OVERVIEW OF THE NUMO SATETY CASE AT PRE-SITING STAGE

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Abstract

NUMO has developed a safety case for geological disposal at pre-siting stage in Japan. This safety case provides the multiple lines of arguments and evidence to demonstrate the feasibility and safety of geological disposal, which will encourage stakeholder confidence in the safe implementation of geological disposal and will provide a basic structure for a safety case which will be applicable to any potential site. This paper will provide a brief overview and approach of this safety case, emphasizing practical approaches and methodology which will be applicable for the conditions/constraints during an actual siting process. The geological environments of various potential host rocks are developed as site descriptive models, which are, as realistically as possible, based on the current best understanding of Japanese geology. A rigorous and flexible methodology for tailoring repository design to site descriptive models has been developed. Safety assessment models and data also have been developed and applied for demonstration of the technical basis of the safety assessment.

1. Introduction

1.1 Background

The “H12 Report” (JNC, 1999)[1] published in 1999 by the Japan Nuclear Cycle Development Institute (now the Japan Atomic Energy Agency, “JAEA”) demonstrated the feasibility of safe and technically reliable geological disposal of high level waste (HLW), based on a generic study. On the basis of the H12 Report, the Act on Final Disposal of Designated Radioactive Waste (the Final Disposal Act) came into force and NUMO was established as the implementing body in 2000. Intermediate-level waste generated from reprocessing of spent nuclear fuel and mixed-oxide fuel fabrication (termed “TRU waste” in Japan) was also included in the inventory for disposal in 2007, based on the feasibility demonstrated by the “TRU-2 Report” (JAEA and FEAC, 2007)[2]. These wastes are to be disposed of in stable rock at depths greater than 300 m. NUMO has been developing key technologies required for the safe implementation of the geological disposal project since its establishment and initiated the siting process by open solicitation of volunteer municipalities in 2002. So far, however, no volunteer municipality has appeared and no candidate host rock type has been specified.

The Fukushima-Daiichi NPP accident in 2011 increased nationwide concerns about the feasibility and reliability of safe geological disposal in Japan. After re-thinking the implementation process by advisory expert groups organized by Ministry of Economy, Trade and Industry (METI), “the Basic Policy on the Final Disposal of Specified Radioactive Waste” was amended in 2015, so that the Government leads the search for volunteer sites. This procedure involves nominating more suitable areas from a geo-scientific point of view to initiate discussions and cooperation with local municipalities, finally leading to acceptance of a site investigation, which will be carried out by NUMO.

Under the new Basic Policy, METI and NUMO have enhanced to communicate with the public in order to promote understanding of the HLW management policy, focusing on geological disposal. In parallel, requirements and criteria for nationwide scientific screening has been discussed at the advisory expert groups. The groups have examined the requirements and criteria for geological disposal from the viewpoints of geological environment and its long-term stability, pre-closure safety, safety of the waste transportation, in order to define scientific features with which all areas are classified in a nationwide map. Based on the discussion for about two years, METI published the “Nationwide Map of Scientific Features for Geological Disposal” in July 2017.

In the Map, areas are classified into four categories defined by scientific features with associated criteria[3]. The map does not intend to indicate deterministically specific areas as a candidate site for a geological repository. Stepwise investigations and assessments should be conducted by NUMO, with the acceptance of local communities.

1.2 Purpose of developing the NUMO Safety Case

Publication of the ‘Nationwide Scientific Map of Japan’ would bring a new stage to the siting process and need more convincing explanation of the safety of geological disposal. Taking such changes in boundary conditions into account, it is important at this time for NUMO to integrate required technologies, including the latest R&D output, in order to confirm the feasibility and safety of geological disposal in Japan since the H12 Report, which could be recognized as the first generic safety case in Japan. Thus NUMO has developed the safety case at the pre-siting stage, which, with the site descriptive models (SDMs) recently developed, provides a more advanced site-specific basis than the generic safety case in the H12 Report. This has been developed in a manner that will allow it to provide the basic structure of future safety cases that would be applicable to any site that might arise from the site selection process.

This paper provides a brief overview and the approach for development of the NUMO Safety Case. More detailed discussions are presented in a series of associated papers[4-8] in this conference.

2. Premises of developing the NUMO Safety Case

2.1 Boundary conditions and basic approach

NUMO has developed the Safety Case considering the current constraints that include legal requirements and the current situation of Japanese disposal program, i.e. candidate sites have not been specified yet, safety regulations are still under development, as well as the basic policies mentioned above.

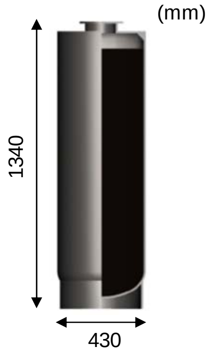
Despite the fact that there has not been a site and specific host rock identified, the NUMO Safety Case has developed detailed geological and hydrogeological models for potential host rock environments, which are based on field data accumulated since the H12 Report and current best understanding of geological environments in Japan. Repository design and safety assessment have been thus performed for these geological models, thereby providing underpinning evidence to demonstrate the technical feasibility and the safety for the various types of Japanese geological environments.

2.2 Features of radioactive waste

The highly radioactive liquid residue separated in the reprocessing of spent fuel is mixed with glass in a glass melter, poured into stainless steel canisters and cooled to form vitrified HLW. Vitrified waste produced by Japan Nuclear Fuel Limited (JNFL) will be responsible for most of the HLW inventory. In this safety case, the specification of the reference waste form shown in Fig.1.

TRU waste includes spent silver absorbent, compressed hull and end pieces, etc. generated as a result of the reprocessing of spent fuel at JAEA and JNFL. They are grouped according to their features as shown in Fig.1. Group 1 includes highly soluble, little sorptive I-129, group 2 also includes highly soluble, little sorptive C-14, group 2 and some of group 4 (group 4H) have significant heat output and group 3 contains nitrate, which may need special consideration in terms of potential chemical perturbations. Specifications of some waste are still being studied in order to improve safety, and therefore have not been fixed yet.

It is currently difficult to estimate the total generation of radioactive waste to be disposed of by geological disposal, because such numbers depend on future nuclear power policies. Therefore, in the Safety Case at this stage, a repository with capacity

HLW (Vitrified waste)

• Weight : 500 kg • Thickness of canister : 6 mm • Number of canisters : 2448 (as of Apr 2017) • Calorific power : 350 W • Surface dose : 160 Sv/h (50 years after production)

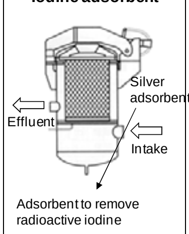
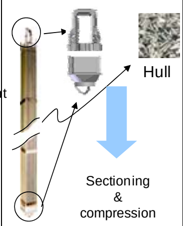
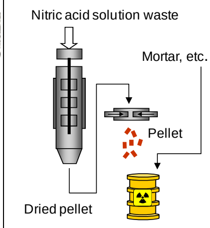
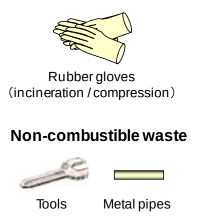
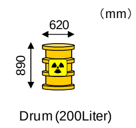
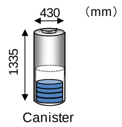
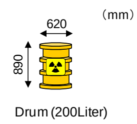
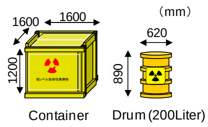
TRU waste Group	1	2	3	4	
				Low	High
Description	**Iodine adsorbent** 	**Hull & endpieces** 	**Concentrated solution, etc.** 	**Organic waste** / **Non-combustible waste** 	
Waste package image (e.g.)					
Features	• Radioactive iodine (I-129) is included • Cemented waste form	• Relatively high heat power • Radioactive carbon (C-14) is included	• Nitrate is contained • Solidified waste with e.g., mother or bitumen	• Incineration ash or non-combustibles • Solidified waste with cement, etc.	
Volume	319 [m³]	5,792 [m³]	5,228 [m³]	5,436 [m³]	1,309[m³]
Calorific power (at time of production)	1 [W/package]	90 [W/package]	1 [W/package]	16 [W/package]	210 [W/package]

Fig. 1. HLW and TRU waste groups and their characteristics

for the following volume of waste was assumed, based on the latest "Disposal Plan for Final Disposal of Specified Radioactive Waste" by METI in 2008:

- HLW: 40,000 canisters of vitrified waste (disposal of 1,000 canister per year)
- TRU waste: 19,000 m^3

In the NUMO Safety Case, co-disposal of HLW and TRU waste is considered.

2.3 Safety functions of repository

In the pre-closure phase, the repository has to ensure the safety of both the local population and workers against both radiation risks and other industrial hazards. The safety functions related to radiation protection during the pre-closure phase are the main focus here. With regard to industrial safety of workers, the repository needs to have safety functions to prevent accidents and establish a healthy working environment during the period up to final closure of the facility.

After closure, the repository will perform its isolation and containment roles based on the safety functions. In terms of isolation, the assurance of protection from geological perturbations is particularly important in Japan due to its location relative to active tectonic plates, which results in significant potential for volcanism, fault movement and uplift/erosion at some locations. In addition, the geological environment should contribute to reduction of the risk of anthropogenic perturbations – predominantly by excluding areas containing mineral resources that might be exploited in the future. These safety functions related to isolation are a role of the geological environment, which will be verified through investigation and evaluation during site characterization.

3. Safety strategy and approach for developing the NUMO Safety Case at pre-siting stage

3.1 Site characterization and synthesis into SDM

(1) Site selection concept

After nominating investigation sites with acceptance of local municipalities, the stepwise site selection process (Fig.2) will be conducted aiming at acquiring information on geological environments in and around the proposed sites in order to develop repository designs and associated safety assessments that verify the proposed sites possess the required safety functions.

Geological disposal has to consider that key properties are determined by attributes of a site that extend over large areas and depths and which are inherently heterogeneous on all scales. Characterization of such environments needs to consider all relevant scales, although the level of detail required is different, being greatest for the volume of rock containing the repository and the most safety-critical parts of the geological barrier. The key features of the geosphere and their spatial extent are determined from the output of the associated safety assessment.

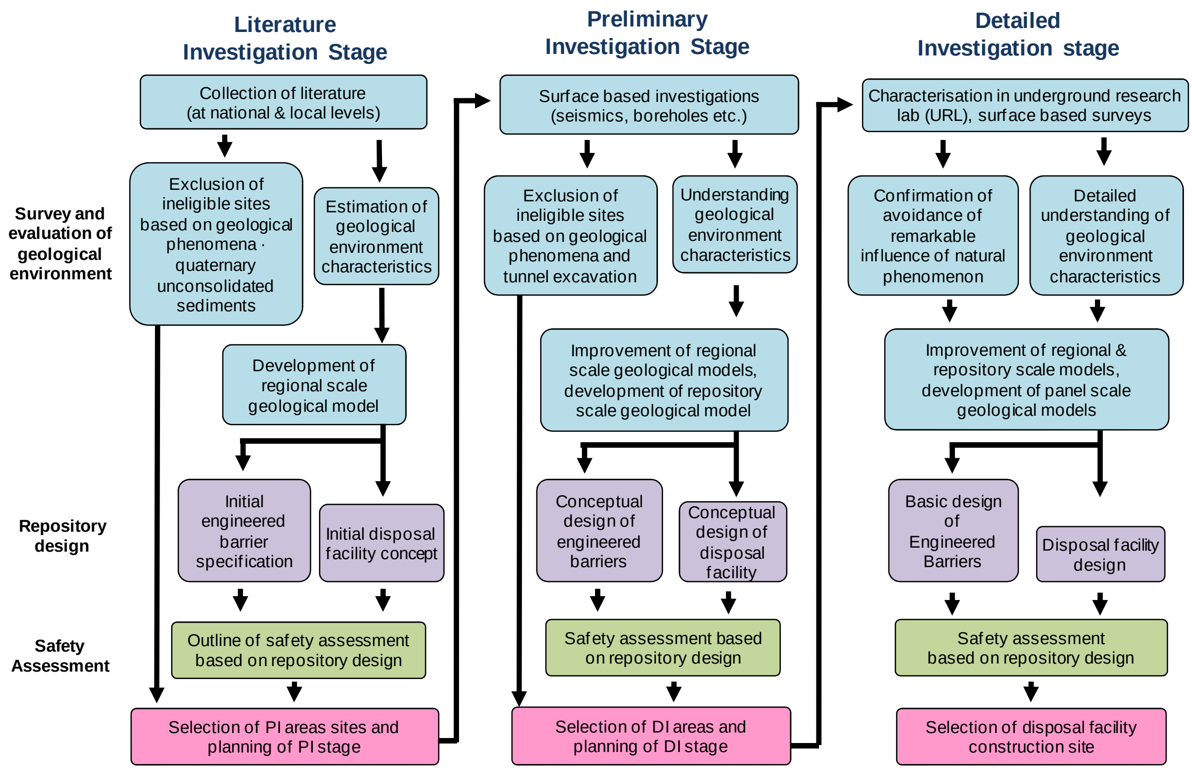


Fig. 2. Site selection stages on the way to implementation

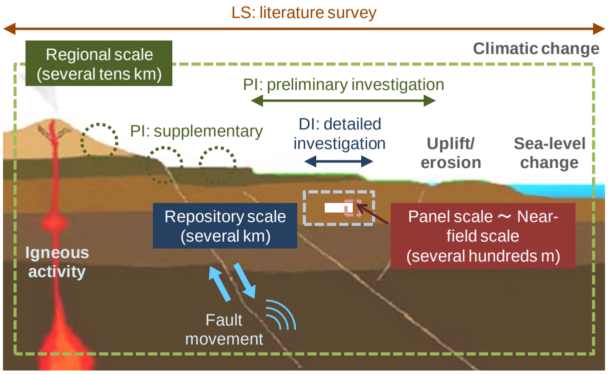


Fig. 3. Components of the three stages of site investigation and scales of SDMs

The information is synthesized into a site descriptive model (SDM). The SDM is the basis of the design of the repository and the safety assessment. Fig.3 shows the relationship between the ranges of the three investigation phases and scales of SDM. SDMs are developed in three spatial scales; regional scale (tens of km x tens of km), repository scale (several km x several km), panel and near-field scale (several hundred meters x several hundred meters). These nested models assure consistency of THMC conditions within and between them, with a level of detail of geological information appropriate to the investigation phases considered, the investigation technology availability, the features of the analytical models, the capabilities of calculation codes, etc.

(2) Approach to site assessment in the NUMO Safety Case

Generic repository design and safety assessment were performed in the H12 and TRU-2 Report for two illustrative geological settings, namely crystalline rock and sedimentary rock. However, geoscientific knowledge has expanded significantly since then due in particular to multidisciplinary research programs; for example, JAEA's underground research laboratory projects. It is thus important to update the previous repository design and safety assessment on the basis of the current best understanding of Japanese geological environments.

In the absence of candidate sites, establishing the basis for demonstration of the capacity to model relevant geological environments at a level appropriate for site selection is based on:

- presentation of a concept for stepwise site characterization along with demonstration of the technology for interpretation and integration of expected output to form the basis for design and safety assessment;
- preparation for the literature study, based on a compilation of geological information on a nationwide scale, involving selection of geological environments that are potentially suitable and can be used for repository design and safety assessment;
- for each candidate host rock, defining a representative geological setting that includes all key features (e.g. faults, fractures and sedimentary structures, etc.) that are required for realistically assessing its advantages and disadvantages as a repository site.

Following the categorization of all potential host rock environments in Japan, rock types are grouped by identifying key characteristics/properties relevant to geological disposal. As a result, three types of potential host rock environments, 'Igneous rocks', 'Neogene sedimentary rocks', and 'Pre-Neogene sedimentary rocks' are examined in the NUMO Safety Case[4].

3.2 Repository design and engineering

(1) Repository design strategy

In a repository design, the specifications of the repository (engineered barriers, surface facilities, underground layout, etc.) are determined so that the safety functions of the repository are assured for the defined SDM. The repository specifications are established based on geological environment information obtained in each investigation phase together with the technological knowledge base available at that time, subject to constraints such as assuring engineering feasibility. The repository will thus be designed in detail and optimized in a stepwise manner, based on the progress of site investigation and input from associated safety assessment. Therefore, NUMO has developed the methodology shown below so that the repository can be designed with required flexibility:

- incorporating multiple requirements as design factors so that the repository can be designed in a consistent manner, responding to policy developed in the stepwise site selection process;
- repository design options will emphasise flexibility in terms of ability to be tailored to the variety of geological environments expected and to respond to the progress of science and technology during the long implementation period.

The term design factors denotes the features and capability that the repository design may be required to have, e.g. long-term post-closure safety, pre-closure safety, engineering feasibility, retrievability and economic efficiency.

(2) Approach adopted in the NUMO Safety Case for repository design and engineering feasibility

As the conditions of the geological environment cannot be specified in detail before candidate sites come forward, demonstration of repository design involves the following[5]:

- Starting from the repository concept developed in the H12 and TRU-2 Report, repository design specifications tailored to the SDMs of three types potential host rock environments are illustrated, which meet pre- and post-closure safety requirements and demonstrate engineering feasibility;
- Specific features of SDMs, such as major fault zones, are specifically assessed to determine their impacts on different disposal concepts; Based on this, determine whether specific SDMs are compatible with developing practical designs with required safety functions;
- Assess the specifications for specific repository designs to determine if implementation is feasible using existing engineering technology or that is reasonably expected to be developed in the future.

3.3 Pre-closure Safety Assessment

(1) Pre-closure safety strategy

Evaluation of radiological safety is generally based on regulations that govern reactors and other nuclear facilities. Since the accident at Fukushima Dai-ichi NPP, such regulations have been under review and this has resulted in new waste management requirements that will apply to a geological repository, although these have not been formulated as yet.

Pre-closure safety assessment considers not only the expected operations, but also the impact of perturbations due either to operational disturbances (e.g. equipment failure) or external events (earthquakes, tsunami, flooding, etc.). Credible scenarios for such perturbations must be developed, their potential consequences assessed and where appropriate, potential counter-measures introduced. Many of the perturbations depend on the geological and geographical setting of the site and cannot be assessed in detail in a generic manner. Nevertheless, the potential for reducing impacts via engineering counter-measures can be illustrated. For other perturbations, counter-measures developed for other nuclear facilities can be referred. Even though the scenarios are not described in detail, for illustrative purposes, the impacts of some “worst case” accidents are assessed in order to determine safety levels and develop approaches to reduce risks.

(2) Approach adopted in the NUMO Safety Case for pre-closure safety evaluation

At present, criteria for geological disposal facilities in relation to the program licensing rule have not been formulated. Further, in the absence of a specific disposal site, the extent to which the surface environmental conditions in which the facility will be constructed is very limited. This in turn constrains sensible evaluation of the impact of site-specific external perturbations such as earthquakes or tsunami. On the other hand, evaluation of safety is possible for maximum design base accidents. Therefore, the NUMO Safety Case at this stage will[6]:

- illustrate the concepts and methodology for radiation safety assessment for both workers and local residents around the facility, focusing on vulnerable transportation and operational processes and with reference to the safety regulations for other relevant nuclear facilities;
- present results of the illustrative pre-closure safety assessment, while verifying the compatibility of potential counter-measures to reduce risks with long-term post closure safety of the repository.

3.4 Post-closure Safety Assessment

(1) Post-closure safety strategy

For long-term post-closure safety assessment, the methodology used internationally has been evaluated. For the repository designs tailored to geological environments at selected sites, such assessments will define representative scenarios to evaluate the radiological impact on the surrounding populace, with full consideration of all uncertainties involved. Such analysis should confirm that the repository meets safety standards and will not have a significant impact on the living environment at any time in the future.

NUMO has been involved in technology development related to fundamental components of the safety assessment: scenario development, modeling and development of a dataset. With a view to subsequent site selection, the preparation of this safety assessment methodology and confirmation of its applicability is necessary. Preparation of an appropriate safety assessment analysis toolkit is especially important to allow objective comparison and evaluation of the performance of alternative disposal concepts, where the methodology must also handle different uncertainties in terms of site conditions and repository specifications.

(2) Approach adopted in the NUMO Safety Case for post-closure safety assessment

The framework of safety assessment (scenarios to be considered, time frame of the safety assessment, radiological standards, etc.) is to be presented by the regulatory bodies. Until then, the safety assessment will be conducted based on a temporary framework of dose standards defined in relation to international guidelines, such as the ICRP recommendations[9].

Scenarios that include events that lead to the loss of the isolation function or a significant reduction of the containment function may not need to be considered if an appropriate site is selected, while the scenarios leading to radiation exposure via groundwater flow are the main focus of the assessment. In handling scenarios with significantly different occurrence probabilities, the risk-informed approach explicitly takes into account not only the consequence but also the likelihood of occurrence.

Based on the above, the Safety Case at this stage assesses post-closure safety involving[7]:

- a framework for safety assessment set on the basis of international guidelines and other considerations;
- a risk-informed approach, introduced in order to appropriately deal with various kinds of uncertainties;
- the safety assessment analysis method is developed in order to allow the objective comparison and evaluation of performance of different repositories, reflecting differences in geological environmental conditions and repository designs;
- the post-closure long-term safety will be assessed for the SDMs developed and the repository designs tailored to them;

It should be noted that, in the absence of a specific site, there are constraints on the extent to which site-specific natural perturbations can be taken into account in the safety assessment. Therefore, such site-specific issues will be dealt with conservatively, based on expert opinion.

4. Conclusions and a look to the future

This paper describes the overview, safety strategy and approach for development of the NUMO Safety Case considering the current boundary conditions, including general purposes and context. In the NUMO Safety Case, the geological environments of various types of potential host rock are being developed as SDMs, which have been developed as realistically as possible based on the current best understanding of Japanese geological environments. A practical methodology for tailoring repository design to volunteer siting environments and advanced safety assessment models and data have been developed and applied for demonstration of technical basis. The preliminary results of the design and safety assessment would underpin the feasibility and safety of geological disposal in Japan. NUMO and relevant R&D organizations have started discussion on the next mid-term R&D plan for geological disposal in Japan, based on the technological issues extracted through the development of this Safety Case. The NUMO Safety Case will form a significant step on the pathway towards repository implementation.

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