DEVELOPMENT OF THE NUMO SAFETY CASE – REPOSITORY DESIGN AND ENGINEERING

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A comprehensive design system has been developed, through which repository design is carried out iteratively, tailored to the evolving site descriptive model (SDM) that integrates understanding of geological structures and thermal, hydrogeological, mechanical, and geochemical features and processes. Prior to volunteer sites coming forward, NUMO has developed a repository concept catalogue to facilitate the process of tailoring concepts, designs and layouts to a given siting environment.

The first step in tailoring repository design to the SDM is to define potentially appropriate host rocks, which is followed by specifying an engineered barrier system (EBS) and a repository layout, together with relevant support facilities and infrastructure. Although a reference EBS concept has been defined for high-level vitrified waste (HLW), a multi-barrier system consisting of a carbon-steel overpack and surrounding bentonite buffer, potential variant options are also to be summarized in the repository concept catalogue. For various types of radioactive waste generated from reprocessing of spent nuclear fuel and mixed-oxide *(MOX) fuel fabrication (termed "TRU waste" in Japan), reference EBS designs and layout have also developed for an option of co-disposal of HLW and TRU waste, although a comprehensive concepts catalogue has not yet been published for this waste.*

A set of design factors has been used to guide the repository design process, which is coupled to siting factors to provide clear linkages between site characterization activities and the repository design work. Design is also closely integrated with safety assessment, which contributes to increasing confidence in the resulting safety case.

I. INTRODUCTION

NUMO is providing a comprehensive technical report, which aims to provide a safety case of geological disposal of HLW and TRU waste, taking state-of-the-art scientific knowledge and technology into account. The siting process of a geological repository in Japan is based on volunteerism and no specific site and geological environments have not yet been identified. As overviewed in the companion paper by Fujihara, et al[1] also submitted to this Conference, the safety case is therefore still generic in which a range of potentially favorable geological environments. For this purpose, a set of potential site descriptive models (SDMs) are under developing (see companion paper by Ota, et al[2]), which should be considered for repository design and safety assessment.

In this paper, development and application of a comprehensive design system of geological repository are discussed for tailoring a repository system for given siting environments and other evolving boundary conditions, which is a key to making a safety case iteratively improved in its confidence.

II. REPOSITORY DESIGN

II.A. Basic Strategy for Developing Repository Design System

As arguments for the reliability of a safe repository system, it should be demonstrated that an appropriate design system (Repository Design System) to assure desired safety functions should be developed by using which a repository system with required functions can be designed. Under a set of given design conditions including siting environments represented as SDMs, socio-economic constraints and available technologies, designing a repository is systematically carried out through the Repository Design System. The Design System should therefore include step-wise processes of definitions on repository concept, functional requirements and associated design requirements of repository system, and configuration of repository specifications. The concept of the design system is shown in Fig.1.

The design conditions would change during the long period of time for repository implementation program. At current stage, any candidate site has not yet been specified and the Design System should scope in particular a range of potential siting environments depending on the volunteered areas and incorporate stepwise increasing information on the candidate sites as site characterization proceeds. Changes in other boundary conditions in the long period of time during repository implementation program should also be taken into account in the design process of repository system. The Design System should be therefore developed to maintain flexibility for such changes in design constraints.

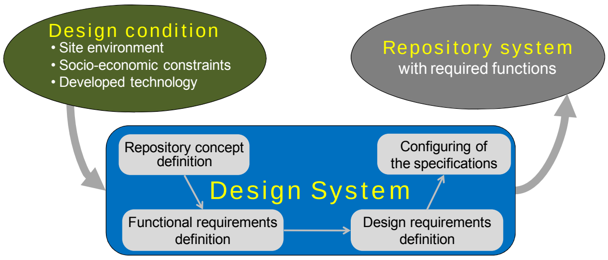

Fig. 1 The concept of design system

Whole process of repository implementation includes different phases such as construction, operation closure and post-closure. For each project phase, different functions of a repository system are required and these functions should be consistent and systematically considered in the Design System.

For maintaining flexibility in the Design System for a range of siting environments and expected changes in other relevant boundary conditions, Repository Concepts Catalogues and Design Factors[3], have been applied. The relationships between key elements of the Design System are on the other hand clearly identified based on a systematic approach in order to reflect coherently changes in design conditions into the designed repository system. Design Factors is used to define potential repository concepts, relevant required functions for whole repository development steps and associated design requirements.

II.B. Repository Design System

The overview of the Repository Design System is shown in Fig.2.

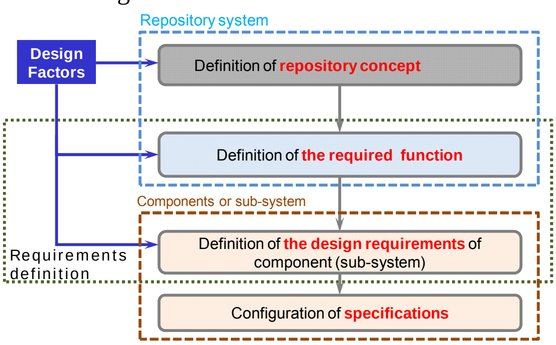

Fig. 2 The overview of Repository Design System

According to the basic strategy described in the previous section, Design Factors is used to define repository concept as the first step in the Repository Design System for a given siting environment (integrated as a SDM). This process is shown in Fig.3. Appropriate repository concepts are developed for any suitable volunteer sites that come forward by applying Siting Factors[4]. Applicability of various options of repository concept summarized in Repository Concepts Catalogues are evaluated for a SDM developed for a suitable volunteer site, based on Design Factors which includes long-term safety, operational safety, engineering feasibility, quality assurance, engineering reliability, site characterization, monitoring, retrievability, environmental impact and socio-economic aspects.

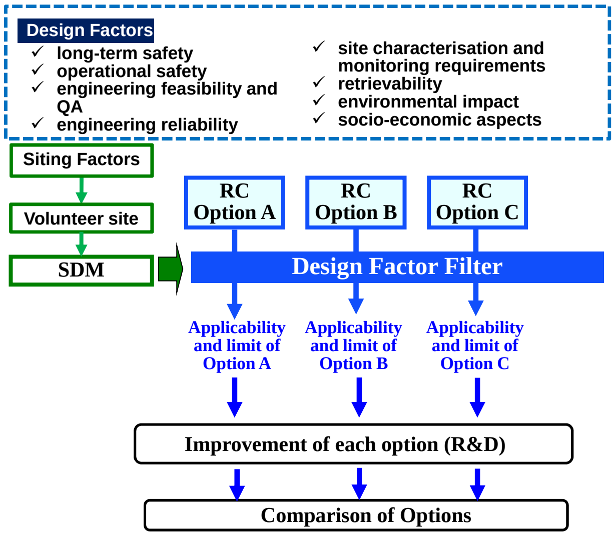

Fig. 3 Evaluation of the repository concepts based on the Design Factors

Comprehensive requirements definition is then conducted at repository system and sub-system/components levels as the second step in the Repository Design System. Based on Design Factors, required function of repository system is identified at each project phase from construction through post-closure of repository concepts applicable to a siting environment. Fig. 4 shows example of the required functions of a repository system identified at each project phase.

The requirements of a repository system are then integrated to the requirements related to each sub-system/component of a repository as shown in Fig.5.

The requirements defined for each sub-system /components are used to define the design requirements, again, by applying Design Factors.

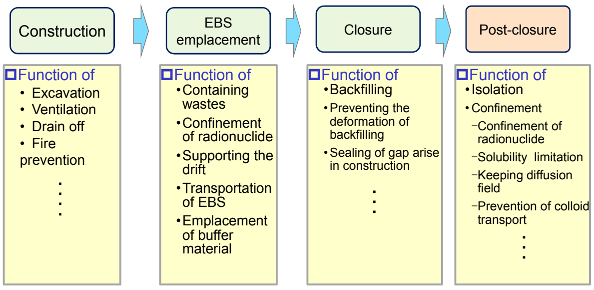

Fig. 4 Requirements definition (1) – Definition of required function of a repository system identified at each project phase

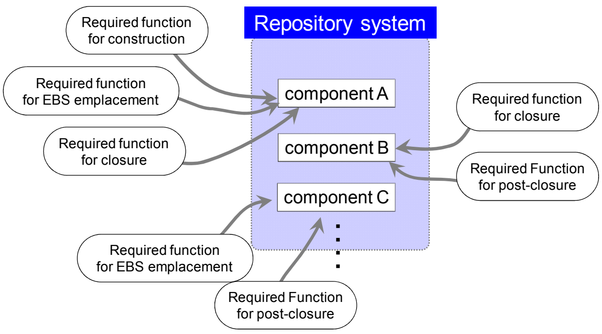

Fig. 5 Requirements definition (2) – Definition of required function of each subsystem/component

As summarized in Fig. 6, design requirements have been classified in three categories for a defined functional requirement to performance requirement, requirement derived from response to the influence factor and ensuring functionality.

The performance requirement includes performance indicators and associated criteria. For identification of influence factors, evolution of the state of a repository system should be taken into account for the period that each component should function to provide expected performance. Furthermore counter measures for such influence should be developed, if necessary, not only for the intended component itself but also for other relevant components. For this case, the design requirement for the intended component is affected by that to other components. Requirements to ensure functionality include implementation practicality, maintainability and robustness. Three categories of design requirements are related each other and should be defined in a systematic way. The application of this classification of design requirements is shown in Fig. 7 for buffer material as an example.

The last step of the Repository Design System is configuration of repository system. Design flow of each component of a repository system has been developed for this process as shown in Fig. 8.

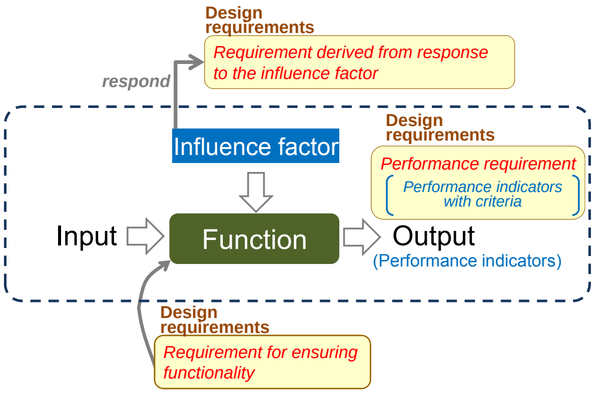

Fig. 6 Requirements definition (3) – Relationship between function and design requirements

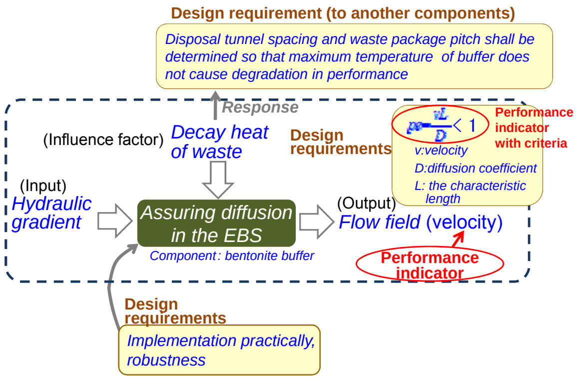

Fig. 7 Design requirements – an example (buffer material)

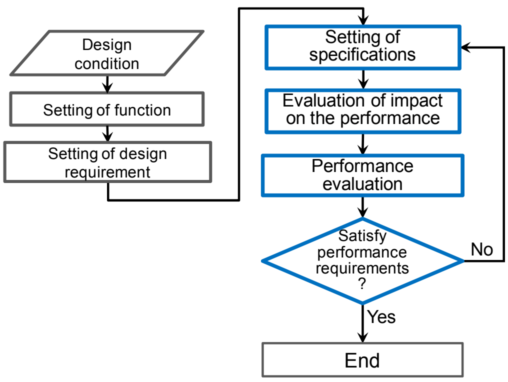

Fig. 8 Design flow of each component of a repository system

II.C. The Design Study by Applying Repository Design System

The aim of the design study is to demonstrate the basis for making a safety case through tailoring the repository system with required functions to a representative SDM by using the Repository Design System discussed in Section III.

Following the procedures developed in the Repository Design System, repository concepts applicable to a given SDM are firstly defined. This process consists of three steps of establishing geometry options, evaluation of applicability and selection of repository concept.

The setting up of geometry options are summarized in Fig. 9.

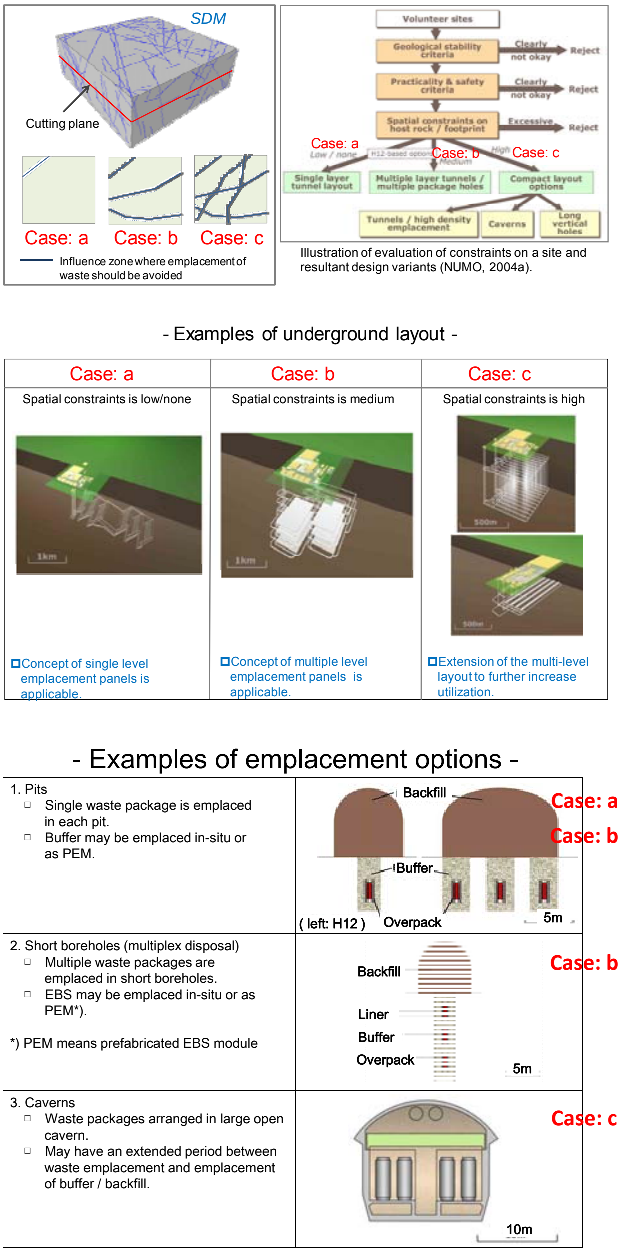

Fig. 9 Definition of repository concept - Setting up of geometry options

Through the evaluation process of volunteer sites, areas with volcanoes and major active faults are excluded from further development of SDM. Geometry options are established by a representative SDM of volunteer sites with identification of density of influence zone where emplacement of waste should be avoided (see Fig.9 top-left). Taking into account the SDM, constraints on a site and resultant design variants are evaluated according the flow shown in Fig. 9 top-right. Examples of underground layout from Repository Concepts Catalogue are illustrated for cases of different levels of site constraints in Fig. 9 middle. A range of emplacement options can also be applied for each case as examples are shown in Fig. 9 bottom.

At this stage of selection of potential repository concept options, evaluation is conducted for specific features of SDM, taking Design Factors into account. Fig. 10 shows an example to discuss of applicability of pit emplacement options to high water conducting feature identified in SDM. In terms of "engineering feasibility and QA" (see Design Factors in Fig. 3), if efficient measures for control of water inflow into pits cannot to be taken and sufficient rock volume not available within the volunteer site, a PEM option is applied.

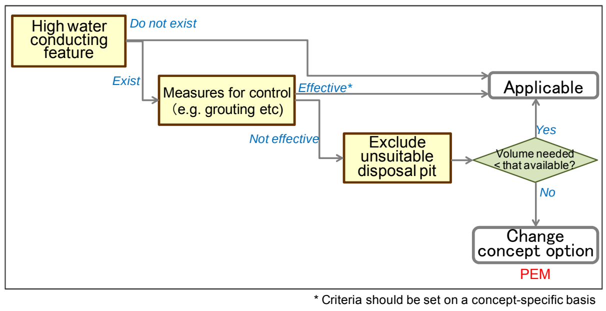

Fig. 10 Evaluation of applicability of pit emplacement options – an example

In current design study, concept options of vertical pit and PEM horizontal emplacements has been selected for HLW disposal, whereas vault emplacement has been for TRU waste disposal that was developed in past study[5] as starting points for structured review of concepts. These concepts are summarized in Fig. 11.

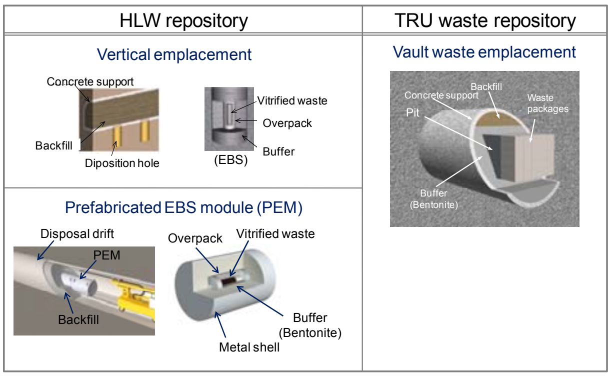

Fig.11 Repository concepts to be considered in design study as a starting point for structured review

For the repository concepts in Fig. 11, following the design flow (see Fig. 8), design requirements and specifications of the EBS, disposal tunnel, panel layout and sealing system (tunnel back-filling and plugs) have been defined consequently. These specifications provide a basis for safety assessment (see companion paper[6]).

As noted in Fig. 4 in section II, a comprehensive approach is applied to define design requirements. For example, ensuring workers safety during construction and operation of a repository, underground atmospheric temperature should be properly limited less than 37°C by the law (Occupational Safety and Health Act). Appropriate configuration of panel layout should be designed for ventilation system efficiently to satisfy the temperature requirement. The long opening of tunnels with high power ventilation would however affect geochemistry in surrounding host rock and such effect should be taken into account to post-closure safety assessment.

High permeable fractures intersecting a disposal pit would make it difficult practically to emplace bentonite blocks in the pit (discussed in next section III.). Grouting by using cementitious material is one of possible countermeasures for this problem, but hyper alkaline plume would also affect long-term performance of bentonite buffer and host rock. Selection of PEM is another solution for this case as shown in Fig. 10.

As mentioned above, conflicts between design requirements such as engineering feasibility and operational safety, and post-closure safety should be traded off carefully in the comprehensive design approach. For this purpose, a multi attribute analysis has been applied with development of practical tools[3].

The EBS should provide safety functions for the long period of time after repository closure. In design of EBS, the long-term evolution of the near field which consists of EBS and surrounding host rock and its effects on the performance requirements for EBS components should therefore be taken into consideration.

Depending on repository concept, various thermal, hydrological, mechanical, and chemical processes including corrosion of overpack, alteration of bentonite buffer by interactions with high alkaline plume from cementitious material used for grouting and tunnel support or overpack corrosion product, bentonite creep and stiffness reduction of concrete support by degradation will occur in the near field. In order to assess impacts of these processes on the performance of EBS components for repository design, more realistic modeling is needed even though reasonable conservatism should be taken into consideration. Such realistic models of near field processes have been developed and applied for design study. Using such realistic models, Saito et al.[7], for example, analyzed mechanical behavior of the near field considering degradation of concrete support, creep of host rock, overpack expansion by corrosion, and creep in bentonite buffer and backfill and indicated that degradation of concrete support greatly affects on the creep of buffer bentonite.

For PEM design, the effects of outer shell on long-term near-field performance should be carefully evaluated. An example specification of PEM has been defined through mechanical and radiation shielding analyses as shown in Table I, assuming practical handling system. Realistic models are under developing for long-term effects of outer shell corrosion (carbon steel) in terms of bentonite alteration with iron[8].

Table I An example design of PEM

・Metal shell: Cylindical, Non-porous, Thickness apprpx. 30 mm
・Size：Diameter approx.2.3 m, Length approx. 3.4 m
・Total weight：Approx. 37 ton
・Surface dose:1.3～2.1μSv/h（After 30-50 years cooling）
・Assembling method: Steel rings

NB: H12 reference EBS design is applied for specifications of overpack and bentonite buffer[9]

An optimum combination of disposal tunnel spacing and waste package pitch are defined so that maximum temperature in bentonite buffer will not exceed allowable value (see Fig. 7), which is conservatively set as 100°C. Therefore the allowable temperature strongly affects panel layout which in turn footprint of a repository. There exist some studies (e.g. Karnland et al.[10]) to indicate that alteration of clay mineral would be critical at higher temperature than 100°C. Here further R&D is very important to define more realistic temperature for mineral alteration.

Design of TRU wastes repository system can follow, in principle, the same approach as described above for

HLW case. However, a more comprehensive Repository Concepts Catalogue has not yet been developed taking various types of waste for which the near field system would be more complex especially in terms of chemical processes. It is a key to conduct the top-down approach through the Repository Design System.

III. DEMONSTRATION STUDY OF REPOSITORY ENGINEERING

The aim of demonstration study of repository engineering is to ensure engineering feasibility and quality assurance of technology used for construction, operation and closure of the repository. Engineering feasibility and quality assurance of technology for construction, operation and closure of the repository presented in the previous sections are described on the basis of experience in relevant facilities.

Concerning engineering feasibility of disposal pit excavation, in Sweden, waterproof sheet was required for emplacement of buffer in a pit (Fig. 12 top). Although this showed engineering feasibility, it clearly indicates major future challenges to assure practicality, especially if all operations are remote-handled.

The excavation of a full-scale disposal pit was demonstrated in soft rock in Horonobe URL (Fig. 12 bottom). In this case, a drier area was selected for pit excavation, but in wetter zones, additional measures such as grouting may be needed, which would further complicate operations.

Comprehensive and rigorous review on practicality should be conducted and impractical options discarded or modified.

PEM concept increases practicality for such problems on emplacement of bentonite block. Applying the designed specification presented in Table I, full-scale demonstration study has been carried out on feasibility of fabrication and handling of PEM (see Fig. 13).

Assuring reversibility and ease of retrieval during repository implementation has been recommended in by a Government Expert Group. For making a safety case, it is therefore needed to demonstrate engineering measures that ensure practicality of retrieval until repository closure.

A demonstration study has been conducted by RWMC on potential technology for retrieving emplaced waste. The retrieval procedure tested was: (1) remove the plug and excavate the backfill in the disposal tunnel, (2) remove the bentonite buffer, and (3) retrieve the overpack. “Over-coring” and “salt-extraction” technologies were considered and the latter demonstrated at full scale. (see Fig. 14).

Fig. 12 Demonstration experiments at Äspö Hard Rock Laboratoryin Sweden[11] (top, crystalline) and Horonobe Underground Research Laboratory in Japan[12] (bottom, sedimentary)

Fig. 13 Demonstration tests for PEM[13]

The key issues identified are how to remove the bentonite buffer without mechanical damage to the overpack. Further issues relating to assuring simple reversibility and maintaining ease of retrieval for longer periods will be also discussed.

"Salt-extraction" by flushing with brine.

The surface of EBS after removing the slurry containing the extracted buffer.

Fig. 14 A full scale demonstration experiment of retrievability technology for a pit disposal concept[14]

IV. CONCLUSIONS

In this paper, development and application of a top-down approach using comprehensive Repository Design System is discussed for tailoring repository concepts to volunteer siting environments, which will be a key part of NUMO safety case project that is ongoing. The basic strategy to develop the System focuses, in particular, to maintain the flexibility in designing a repository for evolving boundary conditions and thereby to increase feasibility in building safety case and its confidence. For this purpose Repository Concepts Catalogue and comprehensive Siting Factors have been applied. Concrete design study based on state-of-the-art scientific knowledge has also been carried out by using the Repository Design System focusing the HLW repository with vertical emplacement and PEM concepts as examples. For TRU waste repository, on the other, as a comprehensive Repository concepts Catalogue has not yet been developed, focused concept for the study is from JAEA and FEPC, 2007.

Linking with design study, various demonstration tests have been conducted to confirm engineering feasibility and quality assurance of repository concepts within and outside Japan. Comprehensive and rigorous review of practicality should be further conducted and impractical options discarded or modified.

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