4.6 Evaluation of predictions

As was described in the Section 2.1, one of the goals of Phase I is "To establish methodologies for evaluating predictions". This goal was set to specify the criteria and detailed methodologies for evaluating predictions made in Phase I by comparison with the data obtained in Phase II.

In order to evaluate prediction properly, it is required to clearly define what to evaluate, how to evaluate, and where and how to obtain data. Aspects to be considered include:

- Was the data used for model development and predictions sufficient?
- Was the data used for predictions accurate?
- Was the conceptual model derived appropriately?
- Was the numerical model derived appropriately?
- Was the data used for evaluations sufficient?
- Was the data used for evaluations accurate?

The ultimate objective is to develop methods and expertise in making accurate conceptual and numerical models for a site. Comparison of actual observations to the predictions made in these models will include an evaluation of the predictions and the degree of accuracy. Evaluations of the predictions will serve as a test of the accuracy and validity of the models and thus provide an assessment of the applicability of the technology and accuracy of the geoscientific data used to build the models. This includes an assessment of the field techniques used to collect the data and an assessment of the analytical methods used to make the predictions.

Thus the evaluation will provide one way to confirm the applicability of the technology for site characterization and selection for waste disposal.

Taking into consideration overseas experience, an approach followed by SKB, Sweden, was examined in Phase I. The outline and possible usefulness, in terms of applicability and lessons learned for the MIU Project, are as follows.

4.6.1 Geological investigations

Predicted geological conditions, the lithologies and structures, will be compared with the geology and geological structures encountered in the shafts, in the stages and in the research galleries excavated in Phase II.

A precedent that established methods for predictions and evaluation was developed by SKB for the HRL project in Sweden (98).

In the HRL Project, geological models with these elements were developed at the following scales:

・Facility-scale (500 to 1,000 m), fracture zones

・Block-scale (50 to 100 m) lithofacies, fracture zones, rock properties, fracture properties

・Detailed-scale (5 to 10 m). Rock properties, fracture properties

For these scales, predictions were made of the following:

- Lithofacies: ratios of constituent lithofacies, location of facies boundaries, frequency of facies boundaries, mineral composition, and alteration
- Fracture zone: location, strike, dip, width, RQD (for large fracture zone only)
- Rock properties: matrix porosity, density
- Fracture properties: number of fracture systems, general trend, spacing between fractures, trace length and filling minerals

Predicted values included confidence intervals and certainty. Expert opinion played a role in estimating uncertainty. When measured values are within the confidence interval, the prediction is assessed as valid. The validity of the prediction was quantitatively expressed by the following equation.

$$\text{Percent absolute error} = \frac{\text{absolute value of difference between predicted and measured values}}{\text{measured value}}$$

4.6.2 Hydrogeological investigations

Predictions can be evaluated by comparing observations in Phase II with the predictions in the hydrogeological model and the groundwater flow simulations.

Methods of prediction and evaluation used in the HRL project in Sweden, which carried out a groundwater flow simulation based on a hydrogeological model were considered. Major water channels were deterministically integrated into the site model during surface-based investigations [99]. The prediction was evaluated by determining the amount of groundwater inflow. Specifically, total inflow into research galleries, inflow along research galleries (inclined galleries and the spiral ramp) and inflow into weirs. However, the assessment done was qualitative.

For the MIU Project, the following can be used for the evaluation.

- Volume of groundwater inflow into shafts and research gallery
- Changes in water pressures in the boreholes (head changes) in response to groundwater drawdown as the shafts and research gallery are excavated.

Concerning inflow, (a) total volume, (b) amount from individual water channels and (c) amount from the sections/locations established in advance for inflow measurement are thought to be predictable. For measurement of inflow, water collection rings or trays can be constructed at selected sections or locations. In fracture zones where significant water inflows are expected, several exploratory boreholes can be drilled for estimating the potential water inflow amounts, if this is possible without disturbing the system.

The drawdown in boreholes due to the advance of research galleries can be measured by the MP monitoring system installed prior to excavation. Intervals for water pressure measurement are determined from the results of long-term pumping tests carried out prior to shaft excavation and predictive simulations. The predictions can be evaluated by comparing the drawdown with the prediction from the simulation and should be done as quantitatively as possible.

4.6.3 Hydrochemical investigations

The spatial distribution and changes of the hydrochemical properties can be predicted on the basis of observations in Phase I and within the framework of the geological- hydrogeological models. The prediction will be evaluated by comparing the predicted and measured data obtained during the drift excavation. Evolution of the hydrochemistry is more difficult. It is time and rate dependent, responding to groundwater flow system changes and the kinetics of water/rock interaction and microbial activity.

One phenomena expected in the research gallery excavations will be a hydraulic pressure drop due to excavation and resultant drawdown of the groundwater flow system [(99)]. It is presumed that the distribution of hydrochemical properties of groundwater is closely related to the groundwater flow system. Therefore, a change in groundwater flow system would cause a change in the distribution of hydrochemical properties of groundwater. For example, a drop in water level can allow oxidizing water to penetrate to deeper levels in the rock mass, in turn resulting in a change in redox potential and location of the redox front [(100)].

To predict changes that originated due to research gallery excavation, it will be necessary to determine items that should and those that could be predicted in Phase I. Based on the 3-D distribution of hydrochemical properties obtained in the Phase I, these items that should be and those that could be are extracted. These items are as follows.

Items that should be predicted:

- All items planned for analysis using boreholes drilled in Phase I

Items that could be predicted:

- Components with no significant difference between surface water and groundwater.
- Components whose analytical quality are not guaranteed.

4.6.4 Rock mechanical investigations

The rock mechanical predictions can be evaluated by determining (a) the response of the surrounding rock mass to excavation and (b) any change in physical properties during the excavation of underground facilities. The distribution of RMR (Rock Mass Rating) was predicted in overseas underground research facilities for predicting the physical properties distribution of the rock mass. However, there was no predictive analysis of the rock mass for the entire facility.

Following predictions are made through modeling and simulation in Phase I.

- 3-D distribution of rock mechanical properties of the rock mass (physical/mechanical properties and in situ stress states)
- Deformational behavior (mode of rock failure) of the rock mass surrounding research galleries in response to their excavation

・ Distribution of the damaged zone resulting from stress change/concentration in the rock mass around research gallery

The first prediction was done by construction of the rock mechanics conceptual model. The latter two are predicted from the results of numerical simulations. All of these predictions are evaluated as follows.

4.6.4.1 Data needed for evaluation of the prediction

Data for evaluating the rock mechanics conceptual model

Rock mechanics conceptual model is constructed by interpreting the data obtained from boreholes and rock samples. The following in-situ data obtained during excavation will be necessary.

- Physical properties (physical/mechanical properties of rocks and 3-D in situ stress distribution)

Data for evaluating the results of predictive simulations

The following results of the predictive simulations are necessary.

- Behavior of the rock mass surrounding research galleries (mechanical failure and development of an EDZ, displacement of the rock mass, displacement along fractures and total displacements)
- The extent of stress changes caused by stress redistribution
- The extent of damage (plastic domain) by stress concentration in the rock mass

4.6.4.2 Method of evaluating predictions

Evaluation of rock mechanics conceptual model

The physical properties, the in situ stress distribution (given as a boundary condition) and the division of the rock mass into zones in the conceptual model are to be compared with the measured data. For the in situ stress distribution, it might be greatly affected by the Tsukiyoshi Fault, depending on the location of the research galleries. Therefore, the results of the simulation of the 3-D stress distribution carried out before research gallery excavation will be evaluated. If the conceptual model is determined to be invalid, the numerical model and simulations will likely be incorrect, unless the numeric model is insensitive to the deterministic properties used.

Evaluation of the predictive simulations

When the rock mechanics conceptual model is evaluated as correct, the simulation results described in the above-mentioned "Data for evaluating the results of predictive simulations" in (4.6.4.1) are compared with the measured rock mass response as an assessment of the accuracy of the numerical models. If they are in agreement, the simulations are considered valid.

If the rock mechanics conceptual model is evaluated as incorrect, the rock mechanics conceptual model should be re-constructed with new, better data or interpretations of the deterministic data. As stated above, if the conceptual model is incorrect, the numerical model is also likely to be incorrect.

As well, if the numerical simulations of rock mass response do not agree with the actual rock mass response, the model must be re-evaluated.

Re-evaluation of the predictive simulations

Two approaches are considered for the re-evaluation. If the conceptual; model developed above is considered appropriate, the numerical simulation is evaluated. If the conceptual model developed above is considered to need revision, this will be done and a new simulation run.

In either case, if there are qualitative discrepancies between the results of the predictive simulations and the measured data, the cause should be examined. If this is the case, the discrepancy is considered to originate in factors that have not been considered in the model. Therefore, the models are adjusted and a re-run of the numerical simulation would be carried out, if possible. When quantitative discrepancies are found, the input parameters for physical or mechanical properties are checked and the model is re-calibrated and re-run.　.

Following should be possible by the above- process.

- Validation of the process from investigations, model construction to a predictive simulation
- Required data and its accuracy acquired in the Phase I assessed
- Optimization of the investigation methodologies for model construction