Development of a design support system for geological disposal using a CIM concept

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Abstract:

The geological disposal of high level radioactive waste consists of five steps: investigation, design, construction, operation, and closure. Together these will form a long-term project lasting some 100 years and involve several generations of engineers. As radioactive materials are environmentally and politically sensitive, the project needs to be open and transparent to ensure the traceability of decisions made at every level and stage of the project. For such a long-term project, it is important to systematically manage the information on design, construction and maintenance, obtained and accumulated during the project period. All the repository components, the engineered barriers (disposal containers and buffers), the underground facilities, the barrier transport and placement machines, and the surface facilities, should have an integrated design so as to function as one system. The designs of all the components are therefore closely connected. As a support system that enables the rational design of a geological disposal repository, we have launched the development of an integrated system for repository engineering (iSRE). The complimentary technique of construction information modeling/management (CIM) has been employed for the development of iSRE. CIM uses a shared three dimensional (3D) model of associated data through common data models.

The goal of the development of iSRE was first defined as a design support system for a geological disposal project, in being able to meet the design requirements and required functions. The basic structure of iSRE was then built to achieve this goal and to meet these requirements. Next came the item attribute information to be saved in the data models and the concepts of the whole system structure. The main databases used within iSRE could then be designed with appropriate interfaces to coordinate with external systems and other databases. Some of the databases and the interfaces were trialed and a data model was then built. A scenario of iSRE operation was also created and the applicability of iSRE using a data model was also examined.

A standardized format, such as the Industry Foundation Classes (IFC) format, is currently not designed for data models used in repository engineering. Instead, data models were built from existing design software and the introduction of IFC is considered to be a future development.

With the assistance of existing software, the development process could be conducted while solving problems for realistic test cases. The prospect of the development of iSRE for geological disposal projects was realized and iSRE was confirmed as being a useful tool for repository design.

Keywords: Geological disposal, Integrated System for Repository Engineering, Construction Information Modeling/Management

1. INTRODUCTION

The geological disposal of high level radioactive waste consists of five steps: investigation, design, construction, operation and closure (NUMO, 2013). Together these will form a long-term project lasting about 100 years and involve several generations of engineers. As radioactive materials are environmentally and politically sensitive, the project needs to be open and transparent to ensure the traceability of decisions made at every stage of the project. For such a long-term project, it is important to systematically manage the information on design, construction and maintenance, obtained and accumulated throughout the entire project. Moreover, a geological disposal repository requires integrated design so that all the components of the repository, the engineered barriers (disposal containers and buffers), the underground facilities, the barrier transport and placement machines, and the surface facilities, function as one system. The design of all repository components are therefore, closely connected. As a knowledge acquisition tool of engineering technology that helps to promote the rational design of a geological disposal repository, we have launched the development of the integrated system for repository engineering (iSRE).

The safety of a geological disposal system is demonstrated by comprehensive assessment results based on geological environment investigation assessment technology, the engineering technology of a repository and the performance assessment technology (JNC, 2000). A repository is designed in accordance with the geological environment conditions set out in the geological environment investigation assessment. Repository design is then used for the analysis conditions of performance assessment. At the construction stage of the underground facilities, additional geological information obtained during excavation is reflected in the geological environment investigation assessment. The repository design is then to be revised through appropriate measures, based on the updated geological environment conditions. The iSRE can be used for such information management and so acts as a knowledge acquisition tool.

The construction information modeling/management (CIM) technique is increasingly being used for civil engineering works, such as for the construction of road tunnels and bridges. Sharing a data model associated with attribute information makes the design, construction and maintenance more effective and efficient. In addition, the simulation function of CIM helps to identify design faults and can check the integrity of the structure in advance. This approach helps to optimize the design and improve understanding of the project as a whole (Fujisawa et al., 2013; Shiiba et. al., 2014; Suzuki et al., 2013). These attractive features of the CIM technique can be employed in the development of iSRE.

The current paper presents the background and the purposes of the development of iSRE. Specifically, it describes iSRE's design requirements, functions and the basic structure built to meet these requirements. The current paper also explores the items necessary for the data model to be saved and the structure of the repository system as a whole. Additional design examples of the main databases of iSRE and the interfaces to coordinate these databases with external systems and other databases are also provided. Some of the databases and their trial interfaces offer examples of the data models. Finally, the paper discusses the applicability of iSRE using a data model to a realistic scenario of iSRE operation in the repository design process.

2. DEVELOPMENT of iSRE

2.1 Development goal of iSRE

The goal of iSRE development is to build a system that achieves the following six objectives:

(1) To help the management of information relating to investigation, design, construction, operation, and closure.
(2) To manage and disseminate knowledge of repository engineering technology in the long-term.
(3) To help consistent design of the disposal containers, buffers, barrier transport and placement machines, underground and surface facilities by sharing and integrating data used in their design and management.
(4) To help in the revision of designs resulting from the increase in information or progress in technology during a project period.
(5) To simulate the operations of the construction machines and barrier transport and placement machines during construction, operation, and closure and help map out a safe work plan.
(6) To help increase public understanding of and confidence in geological disposal of radioactive waste.

2.2 Design requirements and functions of iSRE

The design requirements of iSRE were defined to fulfill the six objectives detailed in Section 2.1. The Japan Atomic Energy Agency (JAEA) developed geological environment investigation assessment (ISIS), the performance assessment (e-PAR) and the knowledge management system (JAEA-KMS) databases have been considered as they are closely connected to iSRE. Table 1 shows the design requirements classified by function. For the six functions shown, 16 design requirements were set. Most of these design requirements are already included in the CIM technique, for example, data archive management data mining and sharing of data, and so the CIM technique is seen to be complementary to the development of iSRE.

2.3 Design concept of iSRE

Figure 1 shows the configuration of iSRE created to meet the design requirements identified in Table 1. Central to the function of iSRE are a viewer and an integrated database. The viewer function enables a visual check of consistency in design. The integrated database function is constructed from the main databases, including the geography and geology database, the design database, the drawing management database, the quantity survey database, and the maintenance and repair archive database.

A data model is defined as a three-dimensional (3D) model associated with attribute information. A data model is created using external design software and data are exchanged as industry foundation classes (IFC) format data, as developed by buildingSMART International Ltd. IFC is a recognized international standard file format, which is an intermediate file interoperable between different software platforms and can be used for the exchange of 3D morphology and attribute information. IFC suitable for data models used for the engineering technology of a disposal repository, however, is not yet available. Instead a data model based on the existing design software was used and the introduction of IFC is considered to be a future development.

The iSRE should have an interface function for efficient access to the integrated database, the main databases and communication with external systems. The system will require an interface for creating, updating and referring to data models. This will also have to include appropriate interfaces to ISIS, e-PAR and JAEA-KMS (Semba et al., 2009; Makino et al., 2012) (Figure 1) and interfaces for coordination with existing analysis systems and databases, as well as monitoring and data measurement systems.

Table 1. Design requirements of iSRE

Functions	Design requirements
Design	Storage of story board on design and construction. Development of 2D design drawing and 3D design model of the surface and underground facilities. Management and display of 3D information of the surface and underground facilities. Interference check between the machine and the underground facility. Prepare suitable input data. Analysis and management of input and output data. Capture and update of common data by multi-access. Design archive management. Estimate validity of the design. Superimpose display of the geological environment model and the design model of underground facility.
Maintenance	Maintenance and management database, management of maintenance and repair work archives.
Coordination with geological environment investigation	Import the geological environment model from the database. Update the geological environment model during excavation, and archiving the updated model in the database.
Coordination with performance assessment	Management of information on underground water flow. Providing attribute data of repository components such as the engineered barrier system and underground facility.
Coordination with outer databases	Obtain and manage information of the waste packages.
Others	Consider safeguard and nuclear security requirements.

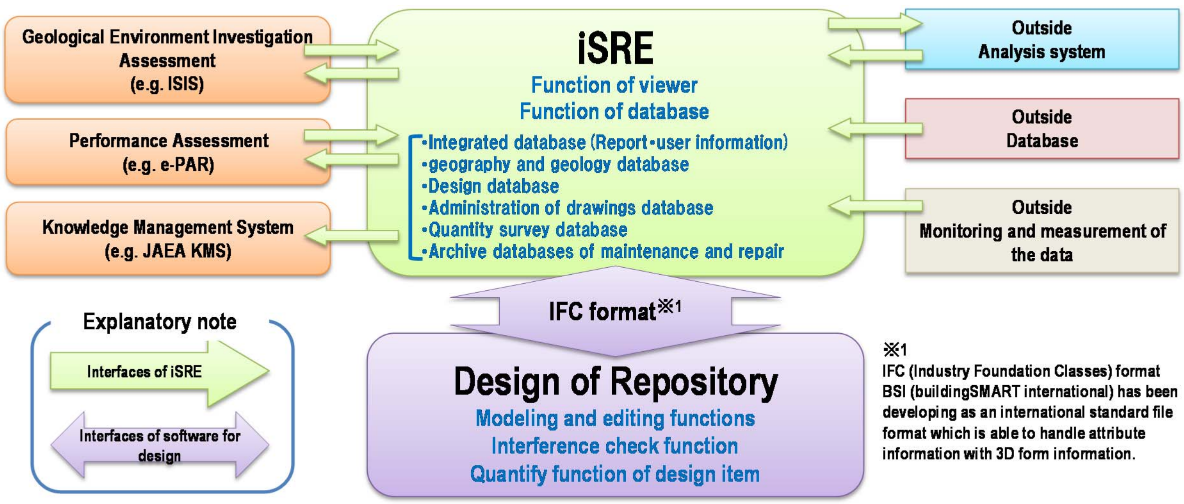

Figure 1. Basic structure of iSRE

2.4 Data model

2.4.1 Listing and classifying attribute information

The iSRE records and stores the changes to a geological disposal repository as a database of data models. The iSRE provides the information to external systems via the framework shown in Figure 1. The elements of the 3D models and attribute information need to be defined and added to the data models. The attribute information can be added to each element, member or to the whole facility.

Attribute information to be added to a data model varies with design, function and needs. In this study, attribute information has been categorized and listed based on present assumptions of 3D model elements. There are about 1200 items of attribute information for host rock, groundwater, tunnel, and other elements; some examples of attribute information are shown in Table 2. The items of attribute information or their data formats may change as the information increases or becomes more detailed during the course of the project. Attribute information may include numerals, images, printed matter, and other data of various types. Thus, the database should be inherently flexible to accommodate these changes and various data types.

Table 2. Examples of attribute information

3D model elements		Attribute information	
		Data storage system	Link system
Host rock	Host rock	ID, density, unit weight, uniaxial compressive strength, adhesive strength, internal friction angle, tensile strength, elastic modulus, *etc*.	Link to the investigation DB
	Fault or rift	ID, permeability coefficient, width	Link to the investigation DB
Tunnel		ID, constructor, construction date, excavation method, falsework pattern, macro unit price	Link to face photo and measurement DB, planned section area, measured section area, digging length, division of heading

2.4.2 Attribute addition method

Two methods were considered to add attribute information to the data models. Either a data storage system is used to directly associate an attribute to a data model or else a link system is used consisting of links to an external database. Table 3 shows the advantages and disadvantages of each method. The attribute information shown in Table 2 can be divided into numerical data, *e.g.* physical properties, or forms, *e.g.* drawings and documents. To handle these types of data, the models are designed to support both the data storage system and the link system. The link system is employed for (1) data that may become huge in size and (2) data unlikely to change by analysis or shown graphically in a 3D model.

Table 3. Attribute addition method

Method	Data storage system	Link system
Outline	All the attributes relating to a data model are stored.	A link is created in a data model and attribute information is stored in a file in the link destination.
Advantage	As many attributes are stored in a data model, data loss due to "linkrot", for instance, by system replacement can be avoided.	Attribute information is managed in a different file and only minimum attribute information needs to be stored in a data model. It does not require a lot of time or labor to enter the data.
Disadvantage	Each of the individual attributes needs to be added manually, one at a time, which is very time consuming.	As attribute information is managed in a different file, linkrot (data loss) may result, for instance, from system replacement. To find attribute information, you have to open files.

2.5 Total system of iSRE

Here it was assumed that iSRE will be operated in a cloud environment in the future and that data will be exchanged as IFC files (Figure 1). A data format suitable for a tunnel in a repository, *e.g.* IFC-Tunnel (Yabuki et al., 2012), however, is not yet ready and furthermore, there are no software programs available that are equipped with functions to support IFC-Tunnel. As a pragmatic development approach, it was decided that software programs available on the market suitable for CIM could be used in the meantime to construct an integrated model and use the standard formats provided with these programs (Table 4).

Table 4. Model classification, outline, software, and extension

Classification	Outline	Software	Extension
Land form model	Load base map information and land survey results and model the land form.	AutoCAD Civil3D® made by Autodesk	dwg
Geological environment model	Model the geological environment using the geological environment model loaded from an external DB and the geological/host rock test results.	GEORAMA for Civil3D® made by CTC	dwg
Structure model	Model the surface and underground facilities and add attribute information to the models.	Revit Structure® made by Autodesk	rvt
Integrated model1)	Load the data models above and synthesize them.	Navisworks® made by Autodesk	nwd

1) An integrated model is formed by combining land form, geological environment and structure models in one space.

3. Design and Production of databases and suitable user interfaces

As shown in Figure 1, iSRE is required to comprise and utilize a wide variety of data, such as geographical and geological environment, analysis, two dimensional (2D) drawings, information on performance assessment, external databases, external monitoring, integrated models, and data models. To contain all this information in iSRE, the system has to store a large volume of data. Searching and browsing performance will likely decline as the volume of data increases and appropriate data management requires special consideration. To avoid such problems, the following policies on database and interface in iSRE need to be considered:

(1) iSRE needs to be linked with other systems being developed by JAEA, *e.g.*, ISIS, e-PAR and JAEA-KMS (Figure 1).
(2) iSRE needs to be linked with external databases, *e.g.*, buffer DB and grout DB, using appropriate data files.
(3) The optimum analysis system available at the time of design should be used with respect to an external analysis system. Analysis input data, analysis results and other data must be stored within iSRE.
(4) Currently available software should be used for the development of iSRE with respect to a design system. The integrated models, data models, 2D drawings and other data must be stored within iSRE.

Database and interface prototypes have been designed and built in accordance with the above policies.

3.1 Databases

The database function consists of the six types of database shown in Table 5. The integrated database contains reports of decisions and their reasons, as well as user information including access authority to databases. The geography and geology database contains geological environment models created from geographic data and geological environment investigation assessment and updates to the geological information obtained during repository construction. The design database contains the analysis results and other data used for purposes of designing the repository. The drawing management database contains 3D data models and the integrated models together with 2D drawings used to create those models. The cost estimate database contains costs calculated using the quantities of members in the data models. The maintenance and repair archive database contains the maintenance logs of surface and underground facilities of a repository after completion. The items of information to be stored in each of these databases are likely to change in the future. The databases should therefore be flexible and scalable to accommodate these changes.

Table 5. Outline of databases

iSRE databases	Outline	Coordination and storing data
Integrated database	Stores storyboard, minutes, reports and user management information to be used for knowledge management, security, performance assessment, information disclosure, etc.	Performance assessment (e-PAR) Reference only for the knowledge management system (JAEA KMS).
Geography and geology database	Stores geographic and geological information necessary for iSRE to use them for analysis, design, data models, integrated models, and performance assessment.	Geological environment investigation assessment (ISIS). Geological information at the time of construction. Updated with information obtained during excavation and construction.
Design database	Stores external analysis input data, analysis results, data of external databases necessary for a design supporting system to use them for data models and integrated models and performance assessment.	External analysis data. External databases.
Drawing management database	Manages 2D drawings, data models and integrated models created and used in every phase of the project.	2D drawings. Data models and integrated models.
Cost estimation database	Stores the operating expenses, other costs and unit prices to use them for budget request, estimation of project cost, etc.	Costs and operating expenses.
Maintenance and repair archive database	Stores information on maintenance and repairs of surface and underground facilities, and equipment and machines relating to the geological disposal engineering after completion of the repository. Also included are monitoring information, such as tunnel convergence, water leak and radiation level.	External monitoring and data measurement.

Prototypes of the geography and geology database have been built and the drawing management database using virtualization. Figure 2 shows the prototype drawing management database. The drawing management database needs to manage an enormous volume of data from the integrated model and the data models comprising the integrated model. The data models are classified by design standard, panel, facility, and other categories, and arranged in hierarchies. The data models in each hierarchy are managed as a group. The drawing management file, thumbnail and 3D-PDF are displayed for each data model to facilitate specific data model searches among a large number of models.

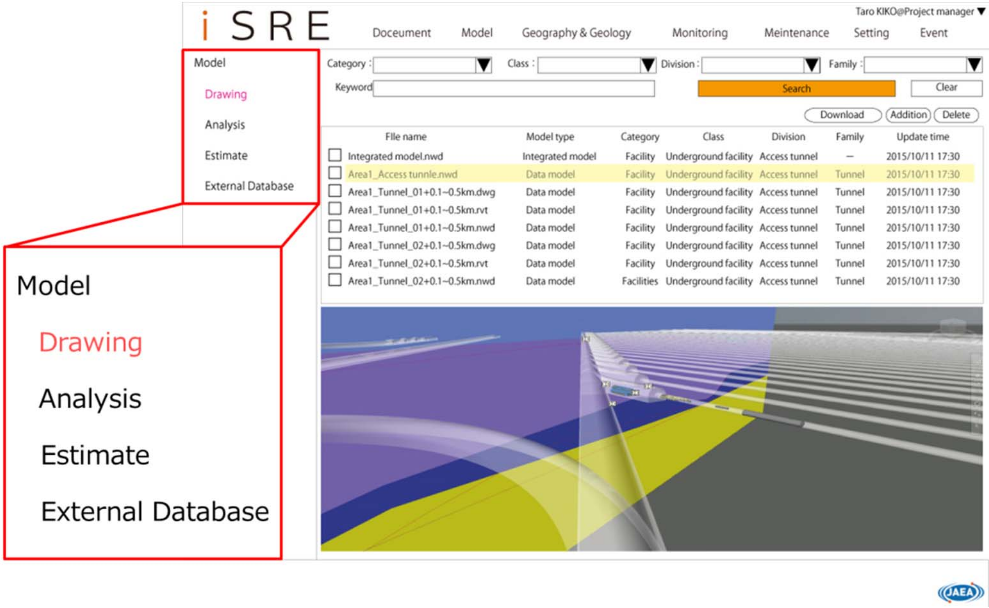

Figure 2. Prototype example of drawing management database.

3.2 Interfaces

The JAEA developed knowledge acquisition tools ISIS and e-PAR are linked with iSRE as shown in Figure 1. Each of the iSRE, ISIS and e-PAR systems is unique in that they were developed independently. Figure 3 shows an example of the interface between iSRE and ISIS. As each system is unique, iSRE constantly monitors for data updates in ISIS and e-PAR. Every time a data set is newly created or updated, iSRE calls up the ISIS or e-Par systems.

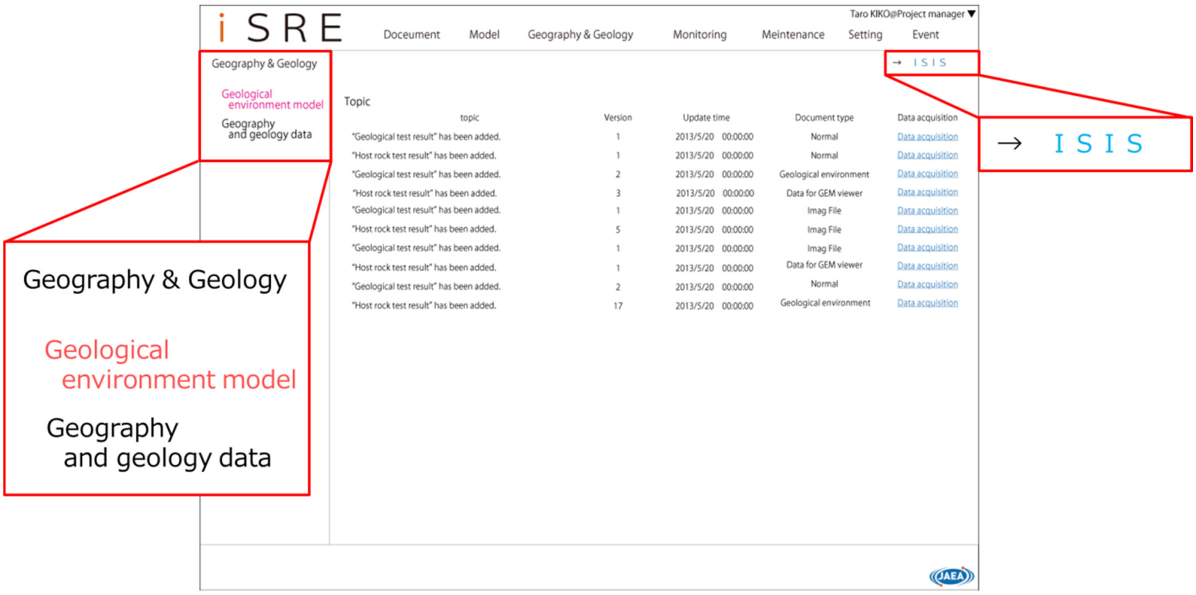

Figure 3. Interface between iSRE and ISIS.

4 VERIFICATION of PRACTICABILITY of iSRE

4.1 Scenario for verification of practicability of iSRE

A test scenario of utilization of iSRE was undertaken to examine the possible uses of the system (Figure 4). During the construction of a geological disposal repository, new geological information is obtained as progress is made in excavation, which may require changes in the construction process or design. Tunnels are excavated based on the initial design of the geological environment model created from the geological survey result. Every time new geological information is obtained during excavation, iSRE provides this data to ISIS. When geological data obtained by excavation differs to the geological environment model (*e.g*. a fault is found in the host rock during construction and excavation), the geological environment model is updated with this information and the design of the tunnel is reviewed based on the updated model. The validity of the revised design can then be checked by safety assessment. Details of appropriate measures taken are stored in the JAEA-KMS and the changes in the design are reflected in the integrated model. Based on the result of the measures taken, changes in the repository design (*e.g*. water cut-off, a change in the falsework, a change in the tunnel line) are reflected in the tunnel excavation.

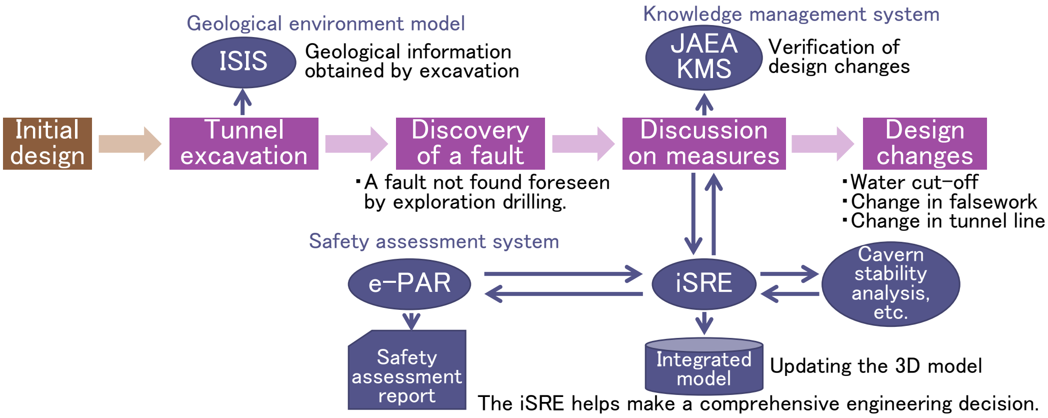

Figure 4. Scenario of iSRE use during construction

4.2 Production of an Integrated model

To define the required functions of iSRE, the following data models have been constructed from an assumed 'generic' repository layout.

(1) Structure (layout) model to include access tunnels (drifts), main tunnels and disposal tunnels.
(2) Land form model and geological environment model.
(3) Waste package placement machine model, and transport machine model for the waste package placement machine.
(4) Engineered barrier and waste package.

An integrated model was built on the combination of these data models,. The integrated model can be used to verify changes in the repository design, such as checking tunnel layout, the operation of transport and placement machines, and the location of waste packages (Figure 5). Attribute information can also be viewed in the integrated model (Figure 6).

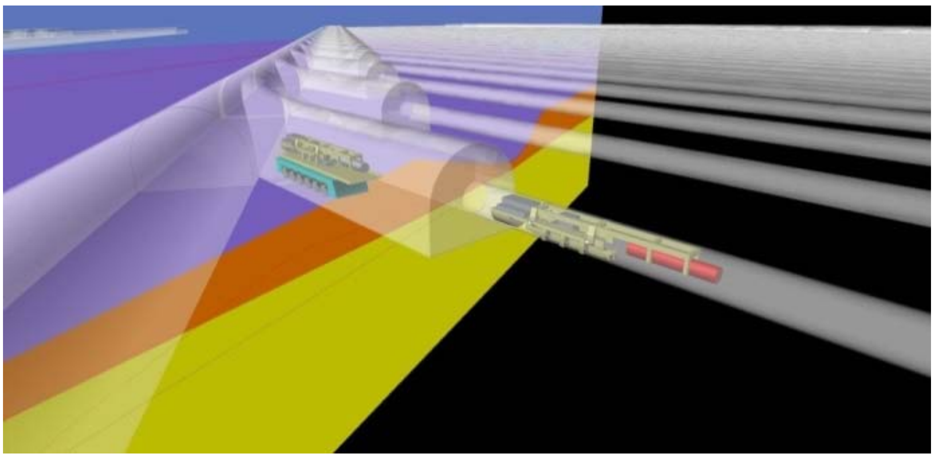

Figure 5. Models (geological, tunnel, placement machine, transport machine and waste package)

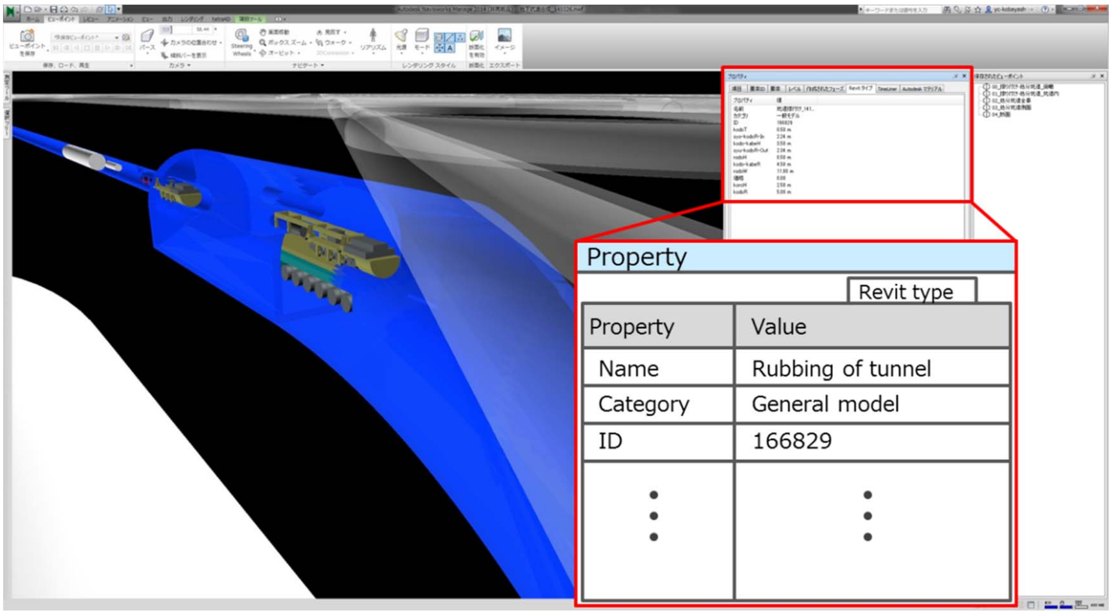

Figure 6. Integrated model and detail of attribute information

4.3 Verification of practicability

Using the prototype iSRE, the operation verification about “design changes using the tunnel data models or the integrated model” have been conducted. Based on the design scenario detailed in Section 4.1 (changing the direction of a tunnel because of a fault), the integrated model comprising tunnels built in Section 4.2 have been used. Figure 7 shows a change in the position of an access tunnel from the planned central (red) line to a revised central (blue) line. If the tunnel is excavated along the planned central line, it will meet another fault, but if the tunnel is excavated along the revised central line a safe distance from the fault will be achieved.

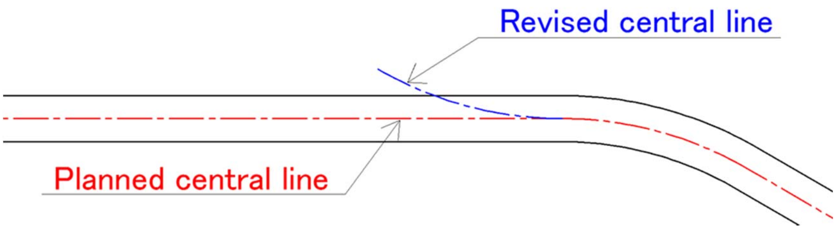

Figure 7. Planned central line and revised central line

(a) Planned central line (b) Revised central line

Figure 8. Tunnel data models along (a) planned and (b) revised central lines

Figure 8(a) shows the data model of the access tunnel built with the Revit Structure® based on the planned central line in Figure 7. This data model is registered in the drawing management database of iSRE. When a change is made, the data model is downloaded from iSRE to an on-site PC. Figure 8(b) shows the data model of the access tunnel based on the revised central line in Figure 7. It shows that a tunnel data model can be adjusted to accommodate unforeseen changes to the geological environment model .

5. DISCUSSION

In section 2, the basic structure of iSRE was described based on the current configuration of development purpose and requirements. Many of the 16 items configured as design requirements are categorized as data management, data archiving or data sharing. As these themes are core concepts of CIM technology, the CIM technology is seen as being appropriate to underpin the development of iSRE. Hereafter, the basic structure of iSRE may need to be revised for the purpose of development or requirements because of changes in technology or social requirements. It is therefore necessary that the basic framework of iSRE should be flexible and expandable. As an example, the analytical software, which will be updated with the development of analytical technologies, may be treated as a plug-in instead of being an integral part of iSRE. Using this approach, the system could be maintained by only minor changes of the interface, and utilize the system on a long-term basis. By adopting an IFC format, it may be effective to avoid problems in data dissemination between generations. Although, IFC is still under development, its progress needs to be closely monitored.

In section 3, the design of the main database of iSRE and the interfaces between external systems and external databases were described. Databases may be changed in the structure or the functions because of the change in basic structure of iSRE. Moreover the database itself may change, and so databases should be inherently flexible and expandable. Databases are required to accumulate the data hierarchically and to extract the data as per the needs of the search requirement. As this is a long-term project of some 100 years, data searching and viewing will be necessary in chronological or special order. The interfaces should also be flexible to accommodate changes in the basic structure of iSRE or changes in external systems and databases.

The iSRE has been configured by combining existing software programs. An integrated model of tunnels was built using the system. Assuming that a fault is found unexpectedly, change in the tunnel data model was simulated and used to verify iSRE operation. Models of tunnel structure, geological environment and transport and placement machines were constructed, and the ability to browse attribute data in the integrated model was confirmed. Also, it was confirmed that changes in the design of the tunnel and transport machine could be easily implemented in iSRE.

Although the above features demonstrate the benefits of developing the iSRE to meet repository design requirements, there are, however, two issues that need to be resolved:

(1) Verification of applicability of IFC

At present, the development of iSRE uses the standard file formats of Revit Structure®, Navisworks® and other software programs (Table 4). In the future, it is expected that IFC-Tunnel will be developed for exchange of data models between iSRE and a design system, which will have to be verified and will also require updates to the iSRE interface.

(2) Development of data searching function

Spatial searching and chronological searching functions are required. In a geological disposal project, several tens of thousands of waste packages are disposed of in several hundred kilometers of tunnels. For the design, construction and maintenance of such tunnels, the search function needs to quickly find the relevant data in what is expected to be an enormous volume of data. As the project will continue for some 100 years, chronological searching is needed to retrieve a past decision promptly.

While addressing these issues, development will proceed by building prototypes of databases and interfaces and verifying their operations.

6. CONCLUSIONS

The current paper describes the development of iSRE as a design support system to be used for a geological disposal project that will continue for some 100 years. The configuration process of the system with case examinations have been shown. First, the goal of the development, design requirements and functions of the system were defined and a basic structure of iSRE that fulfills those requirements was built. It was decided that the complimentary CIM technique is useful for sharing of information necessary for design, which is the main function of iSRE, and management of the history of the information. The information includes all the data relating to design, such as, integrated models, data models, geological environment models, decisions made throughout the project and criteria for the decisions. For configuration of iSRE, data model items to be saved and the structure of the whole system have been examined. The main databases of iSRE and interfaces that enable coordination between those databases and external systems and databases have been designed. Prototypes have been built of some of the databases and the interfaces and built data models. A scenario of iSRE operation was created and the applicability of iSRE using data models was examined.

IFC cannot be used at present and so a combination of existing software programs have been used. With the assistance of these existing software programs, however, the development process could be conducted while solving problems for specific test cases. A realistic prospect of the development of iSRE for a geological disposal project was therefore obtained and the usefulness of iSRE for designing a repository was confirmed.

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