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Horonobe Underground Research Laboratory Project
Plans for Surface-based Investigations (Phase 1)

October, 2003

Horonobe Underground Research Center
Japan Nuclear Cycle Development Institute

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(Translated Document[1])

Junichi Goto* and Katsuhiro Hama*

Abstract

The Horonobe Underground Research Laboratory Project is an investigation project which is planned over 20 years. The investigations are conducted in three phases: investigations from the surface (Phase 1), investigations during construction of the underground facility (Phase 2) and investigations using the facility (Phase 3). Taking into account the results from "H12: Project to Establish the Scientific and Technical Basis for HLW Disposal in Japan - Second Progress Report on Research and Development for the Geological Disposal of HLW in Japan -" (JNC, 2000), research and development goals for the Horonobe URL project were re-defined as follows;

a) Development of investigation technologies for the geological environment,
b) Development of monitoring technologies for the geological environment,
c) Study on the long-term stability of the geological environment,
d) Development of the basis for engineering technologies in deep underground,
e) Verification of technologies for engineered barriers,
f) Development of detailed designing technologies of the repositories, and
g) Improvement of safety assessment methodologies.

Investigations for the goals a) to d) and e) to g) are conducted in the "Geoscientific Research" and "Research and Development on Geological Disposal," respectively.

In Phase 1, a "laboratory construction area" of a few kilometers square is selected based on the results from early stage investigations. Subsequent investigations are concentrated in the selected area and its periphery. Acquisition of data by surface-based investigations, modeling of the geological environment and predictions of changes in the geological environment caused by the construction of the underground facility, are conducted in a) Development of investigation technologies for the geological environment. Development and installation of monitoring equipments and and data acquisition prior to the construction of the underground facility fall under b) Development of monitoring technologies for the geological environment. Information on earthquake/fault activities, uplift/subsidence/denudation processes and crustal activities are collected and integrated by literature survey, surface geological investigations and earthquake monitoring in c) Study on the long-term stability of the geological environment. Designing of the underground facility, examination of construction management methods, and investigation plans for restoration techniques on damages of the construction are focussed in d) Development of the basis for engineering technologies in deep underground. Investigation plans for Phases 2 and 3 include e) Demonstration of technologies for engineered barrier and f) Development of methodologies for detailed designing of deep repositories. Safety assessment models are tested and improved, and items, amount and accuracy of data for safety assessment are confirmed through investigations for g) Improvement of reliability on safety assessment methods.

Environmental survey in the laboratory construction area, and designing and land development for ground facilities are conducted in Phase 1. A part of the research and development for the "Earthquake Frontier Research Project" is also to be conducted.

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[1] This document is an English translation of Technical Document JNC TN1410 2001-001 (in Japanese).

* Horonobe Underground Research Center Co-ordination Group

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幌延深地層研究計画　地表から行う調査研究（第１段階）計画

（翻訳資料[2]）

後藤　淳一[*]、濱　克宏[*]

要旨

幌延深地層研究計画は、調査研究の開始から終了まで 20 年程度の研究であり、「地上からの調査研究段階（第１段階）」、「坑道掘削（地下施設建設）時の調査研究段階（第２段階）」、「地下施設での調査研究段階（第３段階）」の３つの段階に分けて実施する。本計画における研究開発の目標（達成課題）として、「わが国における高レベル放射性廃棄物地層処分の技術的信頼性 - 地層処分研究開発第 2 次取りまとめ - 」(JNC, 1999)における検討結果を受け、

①地質環境調査技術開発
②地質環境モニタリング技術の開発
③地質環境の長期安定性に関する研究
④深地層における工学的技術の基礎の開発
⑤人工バリア等の工学技術の検証
⑥地層処分場の詳細設計手法の開発
⑦安全評価手法の信頼性向上

を設定した。このうち①～④を「地層科学研究」、⑤～⑦を「地層処分研究開発」として実施する。

第１段階の初期に、それまでの調査結果に基づき 2~3km 四方の「研究所設置地区」を選定し、地区内およびその周辺地域において調査研究を展開する。①地質環境調査技術開発では、地表からの調査によるデータの取得、地質環境のモデル化、地下施設の建設による地質環境の変化の予測を行う。②地質環境モニタリング技術の開発では、地下施設建設による地質環境の変化を観測するために、モニタリング機器を開発・設置し、初期状態の観測を開始する。③地質環境の長期安定性に関する研究では、文献調査や現地調査、地震観測などにより、地震・断層活動、隆起・沈降・侵食の過程、現在の地殻活動に関する情報の取得・整理を行う。④深地層における工学的技術の基礎の開発では、地下施設の設計、施工管理方法の検討、および地下施設建設による岩盤への影響の修復技術の検討を行う。⑤人工バリア等の工学技術の検証、および⑥地層処分場の詳細設計手法の開発では、第 2 段階以降の坑道を用いて行う試験研究計画を策定する。⑦安全評価手法の信頼性向上では、安全評価に必要なデータの項目・量・精度の確認と、モデルの適用試験と改良を行う。

第 1 段階ではその他に、研究所設置地区における環境調査、地上施設の設計および造成を行う。また、「陸域地下構造フロンティア研究」の一部を、本プロジェクトでも実施する計画である。

[2] 本資料は核燃料サイクル開発機構技術資料「JNC TN1410 2001-001 深地層研究所（仮称）計画　地表から行う調査研究（第１段階）計画」に基づき英訳したものである。

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Contents

1 Introduction

The Horonobe Underground Research Laboratory (Horonobe URL) project is a research and development project of the Japan Nuclear Cycle Development Institute (JNC), planned at Horonobe-cho in northern Hokkaido. The Horonobe URL is one of the underground research laboratories stated in the "Long-term Program on Research, Development and Utilization of Nuclear Energy (LTP)" (Atomic Energy Commission of Japan (AEC), 1994), and aims to study the deep geological environment in sedimentary rocks. The importance of the underground research laboratories is stated in the revised LTP (AEC, 2000) as providing sites for research and development to confirm geological disposal technologies and to establish safety assessment methodologies, and also serving as a facility for the public to learn about geological disposal.

The Horonobe URL project is to carry out two major researches: "Geoscientific Research,” a scientific study of the deep geological environment, and "Research and Development on Geological Disposal" for improvement of reliability on the geological disposal technologies and advancement of safety assessment methodologies. The Horonobe URL project is planned over a period of 20 years, with investigations conducted in three phases.

Phase 1: surface-based investigations (6 years).
Phase 2: investigations during construction of the underground facility (6 years).
Phase 3: investigations using the facility (9 to 11 years).

There are some overlaps between these phases, and the terms are subject to change according to the progress of the project.

This report summarizes the plan of the surface-based investigations (Phase 1). Contents and amount of the investigation programs are improved according to the progress of the project, incorporating the newest knowledge and techniques.

2 Roles of the Horonobe Underground Research Laboratory

The Horonobe URL project aims to confirm the scientific and technical basis for geological disposal as presented in the “H12: Project to Establish the Scientific and Technical Basis for HLW Disposal in Japan - Second Progress Report on Research and Development for the Geological Disposal of HLW in Japan -” (JNC, 2000) through investigations of the actual deep geological environment in sedimentary rocks.

The results contribute to the formation of the geological disposal program of the implementing organization and to the safety regulation by the government. They are to be considered together with the results of the geoscientific research conducted at the JNC Tono Geoscience Center in Gifu Prefecture, the research and development on geological disposal at the JNC Tokai Works in Ibaraki Prefecture, and with results obtained from international cooperative studies.

Another important role of the Horonobe URL is to enhance public understanding toward the deep geological environment and HLW disposal by visiting the investigation sites and actually being exposed to the deep underground.

3 Goals and key issues of the Horonobe Underground Research Laboratory Project

3.1 R & D requirements following the Second Progress Report (H12)

The second progress report (H12) concluded that:

- It is possible to select a sufficiently stable geological environment in Japan for at least the next hundred thousand years.
- It is possible, although costly, to technically design, construct, operate and close the repository corresponding with the wide range of geological environment in Japan, and if necessary, to actively manage the disposal site for a certain period.
- Regarding long-term stability of a geological disposal system, the risks at the time of maximum influence on man are considerably below the levels of foreign standards currently in force.

H12 also stated that in order to support implementation of geological disposal, it is required for the research and development after 2000 to confirm and improve the technologies reported in H12 by applying them to the actual geological environment. Requirements on research and development are specified in Table 1. Most of the items are deeply correlated with the research and development in underground laboratories.

3.2 Goals and key issues of the Horonobe URL Project

Taking the above requirements into account, goals and key issues of the Horonobe Underground Research Project are re-defined from the master plan (JNC, 1998) (Table 2). Investigations for goals (a) to (d) and (e) to (g) are conducted in the "Geoscientific Research" and "Research and Development on Geological Disposal," respectively[3]. Key issues for the goals are described below and in Table 3.

a) Development of investigation technologies for the geological environment
Qualified data are systematically acquired in the surface-based investigations and in the investigations during and after the construction of underground facility. The data are interpreted, and geoscientific models of geology, hydrogeology, hydrochemistry and rock mechanics are constructed. The models are confirmed or revised when new data are acquired. By alternating these processes, the feasibility of surface-based investigations are verified to understand the geological environment from the surface to the deep underground. Changes in the geological environment caused by the construction of the underground facility are predicted by analysis of the models. The predictions are compared with actual measurements in the Phase 2 investigations. A synthesis of knowledge and experience, including investigation equipment and modeling methods, will contribute to establishing a comprehensive investigation technology for the geological environment.

b) Development of monitoring technologies for the geological environment
Monitoring equipments are developed and installed. Measurement of the geological environment such as groundwater pressure is started before construction of the underground facility to monitor impacts of the activities and their recovering processes. Equipment and methods are improved when necessary. A synthesis of knowledge and experience will contribute to establishing a comprehensive monitoring technology for the geological environment.

c) Study of the long-term stability of the geological environment
Studies are carried out on natural phenomena such as earthquake/fault activities, uplift/subsidence, climatic/sea-level changes and volcanic activities, and monitoring of the earth's crust movement are conducted. The increased understanding contributes to establishing a methodology for assessment of

[3] JNC's research and development on technologies for geological disposal comprises of "Geoscientific Research" and "Research and Development on Geological Disposal". The "Geoscientific Research" is a scientific study on deep geological environment which provides the basis for the "Research and Development on Geological Disposal" (JNC, 2002).

the long-term stability of the geological environmentrequired by the H12 report.

d) Development of the basis for engineering technologies in deep underground
Techniques to design and construct a large facility in deep underground and to restore excavation damages in the surrounding rocks are to be verified through investigations. Investigations to understand the effects of construction against the geological environment are also conducted. In addition, techniques to maintain the safety and stability of the environment in the underground facility are to be developed.

e) Demonstration of technologies for engineered barriers
Techniques of transportation and emplacement of engineered barriers and of backfilling of the repository are demonstrated by applying them to the actual deep geological environment. Based on the results, manuals and guidelines for designing engineered barriers are to be developed.

f) Development of detailed designing methodologies of repositories
Modes of long-term behavior of engineered barriers and host rock are verified through investigations for coupled thermo-hydro-mechanical-chemical phenomena in the underground facility. Based on the results, manuals and guidelines for designing engineered barriers are to be developed.

g) Improvement of safety assessment methodologies
The methodologies of safety assessment in H12 are applied to Horonobe URL as a test example. Handling of data and applicability of models for safety assessment are to be confirmed.

3.3 Location of research and development

Research and development of the Horonobe URL project are proceeded in collaboration with (a) investigations in the actual deep geological environment in Horonobe URL, (b) laboratory scale experiments for verification of phenomena models and engineering techniques in ENTRY[4], and (c) experiments using radioactive isotopes in QUALITY[5]. The work share between the Horonobe URL and ENTRY/QUALTY is described in Table 4.

[4] Engineering Scale Test and Research Facility at the JNC Tokai Works
[5] Qualitative Assessment Radionuclide Migration Experimental Facility at the JNC Tokai Works

Table 1 R&D required for implementation of geological disposal (key issues prior to characterizing potential candidate sites) (excerption from JNC (2000))

Technologies for determining the long-term stability of the geological environment

Goals	Key issues
Development of systematic methodologies for evaluating the stability of the geological environment for siting	- Case studies for improving investigation methodologies of potential impacts caused by natural phenomena - Development of technical criteria of the geological environment to be considered for siting

Technologies for characterizing the relevant geological environment

Goals	Key issues
Verification of methodologies for characterizing geological environments specific to potential candidate sites	- Development and demonstration of systematic and practical methodologies for preliminary investigation of geological environments at potential candidate sites [B] - Development and demonstration of advanced techniques for characterizing geological environments [B] - Development and demonstration of systematic monitoring technologies [B]

Engineering technologies

Goals	Key issues
Demonstration of engineering technologies	- Overpack fabrication technologies (remote-controlled techniques for welding and non-destructive tests, fabrication techniques for composite overpack) [A] - Techniques for transport and emplacement of waste packages [B] - Fabrication and emplacement techniques for buffer material (large mock-up test, remote-controlled emplacement including groundwater sealing techniques, infilling techniques for spaces between rock and buffer material, remote-controlled in-situ compaction techniques, etc. [B, D] - Repository construction technologies (excavation of disposal pits, etc.) [B]

Technologies for detailed design of repository

Goals	Key issues
Development of detailed numerical models and more realistic databases for repository design through long-term experiments / experiments under simulated conditions for the deep underground	- Data acquisition for developing long-term overpack corrosion model [A, C] - Data acquisition and model development for corrosion products (volume expansion, mechanical and chemical properties [A] - Modeling of long-term behavior of buffer material (extrusion / erosion, creep, swelling and degradation, etc. [A, C] - Modeling of re-saturation processes [B, D] - Modeling of gas migration (in-situ gas migration test, etc.) [A, B, C, D] - Acquisition of data on behavior of buffer materials in saline groundwater [A, B, C] - Optimization of buffer materials (density, sand mixing ratio, thickness, etc.) [A] - Development of cement materials (lining, plugs, backfilling of boreholes, etc.) and evaluation of the effects on EBS performance [A, B, C, D] - Development of models of long-term creep of host rock [B, C, D]
Establishment of detailed design methodology (optimization, quality assurance program, etc.)	- Improvement of overpack design methodology for mechanical integrity - Standardization of measurement techniques for design parameters (swelling pressure of buffer materials, etc.) - Development of reasonable specifications for backfilling and plugs [B, D] - Evaluation of integrity of the EBS (development of advanced analytical methods for long-term behavior of complex processes) [A, B, D] - Evaluation of mechanical stability of tunnels (establishment of design methodology for lining, optimization of tunnel spacing and pitch of disposal pits, etc.) [B] - Evaluation of mechanical stability of host rock (effects of corrosion products, etc.) [B] - Establishment of quality control methodologies (establishment of criteria for control, etc.) [A] - Establishment of guidance on seismic design of subsurface facilities and relations to that of existing nuclear facilities, classification of design grade, etc.) [B]

Safety assessment methodologies

Goals	Key issues
Improvement of assessment models and databases (+ verification / validation)	- Development of advanced hydrogeological and radionuclide transport models and associated databases [B, C] - Improvement of model for evaluating overpack lifeline [A, C] - Development of a more realistic assessment model for extrusion of buffer materials [A] - Expansion of geochemical databases to quantify radionuclide migration for safety assessment [A, C] - Application of developed models for hydrogeology and radionuclide transport for specific geological environments [C] - Application of biosphere model for site conditions

Note: A: R&D programs in the ENTRY and QUALITY
B: R&D programs in domestic URLs
C: R&D programs of analogue studies
D: R&D programs in foreign URLs

Table 2 Correlation of R & D goals of the Horonobe Underground Laboratory Project with that in H12

Goals of research and development in the master plan of the Horonobe Underground Research Laboratory Project (JNC, 1998)		Goals and relevant key issues on research and development extracted from H12 (JNC, 2000)		Re-defined goals of research and development o the Horonobe Underground Research Laboratory Project (JNC, 2001)
• Research on the deep geological environment • Development of investigation technologies and related equipment • Development of designing and construction technologies for disposal system in sedimentary rocks • Confirmation of reliability on safety assessment methodologies	⇒	[Technologies for characterizing the relevant geological environment] • Development of systematic and practical characterization methodologies • Development of advanced characterization techniques • Demonstration of monitoring technologies [Technologies for determining the long-term stability of the geological environment] • Case studies for improving investigation methodologies of potential impacts caused by natural phenomena [Engineering technologies] • Demonstration of backfilling technologies • Demonstration of transportation and emplacement of engineered barriers [Technology for detailed design of repository] • Experiments on coupled thermo-hydro -mechanical-chemical phenomena, gas migration, saline environment • Long-term test on buffer material [Safety assessment methodologies] • Expansion of databases relevant to safety assessment • Application of safety assessment models and phenomena models	⇒	a) Development of investigation technologies for the geological environment b) Development of a monitoring technologies for the geological environment c) Study on the long-term stability of the geological environment d) Development of the basis for engineering technologies in deep underground e) Demonstration of technologies for engineered barriers f) Development of detailed designing methodologies for deep repositories g) Improvement of safety assessment methodologies

Table 2 Correlation of goals of research and development of Horonobe Underground Laboratory Project with that in H12

Goals of research and development in the master plan of Horonobe Underground Research Laboratory Project (JNC, 1998)		Goals and relevant key issues on research and development extracted from H12 (JNC, 2000)		Re-defined goals of research and development of Horonobe Underground Research Laboratory Project (JNC, 2001)
• Research on the deep geological environment • Development of investigation technologies and related equipment • Development of designing and construction technologies for disposal system in sedimentary rocks • Confirmation of reliability on safety assessment methodologies	⇒	[Technologies for characterizing the relevant geological environment] • Development of systematic and practical characterization methodologies • Development of advanced characterization techniques • Demonstration of monitoring technologies [Technologies for determining the long-term stability of the geological environment] • Case studies for improving investigation methodologies of potential impacts caused by natural phenomena [Engineering technologies] • Demonstration of backfilling technologies • Demonstration of transportation and emplacement of engineered barriers [Technology for detailed design of repository] • Experiments on coupled thermo-hydro -mechanical-chemical phenomena, gas migration, saline environment • Long-term test on buffer material [Safety assessment methodologies] • Expansion of databases relevant to safety assessment • Application of safety assessment models and phenomena models	⇒	a) Development of investigation technologies for the geological environment b) Development of a monitoring technologies for the geological environment c) Understanding of long-term stability of the geological environment d) Development of basis of engineering technologies in deep underground e) Demonstration of technologies for engineered barriers f) Development of detailed designing methodologies for deep repositories g) Improvement of safety assessment methodologies

Table 3 Investigations of Horonobe Underground Research Laboratory Project

Goals and key issues of Horonobe URL project			Phase 1 (surface-based)	Phase 2 (during construction of URL)	Phase 3 (using URL)
Geoscientific research	a) Development of investigation technologies for the geological environment	- Establishment of a comprehensive investigation technology for characterizing the geological environment	- Acquisition of data (airborn / ground geophysics, geological, surface hydrological and borehole investigations) - Construction and revision of geoscientific models (geological, hydrogeological, hydrochemical and rock mechanical models) - Prediction of changes in the geological environment caused by construction of the underground facility	- Acquisition of data (geological and geophysical investigations, measurement and chemical analysis of inflow in tunnels) - Verification and revision of the geoscientific models from Phase 1 - Verification of prediction from Phase 1 and prediction for Phase 3	- Acquisition of data (detailed geological and geophysical investigations, borehole investigations, and measurement and chemical analysis of inflow in tunnels) - Verification and revision of the geoscientific models from Phase 2 - Verification of prediction from Phase 2
	b) Development of monitoring technologies for the geological environment	- Development and improvement of monitoring equipment - Establishment of a monitoring technology through measurement from Phase 1 to Phase 3	- Development of borehole monitoring equipment for ground water pressure and chemistry, installation and measurement - Development of remotely operated monitoring system (ACROSS), installation and measurement	- Continuation of monitoring and improvement of techniques	- Continuation of monitoring and improvement of techniques
	c) Study on the long-term stability of the geological environment	- Accumulation of data on earthquake / fault activities, uplift / subsidence, climate / sea-level changes and volcanic activities - Establishment of assessment methodologies for long-term stability of the geological environment	- Acquisition of data (literature survey, seismological / diastrophic monitoring, geological investigations, trench surveys)	- Acquisition of data(continued) - Interpretation of earthquake / fault activities, uplift / subsidence, climate / sea-level changes and volcanic activities	- Seismological / diastrophic monitoring (continued) - Prediction on long-term stability of the geological environment
	d) Development of the basis for engineering technologies in deep underground	- Verification of techniques to design and construct a large facility at depth , and to restore excavation damages of rock - Understanding of effects of construction on the geological environment - Development of technologies for safety and environment in the underground facility	- Designing of the underground facility and planning of construction - Basic planning of investigations for effects of the construction of underground facility - Basic planning of investigations for restoration of excavation damage	- Verification of techniques to design and construct the underground facility - Investigations for effects of the construction of underground facility - Detailed planning of investigations for restoration of excavation damage	- Investigations on effects of the construction of underground facility (continued) - Investigations for restoration of excavation damage
R&D on geological disposal	e) Demonstration of technologies for engineered barriers	- Demonstration of techniques of transportation / emplacement of engineered barriers and backfilling - Establishment of manuals and guidelines for designing engineered barriers	- Basic planning of transportation / emplacement and backfilling experiments and relevant laboratory tests	- Detailed planning of transportation / emplacement and backfilling experiments and relevant laboratory tests - Designing of imitated engineered barriers	- Demonstration experiments on transportation / emplacement of engineered barriers and backfilling - Preparation of manuals and guidelines for designing engineered barriers
	f) Development of detailed designing methodologies for deep repositories	- Verification of coupled THMC models for long-term behavior of engineered barriers - Establishment of manuals and guidelines for designing engineered barriers	- Planning of experiments (coupled THMC, cement influence, gas migration, saline environment) and relevant laboratory tests	- Planning of experiments (continued) - Installation of equipment to measure changes in rocks around tunnels	- Acquisition of investigation data - Verification of designing methodology and models - Preparation of manuals and guidelines for designing deep repositories
	g) Improvement of safety assessment methodologies	- Applicability test of safety assessment methodologies in H12 - Confirmation of data handling methods and applicability of safety assessment models	- Verification of scenario construction methods and safety assessment models using data from surface-based investigations	- Investigations on items, amount and accuracy of data from tunnel excavation - Planning of investigations in tunnels to confirm applicability of safety assessment models	- Confirmation of items, amount and accuracy of data from tunnel excavation relevant to safety assessment - Investigations in tunnels to confirm applicability of safety assessment models

Table 4 Places and items of research and development of Horonobe URL Project

<table>
<tr><th></th><th></th><th>Horonobe URL</th><th>ENTRY / QUALITY</th></tr>
<tr><td rowspan="4">Geoscientific research</td><td>a) Development of investigation technologies for the geological environment</td><td>• Acquisition of geoscientific data
• Modeling of the geological environment
• Prediction of changes in the geological environment caused by the construction of underground facility, and validation of methodology
• Synthesis of methodologies for investigation, analysis and validation</td><td rowspan="4">-</td></tr>
<tr><td>b) Development of monitoring technologies for the geological environment</td><td>• Development of monitoring technologies in boreholes
• Development of remotely operated monitoring system</td></tr>
<tr><td>c) Study on the long-term stability of the geological environment</td><td>• Case studies on earthquake / fault activities, uplift / subsidence, climate / sea-level changes and volcanic activities</td></tr>
<tr><td>d) Development of the basis for engineering technologies in deep underground</td><td>• Designing and construction of the underground facility, and validation of technologies
• Validation of technologies for material and engineering
• Validation of technologies for safety and environment
• Experiments on thermal effect of rock
• Study on effect of construction of the underground facility on the geological environment
• Experiments on restoration of excavation damage of rock
• Assessment of re-saturation process of groundwater</td></tr>
<tr><td rowspan="15">Research and development on geological disposal</td><td rowspan="2">e) Demonstration of technologies for engineered barriers</td><td>• Acquisition of experimental data on transportation / emplacement of engineered barriers</td><td>• Designing of transportation / emplacement equipment</td></tr>
<tr><td>• Acquisition of experimental data on backfilling of tunnels</td><td>• Designing of specifications for backfilling</td></tr>
<tr><td rowspan="11">f) Development of detailed designing methodologies for deep repositories</td><td>• Cement influence experiments</td><td>• Assessment of influences of cement on performance of engineered barrier</td></tr>
<tr><td rowspan="7">• Coupled THMC experiments
• Gas migration experiments</td><td>• Development and assessment of coupled THMC models
• Synthesis and assessment of methodologies for emplacement of engineered barrier
• Assessment of creeping behavior of buffer material and rock
• Assessment of gas migration behavior
• Assessment of total reliability on engineered barrier system</td></tr>
<tr><td>• Optimization of specifications for buffer materials</td></tr>
<tr><td>• Assessment of erosion, creeping, swelling, degradation of buffer materials</td></tr>
<tr><td>• Analysis of long-term reliability on performance of rock</td></tr>
<tr><td>• Assessment of long-term behavior and influences of corrosion of engineered barrier</td></tr>
<tr><td>• Assessment of long-term behavior and influences of degradation of engineered barrier</td></tr>
<tr><td></td></tr>
<tr><td>• Saline environment experiments</td><td>• Assessment of performance of engineered barrier under saline environment</td></tr>
<tr><td>-</td><td>• Establishment of quality management methodologies</td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="2">g) Improvement of safety assessment methodologies</td><td>• Confirmation of items, amount and accuracy of field data relevant to safety assessment</td><td>• Acquisition of experimental data on basic properties</td></tr>
<tr><td>• Confirmation of applicability of safety assessment models</td><td>• Analysis on applicability of safety assessment models</td></tr>
</table>

4 Surface-based investigations (Phase 1)

The Phase 1 investigations are conducted over approximately six years, from the fiscal year 2000 to 2005. A “laboratory construction area” of a few kilometers square is selected based on the results from early stage investigations. Subsequent investigations are concentrated on the selected area and in its periphery. For seismological investigations, measurements are also taken in areas apart from the selected area. The actual construction site and layout of the underground facility, and plans of research and development in Phases 2 and 3 are to be determined based on information from surface-based investigations,

4.1 Selection of the laboratory construction area

A “laboratory construction area” is selected based on the results from early stage investigations in the fiscal years 2000 and 2001. The depth of the Horonobe URL was planned at about 500m from an engineering point of view (JNC, 1998). Basic requirements for the site are that:

- Geological formations to be investigated lie at about 500m depth in sufficient extent and thickness.
- Underground facility can be safely constructed.
- There are enough places for investigations.

On the other hand, social factors such as land use and infrastructure are also taken into account in the view of acquiring the land and efficiency of the construction work.

A summary of the procedure for area selection is as follows. Initially, potential areas for laboratory construction are selected based on existing data estimating where geological formations lie in sufficient extent and thickness at about 500m depth. Then surface-based investigations, such as airborne surveys (magnetic, electromagnetic and natural gamma), ground geophysics (electromagnetic survey), geological mapping and borehole investigations, are carried out in the selected areas. Distribution of geological formations and faults, flow and chemistry of groundwater, and rock mechanical properties are interpreted. An area suitable for laboratory construction is selected taking the interpretations and the requirements into account. A candidate laboratory construction site is selected by considering all the investigation results and social factors. And finally, a laboratory construction area of several kilometers square, where detailed investigations are carried out, is decided around the selected site.

4.2 Geoscientific research

In Phase 1 investigations, acquisition of data by surface-based investigations, modeling of the geological environment and predictions of changes in the geological environment caused by the construction of the underground facility are conducted under the “Development of investigation technologies for the geological environment.” Monitoring equipments are developed and installed, and data prior to the construction of the underground facility are to be acquired in the “Development of monitoring technologies for the geological environment.” Information on earthquake/fault activities, uplift/subsidence/denudation processes and crustal activities are collected and integrated by literature survey, surface geological investigations and earthquake monitoring in the “Understanding of long-term stability of geological environment.” Designing of the underground facility, examination of construction management, and investigation plans for restoration techniques on damages of the construction are accounted for under the heading of ”Development of the basis of engineering technologies in deep underground.”

4.2.1 Development of investigation technologies for the geological environment

In Phase 1, the actual data on geology, hydrogeology, hydrochemistry and rock mechanics from surface to deep underground are systematically acquired through surface-based investigations. Based on these data, models of geological environment are constructed and analyzed to predict changes in the geological environment caused by the construction of the underground facility. A comprehensive technology for characterizing the geological environment and methodology for the modeling are to be established.

The goals in developing investigation technologies for the geological environment in Phase 1 are:

- Acquisition of data on geological environment from surface to deep underground;
- Modeling of the geological environment from surface to deep underground; and
- Prediction of changes in the geological environment caused by the construction of underground facility.

Plans for investigations are described in detail in the following sections.

4.2.1.1 Acquisition of geoscientific data from surface to deep underground

(1) Geophysical investigations

a) Airborne surveys

Magnetic, electromagnetic and natural gamma surveys using helicopters are carried out over the candidate laboratory construction areas to estimate distribution of geological formations and geological structures such as faults (fracture zones) and folds up to about 150m below surface. The acquired information is used to select locations for borehole investigations and to select the laboratory construction area.

b) Electromagnetic surveys

Electromagnetic surveys are carried out on the surface of potential areas for laboratory construction to estimate distribution of geological formations and geological structures such as faults (fracture zones) and folds up to 2000m below surface. The acquired information is used to select locations of borehole investigations and to select the laboratory construction area. Surveys with higher resolution may be conducted over the selected area to acquire detailed information up to several hundred meters below surface.

c) Seismic surveys

Reflection seismic surveys are carried out over potential laboratory construction areas to estimate distribution and geometry of geological formations and geological structures such as faults (fracture zones) and folds up to 2000m below surface. Reflection seismic surveys with higher resolution and/or VSP surveys may be conducted over the selected area to acquire detailed information up to several hundred meters below surface.

d) Gravity surveys

Gravity surveys are carried out over the laboratory construction area to estimate distribution of geological formations and structures by detecting contrast of density.

(2) Geological investigations

Data on distribution and characteristics of geological formations and structures are acquired through lineament analysis of satellite and aerial photos, surface mapping, and petrographical, mineralogical, and micro-fossil analyses of rock samples. The interpreted data together with those from the airborne surveys and ground geophysics provide the basis to construct geological models. In particular, investigation results of the fiscal year 2001 are used to select locations of the two boreholes drilled in the same year, subsequently leading to the selection of the laboratory construction area.

(3) Surface hydrological investigations

Meteorological parameters (precipitation, temperature, humidity, wind direction and velocity, sun exposure and evapotranspiration rate), river flow rate and water table are measured in the field to estimate recharge and discharge rates necessary for groundwater flow analyses. Density and permeability of soil and rocks on surface are also measured in the laboratory.

(4) Borehole investigations

Two vertical boreholes of about 700m depth are drilled and investigated using core and boreholes to acquire data for the selection of the laboratory construction area. Later, about 10 boreholes with an average of 500m depth are drilled in and around the selected area to acquire data for the modeling of the geological environment. The data also provide the basis for the construction of the underground facility. The following items are planned in the investigations.

Core investigations

i) core observation (lithology and structure)

ii) laboratory tests

- mineralogical tests (mineral composition, chemistry, age, microfossils)
- physical tests (porosity, density, resistivity, seismic wave velocity)
- rock mechanical tests (uni-/tri-axial compressive strength, tensile strength, stress)
- hydraulic tests (hydraulic conductivity)
- hydrochemical analyses (extraction of pore water and gas, chemical analysis)

Borehole investigations

- geophysical logging (resistivity, density, neutron, temperature, sonic wave, caliper)
- hydraulic tests (hydraulic head, hydraulic transmissivity)
- stress measurement
- hydrochemical analyses (groundwater sampling, gas sampling, chemical analysis)

4.2.1.2 Modeling of the geological environment and prediction of changes caused by the construction of the underground facility

Models of the geological environment (geological model, hydrogeological model, hydrochemical model and rock mechanical model) are constructed based on the data from the surface-based investigations. The models are confirmed or revised by additional data acquired with the progress in investigations. At the same time, decreasing degrees of uncertainty in the models are examined, and items, amount and accuracy of geoscientific data required for the modeling are clarified. Comprehensive technologies for surface-based investigations and methodologies for modeling of the geological environment are established by synthesizing knowledge with experience. On the other hand, changes in the geological environment caused by the construction of the underground facility are predicted by numerical analyses of the models. A database system is also developed for effectively and systematically managing the varied and huge amount of data acquired in this project.

(1) Geological model

Geological models are constructed based on the data from airborne and ground geophysics, geological investigations and borehole investigations. Distribution of geological formations and geological structures such as faults, fracture zones and folds are incorporated in the models.

(2) Hydrogeological model

Hydrogeological models are constructed and revised based on the geological models and data from hydraulic tests in the boreholes and laboratories. Groundwater flow and distribution of groundwater pressure are described by numerical analyses of the models. The numerical analyses also simulate and predict changes in the flow and pressure of groundwater caused by the construction of the underground facility. Parallel to the modeling process, plans for the study on fresh water / saline water boundary in Phase 2 are examined based on current hydrogeological investigations and models.

(3) Hydrochemical model

Hydrochemical models are constructed based on analysis data of pore water extracted from core samples and of groundwater from boreholes. Distribution of chemical properties of groundwater is described in the models. The evolution mechanisms of groundwater chemistry are clarified by coupled interpretations of the models with mineralogical and geochemical data of host rocks in contact with groundwater. Suitability of hydrogeological models such as groundwater flow is verified by the results of hydrogeological modeling. Changes in the groundwater chemistry caused by the construction of the underground facility are predicted by analysis of the models. The prediction is to be verified with the actual data measured in investigations in Phases 2 and 3.

(4) Rock mechanical model

Rock mechanical models are constructed based on data from laboratory tests and borehole investigations. Distribution of strengths and stress state of rocks are incorporated in the models. Mechanical stability of the underground facility is assessed, and change in stress state and deformation of the surrounding rocks are predicted by numerical analyses of the models.

4.2.1.3 Development of investigation techniques and equipment

Research and development for investigation techniques and equipment are conducted principally by utilizing existing techniques and equipment. Drilling and borehole investigation techniques are to be developed applicable to soft, friable and swelling sedimentary rocks, oil and gas bearing rocks, and pressure at about 500m depth.

(1) Borehole drilling techniques

The sedimentary rocks to be investigated in the Horonobe URL project are assumed to be soft, friable and swelling. To protect the boreholes, the use of drilling mud and installation of casing are required. However, they may affect measurements in boreholes such as hydraulic tests, groundwater sampling and chemical analysis, stress measurement. Thus drilling techniques to minimize the influences, and development of drilling mud to avoid borehole swelling are under investigation.

(2) Borehole investigation techniques

The equipment material and structure for hydraulic tests, groundwater sampling, and stress measurement are improved to withstand the existence of oil and gas.

4.2.2 Development of monitoring techniques for the geological environment

In Phase 1, equipment for monitoring of the geological environment is developed and installed, and measurement of initial values obtained before the construction of the underground facility.

4.2.2.1 Development of monitoring techniques in boreholes

Long enduring equipment is required for monitoring groundwater pressure and chemistry in deep underground from Phase 1 to Phase 3. Monitoring equipment material and specifications are developed and improved for installation in the boreholes. Data are obtained to understand the initial values and their changes with time, especially to detect the impact of the construction of the underground facility. Monitoring techniques and reliability of equipment are improved through these processes.

4.2.2.2 Development of remotely operated monitoring system

A monitoring system called ACROSS (Accurately Controlled Routinely Operated Signal System) is employed. The system consists of transmitters which continuously emit relatively small, accurate frequency-controlled seismic and electromagnetic waves and plural receivers which detect the waves travelling underground with accurate time. Initial states of the geological environment before the construction of the underground facility, and changes occurring during and after the construction are observed by the system. At the beginning of Phase 1, the transmitters and receivers were improved to operate accurately for waves covering a wide range of frequency. The whole system has been adjusted and installed for data acquisition.

4.2.3 Development of the basis for engineering technologies in deep underground

The investigations aim to develop technologies for the development and use of the deep geological space. For one, they are to clarify effects of the construction of the underground facility on the geological environment. For another, they are to verify techniques to recover excavation damages of the surrounding rocks. In addition, methods for engineering management are examined to assure the safety of the facility against various phenomena encountered in deep geology and to maintain a stable environment of the facility. The design of the facility is decided by taking the results into account.

4.2.4 Study on the long-term stability of the geological environment

The scope of the study on the long-term stability of the geological environment in Phase 1 is to collect and integrate information on earthquake/fault activities, uplift/subsidence/denudation processes of relatively young geology and structures, and on crustal activities in and around the Horonobe town..

4.2.4.1 Seismological study

The Horonobe town is located in an area characteristic of earthquake swarms, recorded in 1975 at Toyotomi and in 1986 at Horonobe. In Phase 1, seismographs (*i.e.* velocity meter and accelerometer) are installed and data on seismic activities are acquired to understand the characteristics of seismic activities and their correlation with faults in northern Hokkaido, and to assess influences of earthquakes on groundwater through integrated data interpretation over long-term monitoring in boreholes. Time and spatial distribution of earthquakes in northern Hokkaido are described by analyzing the acquired data with those from other institutes such as the Meteorological Agency.

4.2.4.2 Diastrophic study

Diastrophic measurement and geological investigations are carried out to clarify the activity of the Omagari fault, tilting of terraces, uplift/subsidence of the Teshio sedimentary basin and history of sea-level change. The long-term diastrophic measurement using a strain meter and an inclination meter is carried out to understand local diastrophic activities within regional area by integrated analysis of the acquired data with those from other research institutes. Activity of the Omagari fault is clarified by geological investigations such as trench survey. The volcanic history of Mt. Rishiri is also studied by tephra survey.

4.3 Research and development on geological disposal

Investigation plans for Phases 2 and 3 include “Demonstration of technologies for engineered barrier” and “Development of methodologies for detailed designing of deep repositories” of Phase 1. Safety assessment models are tested and improved, and items, amount and accuracy of data for safety assessment are confirmed under “Improvement of reliability on safety assessment methods.”

4.3.1 Verification of technologies for engineered barrier

Real scale experiments are required to demonstrate the quality of engineered barrier (*i.e.* state of emplacement) according to the H12 report. To establish a standard for engineering quality, accuracy of emplacement equipment (*e.g.* position, angle and clearance) and performance of material for back-filling of tunnels are investigated. In Phase 1, laboratory tests are carried out to understand the impact of buffer material emplacement on the corrosion of overpacks and on the performance of buffer material. Based on the results, plans are confirmed for emplacement tests in the underground facility in Phases 2 and 3.

4.3.2 Development of technologies for detailed designing of the repositories

The H12 report requires that technologies for detailed designing of the most suitable repositories be established. Thus the following investigations on engineered barrier including the surrounding rock are planned in Phases 2 and 3.

- Coupled THMC experiments: to investigate thermo-hydro-mechanical-chemical phenomena of engineered barrier and surrounding rock by emplacing imitated overpacks with heaters.
- Cement influence experiments: to investigate influence of alkaline groundwater caused by interaction with cement on engineered barrier.
- Gas migration experiments: to investigate behavior of gas generated by corrosion of overpacks.
- Saline environment experiments: to investigate corrosion of overpacks and swelling of buffer material under saline groundwater.

Initially in Phase 1, similar experiments in overseas underground laboratories are surveyed. In parallel, laboratory tests are carried out to understand preferable conditions for experiments, and to develop and verify prediction methods. Based on the results, plans for experiments in Phases 2 and 3 are being laid out.

4.3.3 Improvement of reliability on safety assessment methodologies

In Phase 1, efficiency of scenario construction methods and safety assessment models of engineered barrier, natural barrier and biosphere are verified by applying actual data from surface-based investigations. In addition, items, amount and accuracy of data for safety assessment are confirmed by uncertainty analysis and sensitivity analysis of the models. Data on radionuclide migration such as sorption and diffusion required for the models are acquired through QUALITY.

5 Environmental survey and facilities on the ground

5.1 Environmental survey

Environmental survey is carried out on JNC's own initiative to avoid negative influence on the natural and human environment from the construction of the underground facility. Initial information on the natural and social environment of Horonobe town, such as rare species and usage of groundwater, is gathered through literatures, interviews and field surveys. Once the laboratory construction area is selected, detailed surveys of the area are conducted, and long-term monitoring started for important items.

5.2 Facilities on the ground

Planned facilities are to house research and administration offices, core storage and workshop. The basic design of the facilities and land development were started in the fiscal year 2001. More detailed designs are being drawn up, with due consideration to the results of land surveys to understand the land condition, positioning of the shafts and determination of the layout of the underground facility.

6 Frontier Research Project on Underground Structures of Land

A unique fundamental research project on earthquakes called "Earthquake Frontier Research Project" is launched by STA[6] in the fiscal year 1995 after the Hanshin-Awaji earthquake. JNC has been assigned one part of the project, "Frontier Research Project on Underground Structures of Land". The project has been carried out at the Tono Mine and the Kamioka Mine in Gifu to understand the mechanism of earthquakes and to develop appropriate measurement methodologies.

Northwestern Hokkaido is located near the boundary between the Eurasian Plate and the North American Plate, where relatively large earthquakes and local earthquake swarms have been recorded around the Horonobe area. The Horonobe area is thus considered suitable for the above research. The research in this area is to compon displacement of the earth crust, but also changes in groundwater flow and chemistry related with earthquakes.

[6] Science and Technology Agency

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