5 Summary

5.1 Geological investigations

With respect to an assessment of (a) the amount of data that can or should be acquired, i.e., the data requirements for each of the investigations and the investigations to be performed and the relationship (b) the quality and accuracy of the results needed for analysis and modeling, geological models are constructed. For the Shobasama Site and the larger study area for groundwater flow simulations (about 4 km× about 6 km), two models were constructed. The first model was based on the data from literature surveys and other geoscientific research. The second model was based on this data plus the results from Phase I-a, in the 1996 to 1999 period.

In the first model, the granite could be divided into only two parts, the deeply weathered zone and the remaining rock mass, because of the lack of information of fractured zones or lithological variations in the granite.

The second model, supplemented with investigation results from Phase I-a, new geological units such as biotite granite, felsic granite, “Upper fracture zone”, “Moderately fractured zone” and “Fracture zone along the fault” are defined by new geophysical logging and borehole investigations.

However, despite the improvements made, the second model still contains uncertainty related to the lack of information on tectonics in the northeastern part of the Shobasama Site, the deep underground exceeding 1,000 m and the fractures with steep inclination.

5.2 Hydrogeological investigations

In surface hydrological investigations, water balance observations and measurement of meteorological parameters were carried out. The aim is to determine the recharge rate for the top boundary condition needed for groundwater flow simulations and to develop techniques to obtain the evaluation data of the simulation results. As a result, it was estimated that groundwater recharge measures approximately 5 to 10% of the annual precipitation.

Hydraulic tests were carried out using the MIU-1, 2 and 3. As a result, groundwater level and hydraulic conductivity of the rock mass were estimated. In addition, hydrogeological properties of highly permeable fractured zones (presumed to be water channels) and the Tsukiyoshi Fault, presumed to be a hydraulic barrier to flow, were estimated.

As was done for the geological investigations, an assessment of the amount of data that can or should be acquired, i.e., the data requirements and the investigations (type, quantity, detail, scope) to be performed and the relationship to the accuracy of the results needed for analysis and modeling, hydrogeological models were constructed and groundwater flow simulations carried out. Both were carried out based on the following two data sets: a) data from literature survey and other geoscientific researches, b) data including the results of Phase I-a. A continuum model was applied to the model construction and groundwater flow simulation using the pre-Phase I-a data. Then, an "equivalent continuum model" was developed statistically for the groundwater flow simulations using the earlier data and data from Phase I-a. As a result, it turns out that the "equivalent continuum model" predicts more realistically groundwater flow in the groundwater flow simulation in a medium-sized domain including structural discontinuities, i.e., fractures and faults. Specifically, an irregular hydraulic head drawdown formed along the distribution trend of fractures. Also, the Tsukiyoshi Fault was expressed as a hydraulic barrier to flow by change in hydraulic pressures.

5.3 Hydrochemical investigations

From the results of the RHS Project and other investigations, groundwater was sampled and its physicochemical parameters analyzed. The analysis indicated that the groundwater in the shallow part (shallower than 300 m in depth) in the Shobasama Site is of Ca^{+2}-Na^{+}-HCO_3^{-} type, neutral (pH=7) and oxidizing (Eh>0 mV). It changes to a Na^{+}-HCO_3^{-} type, weakly alkaline (pH=9), and reducing (Eh<-300 mV) at depths greater than 300 m.

To examine the groundwater evolution, the Fe^{3+}/Fe^{2+} ratio in cores (granite) obtained from the boreholes was measured. It indicates predominance of Fe^{3+} over Fe^{2+} at shallower than 300 m in depth. This indicates that oxidation-reduction environment in the granite varies with depth.

In the future, groundwater will be collected and analyzed in MIU-4 drilled in the Phase I-b. Also, using the data from the MIU-4 and the RHS Project, chemical and mineral compositions of rocks and the groundwater evolution will be examined.

5.4 Rock mechanical investigations

On the basis of the data on physical/mechanical properties and in situ stresses obtained in the AN-1 and the MIU-1, 2 and 3, rock mechanics conceptual models were constructed in the following three steps.

a) Construction using the data from the AN-1 and MIU-1,

b) Revision of Model (a) using the data from MIU-2,

c) Revision of Model (b) using the data from MIU-3.

As a result, three zones with unique physical and mechanical properties as well as in situ stress states were identified: ground surface to 300/400 m, 300/400 to 700 m and 700 to 1,000 m in depth.

In the future, mechanical/physical properties of the Tsukiyoshi Fault and associated fractured zones should be understood. Also, the validity of the model should be evaluated by numerical analysis. In addition, mechanical/physical properties of discontinuity planes should be assessed by the results of joint shear tests. As a result, the model is expected to be quantified.

5.5 Investigation techniques and equipment

Existing investigation techniques and equipment are being improved, including those developed by TGC.

In addition, investigation techniques and equipment that would be needed in and after the Phase II are also developed.

(1) Techniques and equipment for borehole investigations
A drilling system using a reverse aeration, wire-line method was designed. As well, the equipment for development of a partial-casing insertion system was assembled and an operational application test was carried out.

(2) Techniques and equipment for geological investigations
The development of seismic tomography using 1000 m deep boreholes was in progress to determine the extent of discontinuity planes deep underground. So far, testing was carried out in the existing boreholes aiming for application down to 1,000 m depth. In addition, the development of a data analysis technique called "full-wave form inversion analysis" was carried out with the purpose of improving data resolution.

(3) Techniques and equipment for hydrogeological and hydrochemical investigations
Hydraulic test equipment and water sampling equipment for depths to 1,000 m, assembled and utilized by 1998 FY, were improved for use in curved boreholes.

(4) Techniques and equipment for rock mechanical investigations
In situ stress measuring equipment for depths 1,000 m was designed and manufacture is underway.

(5) Techniques and equipment for use during and after Phase II
Continuous-wave radar investigation techniques, a long-term monitoring system in boreholes, and an investigation system for survey of research gallery walls were developed.

(6) Data base construction and management and development of a data analysis and visualization system
A data base management system was introduced and improved for management and utilization of the data. The system used for data analysis/visualization of data on geological environments, which is used for the construction of geological environment models and groundwater flow simulation, was also improved to enhance its function and operation.

(7) Techniques and equipment for information disclosure
Virtual reality (VR) technology was introduced, and VR software introducing the MIU Project was developed. Furthermore, the software was improved to allow visitors more realistic experience by using a head mounted display.

5.6 Evaluation of prediction

In order to evaluate predictions appropriately, it was considered necessary to clearly define an evaluation process. Taking this into consideration, international experience was examined.

5.7 Development of the engineering technology for deep underground

Basic design concepts were examined, domestic and overseas precedents considered and the requirements for underground research laboratories outlined by the Atomic Energy Commission (1994) [(1)] were referred to. According to the examination results, preliminary but conceptual designs of facilities were drawn up.