveness of the technology in different geological environments. The research in this Phase will be confined to the vicinity of the excavations; the shafts and any horizontal developments excavated such as Sub Stages. The research will be of smaller scope compared to the activities in Phase I, but the scale of investigation will be more detailed.

Data on the rock mass adjacent to the research gallery excavations will be acquired for the various geoscientific fields. Sub Stages (small research galleries) will be constructed from the Main Shaft for detailed geoscientific studies at locations where important features such as permeable fractures and fracture zones, and the boundary of oxidation-reduction zones are observed. The accuracy of the facility-scale models constructed in Phase I and therefore the effectiveness of analytical methods used in developing the models can be evaluated. Any changes to the geological environment, to the groundwater flow system or the rock mass, in response to excavation will be observed and studied. The rock mass characteristics in the vicinity of the research gallery extensions will be estimated and gallery-scale models will be constructed based on the new data. .

The details of the investigations performed in Phase II will be revised, if necessary, based on new data and knowledge. It will be particularly important to consider the investigations and results acquired during Phase II-a on the detailed investigation plan of Phase II-b.

The range of research activities to be performed and problems to be solved in Phase III will be identified in this Phase. Scoping of research activities will be used to determine the potential for meaningful studies in the deep geological environment and the investigation plan in Phase III will be detailed. As well, the effectiveness of the engineering technologies to be implemented; construction, maintenance and management of the research galleries, will be evaluated and improved.

3.2.1 Goals

The goals of the Phase II are as follows (Section 2.2).

① **Develop and revise the models of the geological environment using the investigation results obtained during excavation and determine and assess any changes in the deep geological environment in response to excavation**

② **Evaluate the effectiveness of engineering techniques used for construction, maintenance and management of underground facilities**

③ **Establish detailed investigation plans of the Phase III**

3.2.2 Overview of the Phase II investigations

The overview of the investigations expected in the various geoscientific fields to address the first two objectives are outlined in this section. Details are provided in Appendix B. The studies in all disciplines provide great potential to make significant advances to understanding of the subsurface geological environment in Japan.

(i) Geological investigations

The geology in the vicinity of the shafts and research galleries will be determined and the observations compared to the predictions made in Phase I. Thus the geological model (facility-scale) constructed in Phase I will be evaluated using the knowledge acquired from the investigations such as mapping and photography of shafts and gallery walls – details of lithologies and structures and subsequent analysis and borehole drilling from the research galleries. Then the facility-scale model can be revised using the new data in order to improve the representation of the geology in the vicinity of the research galleries. These predictions will form the basis of the geological model at gallery-scale, to be investigated and evaluated in Phase III.

(ii) Hydrogeological investigations

Changes to the groundwater flow system in response to excavations of shafts and research galleries is important to determine and understand. Therefore, observations of groundwater table and hydraulic pressures in existing boreholes with multi-piezometer completion systems will provide needed information. Monitoring and collection of groundwater seepage into the shaft will be done. As excavation progresses new boreholes can be drilled from the research galleries for characterization of hydrogeological conditions (hydraulic testing), monitoring purposes and subsurface hydrogeological experiment activities.

As a result, hydrogeologic characteristics of the major geological units, structural discontinuities and the intact part of the Toki Granite will be determined in more detail. Also, the drawdown of the hydraulic head in response to shaft excavation will be known. The new understanding derived from the above measurements and their analysis can be compared with the predictions made in Phase I and as a result, the appropriateness of the facility-scale hydrogeological model and the associated predictions, including methods used to develop them, will be assessed. The model will be revised on the basis of these results and the hydrogeological characteristics of the rock mass and the induced changes to the groundwater flow system caused by excavation will be better understood.

Based on the new data and understanding, hydrogeological models at the research gallery-scale will be constructed. Groundwater flow and seepage in the vicinity of the research galleries will be estimated based on this model. Also, changes to the groundwater flow system in response to research gallery expansion will be studied using the gallery-scale model.

(iii) Hydrochemical investigations

New data on the hydrochemistry of the groundwater will be available from groundwater discharge collected in the shaft excavations and from new boreholes in the research galleries. Three-dimensional distribution of the hydrochemical characteristics of the groundwater and water chemistry evolution can then be studied in detail. The appropriateness of the facility-scale hydrochemical model developed in Phase I and the analytical methods to do so will be assessed by comparison of the new data with the predictions made in Phase I. The hydrochemical model will be revised in accordance with the results of the comparison and with the improved understanding of the site from the geological and hydrogeological research. If changes to the hydrochemical characteristics occur, for example depression of the redox front in response to excavations, it may be possible to understand the reason (s) for changes and evolution of the system.

From the above, a hydrochemical model(s) at gallery-scale will be constructed. This model will be used for estimating the hydrochemical characteristics of the groundwater at depth. Also, potential changes of the hydrochemical characteristics of the groundwater caused by the excavations can be estimated using this model.

(iv) Rock mechanical investigations

Mechanical behavior of the host rocks in the vicinity of the shafts and the research galleries, mechanical properties of the rocks affected by the excavation, and the in situ stress conditions will be determined by field and laboratory studies. The predictions made in Phase I of deformation, stress changes and the extent of damage caused by concentration of stress in the vicinity of excavations will be determined. The appropriateness of the rock mechanical model at the facility-scale and the analytical methods will be assessed. These results will be reflected in the revision of the rock mechanical model (facility-scale). This research will help in the development of fundamental understanding of any changes of the rock mass mechanical characteristics in the vicinity of the research galleries and in future modeling activities.

A rock mechanical model at the gallery-scale will be constructed and revised as new data become available. This model will be used for estimating the rock mechanical characteristics of the research galleries and their vicinity. The model will also be used for estimating the deformation behavior and stress changes of the rocks caused by expansion of the research gallery. This research also provides fundamental knowledge of rock mass conditions needed to develop research gallery designs and for safe excavations in the underground, in terms of layout and construction safety and ground control measures.

(v) Mass transport investigations

In preparation for mass transport research in Phase III, data on pore structure, sorption and dispersion as well as the geochemical and mineralogical characteristics of the geological units will be evaluated by laboratory tests of drill cores and samples obtained from excavation walls. The data set, augmented with data obtained during Phase I, will be prepared for assessing mass transport pathways and controls in the Toki Granite. Also, in this Phase and the next, the geologically long-term mass transport and retardation potential of the geological system will be assessed using natural nuclides present in the site.

(vi) Investigation techniques and equipment

Investigation techniques and equipment considered necessary for Phase III will be determined and procured and/or developed in this Phase. Requirements for investigations will be accuracy and investigation capabilities within confined space. The applicability of conventional technology will be assessed and will be improved together with new technological innovation, if necessary. The application of these techniques and equipment in different geological environments will be considered and their limitations determined.

(vii) Investigations on engineering technology in the deep underground

The engineering technology in this Phase will be mainly for the assessment of the design process and construction planning completed in Phase I. The assessment will be done using the results of research gallery excavation and changes in design. The system will be established by which the results of the above assessment will be used to improve the detailed design and construction plans.

In cases when the actual geological environment differs significantly from the expected, for example when unexpected geological features of significant scientific research interest are encountered, when unexpected phenomena occur, or if the geological environment is significantly disturbed by research gallery excavation, design changes should be possible and countermeasures should be done effectively. By being able to do so, the effectiveness of design and construction technology will be assessed. Furthermore, engineering technology will be examined for assuring engineering quality and predicting changes in the geological environment that influenced designs. Also technical development regarding maintenance and management of the research galleries and safety will be done.

3.2.3 Planning the Phase III investigations

Once Phase II has begun, the preliminary investigation plan for Phase III prepared during Phase I will be assessed and revised, based on more detailed knowledge of the actual geological environment in the vicinity of the excavations being developed during construction. This will be done by considering the priority of investigations scoped in Phase I and refining the content of the research activities. The investigation results carried out in Tono and Kamaishi Mines and problems to be solved and the items laid out in the AEC assessment report [10] of the JNC's H12 Report will also be considered. For example, design issues relevant to an eventual repository that are dependent on site conditions will be considered.

3.3 Phase III (Operation Phase)

This Phase will proceed in two steps similar to Phase II. The first half (Phase III-a) will be the investigations at the Middle Stage and the second half (Phase III-b) investigations at the Main Stage. As mentioned in Section 3.2, this plan will allow performance of similar investigations in different geological environments. Basically the target of the investigations will be the geological environment in the vicinity of the research galleries, as in Phase II. But geoscientific studies deeper than 1,000 m will also be planned using boreholes drilled from the research galleries.

Understanding the various phenomena that are expected to occur, especially the effect of research gallery excavation on the rock mass and flow system, and the response to earthquakes together with determination of the characteristics of the deep geological environment will be investigated in this Phase. The accuracy of predictions of the geological environment will be assessed together with the models of the geological environment (gallery-scale and facility-scale, if necessary). The effectiveness of the method used for analysis will also be evaluated. The results of this assessment will be used for improving the investigations, analysis and assessment methods for future applications. Also of importance in this Phase is developing an understanding of the various phenomena and processes that occur or are operational deep underground. As in the previous Phases, investigation processes will be repeated and the importance of the items to be assessed will be clarified. The correlation between the investigations performed, the type and the detail relative to the accuracy and applicability of the results should be shown. Finally the investigative, analytical and assessment methodologies considered or determined to be most useful and accurate for understanding the subsurface geological environment will be documented.

Regarding engineering technology, the effectiveness of the technology for long- term maintenance, and ensuring safety within the facility will be verified in practice, through maintenance and management of the research facility. At the same time, engineering technology for restoration and mitigation of excavation effects on the geological environment will be developed in future, if necessary.

The research plan to be performed at each research Stage, the Main, Middle and Sub Stages will be examined and revised as the excavations and research progress. The plan shown below in Section 3.3.2, Overview of the Phase III Investigations is an interim one.

3.3.1 Goals

The goals of the Phase III are as follows (See Section 2.2).

① **Revise and improve models of the geological environment using the results of the underground investigations and determine any change in the deep geological environment in response to the research gallery extension**

② **Evaluate the effectiveness of engineering techniques used for deep underground**

3.3.2 Overview of the Phase III investigations

The overview of the scientific investigations anticipated in the various geoscientific fields intended to achieve the above objectives will be outlined in this section and reported on in more detail in Appendix C, along with some concepts for experimental activities.

(i) Geological investigations

The geological activities will encompass a variety of activities:

- Continued geological characterization
- Develop and improve analytical methods
- Model assessment, evaluation and improvement
- Synthesis activities and integration with other disciplines

One of the principal activities will be detailed mapping of all excavation walls during expansion of the research galleries with associated analysis of all data obtained. The drilling of 1,000 m-deep boreholes from each Stage also requires detailed core logging, and associated analysis of all data obtained. From these activities, the geology and geological structures in the vicinity of the research galleries and to a depth of about 2,000 m will be determined in detail. Also, the gallery-scale geological model constructed during Phase II will be assessed by comparison with the geological observations. This model will then be revised and improved based on the results of the assessment. The geological model at facility-scale and those in the other disciplines will all be improved.

(ii) Hydrogeological investigations

Hydrogeological properties of the intact part of the Toki Granite and the major geological units near the research galleries will be determined by observation of hydraulic pressure heads, water inflows (seepage) into the research galleries during and after gallery expansion, pore pressure in selected zones and by hydraulic tests in boreholes excavated from the research galleries. The hydrogeological models at gallery-scale constructed during Phase II and the analytical methods to develop them will be assessed by comparison between measured data and the results of the estimation. The models will be revised and the boundary conditions re-examined. As a result, accuracy of the groundwater flow analysis and the facility-scale model can be expected to improve. Experiments will be developed for hydrogeological purposes. Careful consideration will be given to the high fluid pressures expected and the impact on design. Experimental activities in other disciplines will also require hydrogeological support.

(iii) Hydrochemical investigations

Groundwater samples from boreholes and from seepage inflow points will be analyzed for a wide range of chemical constituents and properties. The 3-D chemical distribution of groundwater and possibly the changes caused by research gallery excavation (e.g. changes in redox conditions in zones affected by excavation) will be studied in detail. Also, the hydrochemical model (gallery-scale) constructed during Phase II and the analytical methods will be assessed by comparison with the new data. The model will be revised based on the results of the assessment. The models for various scales will be improved on the basis of newly obtained data.

(iv) Rock mechanical investigations

Shafts and research galleries will be excavated in different geological environments; in rocks with variations in degrees of fracturing, in proximity to faults and possibly dykes and with variations in mechanical properties and in situ stress conditions (magnitudes and direction). The rock mechanical conditions will have a strong influence on rock mass stability and hence on gallery design and layout.

The rock mechanical model at gallery-scale constructed during Phase II will be assessed by comparison with the new data. Displacement measurement in the research galleries will be continued, and the long-term stability of the rock mass in the vicinity will be assessed. Also, rock stability questions such as rock bursts and development of an excavation-disturbed zone (EDZ) will be addressed. The model will be revised on the basis of these results and the accuracy of analysis of mechanical behavior of the rock mass will be improved. The models at various scales will be improved on the basis of the new data. Rock mechanical experiments will be developed.

(v) Mass transport investigations

Mass transport pathways and retardation processes in the Toki Granite will be assessed by laboratory tests of drill cores. A mass transport model (gallery-scale) will be constructed on the basis of the knowledge on geology, hydrogeology, hydrochemistry, and the results of the investigations using natural nuclides. Tracer tests and other tests will be carried out in order to understand mass transport and retardation within the Toki Granite and the model will be evaluated and revised. Furthermore, data regarding colloids, organic material and role of microorganisms will be obtained to understand mass transport and retardation processes in granite.

(vi) Investigations on engineering technology in deep underground

Technologies for long-term maintenance of the research galleries and of the environment in the research galleries will be verified. A management system for construction and quality control will be organized, and technical development regarding maintenance and management of the research gallery and safety will be carried out. At the same time, engineering technology regarding restoration and mitigation of the excavation effects on the geological environment will be considered and developed if necessary.

(vii) Earthquake observation

Seismometers and flow meters will be installed at various depths of the research gallery, and seismic activities and changes to the deep geological environment associated with earthquakes will be observed. Using these data, the effect of earthquakes to the research gallery and the deep geological environment will be assessed.

4 Overview of the facilities of the MIU

Facilities at the MIU are comprised of shafts, research galleries and ground facilities. The overview of these facilities is as follows.

4.1 Research galleries

The design of the research galleries will be based on the investigation plans of Phases II and III. Research activities will be located appropriately as Phases II and III progress. The following information will be considered; data on the deep geological environment obtained by surface-based investigations, characteristics of the geological environment around the research galleries and conditions of geological environment estimated from the above. A conceptual layout is shown in Figure 3.

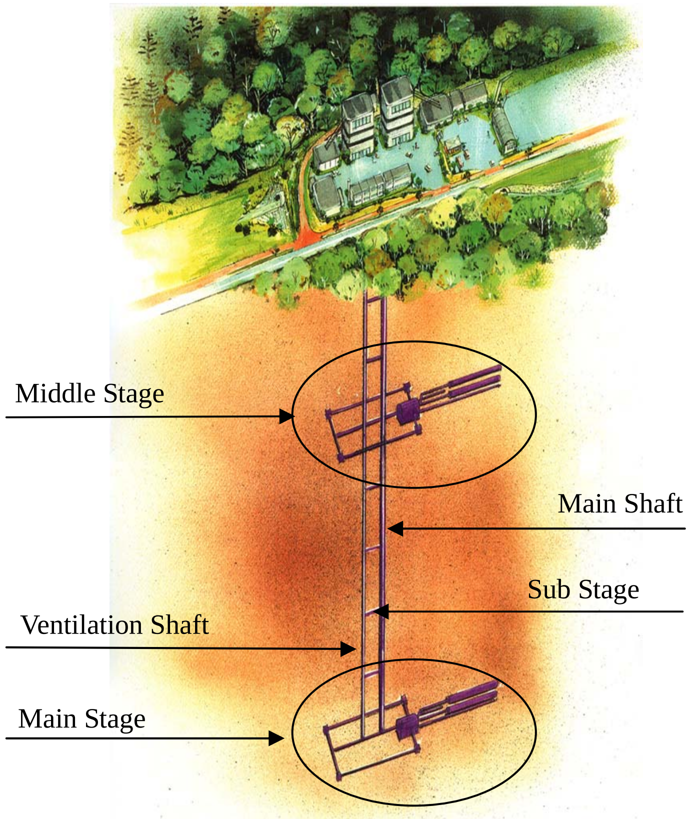
Past studies at the Shobasama Site and for the RHS Project confirm the presence of rock with variable geological characteristics such as variations in fracture density and lithofacies in the Toki Granite [(13)]. Thus it is considered likely that similar variations in geological conditions can occur at the “MIU Construction Site”.

Therefore, the principal research levels, the Middle and Main Stages will be located in two different geological environments, as shown in the layout (Figure 3). Also, the Main and Ventilation Shafts will be excavated and Sub Stages will be constructed approximately every 100 m to connect the two Shafts. Also, by planning to duplicate the Middle Stage investigations at the Main Stage, it will be possible to make incremental improvements in the technology for investigation, analysis, assessment and engineering, prior to the second round of investigations at the Main Stage. Also, it will be possible to evaluate and to demonstrate the effectiveness of the technologies under different geological environments.

This draft layout will be revised as new data on deep geological environment is obtained at the “MIU Construction Site”.

4.2 Ground facilities

The ground facilities will consist of an excavation tower containing the shaft derrick mast for excavating the shaft, hoisting device room, facilities for effluent treatment and water supply, ventilation equipment, concrete-mixing plant, electricity distribute facilities, emergency generating station, instrument storage, joint venture office and MIU construction offices.



The shape and arrangement of facilities are subject to change.

Figure 3　Layout of the ground facilities at the "MIU Construction Site"

5 Management of the MIU Project

5.1 Organization

The organization for implementing the MIU Project will be formed at each Phase. In Phase I, the MIU Project will be carried out with close cooperation between the group responsible for overall management of the planning and coordination of the investigations and the group responsible for executing investigations. In addition to these groups, a group responsible for the designing and construction management was established in preparation for Phase II. TGC will continue to organize itself in accordance with the progress of the Project. Also, the progress of the Horonobe Underground Research Project [19] must be considered and technical cooperation among the various sections of the TGC and JNC Head Office will be strengthened.

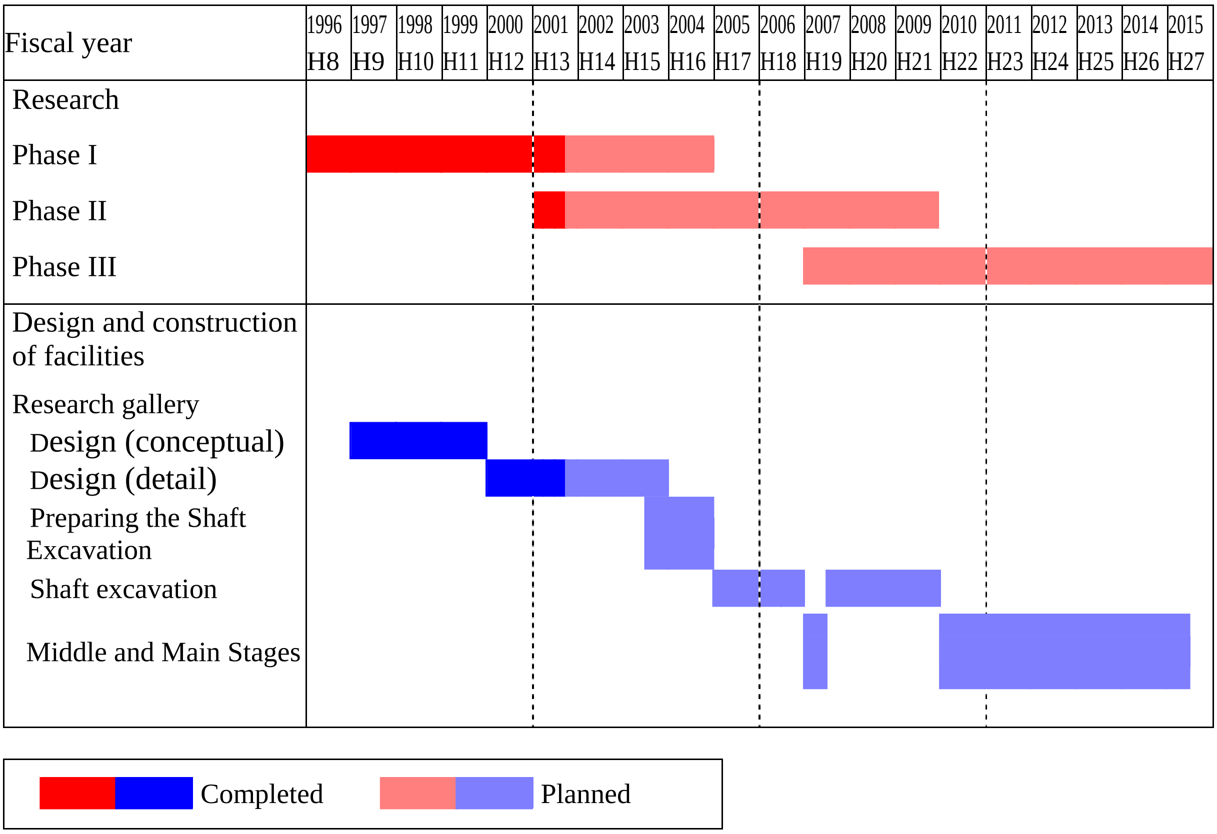
On the other hand, in order to implement the Project efficiently and to attain high scientific and technical level, it will be necessary to obtain external expertise. For this purpose, the “Evaluation Committee of Subjects on Research and Development” has been assessing plans and implementation of investigations in the Phase I and investigation plans in the Phase II [20, 21]. Also, an “Assessment Subcommittee on Underground Facility of the MIU Research Program” was founded in March 2000. The results of investigations up until the 2000 FY and investigation plans for the 2001 FY were assessed by this committee. These committees will be convened periodically. As well, the results of the investigations will be presented at various domestic and overseas scientific meetings.

The geoscientific studies at the MIU will cover a wide range of basic scientific fields including geology, hydrogeology, hydrochemistry, and rock mechanics. Also, it must employ highly sophisticated civil engineering technology. Thus cooperation from domestic and overseas scientific institutions and universities is a must. So far, international collaboration with Nagra (Switzerland) and SNL (U.S.A.) have been successfully carried out, and International Fellows from SKB (Sweden), BGS (U.K.) and AECL (Canada) have been invited to the TGC. This cooperation will be strengthened in the coming years. Also, as underground space is increasingly used for storing material and for human activities, the MIU will not only be used as a research facility of JNC, but will be open for studies by outside institutions. Also, MIU is planned to be a facility open to the public during construction; careful consideration of safety must be made. Also, use by young students for their studies is on the drawing board.

5.2 Schedule

Basically in the MIU Project, planning and implementation of the investigations and assessment of results will be carried out in each Phase. The total duration of the Project is about 20 years and the schedule is shown in Table 1. This schedule will be reviewed and revised in accordance with changes of the investigation plan in each Phase.

Table 1 Schedule of the MIU Project



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Appendix A

Investigation plan at the “MIU Construction Site”
- Phase I (Surface-based Investigation Phase) -

1 Overview

In Phase I, a variety of surface-based investigations will be carried out to obtain detailed information on the geological environment prior to the construction of research galleries at the MIU Construction Site. Surface-based investigations include geological investigations, geophysical surveying and surface hydrological investigations. Several shallow boreholes and a 1,350 m long deep borehole will be drilled for core sampling, borehole geophysics, hydraulic and mechanical testing to obtain detailed information on the deep geological environment. In addition, laboratory tests on rock cores will be carried out.

Based on the information obtained through these investigations, from knowledge of the local geological setting for the Shobasama Site and for the more extensive area of the RHS Project, facility-scale models will be constructed to represent the current understanding of the geology, hydrogeology, hydrochemistry and rock mechanics. Furthermore, based on these models, the character of the geological environment will be predicted prior to the excavations.

Based on the data obtained through these investigations, a detailed investigation plan for Phase II and an outline of the investigation plan for Phase III will be prepared. A detailed layout of the research galleries will be drawn up. In addition, construction techniques, equipment and facilities will be selected in order to develop a detailed construction plan. Proper consideration will be given to minimizing adverse construction and excavation effects on the undisturbed geological environment and conditions. Furthermore, the deployment of observation and monitoring equipment will be done to effectively detect any changes in the geological environment due to excavation.

The goals of this Phase are as follows:

① Construct models of the geological environment from all surface-based investigation results that describe the geological environment prior to excavation and predict excavation response

② Establish methodologies for evaluating predictions

③ Formulate detailed design concepts for underground facilities and to establish detailed plans of the Construction Phase

Following revision of the original investigation plan, Phase I was divided in two; Phase I-a (1996 to1999), gave priority to understanding the properties of the geological environment in the Shobasama Site, and Phase I-b (2000 to 2002), was intended to synthesize the results of investigations in the respective geoscience fields [(1)]. So far, Phases I-a, and I-b investigations for the individual geoscience disciplines were carried out as planned in the Shobasama Site [(2)]. Utilizing and building on the results of the investigations carried out in the Shobasama Site, Phase I will be continued at the MIU Construction Site, Akeyo-cho, Mizunami City.

2 Synopsis of investigation results from the Shobasama Site

As noted above Phase I investigations began at the Shobasama Site in 1996. These investigations were divided into parts; Phase I-a and Phase I-b. The data and understanding developed from these investigations provide background and planning information for the MIU Construction Site.

The Phase I-a priority was to determine the properties of the geological environment in the Shobasama Site, To do so, multidisciplinary investigations were carried out:

- Geophysical surveys, such as electromagnetic and reflection seismic,
- Surface hydrological investigations for water balance determinations,
- Drilling of three boreholes each 1,000 m-deep (MIU-1, 2 and 3),
- Detailed core logging, associated laboratory studies and data analysis,
- Hydraulic testing to determine hydrogeological properties
- Mechanical tests in the boreholes to determine in situ stress state,
- Laboratory tests of rock core
- Long-term observation of pore-water pressure in the boreholes drilled prior to the MIU Project.

Using the information obtained in Phase I-a, geology, hydrogeology and hydrochemistry and rock mechanics models have been constructed to verify the applicability of investigation and analytical techniques [2, 3].

In Phase I-b the MIU-4 borehole was drilled, (inclined 60° to NE and 790 m long), geological and geophysical logging, hydraulic and mechanical testing, water sampling and laboratory tests of rock cores collected from the borehole were done.

2.1 Geological investigations

Two geological models were constructed. The first model was based on existing data including the data obtained from the boreholes AN-1 and AN-3 drilled before the MIU Project commenced. For this model the existing data on the distribution of rock types and fractures was restricted to the southern part of the site; that is, only around these boreholes. This was considered too restricted to estimate their spatial distribution and continuity. As a result, the Toki Granite could only be divided into two parts: the weathered zone and the rest of the rock mass.

The second model was built with data from new boreholes drilled for the MIU Project (MIU-1, 2 and 3) [2] (Figure A-1). With the new information the Toki Granite was divided into two facies; Biotite granite and Felsic granite and three structural domains; the “Upper fracture zone,” the “Moderately fracture zone” and the “Fracture zone along the fault”.

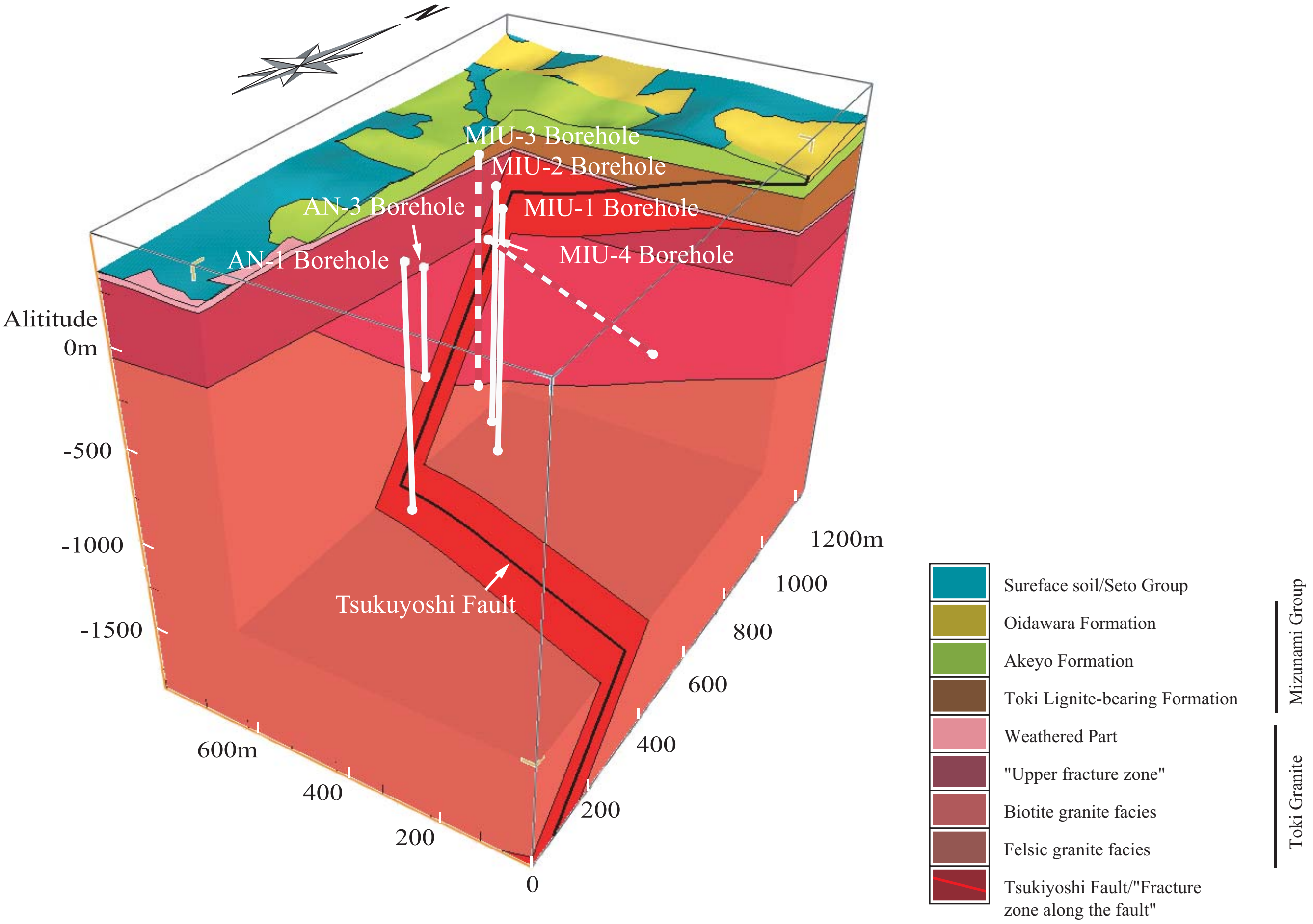

Figure A-1 Geological model in the Shobasama Site

The elements of the geological model are represented in Figure A-1.

In Phase I-b, drilling MIU-4 confirmed the understanding presented in the Phase I-a conceptual geological model. Depth of the unconformity between the Mizunami group and the underlying Toki Granite, distribution of the weathered part of the granite, and the Tsukiyoshi Fault expressed in the geological model were confirmed within 20 meters. Furthermore, new faults, which were not expressed in the existing model have been identified. Fracture analysis, including classification of highly permeable fractures (zones) and the frequency of their intersection with boreholes, will continue.

2.2 Hydrogeological investigations

In Phase I-a, surface hydrological investigations included determination of meteorological parameters in the Shobasama area to estimate the recharge rate, an upper boundary condition requirement for groundwater flow simulations. As a result, it was estimated that the recharge rate can range from several percent to slightly more than ten percent of the precipitation.

Hydrogeological investigations, including hydraulic tests in the MIU-1, 2 and 3, have determined the potentiometric surface in the Shobasama Site and hydraulic properties of the geological and structural units. Construction of the conceptual hydrogeological model and the numerical groundwater flow simulation model (several kilometers square including the Shobasama Site) were carried out using two data sets:

- Data predating MIU Project investigations, including 2 deep boreholes AN-1 and AN-3
- MIU-1, 2 and 3 borehole data with the above pre-existing data.

The objective was to compare two groundwater flow simulations. The first used the hydrogeological model based on pre-MIU data, without structures. The second used the revised model with all data and included structures within an equivalent continuum model. The results from the second indicated that anisotropic drawdown would occur during gallery excavation along the preferential trend of permeable fractures. Therefore, it is thought that the actual flow of groundwater could be simulated by the above continuum model, with structural discontinuities included, in groundwater flow simulations of areas hundreds of meters to several kilometers square.

Furthermore, in order to study the effect of uncertainty, primarily due to insufficient data for the model region, groundwater flow simulations were carried out using different hydrogeological modeling approaches from continuum to discrete fracturing [4].

2.3 Hydrochemical investigations

Sampling and chemical analysis of the groundwater was only possible in MIU-4 at the Shobasama Site. The analysis indicated that the MIU-4 groundwater from the hanging wall of the Tsukiyoshi Fault is weakly alkaline (pH≒9 to10) and of Na^+-HCO_3^- type. The redox potential is not apparently depth dependent, showing wide variations (Eh: -300 to 0 mV).

According to analysis of rock samples from MIU-1, 2 and 3, the Fe^{+3} / Fe^{+2} ratio is greater than 1 above 300 m depth, while it is less than 1 (more reduced) below 300 meters, indicating that the redox boundary could be around 300 meters depth in the Shobasama Site.

2.4 Rock mechanical investigations

The physical properties of the Toki Granite in the Shobasama Site were determined by laboratory analysis to have a range in values: uniaxial compressive strength ranges from 100 to 200 MPa and Young's modulus from 30 to 60GPa. The physical property values change at depths of about 300 meters and 700 meters, the depths at which the fracture density distributions change [(5)].

Concerning in situ stress, the vertical pressure gradient measures about 0.026～0.027 MPa/m. The minimum principal horizontal stress is nearly equal to the vertical stress; the maximum principal stress is about 1.5 to 2 times the minimum principal stress. The maximum and minimum horizontal stresses show a change at a depth of about 300 meters and 700 meters. The maximum horizontal stress trends N-S near the surface, whereas it trends NW-SE at about 300 m depth. The NW-SE direction is considered representative of the regional stress. It corresponds to the maximum compressive strain direction in the Tono area obtained by triangulation using the surface-based, regional strain monitoring network covering large parts of Japan [(6)].

The rock mechanics conceptual model was improved by adding data stepwise to enhance the understanding of mechanical properties of the rock mass. The present understanding is that the Toki Granite can be divided into three zones:

- Surface to about 300/400 meters depth,
- About 300/400 meters to about 700 meters depth, and
- About 700 meters to 1,000 meters depth,

These differ from each other in mechanical properties (physical properties, deformational properties, strength) and in situ stress state.

2.5 Investigation techniques and equipment

Major developmental work on investigation techniques and equipment in Phase I-a are as follows:

- Borehole investigations
  - Drilling system using reverse aerated wire-line method to minimize borehole collapse.
  - Partial casing insertion equipment to cope with partial collapse of boreholes.
- Geological investigations

  Nondestructive seismic source (sparker) for seismic tomography between boreholes [7].
- Hydrogeological/hydrochemical investigations

  Hydraulic test equipment, chemical probe, pumping test equipment and long-term pressure monitoring system; applications to 1,000 m depth and high temperature (70℃) [8, 9, 10, 11].
- Rock mechanical investigations

  In situ stress measuring equipment designed and partially manufactured.
- Techniques and equipment for use during and after Phase II

  Continuous-wave radar investigation techniques [12] and analysis method for tomographic data,
- Techniques and equipment for efficient data management and model construction

  Database and data analysis/visualization system were constructed and utilized.

2.6 Engineering technology for deep underground

The research activities for Phases II and III were selected in consideration of the previous domestic and foreign research and on the requirements of the Atomic Energy Commission of Japan [13]. As well, the procedures for excavation and the design process to develop the specifications of the research galleries were examined [14]. The layout of the research galleries was drafted based on the knowledge of the deep geological environment obtained at the Shobasama Site and the construction plan of the research galleries were prepared on the basis of this draft layout [13, 15]. The design should also consider the research objectives and requirements of the research plans to be developed for Phases II and III.

3 Overview of the investigations in Phase I

The overview of investigations in each field and synthesis of the investigation results of Phase I to be carried out for characterization of the MIU Construction Site are described in this section. The synthesis will be carried out to achieve the three Phase I goals of the project and the overall goals of the MIU Project.

The research carried out during Phase I will follow the investigation strategy described earlier, in the Overview, which is to continue with the following process:

- Basic concept → Plan → Investigate → Analysis and modeling → Evaluate → Revise

In doing so, existing and newly developed investigation, analysis and evaluation methods and equipment can be applied.

Investigations in the various geoscience fields are carried out from surface at the MIU Construction Site. However, various limitations could be imposed on the activities: limitations such as borehole location and investigation methods together with restrictions on the number of boreholes, drilling depth and duration of the investigations. Therefore, with such constraints imposed, high accuracy must be targeted and achieved and reasonable and effective implementation of investigations is required.

3.1 Synthesis of the investigation results

Synthesis of results is important to ensure usefulness and completeness of the data for all end users. The data and knowledge of the geological environment from surface to the deep underground of the MIU Construction Site will be summarized for each research discipline. At the same time, conformity and consistency of results will be ensured by discussions, interpretations and feedback across disciplines. Construction of models of the geological environment will be carried out on the basis of synthesized results; in this way comprehensive understanding of the deep geological environment of the study area will be facilitated and demonstrated.

Individual methods used for investigation from the surface and their effectiveness will be assessed. The systematic process for evaluating the geological environment will be implemented with resultant acquisition of quality controlled and assured data and the application of useful analytical and assessment methods. During this process, research targets to be investigated at the MIU Construction Site will be determined, and the relative importance of these items clarified. And, at the same time, the type of investigations to be performed can be assessed in terms of the usefulness and accuracy of the results required and the data requirements needed to attain the level of accuracy. Thus the methods of survey, analysis, and evaluation for assessing the deep geological environment will be prepared.

The investigation plans for Phases II and III and the detailed designing of the research galleries will be a major output of Phase I and provide demonstrated application of the research results from the surface-based investigations. During the surface-based investigations, the following are considered; what data is acquired and is it necessary. If so, is it sufficient, are methods of data acquisition and analysis appropriate and sufficient, how should inter-disciplinary interpretations and modeling be done? As a result, the extent of the understanding of the geological environment will be assessed and predictions made.

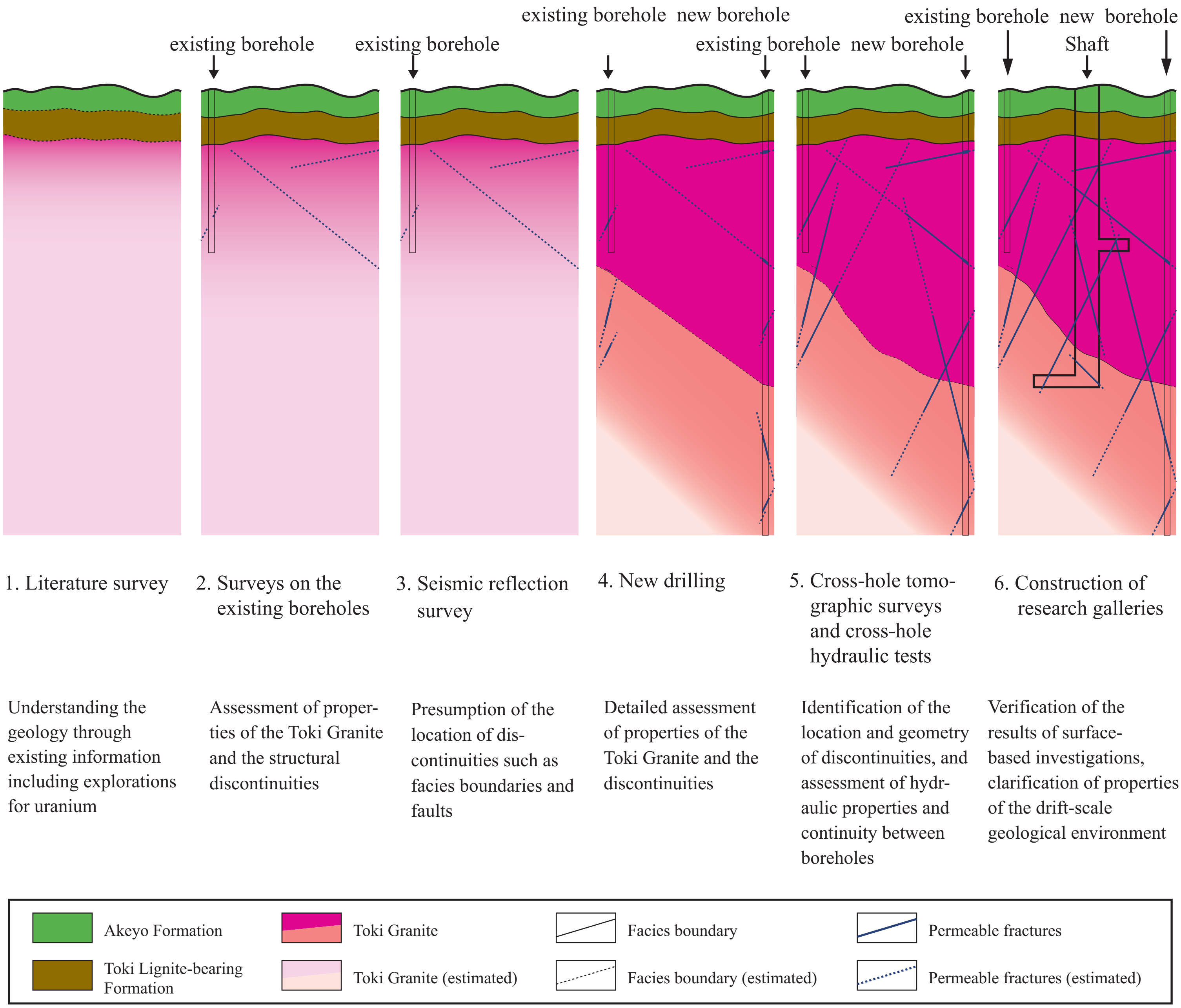

Figure A-2 Procedures for research during Phase I at the "MIU Construction Site" (Concept)

3.2 Geological investigations; MIU Construction Site

3.2.1 Objectives

The objectives of the geological investigations are understanding geology and geologic structures at the MIU Construction Site, identifying geological units expected to control the hydrogeology and chemistry of groundwater, and to construct geological models at facility-scale.

3.2.2 Investigations

The geology of the MIU Construction Site will be determined by various methods including ground geophysical surveys (reflection seismic survey), borehole investigations using shallow and deep boreholes including core logging and analysis, borehole geophysics, BTV surveying, VSP survey, cross-hole tomography and laboratory tests on drill cores. Of particular importance will be clarification of the distribution and characteristics of the geological units considered to control the flow and chemistry of groundwater such as lithofacies, weathered zones, alteration zones, permeable fractures, faults, and dikes. Also the oxidation-reduction zones will be investigated by laboratory drill core studies and groundwater sampling/analysis. These investigations will start with the construction of the geological model (facility-scale) using existing data on the Toki Granite. The appropriateness of the model will be assessed and the model will be revised repeatedly during the investigation (Figure A-2). Finally the 3-D geological model for the MIU Construction Site will be constructed.

(i) Acquisition of the data on geology and geologic structure

・Ground geophysical survey

Reflection seismic surveying will be carried out at and around the MIU Construction Site to locate and develop 3-D information on geological structures. Results will be used for the construction of a geological model (facility-scale) and to provide indications of the subsurface geometry of structures as an aid to determining the location of boreholes. The location of the survey lines will be determined based on consideration of the existing data (existing geological maps, lineament interpretation, known or suspected faults and fracture location.). In addition, VSP investigations will be carried out in the existing and new boreholes. These data will be used for the construction of a geological model at facility-scale.

In addition, ground geological surveying will also be carried out at the site.

・Borehole investigations

Several new boreholes are planned; four shallow boreholes (MSB- Series) to obtain data on the sedimentary rocks and shallow parts of the granite and a deep, 1350 m long borehole (MIZ-1) to investigate the deep geological environment at the site. Borehole investigations include detailed core logging, borehole geophysical surveying and BTV investigations in the new boreholes, as well as petrological, mineralogical and geochemical characterization. In the existing borehole, DH-2, re-logging of core, new borehole geophysics and BTV investigations will be carried out. In addition, VSP investigations will be carried out in the existing and new boreholes. These data will be used for the construction of a geological model at facility-scale.

・Cross-hole tomography survey

Two adjacent boreholes (the existing DH-2 borehole and one of the new boreholes) will be selected to carry out a cross-hole seismic tomography survey to obtain geological and rock mass data (particularly on the continuity of geology and geologic structures intersected by the boreholes) for the construction of a geological model (facility-scale).

(ii) Development of a geological model (facility-scale)

A facility-scale geological model will be developed for representing the spatial distribution of geological units and structures that are expected to control the flow and chemical evolution of groundwater. This model will form the basis of the hydrogeological model at the same scale. In developing the model it will be necessary to clarify the varieties and the scales of geological units to be considered. A 3-D visualization method is very useful to this exercise.

Initially in this Phase, a geological model will be constructed on the basis of the existing data. As new data is generated, the model will be revised. New interpretations are possible based on the results of the ground geophysical surveying, the new borehole investigations and cross-hole tomography survey results. Furthermore, oxidation-reduction fronts, determined by laboratory tests using rock cores and groundwater analysis will be included in the geological model (facility-scale).

The facility-scale geological model will represent the undisturbed deep geological environment prior to the excavation of shafts and research galleries. Its accuracy will be assessed on the basis of the observations during excavation.

(iii) Synthesis in the development of investigation, analysis and assessment technique

The techniques used and the data generated from the geological research program at facility-scale will be assessed iteratively by following the investigation process of basic concept definition, planning, investigation, analysis and modeling and evaluation, as outlined in the Overview Chapter 2.

In this process, the level of research detail, the data requirements and the type of investigations to perform would be evaluated in terms of the usefulness and accuracy in characterizing the geological environment and assessed in planning the investigations to perform. With this understanding, the scope of the surface-based geological investigations can be determined.

Once the data has been obtained, it is assessed in terms of usefulness to describing the geological environment. To do so the data from the various geological studies are integrated in a systematic data synthesis process. This process consists of analysis of the data, assessment of the data reliability and integration into a geological model to describe the geological environment. Thus, by the end of Phase I, the geological environment will be described in geological models at the facility-scale based on data from all the geological investigations. The model will be used for planning other site investigations and as the foundation for models in the other disciplines.

In addition, through the above process, the techniques used for investigation analysis and assessment of the geological environment will be assessed in terms of their applicability and accuracy and improvements made as necessary.

3.3 Hydrogeological investigations

3.3.1 Objectives

The objectives of the hydrogeological investigations are to develop knowledge of the hydrogeological properties of the geological units in the facility-scale geological model at the MIU Construction Site and from this understanding, to construct the hydrogeological model. This hydrogeological model will represent the understanding of the hydrogeological conditions expected at the site prior to excavation. Changes to the groundwater flow system in response to shaft sinking will be predicted based on this understanding.

3.3.2 Investigations

Hydraulic tests in boreholes (single hole tests and cross-hole hydraulic tests) and hydrological investigations will be carried out for the development of the hydrogeological model at the facility-scale. This model will be based on the hydraulic continuity and hydrogeologic characteristics determined for the geological units in the facility-scale geological model. Also, this hydrogeological model will be used for the prediction of initial hydrogeological conditions at the MIU Construction Site before excavations and as a basis for the mathematical model for groundwater flow simulations. Changes of the groundwater flow caused by the excavations (discharge into the research galleries, changes of groundwater pressure in the vicinity of the research galleries, etc.) will be estimated using this model. The results will be used for detailed design of the research galleries and most importantly, development of the investigation plans for Phases II and III.

(i) Acquisition of data on the hydrogeology

・Shallow hydrogeological investigations

Borehole investigations will be carried out in new, shallow boreholes (to about 200 m vertical) to determine the hydrogeology in sedimentary rocks and the shallow, upper parts of the granite. In addition to the previously stated geophysical logging, BTV investigations and detailed core observation, carefully designed hydraulic testing (single-hole pulse, slug and pumping tests in single and double packer configurations, with groundwater sampling) will be carried out in the new boreholes. Subsequent to these investigations, multi-piezometer packer systems (MP System) will be installed for continuous monitoring of groundwater pressure and sampling. These boreholes will be used to monitor changes caused by shaft and research gallery excavations in Phases II and III.

・Deep hydrogeological surveys

The deep hydrogeological surveys will consist of detailed investigations in an existing borehole at the site (DH-2) and drilling of a deep borehole to below the depth of the Main Stage level. Hydraulic testing (single-hole hydraulic tests- pulse, slug, pumping) will be carried out to understand the hydrogeology prior to the excavation of research galleries at the MIU Construction Site. Furthermore, hydraulic testing in the new borehole will be done using improved hydraulic test equipment designed for performance at depths greater than 1,000 m. While the new borehole is being drilled, pressure response to the drilling will be monitored with the long-term monitoring system installed in the existing borehole (DH-2) to determine hydraulic continuity of permeable fractures or zones. In addition, cross-hole hydraulic tests between existing boreholes and new ones will be carried out to assess hydraulic continuity of permeable fractures. This information and the new data from all these investigations will be used to construct the facility-scale hydrogeological models The information will also provide feedback to refine the geological model.

(ii) Construction of a facility-scale hydrogeological model and groundwater flow simulation to estimate hydrogeology prior to the excavation of the research gallery

A hydrogeological model at the facility-scale will be constructed by assigning hydrogeological parameters (such as hydraulic conductivity, porosity, etc.) to the facility-scale geological model in order to demonstrate the understanding developed of the hydrogeology at the MIU Construction Site. This hydrogeological model will be revised step by step as new data becomes available from the existing and new boreholes and from the cross-hole hydraulic tests. In subsequent Phases, the applicability and accuracy of the hydrogeological model constructed in this Phase will be assessed step by step using the hydrogeological observations obtained during the excavation of the shafts and research galleries.

The groundwater flow simulation is an important step in demonstrating the understanding developed of the conceptual hydrogeology by simulating the behavior of the flow system. It is also important to have a good conceptual model because the predictions of the flow system response will be used for predicting drawdown, seepage into the shafts and from an operational perspective, used for contingency planning in the event of high inflows into the shafts and galleries.

Prior to excavation of shafts and research galleries, the simulations will be used to predict the behavior of the heterogeneous, deep geological environment using the spatially-restricted data obtained by the above-mentioned field investigations. Therefore, the groundwater flow simulation will unavoidably contain some uncertainty derived from the variety and quantity of data and the interpretation methods and techniques of modeling. Accordingly, the following items should be examined in the groundwater flow simulation.

(a) Method to determine processes controlling factors of groundwater flow;

(b) Variety and quantity of data necessary for construction of the hydrogeological models at the facility-scale for the groundwater flow simulation;

(c) Method to estimate the spatial distribution of physical values (continuous vs discrete);

(d) Method to choose technique for groundwater flow simulation (e.g. FEM);

(e) Method to set hydrogeological boundary conditions;

(f) Method to estimate and reduce the uncertainty in the results of groundwater flow simulation (quality of site data, interpolations made, calibrations, sensitivity analysis) .

(iii) Estimation of changes in hydrogeology caused by the shaft and research gallery excavations

Change in hydrogeology (water inflow into the galleries and hydraulic pressure around them, etc.) in response to the excavation of research galleries will be estimated. This estimate will be used for detail designs of the research galleries and investigation plans in Phases II and III. The change will be estimated based on the facility-scale hydrogeological model and the above data set.

(iv) Synthesis in the development of investigation, analysis and assessment techniques

The techniques used and the data generated from the hydrogeological research program at facility-scale will be assessed iteratively by following the investigation process of basic concept definition, planning, investigation, analysis and modeling and evaluation, as outlined in the Overview Chapter 2. In this process the level of research detail, the data requirements and the type of investigations to perform would be evaluated in terms of the usefulness and accuracy needed in characterizing the hydrogeology of the subsurface and assessed in planning the investigations to perform. With this understanding, the scope of the hydrogeological investigations to perform will be determined and the 3-D distribution of hydrogeological conditions will be assessed by the surface-based investigations.

Once the data has been obtained, it is assessed in terms of usefulness to describing the hydrogeological conditions. To do so the data from the hydrogeological studies are integrated in a systematic data synthesis process. This process consists of analysis of the data, assessment of the data reliability and integration into a hydrogeological model to describe the hydrogeological conditions. By the end of Phase I the hydrogeological model developed will be integrated with the geological model at the facility-scale. The model will be used as the foundation for groundwater flow simulation models and for the hydrochemical models and for research program planning and for facility design.

In addition, through the above process, the techniques used for investigation analysis and assessment of the hydrogeological conditions will be assessed in terms of their applicability and accuracy and improvements to techniques and equipment made as necessary.

3.4 Hydrochemical investigations

3.4.1 Objectives

The 3-D distribution of hydrochemical properties of deep groundwater at the MIU Construction Site will be determined. Major water-rock interactions controlling the evolution of groundwater chemistry will be investigated by water-rock interaction tests and thermodynamic analysis. Also, the current hydrochemical model (facility-scale) will be evaluated in reference to the above-mentioned results of sampling and chemical analysis of groundwater.

3.4.2 Investigations

The three-dimensional distribution of geochemical characteristics (physicochemical parameters, chemical composition, and isotope composition) of groundwater in the Toki Granite at the MIU Construction Site will be determined by sampling and chemical analysis of groundwater in existing and new boreholes. Also, major water–rock reactions controlling the water chemistry will be studied by water–rock reaction tests and thermodynamic analysis. Using these results and the results of the sampling and chemical analysis of the groundwater, the present hydrochemical model (groundwater chemistry model at facility-scale) will be assessed. Data on the population of microorganisms, which could affect oxidation-reduction state and reactions, will be acquired.

(i) Acquisition of the data on hydrochemistry of groundwater

・Hydrochemical investigations on groundwater

Sampling and chemical analysis of groundwater from new boreholes will provide the pre-excavation hydrochemistry database and depth-profile on the major and minor dissolved constituents, dissolved gases, environmental isotopes and microorganisms in the groundwater. Rainwater and river water will be sampled to obtain the data on their hydrochemical properties (physico-chemical parameters and chemical/isotopic compositions), which are used to set the initial conditions for evaluating the groundwater chemistry, its age, origin and possible evolution.

・Hydrochemical investigation of the Toki Granite and Miocene rocks

Using the results of the hydrochemical investigations on groundwater mentioned above and the petrological, mineralogical and geochemical investigations on the rock stated in Section 3.2.2, major water-rock interactions influencing or controlling the evolution of groundwater chemistry will be investigated. The results of age dating of groundwater will be re-considered if necessary. The validity of the suspected major water-rock interactions will be assessed through a comparison with the results of water-rock interaction tests and theoretical analyses.

(ii) Construction of a hydrochemical model (facility-scale)

A hydrochemical model (facility-scale) will be constructed based on the results of groundwater sampling and analysis and determination of variations in groundwater chemistry with depth in the existing and new boreholes. The hydrochemical model (facility-scale) expresses the 3-D distribution of hydrochemical properties (physico-chemical parameters and chemical/isotopic compositions) of deep groundwater and the evolutionary mechanism, based on the geological model at facility-scale.

The validity of this hydrochemical model will be assessed on the basis of groundwater sampling and analysis during excavation of the shafts and the research galleries and thus new understanding of the 3-D distribution of hydrochemical properties at depth will improve.

(iii) Estimating change in hydrochemical properties of groundwater caused by excavation of the shafts and research galleries

Based on the constructed hydrochemical model (facility-scale) and the geochemical data sets, hydrochemical properties of groundwater prior to the excavation of research galleries will be estimated. Changes in the chemical properties due to gallery excavation will be monitored and determined by on-going sampling and analysis. For example, potential migration of the redox front as meteoric water drains into the shaft or percolates to greater depths will be monitored.

(iv) Synthesis in the development of investigation, analysis and assessment techniques

The techniques used and the data generated from the hydrochemical research program at facility-scale will be assessed iteratively by following the investigation process of basic concept definition, planning, investigation, analysis and modeling and evaluation, as outlined in the Overview Chapter 2. In this process the level of research detail, the data requirements and the type of investigations to perform would be evaluated in terms of the usefulness and accuracy needed in characterizing the 3-D distribution of groundwater chemistry and assessed in planning the investigations to perform. With this understanding, the hydrochemical research program can be determined. Thus, the hydrochemistry of the groundwater and the 3-D distribution of properties will be determined during the surface-based investigations.

Once the data has been obtained, it is assessed in terms of usefulness to describing the hydrochemistry of the groundwater. To do so the data from the hydrochemical studies are integrated in a systematic data synthesis process. This process consists of analysis of the data, assessment of the data reliability and integration into a model that describes the hydrochemistry of the groundwater and the 3-D distribution of properties. Thus, by the end of Phase I, the hydrochemical properties of groundwater described in a model at the facility-scale will be integrated with the geological and hydrogeological models. The model will contribute to understanding groundwater flow systems and be used for planning Phase II research.

In addition, through the above process, the techniques used for investigation analysis and assessment of the hydrochemistry will be assessed for applicability and accuracy and improvements made as necessary.

3.5 Rock mechanical investigations

3.5.1 Objectives

Rock mass properties (physical and mechanical properties) and the in situ stress states of the Toki Granite at the MIU Construction Site need to be understood three-dimensionally to construct the rock mechanical model (facility-scale). Using this model the in situ stress states will be estimated prior to the excavation of research galleries. Also, deformational behavior, stress change and extent of rock failure or damage caused by stress concentration in the rock mass surrounding the galleries, in response to excavation, will be estimated. The results will be needed for detailed design of the galleries and investigation plans for Phases II and III.

3.5.2 Investigations

Mechanical properties of Toki Granite, mechanical characteristics of fractures, and in situ stress conditions of Toki Granite at the MIU Construction Site will be determined by laboratory testing of drill cores and mechanical tests in boreholes (in situ stress measurement by hydraulic fracturing). Also, a 3-D rock mechanical model (facility-scale) of the MIU Construction Site will be constructed. The initial, in situ stress state before excavation will be incorporated in this model. Also, rock mass deformation and the changes in the in situ stress conditions in the vicinity of the excavated research galleries, and the range of excavation induced damage (rock failure) in the rock mass will be estimated. The mechanical stability of the research galleries will be assessed and the results will be reflected in the detailed design of the research galleries and in the investigation plans during the subsequent Phases.

Laboratory tests of core samples provide basic data on rock mass properties and in situ stress conditions with which to predict mechanical behavior of and damage to the rock mass surrounding the shafts and the research galleries. During excavation changes in mechanical properties of the rock mass will be observed. Also, numerical codes will be used and/or developed to model and predict these phenomena quantitatively.

(i) Acquisition of the data on rock mechanics

・In situ and laboratory investigations on mechanical properties using boreholes

Laboratory stress measurements (DSCA method and AE method) using rock core collected from existing and new boreholes and joint-shearing tests using fracture samples will be carried out. In addition, mechanical properties of fracture planes and the Toki Granite, and the in situ stress state of the Toki Granite at the MIU Construction Site will be determined by mechanical tests (e.g. in situ stress measurement by hydraulic fracturing) carried out in new boreholes. These results will be used to construct the 3-D rock mechanical model (facility-scale) for the MIU Construction Site.

・Laboratory tests using rock blocks

Laboratory tests to simulate the excavation of actual research galleries using rock blocks, (50cm by 50cm by 30cm), from the Inada Granite, a well characterized Japanese granite will provide information on the potential mechanical behavior and damage to the rock mass and the associated changes in mechanical properties. Furthermore, shearing tests will be carried out on rock specimens sampled from the tested rock blocks, to understand the relationship between stress history, void structures and mechanical properties.

(ii) Construction of a rock mechanical model (facility-scale)

The rock mechanical model (facility-scale) expresses the 3-D distribution of mechanical properties and in situ stresses in the rock mass represented by the geological model (facility-scale). This rock mechanical model will be used to estimate the in situ stress state prior to shaft and gallery excavations. Deformation and stress changes in the rock mass surrounding research galleries and the extent of development of an excavation disturbed zone (EDZ) in the rock mass caused by stress concentration in response to excavation will be estimated. In addition, the model will contribute to detailed design of the research galleries and for development of the investigation plans.

In this Phase, the facility-scale rock mechanical model is constructed to show the 3-D distribution of mechanical properties and the in situ stress state at the MIU Construction Site, using the results from mechanical tests in new boreholes and laboratory tests on rock cores. The accuracy of the rock mechanical model will be assessed based on measurements of mechanical properties and in situ stress states and observations of the response of the rock mass to the excavation of research galleries, for example accuracy of the prediction of location and extent of an EDZ.

(iii) Estimation of changes in rock mechanical properties of the rock mass caused by the shaft and research gallery excavations

Deformational behavior, stress changes in the rock mass surrounding research galleries, and the extent of damage to the rock mass caused by stress concentration in response to the gallery excavation will be estimated using the rock mechanical model (facility-scale) and the above data set. This estimate will be used for the detailed design of the research galleries and investigation plans in Phases II and III. Important features and processes to be estimated will be determined in consideration of similar case studies from abroad. For the estimate of the analysis results, some analytical models (crack-tensor, MBC, 3DEC etc.) and Examine3d code (3-D elastic boundary element method) will be used. The former have been applied to mechanical analyses for the excavation of large-scale underground caverns and can take the effects of discontinuous planes into account. Furthermore, based on the results of laboratory tests using rock blocks new analytical codes may be developed.

(iv) Synthesis in the development of investigation, analysis and assessment techniques

The techniques used and the data generated from the rock mechanics research at the facility-scale will be assessed iteratively by following the investigation process of basic concept definition, planning, investigation, analysis and modeling and evaluation, as outlined in the Overview Chapter 2. In this process the level of research detail, the data requirements and the type of investigations to perform would be evaluated in terms of the usefulness and accuracy needed in characterizing the mechanical properties and in situ stress state of the granite rock mass, and assessed in planning the investigations to perform. With this understanding, the scope of the rock mechanics investigations will be determined. Based on these surface-based investigations the 3-D distribution of rock mass properties, physical and mechanical, will be determined, models developed and predictions made.

Once the data has been obtained, it is assessed in terms of usefulness to understanding the rock mechanical characteristics of the geological environment. To do so the data from the rock mechanical studies are integrated in a systematic data synthesis process. This process consists of analysis of the data, assessment of the data reliability and integrated into a model that describes the rock mechanical conditions. By the end of Phase I, the understanding of the 3-D distribution of rock mass properties will be represented in the facility-scale rock mechanical model and can be used for facility design and planning of Phase II research.

In addition, through the above process, the techniques used for investigation analysis and assessment of the rock mechanical conditions will be assessed in terms of their applicability and accuracy and improvements made as necessary.

3.6 Mass transport investigations

3.6.1 Objectives

The basic data on the methods of and controls on mass transport will be obtained by borehole investigations and laboratory testing. Tracer tests will be planned in the research galleries, and solute transport analysis will be done using the results of the tracer tests.

3.6.2 Investigations

Investigations of mass transport properties and retardation mechanisms in the Toki Granite are planned. Studies will include studies of pore structure, advection, dispersion, diffusion and sorption properties. As well, the geochemical and mineralogical characteristics of permeable fractures and the rock matrix will be determined by laboratory testing of drill cores with fractures. Laboratory studies using naturally occurring nuclides will be carried out in order to understand the geologically long-term transport and retardation of materials.

(i) Acquisition of data on mass transport in the rock mass

・Laboratory tests

Sorption tests on filling minerals that occur along permeable fractures and their adjacent rock mass will be carried out using rock cores collected from existing and new boreholes to investigate retardation potential of filling minerals. These tests are intended to obtain data on hydrochemical and mineralogical properties, pore structure and sorption properties. Furthermore, the data on hydrogeological and hydrochemical properties of the permeable fractures will be obtained to build a data set for mass transport studies. This database and the research results will be used in the planning of the tracer tests and mass transport studies in the research galleries.

・Investigations using natural nuclides

Using rock core, the data on the distribution and abundance of natural uranium series nuclides and rare earth elements will be obtained in permeable fractures and the adjacent rock mass from the site. Additionally, the data on pore structures and fractures will be used to understand controls on mass transport and retardation phenomena (e.g. sorption and matrix diffusion phenomena), which can extend over geologically long time periods in permeable fractures and the adjacent rock mass.

(ii) Synthesis in the development of investigation, analysis and assessment techniques

The techniques and data generated from the above mass transport studies at facility-scale will be assessed iteratively during the overall investigation process of: basic concept definition, planning, investigation, analysis and modeling and evaluation. In this process, the level of research detail, the data requirements and the type of investigations to perform would be evaluated for usefulness and accuracy and assessed in planning the investigations to perform. With this understanding, the scope of the mass transport studies of controls and processes can be determined for investigation.

Once the data has been obtained, it is assessed in terms of usefulness to describing mass transport in the geological environment. To do so the data from the mass transport studies are integrated in a systematic data synthesis process. This process consists of analysis and integration of the data, assessment of the data reliability and evaluation of the mass transport processes in the hydrogeological and flow simulation models. Thus, at the end of Phase I the mass transport understanding developed so far will be integrated into the geological, hydrogeological and hydrochemical models at the facility-scale. The model can be used in the other disciplines and for future performance assessment studies.

3.7 Investigation techniques and equipment

3.7.1 Objectives

Existing investigation techniques and equipment necessary for investigations from surface will be improved and investigation techniques and equipment necessary for Phases II and III will be developed. Also, applicability of existing techniques and equipment will be examined.

3.7.2 Investigations

Investigation techniques and equipment, which may be used during Phases II and III will be considered and their applicability and need for improvement and/or development will be evaluated. The application of the equipment and the techniques will be considered, taking into account their suitability in a range of geological conditions.

An overview of the techniques and equipment being considered or under development for each field and the development plans are shown below. This list is not comprehensive. Some equipment improvements will be made as investigations progress and will be reported in reports of activities.

(i) Techniques and equipment for borehole investigations

・Drilling system using reverse aerated wire-line method

Improvement of the reverse aerated, wire-line method, which directs both fresh water and drilling mud into the drilling rod to prevent contact with the borehole wall and minimizes potential for borehole collapse. The examination will include consideration of the applicability of this system to various geological environments.

・Partial casing insertion equipment

Partial casing insertion equipment, intended to cope with borehole collapse, was developed. The system consists of partial reaming and casing insertion equipment. The aim is to applying this equipment in various geological environments.

(ii) Techniques and equipment for geological investigations

・Seismic tomography

The improvement of seismic tomography methods using 1,000 m-deep boreholes will be continued to determine the extent of discontinuity planes deep underground. Also, comparative examinations with seismic reflection survey and VSP method can be done. Analytical techniques to improve the use of full wave-form data will be developed.

・Assess applicability of existing techniques

In summarizing the applications of the existing techniques for geological investigations, the flexibility of each technique will be examined to clarify the conditions and extent of their application.

(iii) Techniques and equipment for hydrological/hydrochemical investigations

・ Improvement of hydraulic test equipment and downhole chemical probe for pressures above 10 MPa and greater than 1,000 m depth

Hydraulic test equipment and downhole chemical probe for depths exceeding 1,000 m and high temperature (70℃) will be further developed.

・ Improvement of pumping test equipment for pressures above 10 MPa and depths greater than 1,000 m

Pumping test equipment to withstand pressures above 10 MPa and depths greater than 1,000 m will be improved by making it possible to measure changes in water pressure and temperature at the upper and lower ends of test intervals, for better control and quality of data. Also, analog flowmeters will be replaced by digital meters for improved efficiency. .

・Long-term pore water pressure monitoring system for high pressure and depths greater 1,000 m

Long-term pore water pressure monitoring device for depths exceeding 1,000 m, which would allow continuous, long-term measurement of the distribution of pore water pressures under high differential pressure conditions developed as drawdown occurs and in underground applications. Based on trial application tests, improvements for practical use, including enhanced handling convenience and manufacturing cost reduction plan will be examined.

・Analysis of hydraulic tests data

Techniques will be investigated for improved analysis of test data from complicated hydraulic field conditions. Also, techniques for survey, analysis and evaluation applicable to hydrogeological investigations on the Toki Granite will be developed. The validity of analytical equations for complicated hydraulic fields will be examined by applying them to hydraulic tests in the hydrogeological investigations. Techniques for survey, analysis and evaluation, which range from selection of a hydraulic test method to analysis of its results, will be examined for application to hydraulic tests in borehole investigations.

(iv) Techniques and equipment for rock mechanics investigations

In situ stress measuring equipment for the depths to 1,000 m will be assessed and improved to allow measuring in situ stress of the rock mass by a stress relief method in boreholes deeper than 1,000 m. The above ground equipment (e.g. data recorder) will be manufactured and performance tested in the laboratory before final application tests in existing boreholes.

(v) Techniques and equipment for use during and after Phase II

・Continuous-wave radar investigation techniques

Radar investigation techniques, which use continuous-wave radar signals and are applicable to exploration on a scale exceeding tens of meters will be useful. Basic tests on antenna properties will continue. Besides expanding frequencies to a lower frequency range, the application of synthetic aperture processing and Sompi event analysis will be examined with the intention to expand the exploration distance and enhance spatial resolution.

・Remote monitoring techniques of geological environment

Seismic and electro-magnetic exploration techniques, which are based on the ACROSS (Accurately Controlled Routinely Operated Signal System) and synthetic aperture processing technique, will be developed. The techniques aim at coping with both high-resolution and great exploratory depths and for carrying out remote monitoring of the deep geological environment. Preparation will be made for transmit-and-receive-array-observation tests to be carried out in Phase II, which will use existing equipment for seismic and electro-magnetic ACROSS.

・Investigation and observations system for gallery walls

A system is needed for efficient geological observation of gallery walls during excavation. Technical examinations will be made for applying an existing tunnel face scanning system for practical use in Phase II.

・Cross-hole sinusoidal test instrument

A test system, with which to determine hydraulic properties of the rock mass under complicated hydraulic conditions that vary with the progress of gallery excavation, will be developed. Based on the results of application tests of a cross-hole sinusoidal test instrument used in the Kamaishi *in-situ* study (14), a method of model construction using flow-dimension, analytical techniques of the test results (e.g. estimating methods of the spatial distribution of hydraulic continuity/properties) will be examined.

・Improved techniques for tomographic data analysis

Improvement of analytical techniques will be attempted for precise determination of the extent of structural discontinuities underground by tomographic surveys in boreholes drilled from research galleries. Based on the examination results of a full-waveform inversion analysis for enhancing the resolution of seismic tomographic data, the analytical techniques will be improved. Also, data acquisition and quality control will be implemented to support improvement of the techniques.

・Development and improvement of tracer/hydraulic test equipment

Test equipment for understanding geological, hydrogeological, mass transport and retardation properties of permeable fractures using boreholes drilled from research galleries will be developed. Based on field tests of tracer/hydraulic test equipment and resin-injection test equipment [(15)] and case studies in overseas underground research facilities [(16)], technical examinations for improvement of test equipment will be carried out.

(vi) Database construction

・Database construction for investigations

A database management system is needed and will be developed for the management and efficient utilization of the enormous quantity of data expected to be developed during future investigations. The database will include a manual/system to guarantee the data quality.

・Database construction for project management

A database for schedule and project management will be utilized to control investigations carried out simultaneously, to understand the inter-relationship between them and to preserve the investigation records.

(vii) Development of system for model construction and data visualization

A computer system will be assembled for developing 2-D and 3-D models of the geological environment (geological, hydrogeological, hydrochemical and rock mechanical models) and for visualizing in three-dimensions the predicted changes in the deep geological environment caused by the excavation of research galleries. The current system capable of saturated / unsaturated flow analysis will be applied to the investigations of each geoscience field by adding a function to take the heterogeneous permeability of permeable fractures into account.

3.8 Engineering technology for deep underground

3.8.1 Objectives

Detailed layout of the research galleries will be prepared based on the understanding of the deep geological environment in the MIU Construction Site developed in Phase I and the investigation plans for Phases II and III. Also, the construction plan will be decided in detail and engineering methods and instruments to be used will be selected.

3.8.2 Investigations

The main engineering technology in Phase I concerns the designing and planning of the construction of the underground facilities. Multidisciplinary geoscience research investigations will be carried out during Phases II and III. These investigations will likely have different objectives and experimental requirements and therefore, the research galleries should be designed so that various investigations can be implemented effectively. Therefore, the construction must be planned accordingly and integrated with research activities.

During this Phase, investigations considered important and necessary to be carried out during Phases II and III will be determined. These will be selected considering results from this Phase as well as previous work within Japan and abroad. Also, the research gallery layout based on current knowledge of the deep geological environment at the MIU Construction Site will be presented (Figure A-3). The research gallery layout will become more established as the investigations on the deep geological environment of the MIU Construction Site proceed. Finally the details of the research gallery layout will be determined and the construction technology and equipment will be decided. Care will be taken during construction to minimize disturbance of the geological environment.

Requirements to be considered in designing research galleries and planning construction are mentioned below.

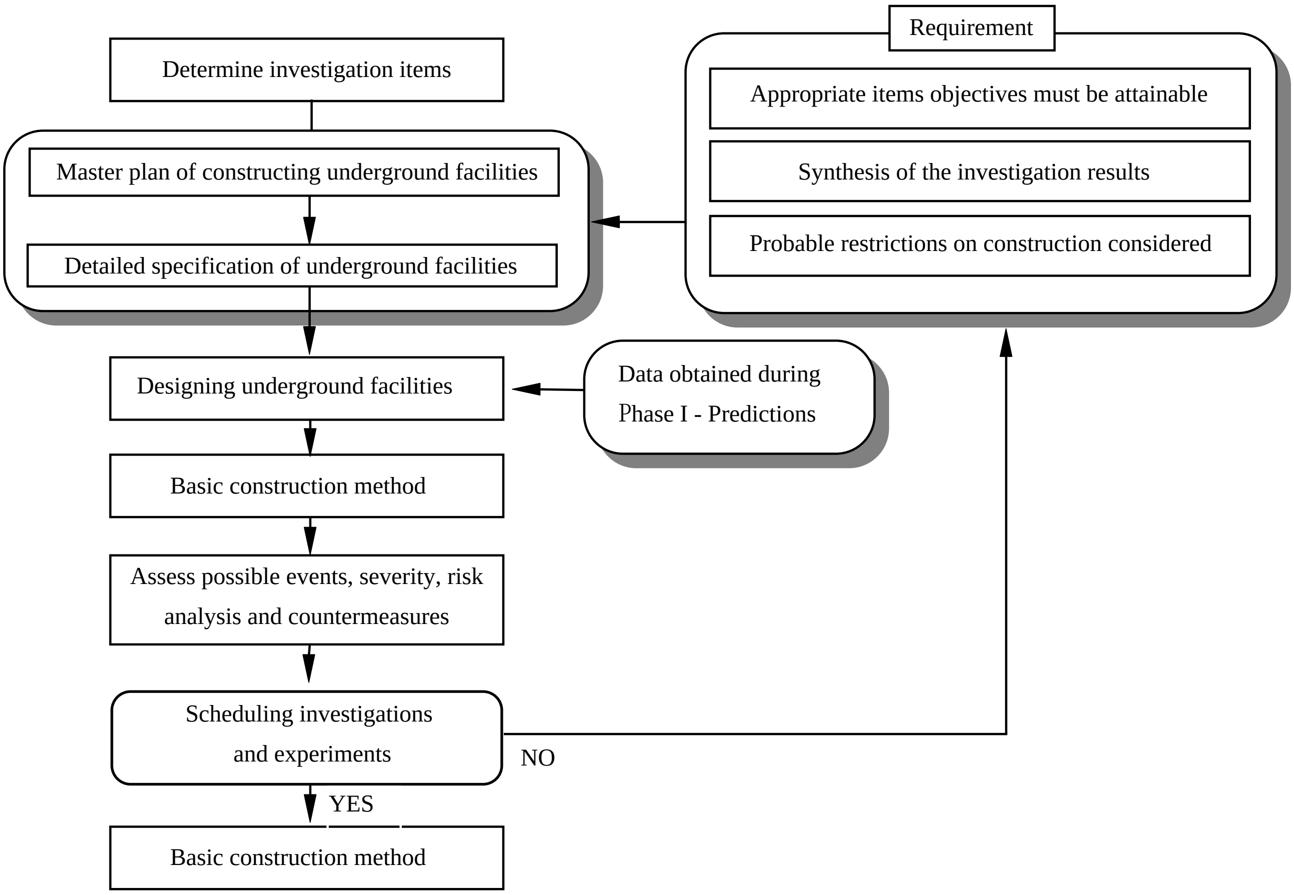

Figure A-3 Procedure for designing research galleries and planning construction activities

① Investigation items to allow the above objectives to be attainable

- Conditions in the deep geological environment required for investigations in each geoscience discipline for Phases II and III should be defined clearly. (e.g. permeable fractures or faults intersected by research galleries)
- The iterative process to evaluate the deep geological environment should be repeated at appropriate steps; at surface, at Sub Stages and at the Middle and Main Stages).
- Depth-dependent investigations, in particular the hydrogeological and rock mechanical, should be carried out at several Sub Stages as well as the Middle and Main Stages.
- The period required for investigations in each discipline, for each Phase, should be carefully considered and planned.

② Synthesis of the investigation results

With the overall purpose of establishing comprehensive investigation techniques for geological environments in Japan, it is important to synthesize the investigations in each discipline leading to the development of comprehensive geosynthesis methodologies that integrate the results from all disciplines. For this requirement, the targets for individual investigations in the underground (e.g. fractures, fracture zones, faults), the location of research targets in the underground and periods when the targets can be investigated must be taken into account.

③ Probable restrictions on construction should be taken into account

- Conditions in the geological environment that could impact on the construction schedule must be specified in order to carry out research investigations efficiently. Interruption of construction or maintaining flexibility in the scheduling of research investigations and construction should be considered.
- The location of some Sub Stages and research galleries will depend on the geological conditions, which in turn will influence the excavation method used.
- Restrictions on the installation of operational equipment/furnishings/facilities in research galleries must be specified so that they do not interfere with investigations; thus research can be carried out efficiently and at the most appropriate location.
- Construction could be suspended if it is anticipated that a research gallery will intersect or if it has already intersected permeable fractures/faults. Likewise, if the geological environments is greatly different from the predicted and is of important scientific value, construction may need to be halted.
- If unexpected events (serious water inflow, severe rock burst problems, etc.) occur the conditions for suspension of construction must be specified. Time required for remedial action

must be considered in terms of scheduling and the science activities.

4 Planning of investigations in Phases II and III

4.1 Objectives

Based on the data obtained in the surface-based investigations in Phase I on the deep geological environment and tasks to be carried out in the future, the detailed investigation plan in Phase II and a conceptual investigation plan in Phase III will be prepared.

4.2 Planning

Based on the data obtained on the deep geological environment, similar overseas case studies and results expected from deep underground facilities indicated by the Atomic Energy Commission of Japan (1994) [17], investigation items to be carried out in Phases II and III will be selected [18] and priorities examined.

Based on the data obtained in this Phase on the deep geological environment, the investigation plan in Phase II will be considered in detail. Also, a conceptual or approximate investigation plan for Phase III will be developed.

In developing the investigation plan, tasks indicated in the JNC's H12 Report [19] will be considered. The need for and the priority of the defined investigation tasks will be examined so that the detailed models of the geological environment at the gallery-scale can be constructed and the investigations carried out to verify the appropriateness of the estimated geological environment. New investigation items will also be developed if necessary.

5 Schedule

The investigation plan for Phase I at the MIU Construction Site has been based on the results of the previous investigations at the Shobasama Site. The plan will be revised in response to technical needs as the Project proceeds. The investigations at the MIU Construction Site are to commence in 2001 FY. In particular, the surface-based investigations are to be carried out until 2004 FY, with the exception of the long-term monitoring activities. Tasks in the surface-based investigations are shown in Table A-1.

Table A-1 Schedule of investigations in Phase I (1 of 3)

Investigations	2001FY	2002 FY	2003 FY	2004 FY
1. Synthesis of the investigation results				
① Clarifying where to focus investigation results and what data to synthesize				
② Develop investigation, analysis and assessment techniques				
2. Geological investigations				
① Ground geophysical survey				
② Borehole investigations				
● Shallow boreholes				
● Existing boreholes				
● Deep borehole				
③ Cross-hole tomography survey				
④ Development of a geological model				
⑤ Synthesis in the development of investigation, analysis and assessment techniques				
3. Hydrogeological investigations				
① Shallow hydrological investigations				
② Deep hydrogeological surveys				
● Existing boreholes				
● Deep borehole				
● Cross-hole hydraulic tests				
● Long-term monitoring of hydraulic conditions				
③ Construction of a facility-scale hydrogeological model and groundwater flow simulation				
④ Estimation of change in hydrogeology caused by the shaft and research gallery excavation				
⑤ Synthesis in the development of investigation, analysis and assessment techniques				

Planned (carried out selectively) Planned (carried out if necessary)

Table A-1　Schedule of investigations in Phase I (2 of 3)

Investigations	2001FY	2002 FY	2003 FY	2004 FY
4. Hydrochemical investigations				
① Hydrochemical investigations on ground-water				
● Shallow boreholes				
● Existing boreholes				
● Deep borehole				
② Hydrochemical investigations of the Toki Granite and Miocene rocks				
● Existing and deep boreholes				
● Determine water-rock interactions / Groundwater age dating				
③ Construction of a hydrochemical model (facility-scale)				
④ Synthesis in the development of investigation, analysis and assessment techniques				
5. Rock mechanical investigations				
① In-situ and laboratory investigation on mechanical properties using boreholes				
● Existing boreholes				
● Deep boreholes				
② Laboratory tests using rock blocks				
③ Construction of rock mechanical model (facility-scale)				
④ Estimation of change in rock mechanical properties				
⑤ Synthesis in the development of investigation, analysis and assessment techniques				
6. Mass transport investigations				
① Laboratory tests				
② Investigations using natural nuclides				
③ Synthesis in the development of investigation, analysis and assessment techniques				

Planned (carried out selectively)　　Planned (carried out if necessary)

Table A-1 Schedule of investigations in Phase I (3 of 3)

Investigations	2001FY	2002 FY	2003 FY	2004 FY
7. Investigation techniques and equipment				
① Techniques and equipment for borehole investigations				
● Drilling system using reverse aerated wire-line method				
● Partial casing insertion equipment				
② Techniques and equipment for geological investigations				
● Seismic tomography				
● Assess applicability of existing techniques				
③ Techniques and equipment for hydro-geological/hydrochemical investigations				
● Improvement of hydraulic test equipment and downhole chemical probe for pressures above 10Mpa and greater than 1,000 m				
● Improvement of pumping test equipment for pressures above 10MPa and greater than 1,000 m				
● Long-term pore water pressure monitoring system for pressures above 10MPa and greater than 1,000 m				
● Analysis of hydraulic test data				
④ Techniques and equipment for rock-mechanical investigations				
⑤ Development of techniques and equipment for use during and after Phase II				
● Continuous-wave radar investigation techniques				
● Remote monitoring techniques of geological environment				
● Investigation and observation system for gallery walls				
● Cross-hole sinusoidal test equipment				
● Improved techniques for tomographic data analysis				
● Developmemt and improvement of tracer / hydraulic test equipment				
⑥ Database construction				
● Database construction for investigations				
● Database construction for project management				
⑦ Development of system for model construction and data visualization				
8. Engineering technology for deep underground				
① Detail design of research galleries				
② Construction planning				

Planned (carried out selectively) Planned (carried out if necessary)

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Appendix B

Investigation plan at the "MIU Construction Site"

- Phase II (Construction Phase) -

1 Overview

Phase II investigations and excavations will be divided in two. The first half (Phase II-a) will be investigations carried out together with construction of the Main and Ventilation Shafts to the depth of the Middle Stage (about 500 m; See Chapter 4). Construction of the Middle Stage will begin in Phase II-a. The second half (Phase II-b) will consist of investigations carried out simultaneously with excavation to the final depth (about 1,000 m) of the Main Shaft, the Ventilation Shaft, and the Main Stage (about 1,000 m).

By carrying out investigations in two parts, it will be possible to assess and improve the Phase I-a investigations, analyses, and assessment techniques and engineering technology before Phase II-b commences. This will also enable an assessment of the applicability and effectiveness of the investigation techniques in different geological conditions. That is, under different in situ stress and groundwater flow conditions. This approach is consistent with the investigation process outlined in the Overview and being followed in Phase I: basic concept → planning → investigation → analysis and modeling → evaluation leading to the development of techniques for understanding and assessment of the deep geological environment

Research in this Phase will be confined to the vicinity of the shafts and galleries and it will be smaller scale compared to Phase I, whereas greater detail (resolution) will be required. The Sub Stages will be located about 100 m apart and at the most appropriate depth for research based on the geological features and conditions as excavation progresses.

Goals of Phase II are as follows.

① **Develop and revise models of geological environment using the investigation results obtained during excavation and determine and assess changes in the geological environment in response to the excavations.**

② **Evaluate the effectiveness of engineering techniques used for construction, maintenance and management of underground facilities**

③ **Establish detailed investigation plans for Phase III**

Data regarding the geological environment will be acquired for various geoscientific fields parallel to the gallery excavations. Horizontal galleries (Sub Stages) will be constructed from the Main Shaft for detailed geoscientific study at locations where important features such as permeable fractures and fracture zones and redox fronts are observed. The accuracy of the facility-scale models constructed in Phase I can be evaluated by comparison with actual conditions and the effectiveness of analytical methods used to develop the models will be assessed. Also changes to the deep geological environment in response to excavation can be observed, monitored and assessed. Then models at gallery-scale will be constructed using new data. The geological characteristics in the vicinity of the galleries will be estimated and expanded on in Phase III. The process of assessing the methods for investigation, analysis and assessment of the deep geological environment will be followed.

The issues and problems to be solved in Phase III will be identified and determined more specifically upon analysis of the data on the geological environment acquired in Phase II. Also, once data from Phase II becomes available, the investigation plan in Phase III can be developed in more detail. It is expected that the plans, in addition to the planned characterization and monitoring activities, will include specific research programs and that preferred research locations in the underground will be recommended. As well, the effectiveness of the existing engineering technologies regarding construction, maintenance and management of the research galleries will be evaluated and, to the extent possible and necessary, will be improved.

The investigations to be implemented in this phase will be revised on the basis of the data and knowledge which will be acquired at the "MIU Construction Site". It will be particularly important to consider and evaluate the methods and the results acquired during Phase II-a in preparing the detailed investigation plan for Phase II-b.

2 Construction plan of the MIU facilities

The design of the research galleries will be based on the scientific investigation plans and objectives of Phases II and III. The following information will be considered;

- Data regarding the deep geological environment obtained by surface-based investigations,
- Characteristics of geological environment around the galleries and
- Conditions of geological environment estimated from the above.

A draft layout is shown in Figure 3 in Overview of the Project.

Past studies at the Shobasama Site and for the RHS Project confirm the presence of rock masses with a range of geological characteristics such as variations in fracture density and lithofacies in the Toki Granite. Thus it is expected that similar variations in the geological environment will occur at the MIU Construction Site.

As shown in the facility layout (Figure 3 in Overview of the Project), the major research locations where most research will be concentrated, the Middle and Main Stages, will be located in two contrasting geological environments in the “MIU Construction Site”. Access to these horizontal developments will be via the Main and Ventilation Shafts. Sub Stages will be constructed about every 100 m to connect these Shafts horizontally. Repetition of the Middle Stage investigations at the Main Stage is planned. By doing so it will be possible to modify, improve and re-apply the techniques for investigation, analysis, assessment, and engineering. Also, it will be possible to demonstrate the effectiveness and applicability of the applied technologies for a range of geological conditions by repeating many of the planned geoscientific investigations under the different geological conditions available.

The draft layout will be revised as new data on the geological environment is obtained at the “MIU Construction Site”. During construction, care will be taken to ensure that the excavation disturbance to the initial state of the geological environment prior to the excavation of research galleries is minimized.

3 Overview of the investigations in Phase II-a

As mentioned in Chapter 1, the techniques for investigation, analysis and assessment and the engineering methods will be tested in the different geological environments. Furthermore, using the data obtained through the excavation of research galleries, the models of the geological environment at facility-scale will be revised and their accuracy will be assessed. Models at gallery-scale will be constructed. Individual investigations will be developed in detail on the basis of the data obtained on the deep geological environment in Phase I and the research priorities.

Investigations in Phase II-a will be carried out while excavating the Main and Ventilation Shafts down to the depth of the Middle Stage and while excavating the Middle Stage. Specifically, the investigations will focus on the upper halves of the Main and Ventilation Shafts (between surface and the Middle Stage), the horizontal research galleries at the Middle Stage and Sub Stages connecting the Main and the Ventilation Shafts at intervals of about 100 meters. The Middle Stage will be expanded in Phase III.

In Sections 3.1 to 3.7, investigation plans to be carried out in Phase II-a are presented. In Chapter 4, investigation plans to be carried out in Phase II-b will be shown.

3.1 Geological investigations

The activities will consist of data acquisition and model revision. The observations made while excavations advance will be compared with the predictions of the geology in the vicinity of the galleries made in Phase I. Thus, the geological model (facility-scale) constructed in Phase I can be assessed using the knowledge acquired through investigations in the shafts and galleries and in boreholes drilled from the galleries. The facility-scale model will be revised using the new data to improve the site model. Next, the geological model at gallery-scale will be constructed and prediction of the geology in the vicinity of the galleries to be studied in Phase III made.

3.1.1 Data acquisition on geology and geological structure

(i) Geological investigations on shaft and gallery walls

Through shaft and gallery wall observations and photography during excavation, the distribution and properties of geological structures (lithofacies, weathering zones, alteration zones, permeable fractures, faults, dikes, etc.) will be determined and studied in detail. Also, data on filling minerals and the location of groundwater seepage points from individual permeable fractures will be obtained and included in the geological maps of the shaft and gallery walls. The investigations will be carried out throughout the shafts and research galleries. Rock specimens will be properly sampled and undergo microscopic observation, chemical analysis and X-ray diffraction analysis to understand petrological/mineralogical properties of the rock mass and fracture filling minerals and their distribution. A schematic diagram for the investigations is shown in Figure B-1. In addition, oxidation-reduction regions will be better understood based on the result of the geological investigations mentioned above and the hydrochemical investigations of groundwater, and will be reflected in the geological model (facility-scale).

(ii) Geological investigations ahead of excavations

Based on knowledge of the geology and geological structure, seismic surveying and/or borehole investigations carried out at the excavation face in the shafts and galleries, the potential location of permeable fracture zones and/or faults will be predicted prior to excavation. A variety of forward looking techniques will be considered and applied for assessing their applicability.

3.1.2 Construction of geological model and geological analysis

The validity of the geological model at the facility-scale constructed in Phase I will be assessed by comparison with the data obtained in Phase II-a. The model will be revised to enhance the accuracy of predicted geology and geological structure around the shafts and research galleries. In particular, geology and geological structures observed around the Middle Stage and the Sub Stages will be included in the re-constructed geological model at gallery-scale.

3.1.3 Synthesis in the development of investigation, analysis and assessment techniques

The techniques used and the data generated from the geological research program at facility- and gallery-scales in Phase II will be assessed and developed iteratively by following the investigation process of basic concept definition, planning, investigation, analysis and modeling and evaluation discussed in the Overview and Appendix A. In this process, the level of research detail, the data requirements and the type of investigations to perform or performed would be evaluated in terms of the usefulness and accuracy in characterizing the geology and assessed in planning the investigations to perform.

The data and the techniques used will be assessed in terms of their usefulness to increasing the understanding of the geology in the subsurface. The data from the geological studies in Phase I will be integrated with Phase II data in a systematic data synthesis process. This process consists of analysis of the data, assessment of the data reliability, integration into a revised geological model and its evaluation in describing the geological environment. Thus the geological model developed in Phase I would be investigated in the subsurface in Phase II, the 3-D distribution of geological units and structures determined in more detail and the facility-scale model evaluated and improved. At the end of Phase II, the geological environment will be described in revised and improved geological models at the facility-scale and detailed models at the gallery-scale developed. The models will be used as the foundation for models in the other disciplines, for planning Phase III research and potentially for future performance assessment studies.

Through the above process, the techniques used for investigation analysis and assessment of the geological environment will be assessed with respect to applicability and accuracy. Recommendations and improvements to techniques and equipment used in Phases I and II can then be made, as required.

3.2 Hydrogeological investigations

Hydrogeological investigation will consist of monitoring hydraulic conditions at surface and in new excavations, testing structures in boreholes and model revision.
Changes to the groundwater flow system in response to excavations of shafts and research galleries are important to determine and understand. Therefore, observations of groundwater level and hydraulic pressures in existing boreholes with multi-piezometer completion systems will provide needed information. Monitoring and collection of groundwater seepage into the shaft will also be done. As excavation progresses new boreholes can be drilled from the research galleries for characterization of hydrogeological conditions (hydraulic testing), monitoring purposes and subsurface hydrogeological experiment activities.

As a result, hydrogeologic characteristics of the major geological units, structural discontinuities and the intact part of the Toki Granite will be determined in more detail. Also, the drawdown of the groundwater in response to shaft excavation will be known. The new understanding derived from the above measurements and their analysis can be compared with the predictions made in Phase I and as a result, the appropriateness of the facility-scale hydrogeological model and the associated predictions, including methods used to develop them, will be assessed. The model will be revised on the basis of these results and the hydrogeological characteristics of the rock mass and the induced changes to the groundwater flow system in response to excavation will be better understood.

Based on the new data and understanding, hydrogeological models at the research gallery-scale will be constructed and groundwater flow and seepage in the vicinity of the research galleries will be predicted using this model. Also, changes to the groundwater flow system in response to research gallery expansion will be incorporated into the gallery-scale model.

3.2.1 Data acquisition on hydrogeology

(i) Surface hydrological investigations
Observations on river flow, meteorological conditions and events and groundwater pressure using the multi-packer system (MP system) will be continued to understand changes in the groundwater flow system caused by the excavation of research galleries. Additionally, investigations and observations related to groundwater utilization around the “MIU Construction Site” will be carried out. Monitoring will continue to develop a database for comparison with baseline data.

(ii) Groundwater hydrogeological survey
Long-term monitoring of groundwater level and pore water pressure (monitoring of the geological

environment) using equipment installed in the existing boreholes will be carried out to determine if there is any change in the groundwater flow fields caused by excavation of shafts and research galleries. Also, observation of water inflow into the galleries will be carried out.

(iii) Investigations on hydraulic properties of major permeable fractures

The continuity and hydraulic properties of major permeable fractures that are expected to be intersected by the gallery excavations will be investigated before the excavations disturb them. The investigations will be carried out by pressure response tests between boreholes drilled from the excavation face after the excavation is halted and also in boreholes drilled from the ground, if the fracture is intersected by a surface borehole. A schematic diagram of the investigations is shown in Figure B-2.

3.2.2 Construction of hydrogeological model and groundwater flow simulation

The groundwater flow system at the "MIU Construction Site" prior to excavation of the shafts and the research galleries will be estimated by groundwater flow simulations based on the facility-scale hydrogeological model constructed in Phase I.

In Phase II, the validity of the facility-scale hydrogeological model and the associated analytical techniques used to derive the data for the model will be evaluated. This evaluation will be made by comparing predictions of hydraulic head drawdown in boreholes and seepage into the shafts with the actual. In addition, measured hydraulic properties of the major geological structures recognized in research galleries and the Moderately Fracture Zone will be determined. These data, together with the evaluation results, will be used to revise the hydrogeological model. It is expected that changes in groundwater flow fields in response to excavation of research galleries will be understood.

A hydrogeological model at gallery-scale in the Middle Stage and Sub Stage regions (down to the Middle Stage level), where investigations will be carried out in Phase III, will be constructed. Based on this model, groundwater flow fields around the Middle Stage will be simulated. Also using this model, changes in the groundwater flow fields around the research galleries to be extended in Phase III will be predicted.

3.2.3 Synthesis in the development of investigation, analysis and assessment techniques

The techniques used and the data generated from the hydrogeological research program at facility- and gallery-scales in Phase II will be assessed and developed iteratively by following the investigation process of basic concept definition, planning, investigation, analysis and modeling and evaluation discussed in the Overview and Appendix A. In this process, the level of research detail, the data requirements and the type of investigations to perform or performed would be evaluated in terms of the usefulness and accuracy in characterizing the hydrogeology of the site and assessed in planning the investigations to perform.

The data and the techniques used will be assessed in terms of usefulness to understanding and describing the subsurface hydrogeological environment. The data from the hydrogeology studies in Phase I will be integrated with the Phase II data in a systematic data synthesis process. This process consists of analysis of the data, assessment of the data reliability, integration into a revised hydrogeological model and evaluation of the description of the hydrogeological environment. Thus the hydrogeological characteristics of the granite and the model determined in Phase I can be evaluated with Phase II investigation observations during excavation and a better understanding of the 3-D distribution of hydrogeological properties developed. At the end of Phase II the revised and improved hydrogeological model will be integrated with the geological model at the facility-scale and new gallery-scale models developed. The model will be used for continued research in Phase III and for the hydrochemical models in and potentially, for future performance assessment studies.

Through the above process, the techniques used for investigation analysis and assessment of the hydrogeological environment will be assessed with respect to applicability and accuracy. Recommendations for improvements to Phases I and II techniques and equipment can be made, as required.

3.3 Hydrochemical investigations

New data on the hydrochemistry of the groundwater will be available from groundwater seepage collected in the shaft excavations and from new boreholes in the research galleries. Three-dimensional distribution of the hydrochemical characteristics of the groundwater and water chemistry evolution can then be studied in detail. The appropriateness of the facility-scale hydrochemical model developed in Phase I and the analytical methods to do so will be assessed by comparison of the new data with the predictions made in Phase I. The hydrochemical model will be revised in accordance with the results of the comparison and with the improved understanding of the site from the geological and hydrogeological research. If changes to the hydrochemical characteristics occur, for example depression of the redox front in response to excavations, it may be possible to understand the reason (s) for changes and evolution of the system.

From the above, a hydrochemical model(s) at gallery-scale will be constructed. This model will be used for estimating the hydrochemical characteristics of the groundwater at depth before the research galleries will be expanded in Phase III. Also, potential changes of the hydrochemical characteristics of the groundwater caused by the expansion can be estimated using this model.

3.3.1 Data acquisition on hydrochemistry

(i) Hydrochemical investigations on groundwater

Sampling, measurement of physico-chemical parameters, and chemical analyses (concentrations of major/minor dissolved solids, dissolved gases, environmental isotopes, microbes, etc.) of groundwater will be carried out in boreholes drilled from the surface to understand the 3-D distribution of hydrochemical properties of groundwater and any changes caused by the excavation of research galleries. In addition, the same hydrochemical investigations will be applied to water inflow from permeable fractures in the research galleries.

(ii) Investigations on hydrochemical properties of major permeable fractures

When the shafts and the Middle Stage pass through permeable fractures, hydrochemical properties of ground water in the fractures are expected to change through time. Using the MP system for sampling, any change observed in and around the major permeable fractures crossing the Middle Stage will be detected. Schematic diagram of the investigations is shown in Figure B-3.

(iii) Investigations on evolution of water chemistry through water-rock interactions

Rock specimens will be collected from permeable fractures, from which groundwater will be sampled, to analyze their mineral compositions, and the chemical/isotopic compositions of fracture-filling minerals and alteration minerals. In addition, laboratory tests will be carried out using the collected rock specimens to study water-rock interactions.

3.3.2 Construction of hydrochemical model and hydrochemical analysis

In Phase I, a facility-scale hydrochemical model will have been constructed to express the 3-D distribution of hydrochemical properties (physicochemical parameters, chemical/isotopic compositions) of groundwater in the Toki Granite at the "MIU Construction Site".

In this Phase, measured data of hydrochemical properties of deep groundwater will be compared with the predictions. The aim is to evaluate the accuracy of the hydrochemical model (facility-scale) constructed in Phase I and the associated analytical techniques. Based on this evaluation result, the hydrochemical model (facility-scale) can be revised. Changes in hydrochemical properties of groundwater after gallery excavation will be monitored and studied.

3.3.3 Synthesis in the development of investigation, analysis and assessment techniques

The techniques used and the data generated from the hydrochemical research program at facility- and gallery-scales in Phase II will be assessed and developed iteratively by following the investigation process of basic concept definition, planning, investigation, analysis and modeling and evaluation discussed in the Overview and Appendix A. In this process, the level of research detail, the data requirements and the type of investigations to perform would be evaluated in terms of the usefulness and accuracy in the determination of the hydrochemical properties and assessed in planning the investigations to perform.

Once the data has been obtained, it will be assessed in terms of usefulness to describing the groundwater hydrochemistry. To do so the data from the hydrochemistry studies will be integrated in a systematic data synthesis process. This process consists of data analysis, assessment of the data reliability, integration into a revised hydrochemical model and evaluation of the description of the hydrochemistry. Thus the hydrochemical characteristics of the groundwater determined in Phase I will be evaluated as detailed Phase II investigations in the subsurface provide more knowledge of the 3-D distribution of groundwater hydrochemistry properties and conditions. At the end of Phase II the additional knowledge of hydrochemistry of groundwater will be used to improve the existing model at the facility-scale and for the development of new gallery-scale models.

Through the above process, the techniques used for investigation analysis and assessment of the hydrochemistry will be assessed. Recommendations for improvements to Phases I and II techniques and equipment can be made, as required.

3.4 Rock mechanical investigations

Mechanical behavior of the host rocks in the vicinity of the shafts and the research galleries, mechanical characteristics of the rocks affected by the excavation, and the in situ stress conditions will be determined by field and laboratory studies. The predictions made in Phase I, of the deformation, stress changes, and the extent of damage caused by concentration of stress in the vicinity of excavations, will be determined. The appropriateness of the rock mechanical model at the facility-scale and the analytical methods will be assessed. These results will be reflected in the revision of the rock mechanical model (facility-scale). This research will help in the development of fundamental understanding of changes in the rock mass mechanical characteristics in the vicinity of the research galleries.

A rock mechanical model at the gallery-scale will be constructed. This model will be used for estimating the rock mechanical characteristics of the research galleries and their vicinity and for estimating the deformation behavior and stress changes of the rocks caused by the expansion of the research galleries. This research also provides fundamental knowledge of rock mass conditions needed to develop research gallery designs and for safe excavations in the underground, in terms of layout, construction safety and ground control measures.

3.4.1 Data acquisition on rock mechanics

(i) Investigations on mechanical properties of the rock mass

Rock mechanical tests, in situ stress measurement using hydro-fracturing and sonic velocity logging will be carried out in boreholes drilled from Sub Stages to verify the undisturbed variations in mechanical properties with depth and the distribution of in situ stress estimated in Phase I. In order to avoid any influence on the data due to gallery excavation, the testing in the rock mass will be at a suitable distance from the research galleries, generally greater than three times the gallery diameter.

(ii) Displacement measurement in shafts

Displacements of the rock mass can be measured in several ways. The installation of convergence pins in the Main and Ventilation Shafts and measurement of convergence is one option. Another is the use of boreholes in the Main and Ventilation Shafts, from Sub Stages if necessary, to study deformational behavior, strain, stress change, and development of an excavation disturbed zone caused by stress concentrations. In the Main Shaft, optional boreholes about three times as long as the shaft diameter may be drilled in at least four directions (along the maximum/minimum principal stresses if known) to measure the displacement using in-situ strain gauges. On the other hand, horizontal boreholes will be excavated from Sub Stages near the Ventilation Shaft to obtain data on the rock mass displacement before the excavation of the Ventilation Shaft reaches the boreholes.

(iii) Investigation on Shaft Excavation Effect

Horizontal boreholes will be drilled at appropriate depths from the Main Shaft to understand the extent of the excavation effects and changes in mechanical properties. P- and S-wave logging and loading tests at various distances from the shaft wall may be done. The disturbance caused by stress concentration will be monitored by establishing an AE measurement system in boreholes drilled parallel to the Main Shaft from the Sub Stages. Variations in the volume of rock affected by the shaft excavation will be evaluated based on these data. Schematic diagram of the investigations is shown in Figure B-4.

3.4.2 Construction of rock mechanical model and mechanical analysis

In Phase I, a rock mechanical model at the facility-scale will have been constructed to represent current understanding of the 3-D distribution of mechanical properties and in situ stress states of the granite at the MIU Construction Site. Based on this model, a mathematical analysis (2-D, 3-D FEM) to predict deformational behavior and stress change in the rock mass as well as the extent of damage around the research galleries caused by stress concentration resulting from the gallery excavation, will be used.

In Phase II, the validity of the rock-mechanical model (facility-scale) and analytical techniques developed in Phase I will be evaluated. This evaluation is based not only on the data on mechanical properties and in situ stress states but also on the deformational behavior and extent of damage in the rock mass surrounding the research galleries in response to gallery excavation. Furthermore, based on the result of the evaluation, not only can the rock mechanical model (facility-scale) be revised but changes in mechanical properties caused by the gallery excavations can be investigated.

Furthermore, a new rock mechanical model at gallery-scale will be constructed and revised on the basis of the new data, if necessary. Using the models, rock mechanical properties around the research galleries extended in Phase III will be estimated. Also, deformational behavior and stress changes caused by the extension of the research galleries in Phase III can be estimated.

3.4.3 Synthesis in the development of investigation, analysis and assessment techniques

The techniques used and the data generated from the rock mechanics programs at facility- and gallery-scales in Phase II will be assessed and developed iteratively by following the investigation process of basic concept definition, planning, investigation, analysis and modeling and evaluation discussed in the Overview and Appendix A. In this process, the level of research detail, the data requirements and the type of investigations to perform would be evaluated in terms of the usefulness and accuracy in developing knowledge of the rock mechanical character of the rock mass and assessed in planning the investigations to perform.

Once the data has been obtained, it is assessed in terms of usefulness to describing the subsurface rock mass properties and the in situ stress conditions. To do so the Phase I and II data from the rock mechanics studies will be integrated in a systematic data synthesis process. This process consists of analysis of the data, assessment of the data reliability, integration into a revised rock mechanical model and evaluation of the description of the rock mass and the mechanical properties and stress state. Thus the rock mechanical properties and distributions in the granite determined in Phase I can be evaluated with the results from Phase II investigations obtained during excavation and a better understanding of the rock mass properties and in situ stress conditions in 3-D developed. At the end of Phase II the rock mechanical model will have been revised and improved, and a new rock mechanical model at gallery-scale developed. The model will be used for planning future research.

Through the above process, the techniques used for investigation analysis and assessment of the mechanical properties of the rock mass and the in situ stress state will be assessed with respect to applicability and accuracy. Recommendations for improvements to techniques and equipment can be made, as required.

3.5 Mass transport investigations

In preparation for mass transport research in Phase III, data on pore structures, sorption and transport pathways as well as the geochemical and mineralogical characteristics of the geological units will be evaluated by laboratory tests of drill cores and samples obtained from excavation walls. The data set, augmented with data obtained during Phase I, will be prepared for assessing mass transport in the Toki Granite. Also, in this phase and the next, geologically long-term mass transport and retardation potential of the geological system will be assessed using the natural nuclides present in the site.

Specifically, based on observation of gallery walls, core samples will be obtained from permeable fractures and/or faults. Laboratory testing of these samples (e.g. sorption testing) should provide quantitative data for evaluating mass transport and retardation phenomena. The data include channeling in permeable fractures, void structures and porosity contributing to mass transport and retardation phenomena and sorption properties of fracture-filling minerals.

3.6 Investigation techniques and equipment

Investigation techniques and equipment considered necessary for Phase III will be determined and, if necessary, procured and/or developed in this Phase. Requirements for investigations during Phase III include accuracy and investigation capability within confined spaces. The applicability of conventional technology will be considered in planning and will be improved together with new technological innovation, if necessary. The application of these techniques and equipment in different, often harsh, geological environments will be considered and their conditions and limitations determined.

In particular, it is thought that the development of the following techniques and equipment is necessary. There is some overlap with techniques mentioned in Appendix A because the same techniques may be used in both Phases.

3.6.1 Long-term groundwater monitoring equipment for depths exceeding 1,000 m

Long-term monitoring equipment that can cope with high differential pressure situations will be necessary to continuously measure the lowering of groundwater level caused by either large-scale pumping tests, drawdown related to facility excavation and in gallery boreholes, with packers used to isolate high-pressure zones. Based on the result of examinations in Phase I-b (see Section 3.7 in Appendix A), testing of equipment will be attempted. The equipment will be installed in a borehole drilled near the Main Shaft for long-term observations of groundwater level and pore water pressure for investigations in Phases II and III as well as for sampling of hydrochemical properties of groundwater.

3.6.2 Remote monitoring technique of geological environments

For remote monitoring of deep geological environments, techniques for seismic wave and electro-magnetic surveying will be developed on the basis of the ACROSS (Accurately Controlled Routinely Operated Signal System) technology and synthetic aperture processing technique. The method allows both a high resolution and a large exploration depth.

Also of interest to underground research programs is the development and practical use of robust, wireless, remote monitoring equipment that can be installed in boreholes and in underground excavations. These are considered useful during operational phases but also in closure of disposal facilities when remote, wireless monitoring will be very cost effective.

3.6.3 Prediction techniques in advance of excavations

As mentioned in Section 3.1, existing non-destructive exploration techniques will be applied to predict the distribution of highly permeable fractures and/or faults in the rock mass ahead of the excavation. This is important to avoid prematurely excavating into highly transmissive zones that could result in excessive water control problems. It is also important to avoid unnecessary disturbance of geological features that could provide vital information for understanding of the geological environment or be suitable targets for more detailed study.

3.6.4 An investigation system for research gallery walls

The Main and Ventilation Shafts will be lined with concrete almost immediately after the observation of their walls. Time for surveying, mapping, photography, sampling, testing and installation of any instrumentation will be very limited and there is not likely to be opportunity for visiting the same section twice. The complexity of the intersected geology will also be a factor in determining the time required for mapping and other activities. Therefore, the observations should be carried out as efficiently and accurately as possible. Consequently, an observation basket or cage and photography will be used to make a permanent record of the walls. If the photo imagery is stereographic, subsequent structural analysis may be possible. The equipment will be developed in Phase I (see Section 3.7 in Appendix A) and trial tests attempted to be put the system into practical use.

3.7 Engineering technology for deep underground

The engineering technology to be used and developed in this Phase will focus on three elements as outlined below.

- Techniques for designing and construction planning of research galleries,
- Techniques for excavating and constructing research galleries,
- Techniques for safety.

Naturally there will be overlap to similar engineering technology studies in Phase III.

The engineering technology will mainly focus on the detailed design process and construction planning in Phase I and application of the techniques and equipment in Phase II. The assessment will be done using the experience from gallery excavation, including achievement of the research objectives, and flexibility to modify the design as needed during excavation. Methods will be established by which the results of the assessment will be reflected in the detailed design and construction plan.

Application of the engineering technology being investigated has a broader application than the MIU facilities. As directed in the overall project goals specified in the Long–Term Program, the technology is intended for use in the waste management program in Japan. This program has specific requirements to be met to satisfy performance assessment goals; these include minimization of excavation induced damage, optimization of facility layouts to take advantage of stress orientations to minimize development of an EDZ with associated permeability changes in wall rock and the use of appropriate engineering materials that could enhance the long-term safety of a waste repository. Some of these issues can be addressed in this phase and Phase III.

The analysis of the mechanical stability of the excavations carried out in Phase I will be evaluated. This will include an analysis of the effectiveness of setting initial boundary conditions and the analysis and evaluation method .

In cases when the actual geological environment encountered differs significantly from the predicted, when unexpected phenomena occur, or when the geological environment is significantly disturbed by gallery excavation, design flexibility will be necessary to accommodate any new requirements. One measure of successful design and construction planning will be the ability to adapt to these new requirements.

Furthermore, engineering technology will be examined for assurance of the engineering quality and accuracy of prior predictions of changes to the geological environment due to excavations. Also technical development regarding maintenance and management of the research gallery and security will be carried out.

3.7.1 Techniques for designing and construction planning of research galleries

Based on the experience obtained by excavating the research galleries, the design and construction plans made in Phase I can be evaluated. Furthermore, the methodology for revising the design and construction plans based on the actual construction results and the research investigations, techniques for developing a construction plan in order to prevent disturbance to the geological environment, and methods to feedback results of construction to design teams, will be developed and applied to the actual work. By analyzing research results from various investigations and tests performed during the excavation of research galleries from the viewpoints of efficiency and safety, an evaluation will be made regarding whether or not the design and construction programs are flexibly enough to allow effective changes to the original design.

3.7.2 Techniques for excavating and constructing research galleries

Based on construction experience from existing underground facilities in Japan and overseas, the range of existing excavation methods will be evaluated. One consideration is the ability of excavation techniques to cope with changes in geological environments during the excavation of research galleries deep underground. Other considerations are cost, ease of access, efficiency, ability to minimize wall rock damage and safety. Also, the applicability of current technology such as ground control measures that could be used to minimize or prevent disturbance of the geological environments or mitigate against sudden incidents such as large water inflows or severe rock burst problems, etc.) will be assessed. Techniques for assessing quality of the countermeasures, optimization techniques and construction management systems related to the series of construction works (e.g. excavation, supporting and mucking) will be developed.

3.7.3 Techniques for safety security

To ensure personnel safety during excavation, access to the underground and site in general should and will be carefully controlled. Nevertheless, it can be expected that researchers, contractors, and general visitors may enter research galleries, perhaps simultaneously from time to time. It is absolutely essential that more than sufficient safety measures be taken for each of them. In Phase I, preventive measures against accidents and hazardous events conceivable in the current and subsequent Phases will be examined to work out the requirements for a safety management system (evacuation plans, ventilation, daily ground stability checks, emergency communications, refuge stations, emergency supplies, chain of command, etc.). Following this safety management system, observation equipment for the safety management will be installed in Phase II. Additionally, periodic verification and evaluation of the safety will be carried out to properly improve the safety management system.

4 Overview of the investigations in Phase II-b

Investigations in Phase II-b will be carried out while excavating the Main and Ventilation Shafts from the Middle Stage to the target depth of 1,000 m. Specific excavations are the lower halves of the Main and Ventilation Shafts and the Sub Stages connecting the Main and the Ventilation Shafts at approximately 100 meters intervals. Excavation of the Main Stage will commence during Phase II-b and continue during Phase III.

The planned investigations in Phase II-b will be a repetition of the investigations done in the shafts and at the Sub Stages during Phase II-a, if these have been successful. If the investigations have not been satisfactory or did not meet expectations, they will be revised during Phase II-b by evaluating the techniques employed, the analyses possible and the inter-relationship with the construction activities.

4.1 Basic techniques for systematic investigation, analysis and evaluation of the deep geological environment

The iterative investigation process initiated in Phase I, basis concept, planning, investigations, analysis and evaluation, and to be carried out in Phase II-a will also be continued in Phase II-b. Thus, the validity of the iterative investigation process, as applied in Phases I and II-a, can be evaluated in different geological environments. Based on results, effort to improve the techniques for investigation, analysis and evaluation will be made in Phase II-b to confirm the applicability to deep geological environments.

4.2 Basic engineering technology for deep underground

The assessment and improvement of engineering techniques performed in Phase II-a will be evaluated. In Phase II-b, in situ stress in the rock mass and groundwater pressure is expected to be larger than in Phase II-a. Therefore, it will be important to investigate and employ construction techniques to cope with potentially adverse conditions, especially if they affect safety. These would include severe or sudden water inflows; possible under high pressure from highly transmissive zones or severe rock burst problems.

5 Schedule

The investigation plan for Phase II as shown in Chapters 3 and 4 are, in principle, based on the knowledge and understanding of the geological environment developed during the investigations carried out at the Shobasama Site. Details of the research investigation plans, layout of research galleries and the construction plan may be revised on the basis of the results of the investigations carried out in Phase I at the MIU Construction Site. The planned investigations in Phase II-b will basically be a reiteration of the investigations in Phase II-a.

The overall schedule of the MIU investigations is shown in Table 1 of the Overview in this report. Phase II investigations, including preparatory analysis and preparation for monitoring of the geological environment, commenced in 2001 FY. The full-scale excavation of the Main Shaft will commence in around 2004 FY. Timing the commencement of Phase II-b will be dependent on the excavation progress, for example when the depth of the Middle Stage is reached. Phase II is planned to finish in 2009 FY.

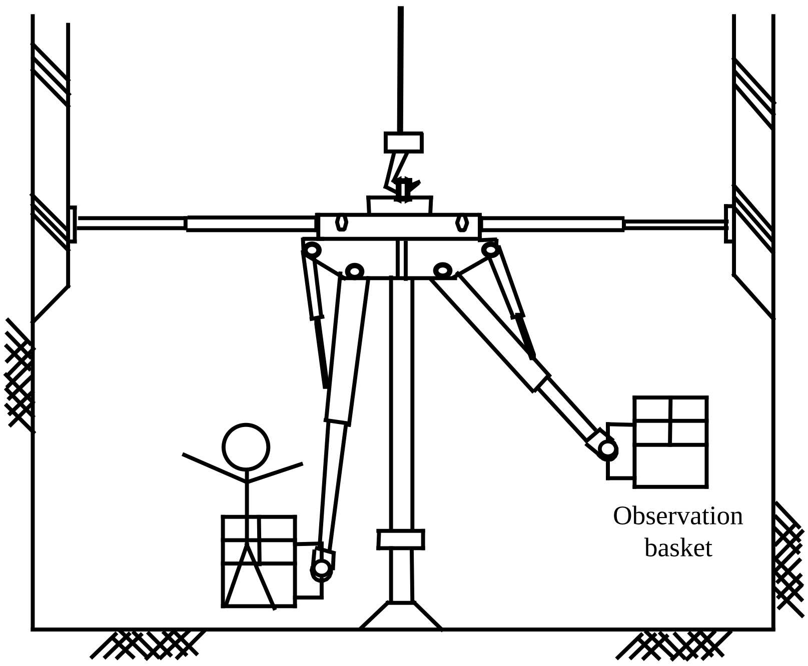

Figure B-1 Geological survey of shaft wall

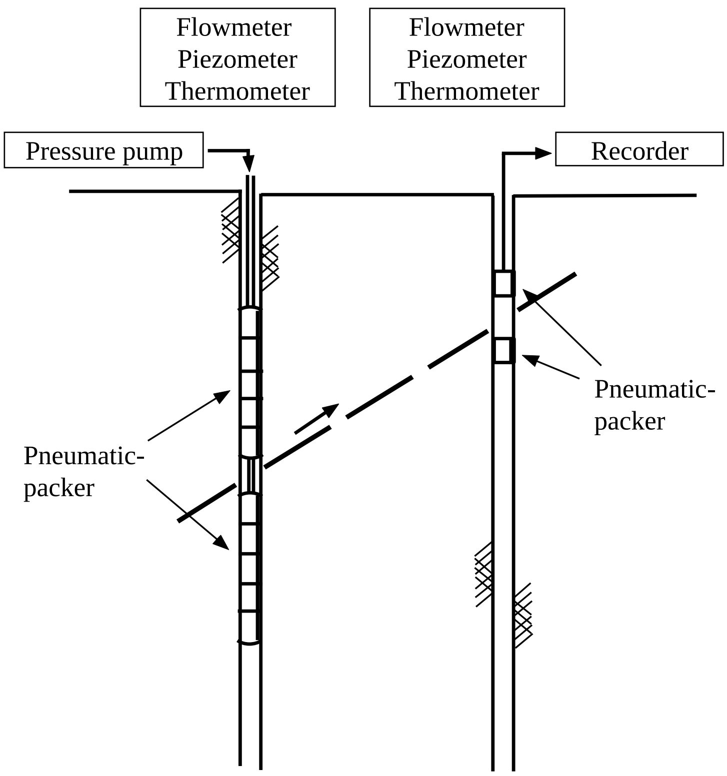

Figure B-2 Hydraulic packer testing of permeable fractures

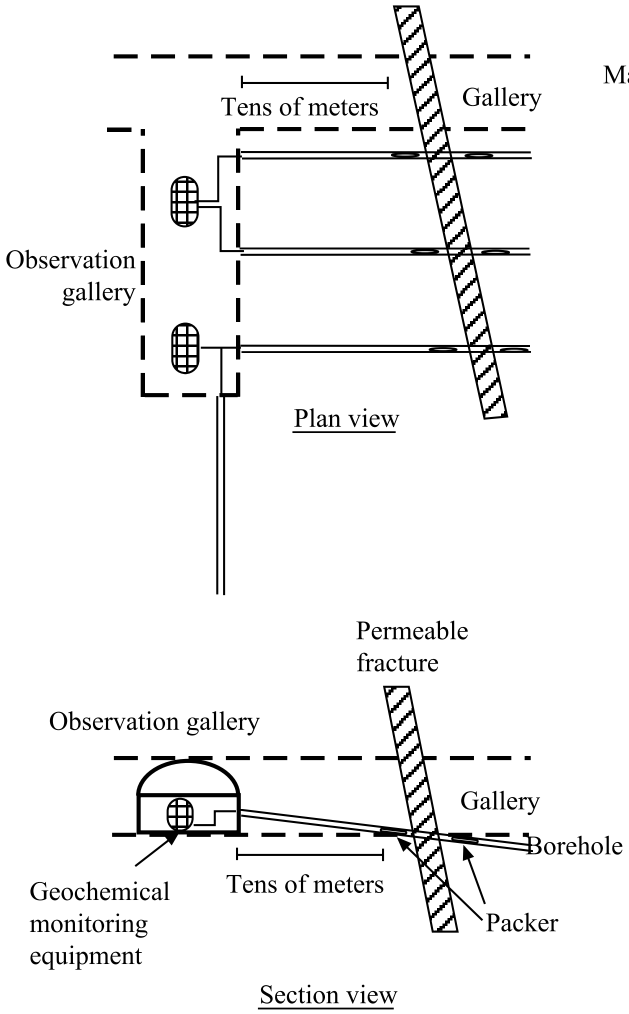

Figure B-3 Research on geochemical properties of major permeable fractures

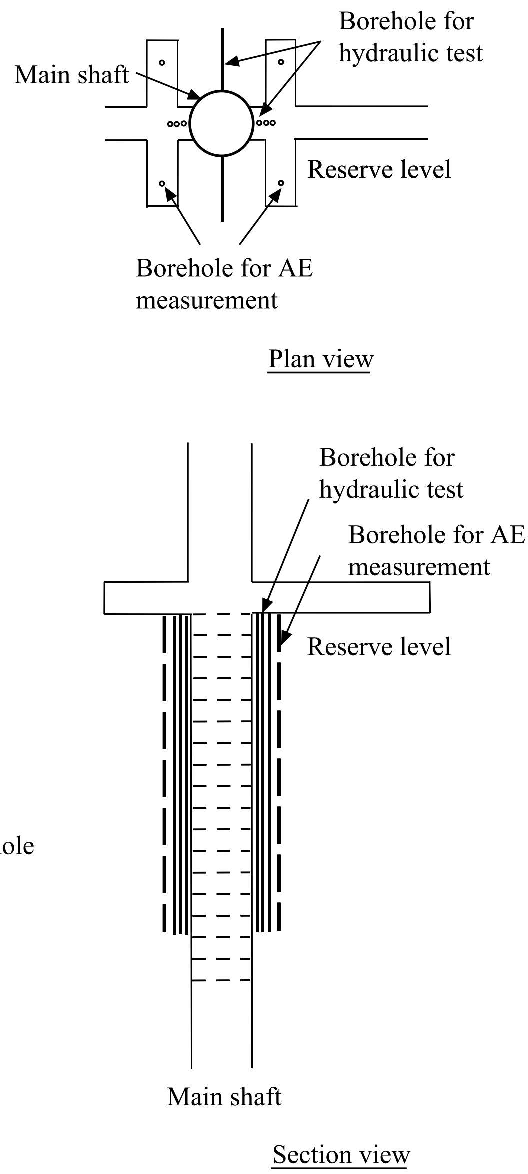

Figure B-4 Determination of EDZ in the rock mass around shafts

Appendix C

Investigation plan at the “MIU Construction Site”

– Phase III (Operation Phase)－

1 Overview

Phase III will proceed in steps similar to Phase II: the first half, Phase III-a will be the investigations at the Middle Stage; the second half, Phase III-b will comprise investigations at the Main Stage. As mentioned in the "Overview of the Project", Chapter 4 and Figure 3, this plan will allow investigations in different geological environments; environments with contrasting in situ stress states and hydraulic pressure conditions. The principal target of the investigations will be the geological environment in the vicinity of the research galleries, as in Phase II. However, geoscientific studies deeper than 1,000 m will also be performed using boreholes drilled from the research galleries.

The goals of Phase III are as follows.

① **Revise and improve the models of the geological environment using the results of underground investigations and determine any changes in the geological environment in response to research gallery extension**

② **Evaluate the effectiveness of engineering techniques used for deep underground**

Understanding the various phenomena and processes which can be expected to occur, for example the effects of gallery excavation on the rock mass and on controls of mass transport, earthquake effects, etc., together with determination of the characteristics of the deep geological environment are emphasized as the main objectives of this Phase. In going underground, direct observation of the rock mass in 3-dimensions will be possible; thus the 3-D distribution of site characteristics will be determined. With this advantage, the accuracy of previous predictions of the geological environment will be assessed together with the 3-D models of the geological environment at gallery-scale and facility-scale. The effectiveness of the methods used for analysis and model development can also be assessed. The results of these assessments will be used for improving the investigations, analysis and assessment methods.

In this Phase, the establishment of technologies for site characterization began in Phase I, including developing methods for understanding the various processes and phenomena that occur in the deep underground will continue. To re-state, the process begun in Phase I consists of development of basic concept → planning → investigation → analysis and modeling → evaluation. Research in this Phase will, in general, be in greater detail than in the previous Phases. The end result will be affirmation of the applicability of techniques developed in the three Phases as demonstrated by the understanding and assessment of the deep geological environment. Thus the investigation, analysis and assessment methods for understanding the subsurface geological environment will have been developed and be available for future activities.

Regarding engineering technology, the effectiveness of the technology for long-term maintenance of shaft and gallery stability and assuring safety within the gallery will be demonstrated through operational maintenance and management of the research galleries. At the same time, engineering technology regarding restoration or reversal and mitigating of the excavation effect on the geological environment will be developed, if necessary.

The investigation plan and research activities for each Stage will be examined and revised on the basis of the actual conditions encountered.

2 Overview of the investigations

In Phase III, the investigations, analyses and evaluation methods and the engineering techniques will be applied at both the Middle and the Main Stages to test and assess their applicability in different geological environments. Extension of the research galleries excavated in Phase II could disturb the geological environment by excavation induced damage, stress redistribution/ concentration and changes to the flow system. These disturbances and associated phenomena (EDZ development) observed around the galleries will be subject to detailed study. Especially in Phase III-b, new horizontal galleries will be excavated to examine changes in rock mechanical properties related to their excavation. The details of the investigations will be planned taking the results of investigations carried out in the previous Phases into account.

In this chapter, an overview of the investigation plan is shown. At this time, all activities are conceptual and provisional. Preliminary and detailed plans will be developed as excavations progress and characterization and evaluation work is done. Such plans will be largely dependent on the actual site conditions encountered.

2.1 Geological investigations

Geological investigations will consist of gallery wall characterization as excavations proceed, characterization activities in 1,000 m-deep boreholes to be drilled from each Stage and detailed characterization work for all experimental and research activities and modeling work. As a result, the geology and geological structure in the vicinity of the research galleries and to a depth of about 2,000 m will be investigated in detail. An important activity is updating the geological models at gallery and facility-scales constructed during Phase II. The geological characterization work should also be done quickly enough for design decisions to be made and for other research activities to be located appropriately in the galleries.

(i) Geological investigations at gallery walls

The first activity will be the geological mapping of all excavations. This consists of determining the distribution of all rock types and the characteristics of all geological structures including faults, fracture zones, joints and dykes. From these maps and with the associated geological and structural analysis, the 3-D geology of the rock mass at each Stage will become clear. Geophysical surveying and investigations using short boreholes from the research galleries will also be used to develop the understanding. As well, any cored boreholes for other investigations should be logged in detail in support of the other study and also to add to the geological database. Geophysics and the short boreholes will be useful to investigate the distribution and continuity of geology and geological structures in the galleries walls. As well, prediction of important and/or permeable structures in advance of gallery excavation can be done with detailed structural analysis and appropriate, well-planned geophysical surveying. These predictions are especially important to mitigate possible large inflows of high-pressure groundwater during excavation and for research purposes, if scientifically important features can be predicted before they are disturbed.

An important activity will be updating the geological models based on the observations. This will serve as a test of the accuracy of the conceptual models developed in Phases I and II and improve the model building expertise and also confirm the applicability of the techniques used to investigate, analyze and assess the geological environment. The new models should be the best representation so far of the geological environment and provide the most sound basis for further modeling exercises such as new flow simulations.

(ii) Geological investigations at depths greater than 1,000 m

Almost all of the data used to construct the models of the geological environment in the previous Phases was from 1,000 m depth or less. Therefore, 1,000 m deep boreholes will be drilled from the research galleries to 1,000 m below the Stages. Using multiple boreholes, cross-hole tomography (seismic and radar) will also be carried out to confirm its effectiveness.

2.2 Hydrogeological investigations

Hydrogeological properties of the major geological units in which the research galleries are located will be clarified by observation of water inflow into the research gallery, by changes in groundwater level and hydraulic pressures in monitoring boreholes associated with gallery expansion and by hydraulic testing in boreholes drilled from the gallery. The hydrogeological models constructed during Phase II and the analytical methods to derive them will be assessed by comparison of the observations and measured data with the predictions made, such as actual versus predicted seepage. The models will be revised with new input parameters and for example, the boundary conditions re-examined. As a result, accuracy of the groundwater flow analysis will be improved.

In the event of unexpectedly high groundwater inflows, hydrogeological information will be useful for development of a remediation plan. Also important from an operational perspective will be the prediction of hydraulic conductivity and flow volumes that could be produced from large water conducting features.

(i) Surface hydrogeological investigations

Surface hydrology, including meteorological observations and groundwater use around the MIU

Construction Site, and observation of groundwater pressure using multiple packer system (MP system) installed in the boreholes will be continuously monitored to understand the changes in the groundwater flow regime as a result of the excavation of the research galleries.

(ii) Groundwater hydrogeological survey

To understand hydrogeological properties of the Toki Granite at facility and gallery-scales, various hydraulic tests will be carried out in the research galleries, generally from dedicated hydrogeological boreholes. If water-conducting features are intersected in boreholes for other investigations, hydraulic testing and pore water pressure measurement will also be done.

・Hydrogeological monitoring

Long-term observations of groundwater level and hydraulic pressure within monitoring boreholes at surface (MP System) and water seepage into the research gallery will be continuously carried out. At the same time, multiple radiating horizontal boreholes will be drilled from the research galleries at each Stage, taking particular care not to disturb the surface monitoring network. Also, equipment for hydraulic pressure measurement will be installed to monitor horizontal variations of pressure around the Main Shaft. Hydrogeological investigations to support other activities will be done.

・Hydraulic tests in the laboratory

If new rock types or facies are encountered during gallery development, hydraulic testing of core samples in the laboratory will be done as a routine characterization procedure .

・Hydraulic tests in the research galleries

To examine the validity of the equivalent heterogeneous continuum modeling approach, permeability at gallery-scale, scaling effect, and characterisation of fractures affecting permeability will be studied. The equivalent heterogeneous continuum model is thought to be an effective method for modelling heterogeneous, anisotropic distribution of permeability within the Toki Granite. Also within the research galleries, several tens of boreholes will be drilled within rock blocks of about 100 m^3, and various concentrated hydraulic tests will be carried out. The model will be improved as a result of the improvements in the understanding of the geological structures used in the revised hydro-structural model.

・Hydraulic testing of a single permeable fracture

Groundwater flow within the permeable fractures can be controlled by channelling and consequently is heterogeneous. To evaluate the heterogeneous groundwater flow, hydraulic testing of a single permeable fracture intersected by a horizontal gallery will be carried out. Multiple boreholes will be drilled into a single permeable fracture and water will be injected to see pressure response. Injection of water and pressure response will be observed at intervals separated by packers to look for variation of permeability in intervals. Schematic diagram of this test is shown in Figure C-1.

・ Hydraulic testing of multiple permeable fractures

Hydraulic testing using tracers will be carried out in permeable fracture zones between boreholes to determine the network of permeable fractures and to understand groundwater flow properties of the network. The objective is to advance the understanding of continuity and hydrogeological characteristics of permeable fractures such as porosity and flow velocity.

・Hydraulic testing of excavation effect on permeability

To develop an understanding of hydraulic properties of rocks around galleries, the following study is being considered. First, a water reservoir will be constructed at an appropriate location on the floor of a research gallery. Water will be allowed to seep through the floor into a trench excavated across the gallery floor and the seepage measured to test permeability of the research gallery floor. Also, seepage will be collected at different depths along the wall of the trench to determine if permeability varies vertically with depth into the floor. The schematic diagram for this test is shown in Figure C-2.

・Hydraulic test under thermal stress

To evaluate changes in hydraulic properties from normal- to high-temperatures, hydraulic testing of rock samples from the research gallery will be tested under variable thermal loads. Also, various *in situ* hydraulic tests will be carried out in boreholes with a heat source installed in the rock mass.

2.3 Hydrochemical investigations

A range of hydrochemical studies will be done. Groundwater sampled from boreholes drilled from the research gallery and at seepage points in the galleries will be analyzed to determine the 3-D chemical distribution of groundwater. Changes resulting from gallery excavation (e.g. changed oxidation -reduction conditions caused by excavation) will be investigated. Also, the hydrochemical models constructed during Phase II and the associated analytical methods can be assessed by comparison with the new data. The model will be revised as necessary. The expertise in building the models at the various scales will also be improved.

(i) Hydrochemical investigations on groundwater

Collection and chemical analysis of groundwater from surface boreholes as well as the seepage water into the shafts and the galleries will continue. Collection and chemical analysis of groundwater from boreholes drilled in the research gallery will be carried out. A schematic diagram for tests around boreholes in the research galleries is shown in Figure C-3. Contributions to mass transport and retardation investigations will be made by collecting data on colloids and micro-organisms in the groundwater.

(ii) Investigations on water-rock interactions

When a research gallery is enlarged, rock samples will be collected from the gallery walls and boreholes. Using these samples, mineralogical compositions of the rock mass and the chemical and isotopic compositions of fracture-filling/alteration minerals will be determined. Using the rock samples, water-rock interactions will be studied in the laboratory. Other in situ tests are possible such as long-term diffusion tests in boreholes using de-ionized water in isolated zones. Other studies of the interaction of the groundwater with engineering materials that are likely to be used in the underground can also be done. For example, coupons of engineering material expected to be used in the underground can be isolated in boreholes with natural groundwater for extended periods.

(iii) Investigations on oxidation/reduction state in the rock mass around research galleries

To understand changes to the oxidation/reduction front through time and with depth, boreholes a few meters long will be drilled from the research gallery and groundwater collection equipment using multiple packers will be installed. Continuous monitoring of physico-chemical parameters and dissolved gas will be carried out in the groundwater.

(iv) Investigations on oxidation/reduction buffering ability of rock mass around the research gallery

To monitor oxidation/reduction buffering ability of rock mass around the research gallery, two boreholes at intervals of a few meters will be drilled from the research gallery. Water collection equipment and water injection equipment using multiple packers will be installed in the respective boreholes. The water collected will be analyzed for changes in physico-chemical parameters. A schematic diagram of this arrangement is shown in Figure C-4.

(v) Investigations on complex interaction of hydro-mechanical and hydrochemical phenomena

To understand changes in hydrochemical properties caused by extension of new research galleries and changes in properties described in the rock mechanics section, continuous hydrochemistry monitoring equipment will be installed in the boreholes drilled in the research gallery. With this equipment, changes in the hydrochemical properties of groundwater induced by excavation of research galleries can be observed.

2.4 Rock mechanical investigations

Shafts and new horizontal galleries will be excavated in different geological environments; variations determined from Phase I investigations include depth related differences in the in situ stress magnitudes and direction, different mechanical properties and increasing hydraulic pressure with depth. Several items are to be investigated.

- Changes in rock mechanical properties in the different environments will be investigated,
- Displacement measurements in the gallery will be continued,
- The long-term stability of the rock mass in the vicinity of the galleries will be assessed,
- Rock failure phenomena such as rock bursts will be studied at all subsurface levels,
- The rock mechanical model (gallery-scale) constructed during Phase II will be assessed by comparison of the predicted with the actual rock mass response. The model will be revised on the basis of these results and the accuracy of the analysis of mechanical behavior of the rock mass will be improved.

(i) Investigations on rock mechanical properties of the rock mass

To determine if changes in mechanical properties and distribution of in situ stress are depth dependent, as was predicted, boreholes will be drilled from the research galleries for in situ testing. Also, mechanical tests, in situ stress measurement, loading tests and velocity logging will be carried out. To obtain data from the area away from the influence of gallery excavation, these tests will be carried out at a minimum distance of three gallery diameters from the gallery wall.

(ii) Test on the effects of horizontal gallery excavation

To understand the extent of influence of horizontal gallery excavation and changes in mechanical properties, a research investigation to examine the effect of gallery excavation will be carried out. Specifically, several parallel galleries will be excavated at three levels with yet to be determined orientation, dimension and aspect ratio. The possibility of mechanical excavation using a tunnel boring machine (TBM) for comparison of excavation induced damage with planned controlled, smooth wall blasting methods will be considered. Specific investigations will include reflection seismic surveys using three dimensional installed survey lines along the gallery, deformation measurement (convergence and or EDZ), AE measurement and loading tests will be carried out. The aim of these is to identify regions in which mechanical properties have changed, for example due to increased fracturing in a low velocity zone. Also, stability of the gallery walls will be evaluated. Furthermore, for a detailed examination for distribution of fractures in the rock mass, parts of a research gallery will be enlarged. A schematic diagram of this test is shown in Figure C-5.

(iii) Investigations on long-term stability of research gallery

To evaluate analysis method for long-term stability of the rock mass around research galleries, deformation and AE monitoring will continue in the Excavation Effect Test. Furthermore, to evaluate enlargement trend of a damaged region caused by stress concentration due to the excavation, a reflection seismic survey will be carried out after the excavation.

(iv) Shaft Excavation Effect Test

To understand the extent of excavation effects in the region around the shafts and its effect on mechanical properties, a Shaft Excavation Effect Test will be carried out. The target zone is in Toki Granite where the Main Shaft and the Main Stage meet. Changes in distribution of affected regions and mechanical properties by depth will be evaluated. Also, using boreholes drilled in the shaft, the same tests as in the horizontal gallery will be carried out.

2.5 Mass transport investigations

Aspects of mass transport such as the characteristics of pathways, and the retardation potential (sorption and other mechanisms) of the Toki Granite will be assessed by laboratory tests of drill cores. A mass transport model at gallery-scale will be constructed on the basis of the knowledge on geology, hydrogeology, hydrochemistry, and the results of the investigations using natural nuclides. Tracer tests and other tests will be carried out in order to understand the controls on mass transport, transport pathways and retardation within the Toki Granite and the model will be evaluated and revised. Furthermore, data regarding colloids, organic material and microorganisms will be obtained to understand the mass transport and retardation process in granite.

(i) Mass transport investigations using rock core

Core samples will be collected from the single permeable fracture studied by the hydrogeological characterizations; an in situ tracer test described below will also be carried out in this fracture. Using core from the fracture, mass transport tests (matrix diffusion, sorption, desorption, transport time) and hydrochemical and mineralogical investigations will be carried out. From the test, data on channeling, estimated time required for solute transport during the tracer test and sorption/diffusion properties in the fracture will be determined. Schematic diagram of this test is shown in Figure C-6.

(ii) Mass transport test in a single permeable fracture

A tracer test with both conservative and non-conservative, non-active tracers will be carried out in the single permeable fracture mentioned above. Using a borehole selected from the suite of boreholes drilled into the fracture, tracer solutions (yet to be determined) will be injected and breakthrough monitored in separate boreholes. From the tests, knowledge such as groundwater travel time and estimates of path length will be determined. Also, the fracture will be excavated to analyze the tracer distribution, to determine the solute transport pathway and to investigate the retardation mechanism. A schematic diagram of this test is shown in Figure C-7.

(iii) Mass transport test in a fracture zone

To understand mass transport and retardation mechanism(s) in a fault or fracture zone, a gallery for injection testing and measurement will be excavated. Tracer solutions (yet to be determined) will be injected in the injection gallery and recovered from the measurement gallery. Chemical changes of tracer solution will be continuously monitored. Schematic diagram showing this test is shown in Figure C-8.

2.6 Engineering technology for deep underground

Technologies for maintaining long-term stability of the research galleries and for the environment in the gallery will be assessed. Management system for construction and quality control will be organized, and technical development regarding maintenance and management of the research gallery and security will be carried out. At the same time, engineering technology regarding restoration and to mitigate excavation effects on the geological environment will be developed in future, if necessary.

2.7 Earthquake observation

Seismometers and flow meters will be installed in galleries and in boreholes at several of the Sub Stages and at the Main and Middle Stages. Seismic activities and changes in the geological environment associated with earthquakes will be observed. Using these data, the effect of earthquakes on the gallery and the deep geological environment will be assessed.

3 Schedule

The investigation plan of this Phase is shown in Chapter 2 and is, in principle, based on the understanding of the subsurface geology developed during the investigations carried out in the Shobasama Site. Details of the investigation plan, layout of research gallery and the construction plan will be developed on the basis of the investigations carried out in Phases I and II, and revised at appropriate times. Details of the investigation plan of the latter half of Phase III will be revised based on the results of the investigations in Phase III-a.

This Phase will commence in around 2007 FY and finish in 2015 FY.

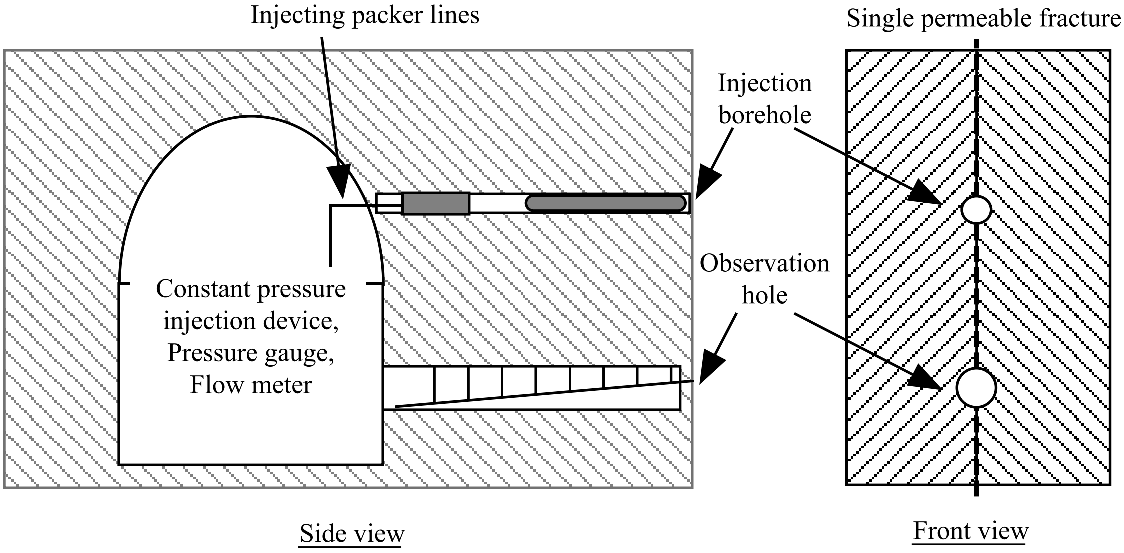

Figure C-1 Hydrologic test in a single fracture

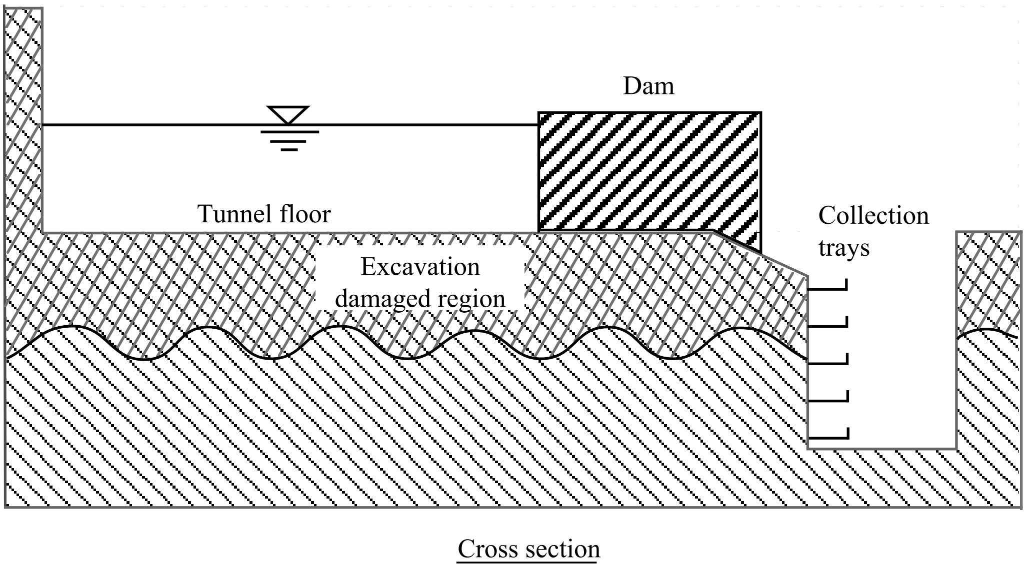

Figure C-2 Permeability test of tunnel floor

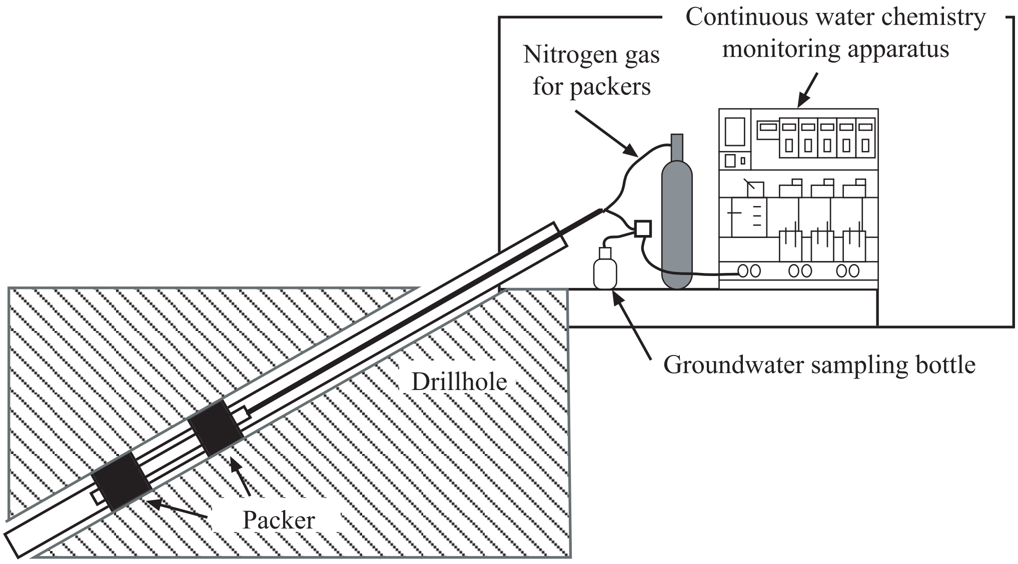

Figure C-3 Geochemical test of groundwater

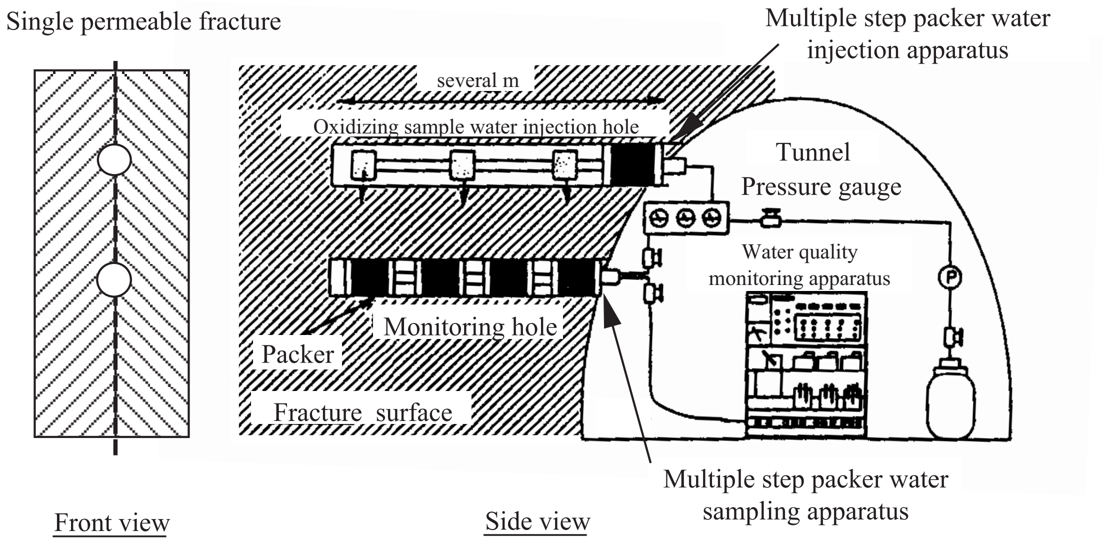

Figure C-4 Oxidation-reduction buffering potential test on surrounding rocks of the tunnel

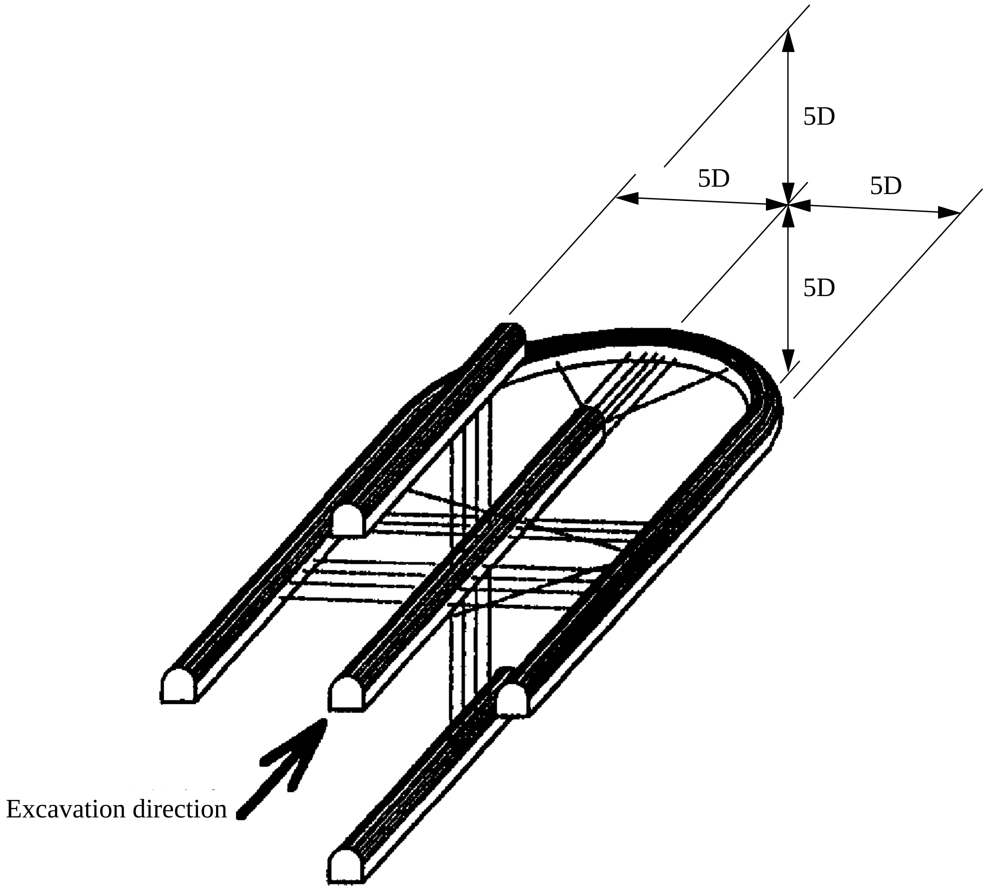

Figure C-5 Horizontal tunnel excavation test

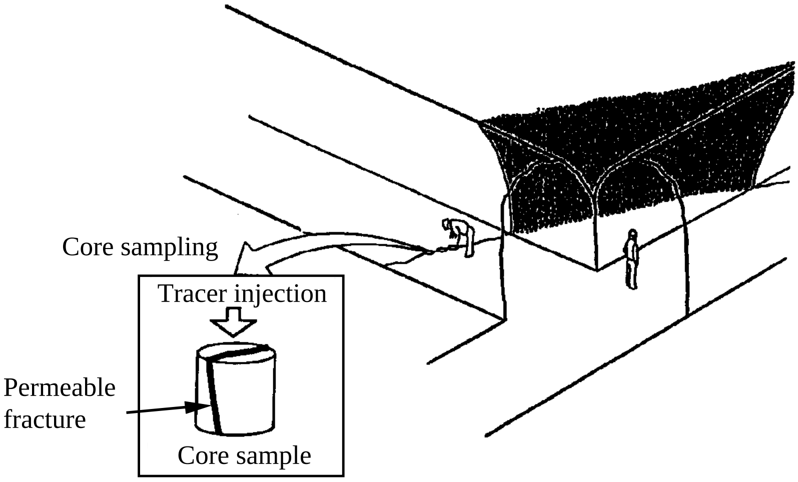

Figure C-6 Solute transport test using drill core

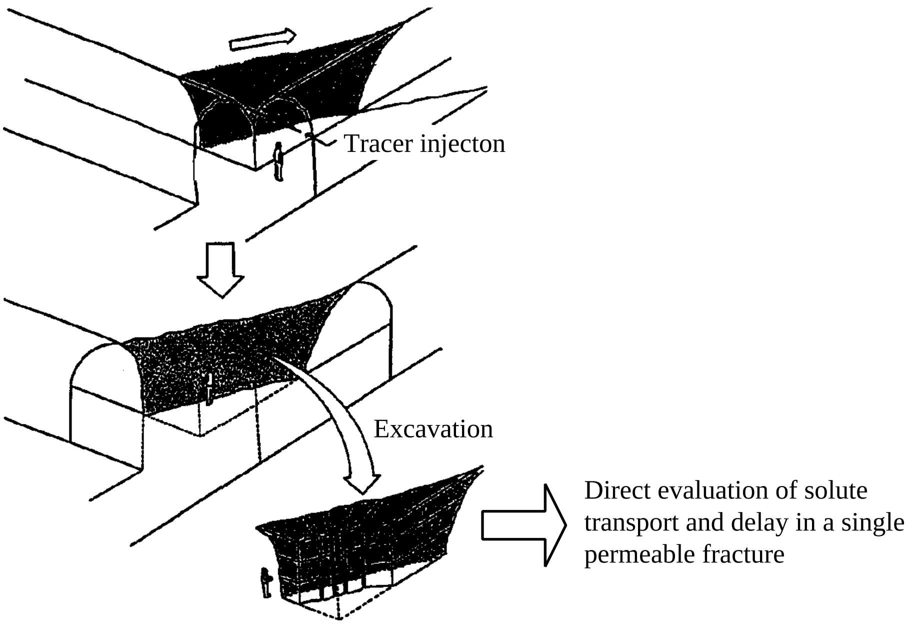

Figure C-7 Tracer tests in a single permeable fracture

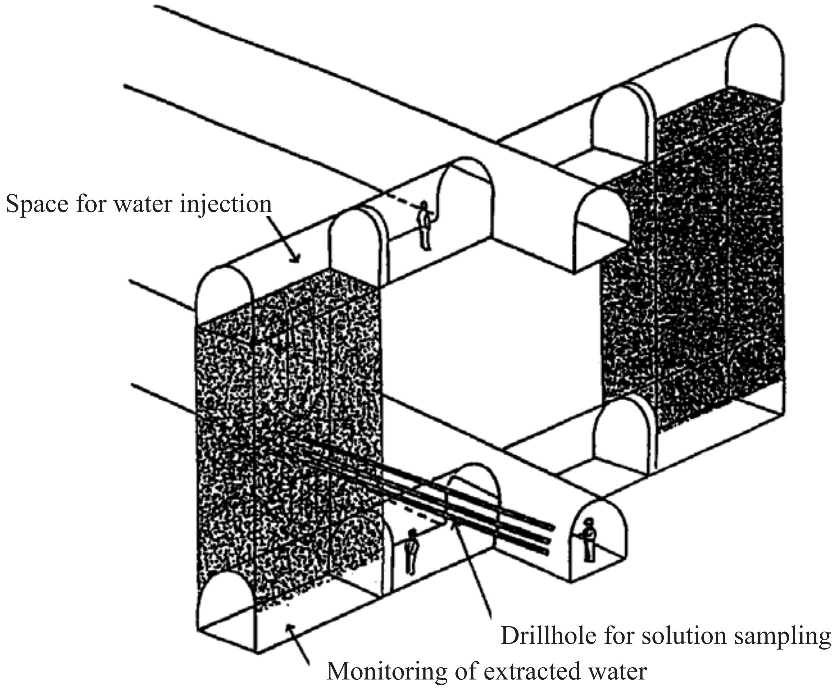

Figure C-8 Solute transport test in a fracture zone

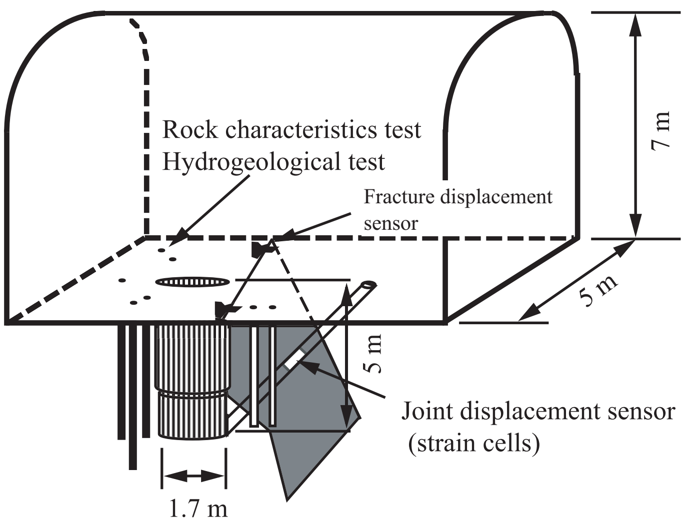

Figure C-9 Coupled response test for heat, water and stress

Appendix D

Investigation plan at the Shobasama Site

- After 2001FY -

1 Overview

The Shobasama Site will continue to be an important component of the MIU Project. It will be utilized for long-term monitoring purposes and for development and improvement of various techniques related to investigation/analysis/evaluation of the deep geological environment, one of the goals of the MIU Project. The resources at the site are considerable. They include:

- Several years of hydrological monitoring data,
- Several deep, well characterized boreholes, with detailed core logs and geophysical data,
- An extensive database of hydrogeological testing and monitoring information,
- Geological and hydrogeological data on several structures including the Tsukiyoshi Fault,
- Rock mechanical database from in situ testing and laboratory analysis,
- Borehole completion systems (MP) installed for long-term monitoring,
- Conceptual and mathematical models developed and utilized.

These resources can be actively utilized for development of field techniques for each study discipline. The results will be used to complement the research at the “MIU Construction Site”. The models of the geological environment constructed using the results of the surface-based investigations at the Shobasama Site can be re-evaluated and improved as understanding of the site improves with the long term monitoring data and possible re-evaluation of the existing databases.

In addition, the effect on the regional groundwater flow system of shaft excavation at the “MIU Construction Site” can be investigated by continuous groundwater pressure monitoring using the existing boreholes

With respect to activities at the site, the following are considered for on-going activities, though the timing will be coordinated with the research program at the MIU Construction Site.

- Continue to develop the methodology for identification/classification of permeable fractures using core log data, anomalies in the geophysical borehole profiles and flow meter logging results.
- Aspects of constructing the geological model may be re-evaluated if core is re-logged and new interpretations made of structures and lithologies intersected.
- Long-term monitoring of surface water and groundwater will continue at the site for an indeterminate time. At some time afterwards it may be desirable to perform another long-term pumping test to re-evaluate the basis for the hydrogeological model, which

can then be updated.

- As the long-term monitoring continues the groundwater flow system will gradually re-establish. It may then be possible to collect representative groundwater samples from MIU-1, 2 and 3, to provide the information that could not be collected in Phase I. In addition, the MP system will be used to routinely collect groundwater samples in all isolated zones. The new hydrochemistry database, together with new age dating of deep groundwater in the Toki Granite, will be used to construct a revised hydrochemical model.
- Time dependent changes to the flow system may occur. For example permeability of fracture zones may change and changes could be detected during the long-term monitoring period. Such understanding would be valuable for the predictions of flow system behavior for long-term assessment modeling.
- The site can also be used as a testing site for new hydrogeological equipment, borehole geophysical tools and rock mechanical instruments that for operational and /or research reasons could not be done at the MIU Construction Site. It could be used to investigate new testing methods, improve field methods such as flow meter logging techniques and used for the calibration of instruments.
- It may be used to improve techniques of rock permeability measurement including packer testing methods and flow meter logging.

2 Overview of the investigation in the Shobasama Site

2.1 Improvement of modelling techniques for the geological environment

Repeated testing and analysis will allow improved accuracy of the models as the amount of data increases on the geological environment. Details of investigations planned in the Shobasama Site are as follows.

2.1.1 Geological investigations

(i) Development of identification/classification techniques for permeable fractures

Data obtained from the Shobasama Site can be re-examined to improve the identification and classification techniques for permeable fracture used in the fractured rock model. The data includes existing core logs, possibly re-logged in whole or in part, geophysical logging data, including BTV and flow meter logging. If necessary, in-hole tests such as VSP and fluid logging could be re-done. Based on new data and interpretations, identification and classification methods of fracture zones with high permeability can be improved.

(ii) Construction of modeling technique for geology

The factors contributing to the uncertainty such as limits on the amount of data available on the geological environment, the quality of the data, the spatial distribution of the data and the method of model construction will be examined. Core could be re-logged if necessary. The uncertainty introduced to the groundwater flow simulations can be better understood using multiple modeling techniques.

In fact the models could be revised taking a new integrated database into consideration. This would include results of all borehole investigations at Shobasama, long-term pumping tests, VSP testing, borehole geophysical surveys and other borehole investigations carried out for the Regional Hydrogeological Study Project.

2.1.2 Hydrogeological investigations

(i) Long-term pumping test

Long-term pumping tests done in Phase I-a completely covered the hanging wall and the footwall sections of the Tsukiyoshi Fault. Such testing aimed to determine the average hydraulic properties of a large volume of the rock mass at the site. It also was intended to test the geological model and aspects of the hydrogeology, such as the flow model adopted and boundary conditions applied for the flow simulations. As long-term monitoring continues, there may be indications of changes to the flow system. If considered significant enough, re-investigation of the flow system with a long-term pumping test may be desirable.

(ii) Long-term monitoring of groundwater

Long-term observations of water balance from meteorological and stream flow data and groundwater pressure in the boreholes with MP systems installed will continue. As the groundwater flow system re-establishes data on hydraulic head in isolated zones and the potentiometric surface will be collected. Groundwater sampling will also continue.

(iii) Modeling technique for hydrogeology

Groundwater flow simulation will be continued for an area of several km square to several hundred meters square. Data from the on-going studies will be used for setting boundary conditions of the models, to estimate the effect of shaft excavation at the “MIU Construction Site” and for evaluation of analytical results in multiple modeling techniques.

2.1.3 Hydrochemical investigations

(i) Collection of groundwater using MP system

Accumulation of data related to hydrochemical properties of deep groundwater in the Toki Granite will be carried out using the MP system installed in each borehole. In particular, major permeable fractures, the Tsukiyoshi Fault and associated fracture zones and the footwall of the Tsukiyoshi Fault will be targeted. During Phase I groundwater could not be collected from MIU-1, 2 and 3. This may be possible as the system re-establishes and any contaminated water from the Phase I drilling flushes from the system.

(ii) Construction of hydrochemical model If new data and new understanding is developed, the hydrochemical model (facility-scale) will be re-constructed by integration and interpretation of the accumulated data. This is expected to result in an improved model of the hydrochemistry and improved modelling expertise.

(iii) Age dating of deep groundwater in the Toki Granite

Correction of groundwater ages (e.g. estimation of dead carbon supply in ^{14}C) could be done if new geological data on fracture-filling minerals (mineralogical, chemical and isotopic compositions) and hydrochemical data of surface- and groundwater and fracture network becomes available. An objective is to revise the groundwater flow model if enough data is available on the variability and distribution of isotopes.

2.1.4 Borehole equipment investigations

As long as the MP system is installed at the Shobasama Site for monitoring purposes during shaft sinking, it will not be possible to carry out any tests of other downhole systems at the site. Nevertheless, if the MP system is removed from any borehole(s), it may be possible to perform trial equipment tests. These could be for any of the disciplines, geology, geophysics, hydrogeology, hydrochemistry and rock mechanics. In addition, given the well-characterized boreholes, it may also be possible to calibrate new instruments prior to use at the MIU Construction Site and to do repeat surveys to determine the precision of instruments.

Consideration will be given to future use of the boreholes for teaching borehole investigations for domestic and foreign nationals.

2.2 Development of investigation techniques and equipment

Applicability of following techniques will be examined.

(i) Evaluation of applicability of flow meter logging technique

To identify and classify low permeability fractures intersected by boreholes, a more sensitive fluid logging detection method than the ones currently used is desired. Therefore, the application of highly sensitive and accurate hydrological fluid logging techniques will be examined. At this time, *Posiva flowlog* of Finland is recognized as the most advanced in the world. Thus, fluid logging using *Posiva flowlog* will be tested and its applicability to rock in Japan will be evaluated.

(ii) Examination of evaluation techniques of permeability in rock mass

When calculating rock permeability, which forms an upper boundary condition in groundwater flow simulations, the following points should be taken into account: mechanism of infiltration from the ground surface to depth, storage capacity of surface rocks, transpiration/evaporation effect on water balance in vegetated areas and up-scaling of data obtained from a small area to a wider area.

At the Shobasama Site, a weather observation system, parshall flume, groundwater level meter and tensiometer (for soil moisture monitoring) have been installed. Thus the infrastructure to address the above points is in place. Therefore, long-term monitoring and data analysis on vertical rock permeability will continue.

3 Schedule

An interim investigation schedule in the Shobasama Site is as follows.

Table 1 Schedule of investigations in the Shobasama Site

Investigations	2002FY	2003FY	2004FY	2005FY
1 Improvement of modelling technique for the geological environment				
(1) Geological investigations				
① Development of identification/classification techniques for permeable fractures	■	■	■	
② Construction of modelling technique for geology	■	■	■	
(2) Hydrogeological investigations				
① Long-term pumping test		■		
② Long-term groundwater monitoring	■	■	■	■
③ Construction of modelling technique for hydrogeology	■	■	■	
(3) Hydrochemical investigations				
① Collection of groundwater using MP system	■	■	■	■
② Construction of hydrochemical model	■	■	■	■
③ Age dating of deep groundwater in the Toki Granite	■	■	■	■
2 Development of investigation techniques and equipment				
① Evaluation of applicability of flow meter logging technique	■	■		
② Examination of evaluation technique of permeability in rock mass	Carried out in 1(2)③			