Development of a Design Support System for Geological Disposal of Radioactive Waste Using a CIM Concept

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Abstract:

The project period for the geological disposal of radioactive waste in a purpose built repository could be as long as a hundred years and require the involvement of several generations of engineers. Throughout such a long project period, it is important to manage systematically the information accumulated on design, construction, operation and closure, and to be able to track decisions made at each stage of the project. In addition, the repository comprises a wide variety of elements like engineered barriers (containers/buffer materials), underground facilities, transportation/emplacement equipment, and surface facilities, and they are closely related each other as one system. To help rational design of the repository system, a design support system (referred to as the Integrated System for Repository Engineering: iSRE) has been developed. Core functions of iSRE are a database function (DB) and an interface function (IF). A plug-in method has been adopted for simulation codes used in iSRE for design and analysis, so that the latest codes can be used and that iSRE avoids becoming obsolete. In this paper, the following items are presented: (1) characteristics of information management on engineering technology in the disposal project, (2) iSRE's functions and goals, (3) realization of iSRE functions as a prototype, (4) confirmation of functions in prototype of iSRE, (5) outcomes achieved and future issues identified through the prototype development and trials. In order to confirm that the iSRE prototype functions well, test runs of the prototype based on the scenario illustrating typical works in the geological disposal project were made (e.g. change of design due to new information). This resulted in the iSRE core functions of DB and IF forming the foundation of information management on engineering technology. Test runs of the prototype of iSRE helped to identify practical issues for the development and use of such a design support system.

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

1. INTRODUCTION

Nuclear power generates waste that remains radioactive for a very long time. Geological disposal is currently the favored means to isolate radioactive waste from the human environment (OECD/NEA, 1984). Like other countries, the Japanese concept of geological disposal is based on multi-barrier systems consisting of an engineered barrier system (EBS) located in a stable geological environment. The EBS is composed of the radioactive waste itself, a metal container and a clay (buffer) material. Japan is located in a tectonically active zone and so the long-term stability of the geological environment must be given careful consideration.

To ensure the long-term safety of geological disposal, the following three items should be confirmed (JNC, 2000):

1. Selection of an appropriate geological environment for geological disposal (site selection).
2. Proper design and construction of engineered barriers and disposal facilities for stable geological environment (engineering measures).
3. Evaluating the safety of the constructed geological disposal system (safety assessment).

The geological disposal project of radioactive waste will proceed in five steps: 1) site investigation, followed by repository 2) design, 3) construction, 4) operation and 5) closure, which are expected to last for 100 years (NUMO, 2013). Site investigation includes literature surveys and preliminary and detailed investigations of candidate sites, which leads to an increased understanding of favorable geological conditions and optimized site selection. Correspondingly, the engineering measures will be designed. Based on the results of site investigation and repository design, safety assessment will be carried out for each investigation stage repeatedly. The safety assessment will therefore be continuously reviewed reflecting more detailed geological environmental conditions acquired during the construction of the repository. Due to this iterative process of geological disposal projects, it is important to manage information properly about engineering technology for design, construction, operation, and closure, which will involve several generations of engineers.

In this paper, the Integrated System for Repository Engineering (iSRE) is presented as an information management tool for the geological disposal project. The following items are presented: (1) Characteristics of information management on engineering technology in the disposal project, (2) iSRE's functions and goals, (3) Realization of iSRE functions as a prototype, (4) Confirmation of functions in prototype of iSRE, (5) Outcomes achieved and future issues identified through the prototype development and trials.

2. CHARACTERISTICS OF INFORMATION MANAGEMENT ON ENGINEERING TECHNOLOGY IN DISPOSAL PROJECT

2.1 Iterative design during the project period

The EBS will be constructed in a stable geological environment where long-term safety can be demonstrated. As shown Figure 1, the repository will be more than 300 meters below the surface and cover an area of several square kilometers. A disposal panel is a group of disposal tunnels in which the engineered barriers are installed. The size and arrangement of disposal panels will be determined according to the geological conditions, such as the thickness and extent of the geological formation or the location of faults.

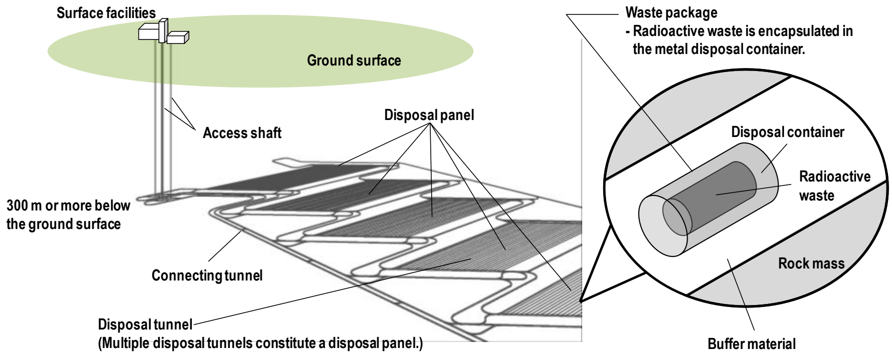


Figure 1. Schematic view of repository

The repository is designed under the conditions obtained by site investigation, and the safety assessment will be done. This design and safety assessment process will be repeated as the geological environmental information is updated. Figure 2 shows an example of a change in repository design because of an update in the geological environmental condition.

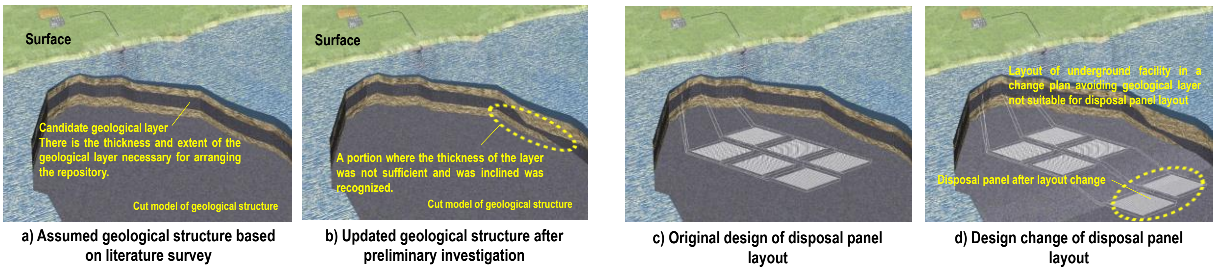


Figure 2. Geological environmental condition based on (a) literature survey and (b) preliminary investigation and (c) example of repository design and (d) change of disposal panel layout considering updated geological environmental condition

Figure 2 a) shows a cut model of the assumed geological environment conditions based on a literature survey. It is assumed that this area was selected as a candidate site for the repository because the rock mass was homogeneous, widely distributed and considered to be stable in the long term. After the literature survey, a drilling exploration on this candidate site was conducted as a part of the preliminary investigation. As shown in Figure 2 b), it was found that the candidate geological environment conditions were not homogenous, but instead contained a variable layer thickness, which was inclined. Such a thin, inclined layer is considered unsuitable for the long-term safety of the repository. Figure 2 c) and d) show the required changes in the repository design before and after the preliminary investigation of the geological environment conditions. In this way, updates in the geological environment conditions as the disposal project progresses can affect the repository design.

2.2 Characteristics of information management on engineering technology

Features related to information management on engineering technology in disposal project (hereinafter referred to as engineering technology) can be roughly divided into three categories.

The first is the systematic management of various information on the repository during the geological disposal project (IAEA, 2011). It is necessary to have a management system whereby information on investigation, design, construction, and operation, obtained and accumulated in a long-term project period lasting 100 years will be successfully passed on over several generations of engineers. It is also necessary to be able to refer to appropriate information at different times of the geological disposal project, such as confirmation of the latest information at that time or of previous circumstances.

The second is the relevance of various information on the repository. As shown in Figure 1, all the components of the repository, including the underground facilities, the waste package, the buffer material, the transportation/emplacement equipment, and the surface facilities, must be designed to operate as an integrated system. Functioning as an integrated system ensures that there is no inconsistency among multiple design elements at any point in time. This also has to accommodate changes in the various design elements of a disposal project period lasting 100 years, such as a change in EBS specification caused by technological innovation, update of geological environment conditions *etc*. In this way, the design of the repository must be carried out with comprehensive and careful consideration of various repository relevant information.

The third is the succession of decision-making history at each stage that corresponds to milestones of the geological disposal project period. It is important that such decisions are transparent and traceable throughout the entirety of the project so that it may proceed with no social or political persecution.

There are cases of research on the operation technology of monitoring equipment (Constantinou et al., 2011) and the development of the radioactive waste management program (Chen et al., 2013). However, there is no known equivalent of iSRE, which has been designed, prototyped and tested to manage technical information on engineering technology that considers the entirety of the geological disposal project lasting 100 years.

3. iSRE'S FUNCTIONS AND GOALS

iSRE is a knowledge acquisition tool that manages technical information on engineering technology (Sugita et al., 2016). iSRE works with other knowledge acquisition tools to manage information on site investigation and safety assessment, or knowledge management system on geological disposal project. The overall goals of iSRE were defined as follows:

1. A system that can support the management and inheritance of technical information related to the investigation, design, construction, operation, and closure over a long-term project period, ensuring transparency and traceability of decision-making in design and construction.
2. By sharing data, a system that can support consistent design of disposal containers, buffer materials, transportation / emplacement equipment, underground facilities, and surface facilities respectively. Also, that the traceability of individual design according to the increase of information or the advancement of technology during the disposal project is supported.
3. A system that can manage the data by adopting the concept of Construction Information Modeling/Management (CIM), which is a concept of collectively managing all projects from planning, design, construction, operation, and closure using information technology. Here, CIM manages a series of design information as a system, enabling unified information management (Fujisawa et al., 2013; Shiiba et al., 2014; Shimizu et al., 2013), and is known as Building Information Modeling (BIM) in the civil engineering field.

Figure 3 shows the configuration of iSRE to realize the above goals. Engineering technology is required to utilize a wide variety of data groups such as topography/geology, analysis, 2D drawing, performance assessment, external database, external monitoring, and 3D models. When compiling all of the information in iSRE, the data capacity of the system itself becomes enormous, retrieval and browsing of the data are deteriorated, and it is assumed that a great deal of labor will be required for data management. Therefore, iSRE is aimed to be a system that functions as follows:

1. With regard to the analysis system itself, an external analysis system outside of iSRE was used to make it

easier to use the optimal analysis system at the time of design. Input data of analysis and analysis results *etc*. are stored in the databases of iSRE.

2. Various technical information on design other than those identified above are stored in the databases of iSRE.

3. Knowledge acquisition tools, such as "ISIS" for geological environment investigation assessment (Semba et al., 2009), "e-PAR" for performance assessment (Makino et al., 2012) and "JAEA KMS" for knowledge management (Makino et al., 2012), are used accessible from within iSRE by interfaces.

4. External databases, such as the buffer material DB and grout material DB), they also cooperate with iSRE by interfaces.

In this way, the core function of iSRE is the database function (hereinafter DB) and the interface function (hereinafter IF). In iSRE, a 3D model is registered as a data model that associates attribute information. Such a data model is prepared on the basis of elements and parts of the repository.

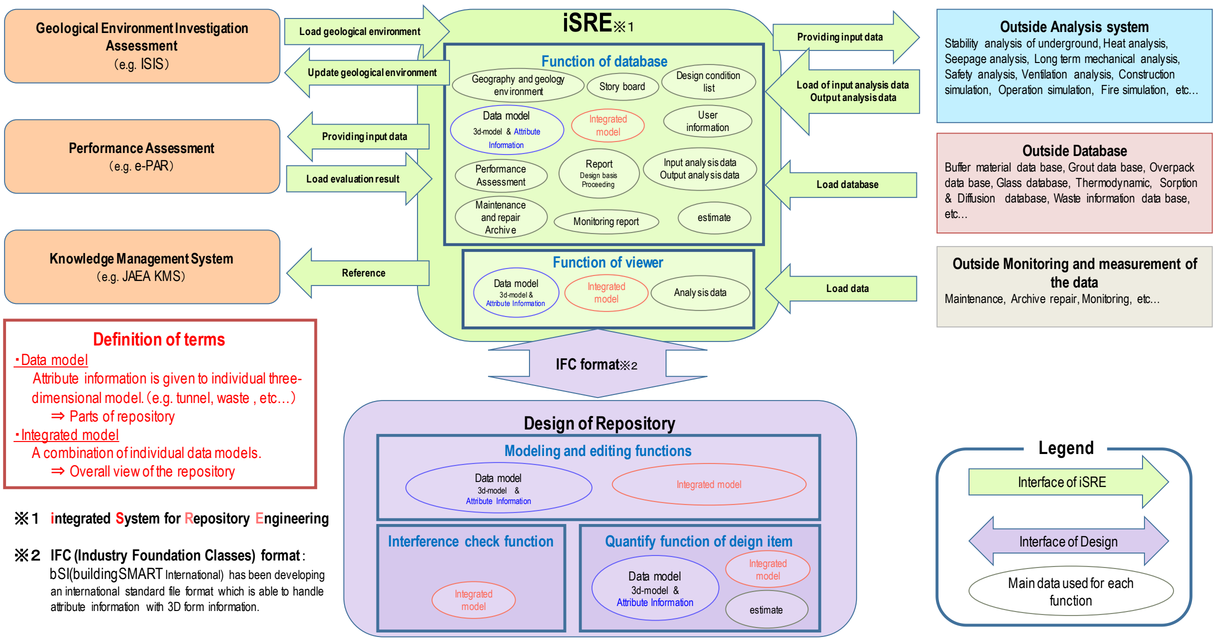


Figure 3. Basic structure of iSRE and interaction with outer systems

4. REALIZATION OF iSRE FUNCTIONS AS A PROTOTYPE

Figure 4 shows the main functions implemented in the iSRE prototype, which are the DB and the IF. As for DB, six kinds of databases (Table 1) are set to store various kinds of information about engineering technology as used in the project. As for IF, four kinds of interface between each DB and external system are set. Figure 4 also shows the correspondence of each DB and IF that depends on the kind of information.

The amount of information/data stored in iSRE quickly become enormous as the disposal project progresses. It is therefore important that iSRE can retrieve necessary information without difficulty from the DB where enormous information/data are stored. A variety of situations are expected in the future for which various information will be needed, such as the latest data, archival records from the past, decision making process, and so on. To cope with these situations, a search function of iSRE is fundamental for information management. In order to make this possible, the search function of information/data from both temporal and spatial viewpoints are studied.

Firstly, the data search method from a temporal viewpoint is focused on the temporal change of information as the project progresses. The disposal project progresses through the stages of literature survey, preliminary investigation, detailed investigation, construction, operation and closure, so that each stage represents a milestone in the geological disposal project. Here the "event function" (shown in Figure 4 as "Events") is defined as a function to research data utilizing those milestones or events that are registered beforehand in iSRE as keywords identifying various "event" during the project. To use this function, keywords of events are attached to data in the DB as attribute information. For example, in registering data about a repository design based on the literature survey, "design" at the time of "literature survey" are keywords of the event, and these keywords are attached to the data as attribute information.

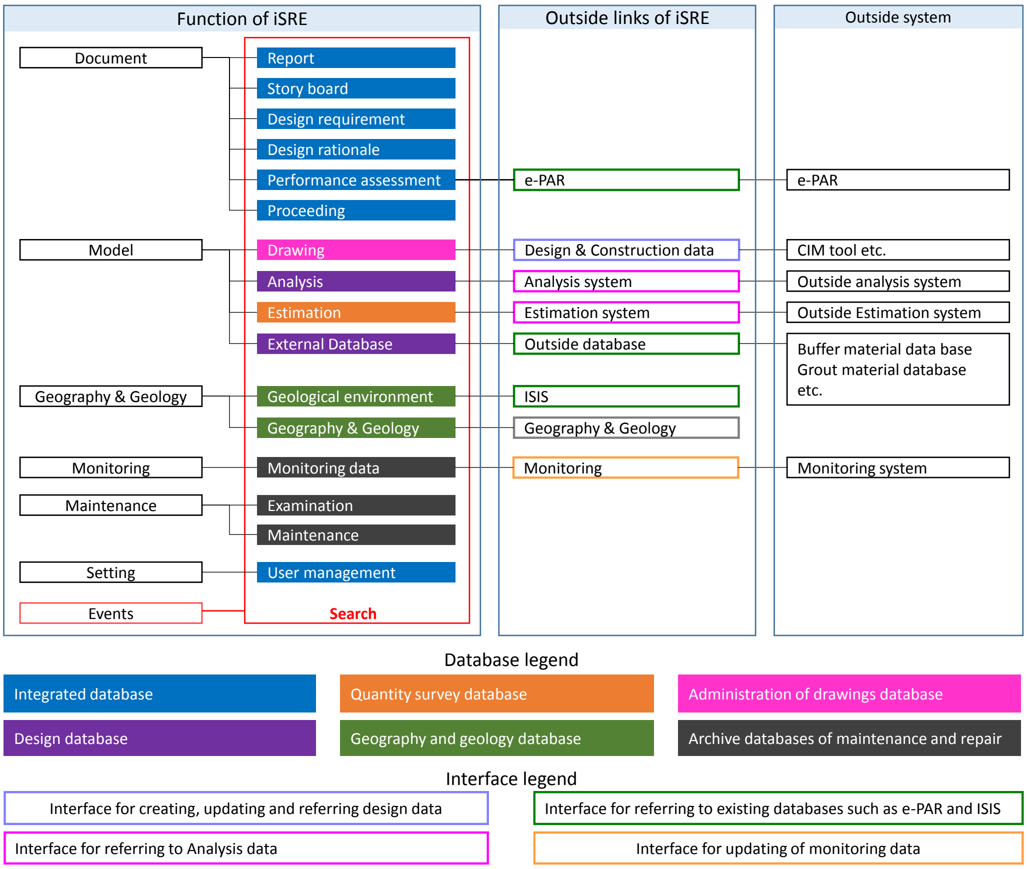


Figure 4. Functions of iSRE and correspondence between the DB and the IF

Table 1. Outline of DB

iSRE databases	Contents
Integrated database	Stores storyboard, minutes, reports, design condition, design basis, user information, etc.
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.
Design database	Stores input data and results of external analysis, data of external databases necessary for iSRE to use them for development of data models and integrated models and performance assessment.
Drawing management database	Manages 2D drawings, data models and integrated models created and used in every phase of the project.
Cost estimation database	Stores operating expenses, other costs and unit prices to use them for budget request, estimation of project cost, etc.
Maintenance and repair archive database	Stores information on inspections and repairs of underground and surface facilities, equipment and machines relating to the geological disposal engineering after completion of the repository and monitoring information, such as tunnel convergence, water leak and radiation level to use them for operations.

A search of each DB can be performed individually (blue arrows in Figure. 5), although this may result in a search failure. On the other hand, using the events function is seen as a more useful search means as it allows six types of DB to be cross-searched with the same keyword (orange arrow in Figure 5), which is far less likely to result in a search failure. It is also important for iSRE to handle a wide variety of information properly so that it is updated without omission as the project progresses.

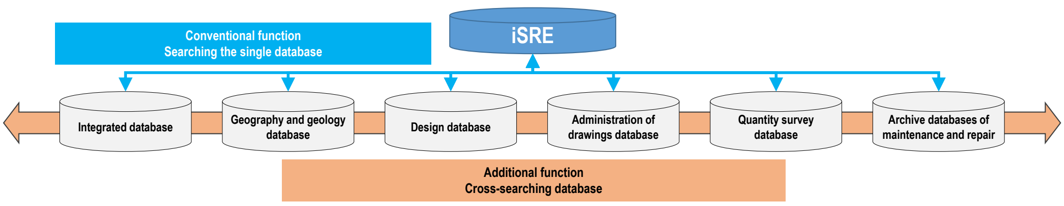


Figure 5. Conceptual diagram of data search method

Secondly, from the spatial point of view, since various facilities are scattered in the geological disposal site (see Figure 1), the search method focuses on such attributes as spatial arrangement, positional relationship, etc. In this method, information related to a component of the repository, for example, a disposal tunnel, is extracted directly by selecting the component on the display.

To realize this, a 3D viewer function, which can search the drawing file while checking the attributes of a physical object in a 3D model, provided by iSRE was considered to be an effective means to visualize the information. If information can be browsed and registered by designating not only drawing files but also other attributes (*e.g.* design data of the tunnel, tunnel specifications, support material of the tunnel, construction date, etc.) linked to the drawing file within the 3D model, it is possible to more intuitively and directly select and access information.

The conventional file management method of "file management by function" (Figure 6 a) and Table 2), a "file management by 3D data model" (Figure 6 b)) is also considered. Figure 7 provides an example of what such a file management by 3D might look like. Selecting the drawing file (orange frame), the content of the 3D model is displayed on the screen. When a part of the 3D model is clicked (e.g. one of the disposal panels Figure 7 illustrate), a list of DBs storing various information files linked to the disposal panel is displayed.

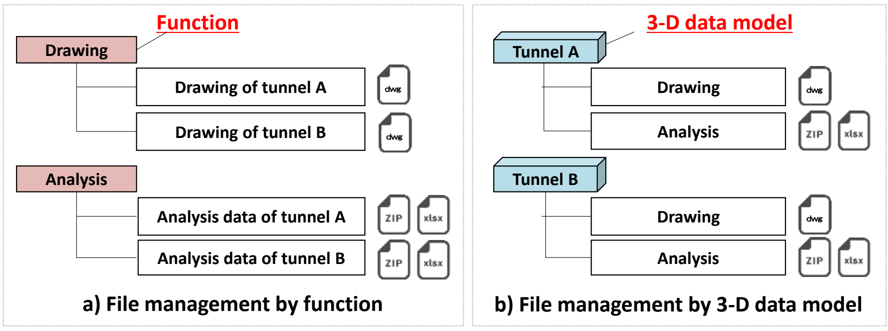
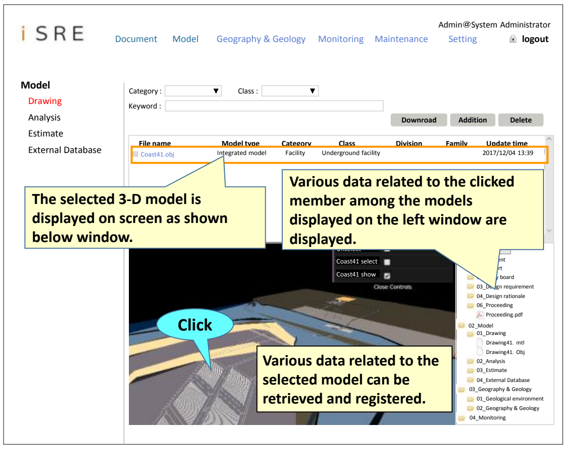


Figure 6. Conceptual comparison of file management methods

Table 2. Characteristics of file management methods

Methods	Advantages
File management by function	The file to be added to iSRE can be any unit and data registration work is easy.
File management by 3D data model	With respect to the search function, since the three-dimensional position of the object is specified visually, the search with the position as a condition can be intuitively performed.



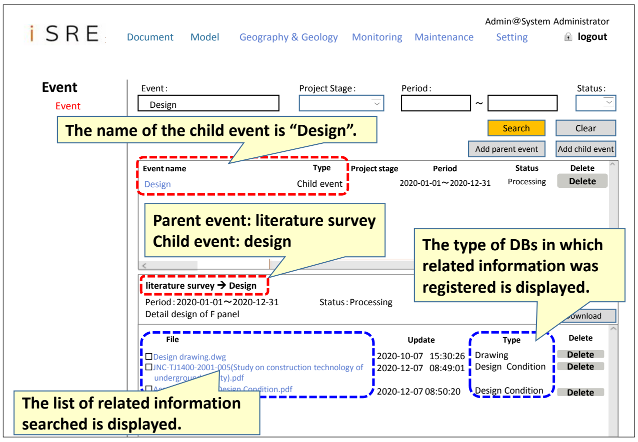


Figure 7. Drawing management function

Figure 8. Utilization of iSRE

5. CONFIRMATION OF FUNCTIONS IN iSRE PROTOTYPE

A prototype of iSRE that embodies the functions described above was developed to confirm the applicability and to identify challenges of the functions through test trials simulating the actual work assumed in the geological disposal project.

The confirmed function of iSRE focused on the following two items with emphasis on DB function.

1. Development of the DBs which handle expected storage data in the geological disposal project.

2. Search for necessary data files from a large amount of data files registered in the DB.

In order to confirm the above functions, revisions to repository design caused by the update of the geological condition from the information obtained by literature survey and by the preliminary investigation were used in test trial scenarios (see Figure 2). Table 3 summarizes examples of information that were browsed and registered for repository design based on the literature survey and the preliminary investigation.

Table 3. Examples of information browsed and registered for design of the repository

Design of the repository	Information to be browsed	Information to be registered
1) Repository design based on literature survey results	Literature survey report (geography, geology, groundwater data, etc.)	Design document of the repository at the time of literature survey (Design conditions, analysis results, design drawings, minutes etc.)
2) Repository design based on preliminary investigation results	Preliminary investigation report (geography, geology, groundwater data, etc.) Design document of the repository at the time of literature survey (Design conditions, analysis results, design drawings, minutes etc.)	Design document of the repository at the time of preliminary investigation (Design conditions, analysis results, design drawings, minutes etc.)

When designing a repository based on the investigation results, it will be necessary to browse and register various reports and information. In the situation of "Update the design by preliminary investigation" in the trial scenario, preliminary investigation report, a design document of the repository based on the literature survey and the information related to them can be viewed or checked. The updated repository design based on the updated geological condition is registered as the design document of the repository at the time of the preliminary investigation. These reports and information are managed in the database in the form of files, and the trial run is set to confirm the iSRE functions by which files necessary to view can be searched and the created files can be registered properly.

To check the function of iSRE in accordance with the trial scenario, data files of various file formats, such as topography, geology, design conditions, design drawings (Table 3), are firstly prepared and registered in a DB suitable for the file contents. As a result of the trial run, it was confirmed that each DB as the data file registration destination was provided as designed and the function for registering data files to the DB worked properly. It was also confirmed that the event registration function works appropriately by designating the keywords of "literature survey", "preliminary investigation", and "design" as attribute information when relating data files were registered.

Secondly, with regard to the search function, by utilizing the events function for data files registered in multiple DBs, it was confirmed that no data were omitted from search results nor that search failures occurred.

Figure 8 shows an example screen for a series of the iSRE operations in the trial scenario. By specifying the "design" event (outlined by the red dashed line) in the event search, the related information (outlined by the blue dashed line) stored in the different DBs were displayed as search results.

These trial test runs confirm that the function of iSRE works without problems for searching and registering information.

6. OUTCOMES ACHIEVED AND FUTURE ISSUES IDENTIFIED THROUGH THE PROTOTYPE DEVELOPMENT AND TRIALS

Through the development and trial test runs of the functions it was confirmed that the functions of the DB and the IF incorporated in the iSRE prototype work as expected. These functions could therefore be used as the foundation of information management concerning the engineering technology of the geological disposal project.

The issues for putting iSRE into practical use is to improve the function of iSRE and to keep pace with evolution of computer and software. The issues of improving the function of iSRE are summarized in enhancement and qualitative improvement of the functions of DB and IF, the search functions and response to an ever increasing volume of information. Issues related to evolution of computers and software are particularly important since the geological disposal project lasts for about 100 years. It is therefore important to respond appropriately to changes in the computing environment such as new OS and security threats. Selection of the data format for enhancing the continuous availability of information is also important. The data format is ideally in an international standard, such as an Industrial Foundation Classes (IFC). At present, however, IFC-Tunnel (Yabuki, 2008; Yabuki et al., 2012), which is considered as a data format conforming to the underground tunnel of the geological disposal site, is still being developed and early practical application of the IFC-Tunnel is desired.

7. CONCLUSIONS

In this paper, the concept and function of iSRE was examined. iSRE is a system of information management of engineering technology, which allows, for example, repository design to be continuously improved during the disposal project. An iSRE prototype was developed based on repository design and its functions were confirmed by test trial runs simulating the geological disposal project.

As a result, with respect to the functions of DB and IF of iSRE, these functions could be used as the foundation of information management on engineering technology of the geological disposal project. The development of an iSRE prototype and trial test run identified issues for the practical implementation and use of such a system.

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