UNDERGROUND RESEARCH LABORATORIES FOR CRYSTALLINE ROCK AND SEDIMENTARY ROCK IN JAPAN

N. Shigeta, S. Takeda
Japan Nuclear Cycle Development Institute Tono Geoscience Center
959-31, Jorinji Izumi, Tokishi, Gifu, Japan

H. Matsui, S. Yamasaki
Japan Nuclear Cycle Development Institute Horonobe Underground Research Center
Miyazono-cho 1-8, Horonobe, Hokkaido, Japan

ABSTRACT

Underground Research Laboratories for Crystalline Rock and Sedimentary Rock in Japan

The Japan Nuclear Cycle Development Institute (JNC) has started two off-site (generic) underground research laboratory (URL) projects, one for crystalline rock as a fractured media and the other for sedimentary rock as a porous media. This paper introduces an overview and current status of these projects.

The URL project for crystalline rock is located in Mizunami, some 40 km northeast of Nagoya, in the central part of the main island of Japan. This project was initiated in 1996 at the Shobasama site, where construction of URL facilities had been planned. Hydrogeological modeling and groundwater flow analyses in and around the site were performed. The preliminary analyses based on the rock mechanical model of the site were also performed to predict the behavior of deformation caused by the construction of shafts and drifts. The site for the URL facilities was relocated in January 2002, from the Shobasama site to an area of city-owned land nearby (the MIU construction site) after concluding a lease contract with Mizunami City. Surface-based investigations at the MIU construction site started in February 2002. A geological modeling study near the MIU construction site has started based on the information from the previous work at the Shobasama site and related investigations in the surrounding area. Based on this model, ground geophysical surveys and shallow borehole investigations have started. Meanwhile, preliminary design of the facilities at the MIU construction site has been completed, and the groundbreaking for the facilities started in July, 2002.

The URL project for sedimentary rock is located in Horonobe in the northernmost region of Hokkaido, north to the main island of Japan. Actual research activities of this project were started in the middle of the year 2001, which were preceded by an opening of the office, Horonobe Underground Research Center in April 2001. During 2001 and 2002, the first surface-based investigation campaign was conducted with a heli-borne geophysical survey and followed by ground geophysical surveys, geological mapping and borehole investigations. The study has briefly revealed the geological condition of Horonobe. Based on the geological data acquired and other natural and social information such as topography, logistics, land use, an area for site-scale investigations was selected. Here URL facilities will be constructed. The second surface-based investigation campaign has been initiated in and around the area for site-scale
investigations. The investigation campaign consists of ground geophysical surveys, geological mapping and borehole investigations. The data acquired are integrated into geological, hydrogeological, hydrochemical and rock mechanical models. Data and models will also be used to predict the influence of constructing an underground facility on the geological environment. Based on the results of the investigations, designing of underground facilities is being advanced and will be detailed along with the input of geological data to be acquired. The project will enter the next construction phase in 2005.

The results obtained from these URL projects are expected to make timely contributions to Japan's disposal program and the establishment of safety regulations.

INTRODUCTION

One of the features of the geological disposal policy in Japan is the establishment of URLs which are clearly distinguished from the disposal facility, as outlined in the Atomic Energy Commission (AEC) report, "Long-Term Program for Research, Development and Utilization of Nuclear Energy" (1). Research on the deep geological environment will provide the basis for R&D on geological disposal of high-level radioactive waste, and the AEC stipulated that research at the underground laboratories will contribute to Japan's scientific research on the geological environment.

JNC’s URL projects are directed towards improving the reliability of geological disposal technologies and developing advanced safety assessment methodologies. It will ensure that the implementation of geological disposal is based on a thorough scientific and technological basis. The URLs in these projects are classified into purpose-built generic URLs as described in the OECD/NEA report, "The Role of Underground Laboratories in Nuclear Waste Disposal Programmes" (2), and are distinct from on-site (site-specific) URLs to be constructed in potential waste disposal sites. In order to cover the general geological environment in Japan, two URLs (Fig. 1.) for crystalline rock and sedimentary rock have been planned. The research of these projects will be conducted in a stepwise manner as the investigation program progresses forward. Investigations from the surface (Phase I) will be followed by investigations with excavation of shafts and drifts (Phase II) and investigations including in-situ experiments using the underground facilities (Phase III). During each phase, information on the geological environment will be collected and interpreted. The interpretation results obtained in a phase will be evaluated in subsequent phases with new information, and the investigation techniques will be improved and integrated. In this process, it is very important to clarify data flow and systematic integration from field investigation to modeling/simulation. Applicability of engineering technologies for the design and construction of an underground facility will also be verified.

Consistent with international practice, JNC is employing a multi-disciplinary approach within the URL projects to characterize geological environments. This requires the integration of results from the fields of geology, hydrogeology, hydrochemistry, rock mechanics and geotechnical engineering. The ultimate objectives are to establish systematic and integrated characterization technologies applicable at a range of sites and for a range of geological conditions. The results obtained from these URL projects are expected to make timely contributions to Japan's disposal
program and the establishment of safety regulations. The URLs can also provide a wide range of possibilities for underground research by universities or other research institutes, as well as serving as a place for enhancing public understanding of R&D activities related to geological waste disposal.

THE CRYSTALLINE ROCK URL (THE MIU PROJECT)

The shafts and drifts of this project will be excavated in the late Cretaceous Toki Granite. The Toki granite has been faulted, and subjected to several processes of uplift and subsidence in the Miocene to Pliocene, indicated by lacustrine and marine sedimentary formations unconformably overlying the granite. There are two sites for the MIU project, one is called the Shobasama site where the URL facilities were previously planned to be constructed, and the other is called the MIU construction site which is a new location for the URL facilities (Fig. 2.). The relocation of the planned URL facilities has been made assenting to the proposal of a land lease by Misunami City. The MIU construction site is located approximately 2 km southeast of the Shobasama site. From existing geological information, the MIU construction site is inferred to have similar
geological environment as the Shobasama site and methodology developed in the Shobasama site would be applicable. After the relocation of the MIU facilities, activities focusing on hydrogeological monitoring at the Shobasama site would be remained.

Schedule of the MIU Project

The schedule for the MIU project consists of three overlapping phases in a 20-year life. The activities in each phase are as follows:
- Phase I (Surface-based Investigation Phase, 7 years): Fundamental information concerning deep geological environment will be acquired by geological surveys, geophysical surveys and borehole investigations from the surface. Based on the acquired information, predictions of the characteristics of the deep underground environment will be carried out.
- Phase II (Construction Phase, 8 years): Shafts will be excavated in order to evaluate the predictions from Phase I. The influence of excavation of the deep underground will be investigated.
- Phase III (Operations Phase, 9 years): Instrumentation will be installed at the stages and/or in the shafts to monitor displacement of rock mass, hydraulic pressure, groundwater inflow, water quality and hydrogeochemistry.

The project’s activity is from FY 1996 to FY 2015. The planned start of shaft excavation is in FY 2003.

**Results of the MIU Project to Date**

In order to establish systematic and integrated characterization technologies on geology, hydrogeology, hydrochemistry, rock mechanics and geotechnical engineering, an iteration approach is adopted. Investigation, modeling and simulation methods employed in the project will be evaluated in terms of their feasibility and usefulness in the iteration cycle which consists of planning, data acquisition, analysis and evaluation. Also, the iteration approach will provide opportunity for gaining knowledge on uncertainties of data and models.

Prior to the surface-based investigation in the MIU project, JNC had started geoscientific research programs in the Tono Mine close to the MIU project sites (3) and in the area encompassing the MIU project sites. The mine provided a locale in sedimentary rocks, which appear also in MIU sites, for underground research and technology development (4). Knowledge on geological conditions of the subsurface at the mine has been used in the development of models for the MIU project. A geoscientific research program includes investigation of the groundwater flow system over a 100 km$^2$ area and regional geological mapping. Data from these programs have provided important knowledge for the development of the conceptual models of the MIU construction site.

In the MIU Project, Due to the lack of bedrock exposure, a large part of the geological information has been obtained from the borehole data and the geophysical information. The boreholes drilled within the Shobasama site are shown in Table I.

**Table I. Borehole Information in the Shobasama Site**

<table>
<thead>
<tr>
<th>Borehole</th>
<th>MIU-1</th>
<th>MIU-2</th>
<th>MIU-3</th>
<th>MIU-4</th>
<th>AN-1</th>
<th>AN-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drill length (m)</td>
<td>1012</td>
<td>1012</td>
<td>1014</td>
<td>790</td>
<td>1010</td>
<td>409</td>
</tr>
<tr>
<td>Orientation</td>
<td>vertical</td>
<td>vertical</td>
<td>vertical</td>
<td>N25E/60</td>
<td>vertical</td>
<td>vertical</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>98.4</td>
<td>98.4</td>
<td>98.4</td>
<td>123</td>
<td>98.4</td>
<td>98.4</td>
</tr>
<tr>
<td>Depth to Granite (m)</td>
<td>88.8</td>
<td>88.6</td>
<td>88.0</td>
<td>81.3</td>
<td>16.6</td>
<td>30.8</td>
</tr>
</tbody>
</table>

In these boreholes, recovered core was photographed and scanned digitally (only MIU-4) for
fracture analysis. Logging of core was systematic, using coded logging forms onto which the photographic image of the core was printed. A standardized system for core logging includes a description of the lithology, the structures, fracture-filling minerals, fracture frequency distributions, alteration, weathering, rock mass classification and Rock Quality Designation (RQD) (5).

Based on the investigations mentioned above, geological model has been established (Fig. 3.)
- Miocene sedimentary rocks 20 to 80 m thick unconformably overlie the granite.
- Highly weathered zone of granite 15 to 20 m thick occurs immediately below the unconformity.
- The granite is divided into two structural domains based on intensity of fracturing: the upper 300 m part is more highly fractured (upper highly fractured domain), perhaps uplift related, compared to the sparsely fractured domain deeper than 300 m in depth.
- Two lithological phases are predominant, an upper biotite granite phase and a lower felsic granite phase.
- Aplite and pegmatite dykes have been observed in both phases.

Fig. 3. Current geological model of the Shobasama site.
A fault with a very wide damaged zone (> 100 m) was intersected by boreholes at depth in the northern part of the Shobasama site. This fault is correlated with the Tsukiyoshi fault which is described as a reverse fault with 30 m displacement, E-W strike and $60^\circ-70^\circ$ S dip by the previous geoscientific studies.

Hydrological and meteorological measuring stations have been established at the Shobasama site and in the surrounding catchment area in order to collect data to be used to estimate local recharge rates into the bedrock.

Geological studies of the drill cores and ground surface indicate possible hydrostructural domains, which depend on depth and the position relative to the Tsukiyoshi Fault, the dominant structural feature of the site. These domains include:
- Upper highly fractured domain.
- Sparsely fractured zone.
- Fractured zone above the Tsukiyoshi Fault.
- Fractured zone below the Tsukiyoshi Fault.

Hydraulic testing has been carried out in the six boreholes shown in Table I. Zones for the testing, such as water-conducting features, are identified with core, flowmeter logging, borehole TV and geophysical logging. These zones are isolated by either single or double packer systems for determination of hydraulic properties. Depending on the expected hydraulic characteristics of the zone being tested, pulse withdrawal tests, slug withdrawal tests or pumping tests were conducted. Boreholes have been completed for long-term monitoring purposes using the Westbay MP system. During the excavation of a borehole, pressure responses were monitored in the isolated zones of other boreholes.

Groundwater sampling combined with hydraulic testing was adopted in the borehole MIU-4 (5). Groundwater sampling was carried out when a large amount of drilling fluid loss occurred. After drilling had stopped, hydraulic testing was done which targeted on the fluid loss fracture. At the latest stage of the pumping test, water sampling was performed when the monitored tracer content had fallen below a standard assigned level. Even if the tracer content would exceed the level, the content of the major component of the groundwater could be estimated by extrapolating the trend of the tracer content vs. major component.

The goal of the rock mechanics study is to obtain data on the mechanical properties and in-situ stress state of the Toki granite to 1000 m in depth. The principal stresses were measured using the hydraulic fracturing method in the boreholes. This is supported by Differential Strain Curve Analysis (DSCA) and Acoustic Emission (AE) studies in the laboratory. The results of the rock mechanical investigation are as follows:
- Maximum principal stress is horizontal in the hanging wall of the Tsukiyoshi fault.
- Step changes in stress magnitude and in orientation from north to northwest indicate that stress decoupling has occurred.

**On-going Activities and Future Plan of the MIU Project**

Characterization of geological environments is on-going from the surface at the MIU construction site. The knowledge established at the Shobasama site on the following matters is
also useful at the MIU construction site.
- Conceptualization of geological features such as “upper highly fractured domain”, “sparsely fractured domain” and “fracture zone along the faults” identified in the granite of the Shobasama site.
- Investigation technology such as QA/QC methodologies of data acquisition in the fields of geology, hydrogeology and hydrochemistry.
- Drilling technique.
- Technique for Water-conducting feature (WCF) identification.
- Field management system.

Based on the knowledge above, the following items are planned for investigation at the MIU construction site or the surrounding area for surface-based investigations. Some of them are on-going.
- Geological mapping.
- Ground geophysics such as seismic reflection/refraction.
- Shallow borehole investigations.
- Existing borehole investigations around the site.
- Deep borehole investigations at the site.
- Deep borehole investigations around the site.
- Cross hole tomography and hydraulic tests using the boreholes at and around the site.
- Groundwater monitoring such as hydraulic pressure and hydrochemistry.

The investigations of the phase II and phase III have now been discussed. The following are considered to be major activities after the phase I.

Phase II investigation will be done at the main shaft and the drift to be excavated every 100 m between the main shaft and ventilation shaft. Underground facilities will be constructed in the phase II.
- Geological mapping of the main shaft and drift wall.
- Measurement of inflow rate during the shaft sinking.
- Cross hole hydraulic test on the WCFs.
- Groundwater sampling from the shaft and boreholes around the shaft, and chemical analysis of the water sampled.
- AE measurement and borehole expansion test for excavation disturbed zone (EDZ) investigation.
- Hydraulic pressure and hydrochemical monitoring in the boreholes drilled from the surface around the shaft.

Phase III investigation will be conducted at the sub and the main stages.
- Geological mapping of the middle and main drifts.
- Hydraulic interference test focused on a single fracture and a fracture network.
- Redox experiment in the boreholes drilled from the drift.
- Geophysical investigations, AE measurements, etc. in the drift for evaluating the EDZ.
- Tracer experiments focused on the single fracture and fracture zones.
- Hydraulic pressure and hydrochemical monitoring in the boreholes drilled from the surface around the shaft.
THE SEDIMENTARY ROCK URL (THE HORONOE URL PROJECT)

As representative sedimentary rock, Neogene argillaceous sedimentary formations are selected for host formations for the URL, because of its wide distribution in Horonobe. The underground research facility will be excavated from surface to about 500 m deep in the host formation. The regional geology of Horonobe-cho consists of Neogene sedimentary sequences (ascending orders; Souya coal bearing Formation, Masuporo-formation, Koitoi-formation, Wakkanai-formation, Yuchi-formation), which are underlain by Palaeogene and Cretaceous sedimentary and igneous basement (Fig. 4.). There are some faults called Ohmagari fault and Nukanan fault zone in the area of interest within Horonobe-cho.

**Schedule of the Horonobe URL project**

Similar to the MIU project, a wide range of geoscientific research and development activities are planned for this project over three phases that will span a total period of around 20 years: surface based investigation phase (6 years), construction phase (8 years) and operation phases (12 years). Phases are overlapped phase by phase.
**Results of the Horonobe URL project to date**

Surface-based investigation began from April 2001. We selected four areas (Area A, B1, B2 and C) in Horonobe-cho based on the results of a literature survey (Fig. 4.). Afterward, heli-borne electromagnetic, magnetic and gamma spectrometry surveys were performed in the area which includes Area A, Area B1 and Area B2. A relatively resistive zone (30～50 $\Omega$ m) was found along the west side of the Ohmagari fault where Sarabetsu and Yuuchi formations are thought to be distributed based on literature information. MT/AMT methods were performed as a ground geophysical survey, to obtain information of geological structure of the deeper underground which would not be obtained from a heli-borne survey. Sarobetsu and Yuchi formations, which are mainly composed of sandstone and conglomerate, are distributed from surface to 1000 m depth at the west side of the Ohmagari fault according to existing geological knowledge. The result shows a relatively resistive layers (up to 20 $\Omega$ m) in the uppermost portion of the profile west of Ohmagari fault. This resistive layer is thought to correspond to Sarabetsu and Yuuchi formations. On the other hand, Koetoi and Wakkanai formations, which mainly consist of mudstone, show low resistivity (a several $\Omega$ m) as expected. However, they could not be distinguished from each other because of very small resistivity contrast. The geological information from the literature was also confirmed with geological mapping.

After these geophysical surveys, two deep boreholes at 720 m depth, called HDB-1, HDB-2, were drilled in the B1 and B2 areas (Fig. 4.).

Both boreholes found Koetoi and Wakkanai formations. These formations consist of diatomaceous mudstone. Lithological, mineralogical and microscope observations, and X-ray diffraction showed that the degree of diagenesis of the Wakkanai formation is advanced. The in-situ hydraulic tests in HDB-1 and HDB-2 showed a range of hydraulic conductivities of 10E-9～10E-11 m/sec in the measurement sections where the Wakkanai mudstones has some fractures and/or fracture zones (Table II). The laboratory hydraulic tests of the rock matrix of

<table>
<thead>
<tr>
<th>In-situ hydraulic test</th>
<th>Laboratory test with Tranjent Puls method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borehole</td>
<td>Depth(m)</td>
</tr>
<tr>
<td>HDB-1</td>
<td>370.00-395.00</td>
</tr>
<tr>
<td></td>
<td>392.11</td>
</tr>
<tr>
<td></td>
<td>548.00-563.19</td>
</tr>
<tr>
<td></td>
<td>562.92</td>
</tr>
<tr>
<td>HDB-2</td>
<td>344.90-404.90</td>
</tr>
<tr>
<td></td>
<td>389.11</td>
</tr>
<tr>
<td></td>
<td>679.50-695.69</td>
</tr>
<tr>
<td></td>
<td>676.50-682.69</td>
</tr>
</tbody>
</table>

*Negrect gas effect

**Hydraulic conductivity were calculated by Multisim

***Hydraulic conductivity were calculated by Hvorslev's formulation
the Wakkanai mudstone showed a range of 10E-11～10E-13 m/sec. Interesting phenomena have been identified with hydraulic tests. Deeper sections (679-696 m) of HDB-2 borehole have a very high waterhead of about 110m above GL. The groundwater has high content of Na+ and Cl-. The amount of Cl- is about 1/2～1/3 of present seawater. The main component of water-soluble gas in HDB-1 and HDB-2 is identified as methane.

The physical and mechanical properties of the Koetoi and Wakkanai formations are shown in Table III. The rocks in both formations were classified into soft rock. The physical properties (density, porosity, seismic velocity etc.) and mechanical properties (elastic modulus, poisson’s ratio, uniaxial compressive strength etc.) increase with depth in the Koetoi formation. However, such a trend could not be found in the Wakkanai formation. Initial stress measurements with hydraulic fracturing were carried out. In HDB-1, the horizontal maximum principal stress is 1.5 times that of the minimum principal stress and the direction is almost EW in the Wakkanai formation. Minimum horizontal principal stresses are equal to the calculated overburden pressure. Moreover, the borehole breakout was observed in several sections below 400 m in HDB-1. The directions of borehole breakout suggest that the directions of maximum horizontal principal stress are almost EW as well. In HDB-2, the magnitudes of maximum and minimum principal stresses do not show significant difference compared to those in HDB-1. However, the directions of maximum horizontal principal stress are near NS directions. Totally, the properties of the diatomaceous mudstone of the Koetoi and Wakkanai formations do not deviate from those of other Neogene sedimentary rock distributed in Japan.

Table III. Range of the Physical and Mechanical Properties of Cores

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Unit weight (kN/m3)</th>
<th>Porosity (%)</th>
<th>Water content (%)</th>
<th>Seismic velocity</th>
<th>Unit weight (kN/m3)</th>
<th>Porosity (%)</th>
<th>Water content (%)</th>
<th>Seismic velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14-16</td>
<td>60-62</td>
<td>60-70</td>
<td>1.6-1.75</td>
<td>35-50</td>
<td>20-42</td>
<td>1.7-2.5</td>
<td>0.7-1.0</td>
</tr>
<tr>
<td>Mechanical properties</td>
<td>Elastic modulus E50 (MPa)</td>
<td>Poisson ratio</td>
<td>Uniaxial compressive strength (MPa)</td>
<td>Cohesion (MPa)</td>
<td>Internal friction angle (degree)</td>
<td>Elastic modulus E50 (MPa)</td>
<td>Poisson ratio</td>
<td>Uniaxial compressive strength (MPa)</td>
</tr>
<tr>
<td></td>
<td>0.5-1.0</td>
<td>0.25-0.45</td>
<td>0-8</td>
<td>1-2</td>
<td>15-25</td>
<td>2.0-5.0</td>
<td>0.18-0.35</td>
<td>10-35</td>
</tr>
</tbody>
</table>

*Rough estimation for a range of the values in this table

On-going Activities and Future Plan of the Horonobe URL Project

The geological survey, geophysical surveys and borehole investigations suggest that the host Neogene argillaceous formations in Areas A, B1 and B2 are distributed with an appropriate thickness near 500 m deepth and has sufficient rock mechanical strength for URL construction
using normal supporting. Although there exists water-soluble methane gas, construction of underground facilities is thought to be done safely by maintaining a sufficient supply of fresh air combined with degassing the short borehole drilling. Introduction of auto-explosive machines and equipment will also be implemented as additional safeguards. Areas B1 and B2 were both initially thought to be candidate areas for URL. Both areas were compared while also considering practical things, such as topography, access and land use. In consideration of the methane gas content, fracture distribution and practical issues (e.g. access, licence) Area B1 was selected as research area in 2002. This area is about three km by three km. The Ohmagari fault is at the center of the area. The geological environment of area B1 is expected to contain mudstones of the Neogene Koitoi and Wakkanai formations. These mudstones are classified into soft sedimentary rock and have low permeability. Saline water containing dissolved gas could possibly be distributed in these formations.

In 2002, as a part of the second field investigation campaign, Seismic reflection surveys in and around the selected area were performed. The surveys included the first studies to estimate the detail geological structure of the area including Ohmagari fault. The drilling and investigation work of three boreholes at 520 m depth (HDB-3,4 and 5) are in progress. Planning of research and development for the second and third phase is being advanced in parallel to design work of URL.

SUMMARY

Off-site URLs are a fundamental element of Japan's nuclear waste management policy. JNC has started two off-site URL projects, one for crystalline rock as a fractured media and the other for sedimentary rock as a porous media. These two sites will cover a range of geological environment in Japan. The ultimate objectives are to establish systematic and integrated characterization technologies applicable at a range of sites and for a range of geological conditions. Both projects are planned in three overlapping phases of investigation, and are now in the surface-based investigation phase (Phase I). The geological survey, geophysical surveys and borehole investigations from the surface are on-going, and the results from the fields of geology, hydrogeology, hydrochemistry, rock mechanics are being integrated.
REFERENCES


