Report of the Special Review Committee on the NUMO safety case

December, 2019

Special Review Committee on the NUMO Safety Case

Atomic Energy Society of Japan

Executive Summary

The Nuclear Waste Management Organization of Japan (NUMO) has prepared the NUMO Safety Case, entitled "Realization of safe geological disposal of high-level radioactive waste and TRU waste in Japan - development of a safety case for the selection of an appropriate site" (hereafter the Safety Case). The purpose of the Safety Case is to explain how to realize safe geological disposal of high-level radioactive waste and TRU waste, reflecting the latest scientific knowledge and technical developments.

NUMO requested the Atomic Energy Society of Japan (AESJ) to review the Safety Case, with the objective of checking the feasibility of such a Safety Case at a stage where no site has been specified, within the context of the latest scientific and technological knowledge and developments in Japan and overseas, and also from the viewpoint of objectivity, scientific and technical validity, and technical reliability.

The NUMO Safety Case, with readers assumed to be experts with some technical understanding of geological disposal, is a report of a highly specialized nature. The reports making up the Safety Case have been developed as a hierarchical group of documents that vary in detail from the upper-level main report to the lower-level supporting reports, with a traceability that allows experts in various fields to select the information and the level of detail by themselves. The documents consist of an overview report, a main report and supporting reports. Referring to the role and basic structure of a safety case as outlined by international organizations, the descriptions in the reports provide the framework for a safety case that will be updated in the future, along with the information bases. This basic form of safety case will be prepared at each stage when potential sites for geological disposal are being narrowed down and finally the site for the geological repository is approved.

In collaboration with the Division of the Nuclear Fuel Cycle and the Environment, the AESJ established a review group - the Special Review Committee on the NUMO Safety Case (hereafter the Review Committee) – consisting of 14 members. The Review Committee engaged in comprehensive discussions from December 2018 to December 2019. These discussions related to issues of scientific and technical reliability in the context of a generic safety case at a stage where no site has been specified, as well as the technical capabilities and methodologies required by NUMO for site characterization, engineering design, and safety assessment to allow appropriate steps to be taken for future site selection.

The overall findings of the Review Committee on the NUMO Safety Case are as follows:

Compiling a structured NUMO Safety Case

- The NUMO Safety Case describes the information bases underpinning the safety case framework as the starting-point for a safety case to be updated at each stage of the disposal project; these will then provide the basic framework for the safety case after a site has been identified.

- The Review Committee agrees to the compilation of the NUMO Safety Case in line with the structure proposed internationally by the OECD/NEA and IAEA. On the other hand, since it may be difficult to understand the concept of a safety case for readers other than experts in geological disposal, the Review Committee suggested explaining clearly why such a structure is desirable.
- The position, objectives, and assumed readership of the NUMO Safety Case is appropriate.

Basic concept for ensuring safety

- For the basic concept for ensuring safety, the approaches for selection and modeling of the geological environment, for repository design and engineering technology and for safety assessment have been identified as key elements for the upper level of the safety case. It is important to ensure consistency in the context in the NUMO Safety Case.
- In an interdisciplinary field such as geological disposal, collaboration is essential for managing the entire spectrum of technical aspects. For the NUMO Safety Case, a basic management philosophy has been established to ensure close collaboration between the fields of site characterization/evaluation, repository design and safety assessment.
- The Review Committee places a high value on ensuring that the basic concept for ensuring safety is appropriate in terms of consistency with international approaches for safety case development, as well as being designed according to the specific situation in Japan. In particular, the NUMO Safety Case discusses the characteristics of the geological environment of the Japanese archipelago, which is located in a tectonically active zone, from the viewpoint of the basic concept for geological disposal and safety functions, and, on this basis, develops the basic concept for ensuring overall safety. The Review Committee considers it highly important that this study should provide the motivation for moving the geological disposal project one step forward, with the timely presentation by the Government of the "Nationwide map of scientific features for geological disposal".

Scientific-technological basis underpinning the Safety Case

① Selection and modeling of geological environments with characteristics suitable for geological disposal

- Based on the results of compiling a wide range of data on the geological environment, the various geological environments in Japan were categorized specifically from the viewpoint of geological disposal. In addition, site descriptive models of the three types of host rocks to be studied were developed, and the procedure for constructing these models was outlined. The Review Committee can thus confirm that progress has been made since the H12 Report when no site was specified.

- Based on the latest scientific knowledge and the results of categorizing the geological environments of Japan, a basic approach for site selection and investigation/evaluation technologies was systematically developed. An approach that allows the information on the geological environment to be interpreted stepwise in the future and to be integrated into site characterization models of the potential host rocks was shown to be sufficient for the requirements for repository design and safety assessment. The Review Committee places a high value on providing the technical basis for supporting site selection in the future.

- The Review Committee agrees that the NUMO Safety Case addresses the need for future data compilation for sedimentary rocks that contain carbonate / organic material, particularly Pre-Neogene sedimentary rocks (accretionary sedimentary rocks) for which there is currently little information.

② Design of the disposal facility and engineering technology

- Based on the site descriptive model, the methods and procedures for designing, constructing, operating and closing the repository (engineered barriers, surface facilities, underground facilities) which satisfy the design factors are described concretely and in sufficient detail.

- Although uncertainties are unavoidable in engineering design, the Review Committee suggests that, in addition to the uncertainties associated with information/data on the material properties for the geological environment characteristics and engineered barriers depicted by the site descriptive model, uncertainties associated with the boundary conditions and the resulting design specifications should be considered.

- During repository operation, there is a high level of concern for safety of the nuclear facility. Therefore, the NUMO Safety Case addresses safety before repository closure (operational phase) in an independent chapter (Chapter 5). On the other hand, because the considerations are largely site-dependent, key scenarios were developed only for internal initiating events without considering external initiating events. To ensure the completeness of the safety assessment scenarios, the Review Committee recommends also considering externally initiated events.

③ Long-term post-closure safety assessment

- The approach for long-term post-closure safety assessment is consistent with international guidelines and methodologies applied in other countries and is reasonable as an approach that quantitatively demonstrates safety in a situation where no specific site has been identified. The Review Committee considers it particularly important that a site-specific evaluation based on detailed site-specific information should be underpinned by a generic evaluation demonstrating the technical feasibility of geological disposal, in preparation for developing a safety assessment technology based on a more realistic consideration of the geological environment and disposal system characteristics in Japan.

- From the viewpoint of improving the reliability of safety assessment, there is still room for improvement regarding the following points:
  - Clarification of the positioning, role, and relationships of the series of tools and analysis methods (e.g. storyboards, FEPs, attribute analyses, etc.) used for scenario development.
  - Reinforcement of quality assurance for mathematical models, codes, data and analyses related to nuclide migration processes.
  - Demonstration that uncertainties to be evaluated in the safety assessment have been considered sufficiently comprehensively.
  - Specification of the relevance of evaluating possible perturbations of the underground environment before closure, retrievability, and abnormal events during construction and operation.
  - Discussion of differences by comparing safety assessment results with previous results.

Progress since the H12 and Second TRU Reports

- The Japanese archipelago is located in a tectonically active region, and various geological environments with faults and fractures are expected. Against this background, the geological environment was categorized based on the results of compiling information on a wide range of geological data. The technology for developing typical site descriptive models that would provide the basis for assessing the design and safety assessment of the repository was presented. The Review Committee recognizes that these are significant developments since the H12 Report at a stage where no site had been identified.
- A horizontal prefabricated emplacement module (PEM) emplacement method for vitrified waste was introduced as an alternative to the vertical bentonite block method. In addition, enhanced "B-type" packages were introduced for wastes such as TRU. Alternatives such as optimization of overpack thickness were also presented. The Review Committee therefore agrees to an approach that considers alternatives in parallel while leaving flexibility for future decisions.
- The Review Committee finds that significant progress has been made regarding the following aspects of long-term post-closure safety assessment.
  - Adoption of a risk-based approach based on a disaggregated dose/probability approach. This includes assessment of the probability of scenario occurrence and, in developing scenarios, adopting an integrated method that combines a bottom-up approach using FEPs and a top-down approach based on safety functions.

- Development of a safety assessment system considering co-disposal of vitrified waste and TRU waste.
- Development of a nuclide migration analysis model that can consider the effects of multiple faults and fractures in the site descriptive model and the layout of the disposal facility in a more realistic manner.
- Assessment of the biosphere using the latest data and dose conversion factors.

Reliability of the Safety Case

- The required quality of a basic safety case that will be updated as the site selection process progresses was confirmed from the following viewpoints:
  - The NUMO Safety Case is consistent in context and structured in such a way as to properly guide the general conclusions of the Safety Case.
  - The NUMO Safety Case considers the geological characteristics and social conditions of Japan and considers all aspects that are important for a safety case as required at the present stage.
  - The NUMO Safety Case is consistent with basic Japanese policy on final disposal, referring to international standards and similar experience in foreign countries.
  - The NUMO Safety Case uses technical terms in Japanese which are consistent with international definitions and can be understood by geological disposal experts.
  - The main conclusions of the NUMO Safety Case are presented clearly and, regarding the multifaceted reasoning that led to the conclusions, traceability and objectivity are generally ensured based on the supporting reports.
  - The NUMO Safety Case makes a clear distinction between generic issues that do not depend on the site and site-specific considerations, and more site-specific research and development to be carried out in the future.
- After confirming the above, the Review Committee agrees that the NUMO Safety Case considers various site environmental conditions and is reliable as a safety case at the current stage, and consequently is valid as a basic structure for a safety case after identification of a site. In addition, and considering the gradual improvement in reliability as the safety case develops, the Review Committee acknowledges that the topics for research and development up to the next stage are adequately described from the perspective of long-term R&D activities.

The Review Committee expects that their review will contribute to improving the scientific and technical reliability of the NUMO Safety Case and will promote confidence in the reliability of NUMO in discussions on geological disposal.

Content

1. Introduction

1.1 Background to the review

On November 21st 2018, The Nuclear Waste Management Organization of Japan (NUMO) announced the publication of its Safety Case entitled “Realization of safe geological disposal in Japan - development of a safety case for the selection of an appropriate site” (hereafter the NUMO Safety Case). The Safety Case demonstrates how to realize safe geological disposal of high-level radioactive waste and TRU waste, reflecting the latest scientific knowledge and technical development results.

For the smooth promotion of the geological disposal project by NUMO, the Safety Case aims to show comprehensively how the investigation of a site would proceed after acceptance by a local community of the start of a literature survey, how the design, construction, and operation of a safe repository would be implemented, and how long-term safety after closure would be assured, in order to demonstrate that technical preparations are in place to respond to the results of the literature survey.

To achieve this goal, it is important that the safety case report is reviewed by an independent academic third-party. Therefore, NUMO requested the Atomic Energy Society of Japan (AESJ) to review the documentation. The objective is to check feasibility as a safety case at a stage where no site has been specified, from the viewpoint of the latest scientific and technological developments in Japan and overseas, and from viewpoint of objectivity, scientific and technical validity, and technical reliability. With the support of the Division of the Nuclear Fuel Cycle and the Environment, AESJ established a review group - the Special Review Committee on the NUMO Safety Case (hereafter the Review Committee) – consisting of 14 members. The names and affiliations of the committee members can be found in the Appendix. The members consist of five experts in geology, four experts in engineering, and four experts in safety assessment. The chairman is an expert familiar with research and development in the field of geological disposal. The Nuclear Safety Research Association (NSRA) provided the secretariat at the request of AESJ.

1.2 The NUMO Safety Case

In Japan, the “Specified Radioactive Waste Final Disposal Act” (the “Final Disposal Act”) was enacted in 2000, based on the proposal for implementation of geological disposal presented in the report "Basic concept for disposal of high-level radioactive waste", formulated in 1998 by the Special Committee on High-Level Radioactive Waste Disposal, the Japan Atomic Energy Commission and also in the report, “Technical reliability of geological disposal of high-level radioactive waste in Japan - the second progress report on research and development on geological disposal”, prepared in 1999 by the Japan Nuclear Cycle Development Institute (hereafter the H12 Report).

Based on the Final Disposal Act, NUMO was established in 2000 as the implementation body for the geological disposal project. The Final Disposal Act stipulates that the repository site should be selected in

a three-stage process consisting of literature surveys, preliminary investigations, and detailed investigations. From 2002, NUMO started an open solicitation procedure for municipalities nationwide with a view to investigating the feasibility of sites for construction of geological disposal facilities, but no local government has applied to date. A literature survey, the first step in site selection, has not yet been initiated.

For this reason, in 2013 discussions were carried out with a view to restructuring geological disposal policy in order to revise the direction that should be followed for promoting the geological disposal project. In May 2015, the "Basic Policy on Final Disposal of Specified Radioactive Waste" was approved by the Cabinet. In the revised basic policy, the following matters were clarified:

- Not passing on the burden of waste disposal to future generations.
- Ensuring reversibility of the project and retrievability of the waste.
- Periodically evaluating the technical reliability of final disposal with collaboration of the national government, NUMO, and related research institutes.
- The national government should request local governments to cooperate in the literature survey, while indicating areas that are considered scientifically relevant (scientifically favorable areas).

In 2017, to increase public interest and understanding of geological disposal, the government presented a "Nationwide map of scientific features for geological disposal" based on nationwide data. This map aims to provide an overview of the characteristics that need to be considered when selecting a site for geological disposal and how these features are distributed throughout Japan.

In promoting the activities for selecting sites for geological disposal based on the "Nationwide map of scientific features for geological disposal", it is important for NUMO to show the public how safe geological disposal can be realized and to gain the confidence of the public in geological disposal projects, based on the latest scientific and technological knowledge, in addition to knowledge accumulated to date. Accordingly, NUMO, as the implementing organization for geological disposal, has compiled the NUMO Safety Case aimed at showing the latest scientific knowledge and technological developments and explaining methods for realizing safe geological disposal for the specific geological environment of Japan. Referring to the role and basic structure of safety cases presented by international organizations, the framework of the NUMO Safety Case will be described; this will be updated in the future when locations for geological disposal have been narrowed down and, finally, the site for the repository is approved. The objective of the NUMO Safety Case is to present a generic safety case for the Japanese situation (no repository site identified), based on current knowledge, addressing the following matters:

① The technical basis exists for the investigations and assessments aimed at selecting suitable geological environments for geological disposal. Also, site descriptive models which reflect the characteristics of the deep geological environment of Japan are presented.
② The technical basis exists for designing a repository which satisfies the necessary requirements (safety, engineering feasibility, retrievability, environmental conservation, economic feasibility, etc.). Engineering technology also exists for constructing, operating and closing the repository.
③ The technical basis exists for evaluating operational safety prior to closure of the repository as well as long-term safety after closure. Moreover, the repository safety assessment should confirm that there is no significant radiological impact on humans.
④ Through a series of studies applying the latest technologies in the areas of investigating and evaluating the geological environment, repository design and safety assessment, technical measures are identified for further improving the reliability and future action plans for these areas.

The NUMO Safety Case, which assumes a readership of experts with some technical knowledge about geological disposal, is a highly specialized technical report. It has been developed as a hierarchical group of documents with the level of detail increasing from the main report/overview report to the supporting reports, with traceability that allows experts in various fields to select the information and the level of detail by themselves. The overview report summarizes the key points of the main report. The main report is the central document of the NUMO Safety Case and gives an overview of how safe geological disposal can be realized. The supporting reports provide the detailed rationale as well as the analysis methods and results supporting the content of the main report.
It should be noted that "review version" is included in the title of the released NUMO Safety Case report because it is intended for review in terms of technical reliability by domestic and independent overseas organizations. NUMO will then revise the report as required depending on the review comments.

1.3 Scope, objectives and review process

The scope of the review covered only the “main report” of the NUMO Safety Case. It should be noted, however, that the reviewers also referred to the supporting reports where necessary. It should also be noted that not only the supporting reports published at the time of the review but also supporting reports to be published later should be reviewed.

The objective of this review is to check the technical reliability of the NUMO Safety Case for a stage in the program when no site has been specified and to determine whether it reflects the latest technical knowledge in Japan and overseas focusing on the safety case concept presented by the OECD/NEA and the IAEA, which will support the basis for site selection for geological disposal in Japan.

The review process is as follows: Each member of the Review Committee reads through the NUMO Safety Case and expresses their views from the following provisional viewpoints, considering the characteristics and the situation of Japan and referring to the TOR (Terms Of Reference) [1, 2, 3] for reviews of safety

cases in other countries and guidelines for international peer reviews [4]. Based on this, the issues of the Committee members are compiled and reviewed to formulate the overall Committee review. The viewpoints for review are as follows:

Viewpoint 1: Validity of the entire Safety Case

- Is the structure and logic of the "basic concept for ensuring safety (Chapter 2)" applied to achieve safe disposal in the NUMO Safety Case valid as a higher-level approach? Based on this, a detailed discussion is developed on the scientific and technological bases underpinning the Safety Case in separate chapters (Chapter 3 to Chapter 6); these are summarized in Chapter 7 as general conclusions and future tasks. Based on this, can the reliability of the present NUMO Safety Case be confirmed?
- Are there any omissions in the NUMO Safety Case, considering the items that are required for a generic safety case?
- Is the intention behind preparing the NUMO Safety Case consistent with the national basic policy on final disposal?
- Are the multifaceted arguments leading to the main conclusions of the NUMO Safety Case adequately presented in the main report? Are they sufficiently traceable, transparent, and objective?
- Are the remaining major uncertainties clearly stated, as well as how they will be handled in future research and development?
- Is consistency maintained with international standards and good practices of other countries?
- Is the technical terminology consistent with international definitions and are the Japanese descriptions such that their meaning can be correctly understood?
- Are the progress and differences from the H12 Report and the Second TRU Report evaluated and clearly stated for the stage where no site has been identified?

Viewpoint 2: Validity of the scientific-technological basis underpinning the safety case

(Selection of a suitable geological environment)

- Are the selection and modeling of suitable geological environments conducted according to the approach defined in the basic concept for ensuring safety?

- Have the site selection procedure and policy been identified? Has the applicability of the geological environment investigation and evaluation technologies been confirmed? Are they technically feasible?
- Is the selection and modeling of the geological environment applicable to a range of geological environments in Japan?
- Does the developed site descriptive model provide the information necessary for the design and safety assessment of the repository?

(Repository design and engineering technology)

- Has the repository design and engineering technology been formulated according to the approach defined in the basic concept for ensuring safety?
- Is the designed disposal system technically feasible considering the site descriptive model and the characteristics of the waste?
- Are the methods for design, construction, operation and closure of the repository technically proven or an extension of proven technology, and are they technically feasible?
- Has waste retrieval technology been properly examined and its feasibility demonstrated? Have research and development activities for improving feasibility been properly presented?

(Safety assessment)

- Is the safety assessment conducted according to the approach defined in the basic concept for ensuring safety?
- Is the basis for setting the post-closure safety assessment framework (scenario classification, evaluation period, human intrusion, etc.) consistent with international standards?
- Are the post-closure safety assessment models developed appropriately according to the site descriptive model?
- Are the safety functions of the individual barriers of the disposal system described appropriately considering the timescales involved? Are the priorities expected for each barrier considered?
- Are the scenarios and analysis cases assumed in the safety assessment sufficiently comprehensive?
- Are the safety assessment methodology, models and codes appropriate? Is there a scientific basis to support them?
- Are the features, events and processes (FEPs) affecting the evolution of the disposal system clearly documented? Is this sufficiently comprehensive compared to the international FEP database?

- Does the operational safety assessment consider the safety regulations applied to other nuclear facilities and similar underground facilities (mines, tunnels, etc.)?
- Is the influence of retrievability on operational and post-closure safety being assessed?

The review process was as follows:

① The 1st Review Committee meeting was held on December 27, 2018 to confirm how to proceed with the review. Following an explanation by NUMO of the structure of the NUMO Safety Case, the Review Committee discussed priority issues and the main aspects of the review and assigned a review scope to each member.

② Each member prepared comments and questions for each chapter of the NUMO Safety Case. The comments amounted to about 700 sheets in all, and the secretariat compiled these comments and questions as a table and classified the comments for each chapter of the NUMO Safety Case.

③ The responses of NUMO to the members' questions were fed back to the Review Committee. The Review Committee asked NUMO for supplementary explanations if needed. In the review, related attached documents and references were referred to as appropriate. It should be noted that, since the NUMO Safety Case is a highly technical document, aspects of social acceptability, such as whether the report is acceptable to municipalities or how the content should be communicated to the general public, were excluded from the review.

④ For compiling the consolidated opinion of the Review Committee, issues were extracted from the comments presented by each member, supplementary explanations of NUMO, and discussions in the Review Committee, and a draft overview of the aggregated opinions was prepared for each issue. These approaches and draft overviews were also presented and discussed in the Review Committee as appropriate. NUMO was asked to participate in the discussion only to correct misunderstandings of the Committee, in a way that did not compromise the neutrality of the review.

⑤ Regarding Chapters 3 to 7 of the NUMO Safety Case with highly technical content, a working group was established for each area, separately from the Review Committee, to examine the technical material in detail. In addition, because there are relationships between each technical field, task meetings were held by each working group chairman as appropriate in order to exchange opinions.

⑥ The review results were synthesized according to the collective opinions approved by the Review Committee. The Committee confirmed such synthesis with all members at a review meeting or by e-mail.

⑦ The Review Committee submitted a report on the interim status at the General Session of the AESJ 2019 Fall Meeting as "Current Status of Peer Review of the NUMO Safety Case"

⑧ The review results were compiled in the form of the “Report of the Special Review Committee on the NUMO Safety Case” (hereafter the review report). At the same time, an English version was prepared.

⑨ The secretariat was responsible for checking the traceability of cited references and typographical errors in the NUMO Safety Case.

1.4 Review report

Chapter 2 of this review report presents the Review Committee's collective opinions on the descriptions in Chapters 1 and 2 of the NUMO Safety Case. In Chapter 3, summaries are presented of the more detailed review results on the scientific and technical basis for each technical area described in Chapters 3 to 6 of the Safety Case. In Chapter 4, the evaluation results are presented for Chapter 7 “Reliability of the Safety Case” and, finally, concluding statement is provided in Chapter 5.

The review report summarizes the results of the Review Committee and will help NUMO to assess its achievements and make revisions to the NUMO Safety Case draft version in order to fulfill the responsibilities assigned to it by the government. Any factual misconception in the content of the review report is the responsibility of the Review Committee.

2. Concepts and methods for developing the NUMO Safety Case

2.1 Positioning, objectives and assumed audience for the NUMO Safety Case

According to the history and background of the geological disposal program in Japan, NUMO presented the objectives and significance of its Safety Case in terms of how it aims to achieve safe geological disposal, with recognition of NUMO being an organization trusted by society and the importance of dialogue with local communities and the public.

The readers are assumed to be experts with some technical knowledge of geological disposal. The NUMO Safety Case is a highly specialized report and was developed as hierarchical group of documents ranging in detail from the upper-level main report to the lower-level supporting reports, with traceability that allows experts in various fields to select the information and the level of detail by themselves. The documents consist of an overview report, a main report and supporting reports. For more general readers, a separate document will be prepared to explain the Safety Case transparently using simple expressions and as few technical terms as possible.

NUMO defined the objectives and significance of its Safety Case according to the background of the national geological disposal program; NUMO is an organization that should be trusted by a society as an implementing organization, and should realize the importance of dialogue with local communities and the public. The Review Committee places a high value on this recognition. It should be noted that, regarding a safety case to be used as material for dialogue with stakeholders, which was one of the motivations for compiling the NUMO Safety Case, the Review Committee recommends that this point should be stated as an objective of the Safety Case because this is a step further than previous technical reports. The Review Committee also suggests noting that the NUMO Safety Case aims at promoting trust in order to allow the project to move forward to the next stage.

The Review Committee also places a high value on the structure, including overall content and supporting reports containing technical details, being appropriate for the NUMO Safety Case. The Review Committee also agrees that the division of the Safety Case into a hierarchical group of documents according to the assumed readership is appropriate. The report was written on the premise that the content of H12 Report was known to potential readers, but the Review Committee recommended that the basis for the technical feasibility of geological disposal and the concepts for the disposal system in the H12 Report should be briefly explained again at the beginning of the NUMO Safety Case.

2.2 Significance of preparing the NUMO Safety Case with an established safety case structure

The NUMO Safety Case states that information is presented in a safety case framework that can act as a template for future updates after sites are identified at future milestones of the stepwise implementation of the disposal project. The Review Committee agrees that the NUMO Safety Case follows the established form of safety case as shown by OECD/NEA and the IAEA and followed internationally. On the other

hand, for readers other than experts in geological disposal, it seems that the understanding of the safety case concept is not necessarily sufficient. The Review Committee suggests explaining in more detail why the form of the safety case is appropriate.

2.3 Basic concept for ensuring safety

As requirements to be considered in geological disposal in Japan, NUMO states that "the waste", "the safety functions of the repository", and "the key elements for implementing the disposal project as stipulated in the national plan (i.e. stepwise site selection, reversibility and retrievability, and prospects for safety regulations)" should be defined. After defining these requirements, NUMO established upper-level approaches to ensuring safety at each stage of site selection, repository design, safety assessment, and management of geological disposal; this is termed the "Basic concept for ensuring safety".

In the OECD/NEA guidelines on the safety case, an upper-level approach for ensuring safety is defined as a "safety strategy". NUMO replaced this term in its Safety Case with an easy-to-understand and familiar term: "Basic concept for ensuring safety". The Review Committee agrees that NUMO should use the term "Basic concept for ensuring safety", taking into consideration Japanese impressions of the word "strategy".

NUMO presented the basic concept for site selection, repository design and safety assessment as well as management, assuming close cooperation between the different technical fields. In addition, NUMO outlined specific methods for managing an integrated safety case to be updated at each stage.

In addition to the basic concepts for each technical field, NUMO described not only "long-term safety functions after closure" but also basic concepts for ensuring comprehensive safety as requirements to be considered when implementing geological disposal projects. These were "consideration of uncertainty of state setting during system evolution", "basic concept of NUMO for reversibility and retrievability", "efforts for environmental impact assessment and environmental conservation", "necessity for geological disposal-specific monitoring and clarification of the monitoring plan", "study on the relationship between ensuring operational phase safety and site selection", and "consideration of methods for effective use of stable underground areas and design options".

The Review Committee considers it highly important that such a basic concept for ensuring safety is consistent with international safety case development methods and is planned appropriately according to the situation in Japan. The Committee also places a high value on the characteristics of the geological environment of the Japanese archipelago, located in a tectonically active region, being discussed from the viewpoints of the basic concept for geological disposal and the safety functions, and the basic concept for ensuring overall safety was prepared based on these discussions. The Review Committee also considers it important that these discussions should move the geological disposal project one step forward, and recognizes that this provided the motivation for the timely presentation of the "Nationwide map of scientific features for geological disposal" by the government.

It is necessary to set a spatial scale and a timescale when considering the long-term safety functions required for the repository. NUMO outlined a policy in which it considers these scales, including uncertainties in prediction; the site descriptive model, repository design, and safety assessment will be updated to revise the Safety Case in response to the progress of the stepwise site selection process and evaluate the suitability of sites as part of site selection. The Review Committee acknowledges that this approach is extremely important in the development of a safety case.

The H12 Report generally discussed the technical feasibility and reliability of geological disposal in Japan. On the other hand, the NUMO Safety Case is based on the policy of implementing the repository design and safety assessment after developing a site descriptive model based on the classification of rock types which generally describe the site conditions assumed to be selected in Japan; this is a significant development since the H12 Report. The Review Committee places a high value on this point and recognizes that it should be emphasized in the NUMO Safety Case. The advantage of preparing such a site descriptive model is that, when a candidate site is identified, the repository design and safety assessment can be tailored to a model that matches the characteristics of the host rock at that location, providing a starting-point for developing a site-specific model more efficiently.

After the accident at TEPCO's Fukushima Daiichi Nuclear Power Station, new standards were established in safety regulations, which were also implemented for vitrified waste storage facilities. Considering that the geological disposal facility is similar to a vitrified waste storage facility during the operational period before repository closure, NUMO decided to present a concept and method for assessment of the radiological safety of the surrounding public and workers during transportation and operational processes. Furthermore, NUMO clearly stated that not only radiological consequences but also general occupational accidents caused by natural disasters and by operations in disposal facilities were to be considered.

The safety cases in other countries that have been published so far mainly discuss post-closure safety. However, NUMO addressed operational safety as an independent chapter in its Safety Case, considering the strong concerns about safety during the operational phase of a nuclear facility. The Review Committee agrees with this policy**.**

Dealing with uncertainties related to the post-closure safety of a repository

- The Review Committee attaches high importance to the basic idea that uncertainties can be reduced by stepwise incremental data expansion. However, considering the importance of uncertainties, a description of how to deal with uncertainties should not be included in the “Basic Management Concept” section of the NUMO Safety Case. The Review Committee suggests that the structure should be reviewed and the description of uncertainties should be contained in an independent section on “Addressing uncertainties related to safety”.

- The Review Committee suggests showing more clearly that uncertainties can be reduced by assessing performance repeatedly using detailed data obtained prior to repository closure and that the uncertainties in the site descriptive model will be reduced by the gradual progress of site selection.
- The uncertainties associated with models and parameters and the uncertainties in setting scenarios have different implications. The Review Committee suggests explaining the differences in these implications and also specifying the concept for selecting and setting scenarios relating to unlikely events and human intrusion.
- Considering that uncertainties in the fields of site investigation, repository design and safety assessment are propagated to other fields, establishing how to deal with these mutual influences is important as an interdisciplinary approach to dealing with uncertainty. The Review Committee suggests adding an additional explanation on this point.

Implications of stylization in safety assessment

- In the evaluation of the biosphere in the long-term post-closure safety assessment, information on future human life forms cannot be based on scientific evidence. Therefore, the NUMO Safety Case calculates the exposure dose based on the assumption that future humans will live in the same manner as today and evaluates the safety performance of the repository using this as an indicator. The Review Committee suggests that this concept should be described further in the report.

Safety functions and timescales

- The NUMO Safety Case describes safety functions over a timescale exceeding the period after repository closure when the containment functions are expected to gradually decrease due to physical and chemical alteration of the engineered barriers. However, if favorable geological environment characteristics were maintained, the changes to the repository system would be very slow and it is assumed that there would be no significant loss of the nuclide migration retardation function. At a first glance, this could be read as a contradictory statement that the function is not lost even though the performance has degraded. Therefore, the Review Committee recognizes that this needs careful explanation and suggests adding the following explanation: “Although the containment function is expected to decrease, this would be local and, even if some safety functions decline, other safety functions work complementarily to ensure the overall containment performance (multiple safety functions)”.
- At appropriately selected sites, from current understanding of the drivers of natural perturbation phenomena, NUMO justifies the isolation and containment functions of the geological environment based on the premise that the trends of natural phenomena such as volcanic activity and fault activity would likely continue for about 100,000 years in the future.

- Regarding the period of expected predictability of crustal deformation, the Review Committee suggests clarifying the meaning of continuity of safety functions, reviewing key papers in more detail to justify that these continue over the order of 100,000 years, thus making the basis for the period of extrapolation of crustal deformation more certain.

Argument on the stability of the geological environment in a geological disposal facility

- Considering that there is a strong interest in the fact that the Japanese archipelago is located in a tectonically active region, the stability of the geological environment should be described accurately to ensure that discussions of general trends related to crustal deformation and discussions of the geological environment features that are important for the feasibility and long-term safety of a repository are not confusing. The meaning of the geological environment that is relevant in the discussion of geological disposal is defined in the glossary as follows: "The geological environment, i.e. the underground environment from the viewpoint of geological disposal, is composed of the rock mass and the groundwater contained therein. Geological environment characteristics is a general term, meaning the following characteristics: geology and geological structure, thermal and mechanical properties of the rock mass, geochemical properties of groundwater, properties of groundwater flow and mass transfer." The Review Committee suggests that the geological environment characteristics should be described not only in the glossary but also separately in the NUMO Safety Case report and explained in the text.

Approach to selection and modeling of the geological environment

- NUMO's basic concept for site selection is as follows: in response to the stepwise site investigation process proceeding from literature surveys to detailed investigations, the site descriptive model is refined from a regional scale to a repository scale, and then to a panel scale; repository design and safety assessment are repeated using information on the characteristics of the geological environment that will become more detailed with the progress of investigations. Finally, a site will be selected where a repository with the required safety functions can be designed and constructed. The Review Committee places a high value on NUMO's site selection process being an appropriate and effective approach for site selection in Japan. In particular, the stepwise site investigations reduce the uncertainty associated with site descriptive models and increase the reliability of design and safety assessment. This also contributes to building trust in NUMO. The Review Committee recognizes that these are important viewpoints to be described.
- In 2017, the Geological Disposal Technology Working Group of the national government compiled a document with the title "Summary of Requirement and Criteria for Nationwide Map of Scientific Features for Geological Disposal". In this document, eight unfavorable conditions were presented. It is difficult to understand how these are handled as preconditions for the construction of a site

descriptive model in the NUMO Safety Case. The Review Committee suggests that NUMO should explain carefully how to assess boundary conditions for setting the constraints on model representation of events / features and their distribution, together with the process for selecting the geological environment information to be used in the model, to assure avoidance of such unfavorable conditions.

Approaches to repository design and engineering technology

- The basic concept for repository design is outlined as follows: the requirements for the repository are defined in the form of design factors and safety functions; then, a process for obtaining design examples ("specifications" in the NUMO Safety Case) that satisfies these is shown. Thus, the designed component is assessed in terms of "required performance" within the engineering design process. The Review Committee recognizes that this is consistent with a performance-based design approach as defined in the "Agreement on Technical Barriers to Trade (TBT Agreement) of the World Trade Organization (WTO) [5]. The Review Committee places a high value on presenting a design framework which meets international standards.
- The NUMO Safety Case shows that the repository design is performed to current specifications, and this is described more concretely in Chapter 4 as "Design performed based on design requirements and basic specifications (materials, shape, dimensions, etc.)". However, the "specifications" and the "scope that establishes the specifications" in the NUMO Safety Case might be different from those used in general structural design. The Review Committee suggests that the definition of each term should be clarified. Also, it should be clarified that the design of the repository is performance-based rather than specification-based, and NUMO should show an example of designs that would satisfy the design factors.
- The Review Committee suggests that the method for monitoring during the period while retrievability is assured should also be reviewed with the possibility of reducing uncertainties.

Approach to safety assessment

- The NUMO Safety Case refers to the risk-based approach as an approach to long-term safety assessment after closure; this assumes that it is considered reasonable to evaluate the safety of the repository by the magnitude of risk (= probability × magnitude of impact). However, as this can be read as if a risk assessment were performed, it needs to be stressed that only in the scenario categorization is the probability of occurrence considered. A dose/probability disaggregated approach is applied in the NUMO Safety Case, which assesses the impact for specific scenarios when the probability of occurrence is 1. The Review Committee suggests describing that there are two methods

for risk-based approaches: “integrated approaches” and “dose/probability disaggregated approaches”, and that the latter is used in the NUMO Safety Case.

Basic concept of management

- The Review Committee considers it important that, in addition to dealing with uncertainty relating to safety, NUMO should address the attitude of management towards reducing management risks caused by uncertainties regarding policy, socio-environmental change, etc.
- NUMO refers to the basic concept of management for close collaboration between the areas of site characterization and evaluation, repository design and safety assessment. In projects that consist of interdisciplinary areas such as geological disposal, collaboration in managing the entire project is extremely important. Therefore, the Review Committee places a high value on NUMO establishing a basic management concept. It should be noted that the Review Committee suggests adding textual explanations to the figure showing the interrelationships between each field in the report in order to underline specific actions and ensure their effectiveness.
- The validity of the process of developing a safety case by integrating information obtained from the investigation and evaluation of the geological environment and from repository design into the safety assessment is extremely important from the viewpoint of demonstrating the reliability of the safety case. Therefore, the Review Committee suggests adding a description of the information integration methodology.
- NUMO operates various management systems. These are specific management tools for ensuring collaboration and integration between different fields. If these systems are positioned as a “management basis”, it will be easier to understand the effectiveness of such cooperative management. In the NUMO Safety Case, the figure explaining the linkages between each field and the figure explaining the relationship between the Safety Case and each chapter quoted in the summary section are shown. The Review Committee suggests adding an explanation of the figures in the management section.

3. Scientific-technological basis for the NUMO Safety Case

3.1 Selection and modeling of a geological environment suitable for geological disposal

3.1.1 Outline of review

In addition to presenting investigation and evaluation technologies for geological environment characteristics and the basis for design and safety assessment, Chapter 3 of the NUMO Safety Case describes approaches for developing a site descriptive model, and the current level according to the "Basic concept for ensuring safety of geological disposal" described in Chapter 2. The two specific goals are

- Demonstrating that the basic concepts for investigation/evaluation technologies for site selection are developed systematically by showing the latest scientific knowledge and technological developments related to Japan's geological environment.
- Demonstrating that NUMO possesses the technology for interpreting and integrating the geological environment information acquired in the different stages into a site descriptive model of the host rock to be studied, which will provide the basis for the design and safety assessment of the repository.

The Review Committee considered in detail the technical content that has been compiled in line with these two goals, from the specific viewpoint of "validity of the scientific-technological basis underpinning the Safety Case" shown in Chapter 1 of this report. The specific viewpoints are as follows:

- Are the requirements and conditions specified for the geological environment as being suitable for geological disposal specified sufficiently and appropriately according to the basic concept for ensuring safety and the preconditions at the present stage shown in Chapter 2 of the NUMO Safety Case?
- Can all processes from data acquisition to analysis/evaluation and development of a site descriptive model be traced in response to the requirements and conditions specified for the geological environment?
- Is the site descriptive model fully functional as a basis for repository design or safety assessment in the light of the objectives of the NUMO Safety Case?
- Have the developed technologies reached a necessary and sufficient level based on the latest scientific and technical knowledge considering the objectives of the NUMO Safety Case? Can it be said that the level is sufficient considering domestic and foreign technological trends? Does the report mention continuous improvement and introduction of technologies that are considered necessary in the future with reference to overseas precedents?

- Has knowledge about the geological environment characteristics of Japan located in a tectonically active region been updated appropriately and utilized based on the latest research results since the H12 Report.
- Is information collected and analyzed from a broad viewpoint and results derived in an unbiased manner?

In the working group, the opinions submitted by each committee member were compiled, opinions were discussed, and issues considered to be particularly important for the technical review were extracted. The Review Committee's opinions were then consolidated and agreed to as the review results. The overall findings of the review results are as follows.

- Based on the results of collecting and compiling a wide range of geological environment data, the various geological environments in Japan were categorized specifically from the viewpoint of geological disposal. Typical site descriptive models were developed for the three types of host rock. In addition, the construction process for the site descriptive model was specifically shown. The Review Committee places a high value on this steady progress since the H12 Report.
- The Review Committee acknowledges that the two individual goals shown in Chapter 3 of the NUMO Safety Case - to show that the basic concepts for investigation/evaluation technologies for site selection are systematically developed based on the latest scientific knowledge and technological developments related to Japan's geological environment and to show that NUMO possesses the technology for interpreting and integrating the geological environment information into the site descriptive model of the host rock to be studied - have reached a sufficient level in view of the above review points. The Review Committee sets a high value on this as a technical basis in future site selection.
- The NUMO Safety Case covers a wide range of information related to Japan's natural phenomena, geological environment characteristics, geological investigation and evaluation technologies, etc. The Review Committee recognizes that there are many points where further improvement is desirable from the viewpoint of the logic, objectivity and understandability of the described content.

For the above general findings, the following sections are described in detail from the viewpoints outlined below, set considering the two goals presented in Chapter 3 of NUMO Safety Case.

- Basic concept for judgments required in site selection and the status of preparation of investigation/evaluation technologies
  - Integration of information on the geological environment for the development of a site descriptive model
  - Probabilistic assessment technique for assessment of natural phenomena and associated evolution of the geological environment

- Development status of the site descriptive model by integrating information on the geological environment
  - Long-term evolution and timescales of geological environment characteristics
  - Response to uncertainties relating to geological environment characteristics
  - Radionuclide leaching/retardation functions expected in the geological environment
  - How to treat the Darcy flow velocity in the hydrogeological model of fault and groundwater flow analysis
  - Influence of high carbonate concentration groundwater

3.1.2 Basic concept for site selection and status of preparation of investigation/assessment methods

NUMO plans to select a site appropriate for constructing a repository by comparing the results of geological environment investigations and evaluations with statutory requirements and considerations stipulated by NUMO, and has prepared a workflow (flowchart) for literature surveys and preliminary investigations, as well as a list of investigation and evaluation technologies used at each stage.

The Review Committee places high importance on these technical systems, developed based on existing documents and covering a variety of geological environment conditions that are expected in Japan, being compiled as a practical system with a sufficient basis for making judgments in promoting the literature surveys and preliminary investigations. The Review Committee acknowledges that the technologies applied for investigation/evaluation are appropriate based on currently available technologies. However, the Committee suggests clarifying to what stage of the site selection these technologies should be applied for the indicated issues, as well as their scope, by reviewing the latest research results.

Integration of geological environment information for the development of a site descriptive model

NUMO will integrate geological environment information into a site descriptive model that expresses the spatial distribution of the geological environment characteristics in order to put the information obtained from the geological investigations into a form that can be used for the design and safety assessment of the repository. Repeating the loop of investigations and evaluations, repository design and safety assessment, NUMO then checks whether the potential site has sufficient safety functions.

The Review Committee places a high value on the process of integrating geological environment information into the site descriptive model as a very important effort to ensure the reliability of the safety case, particularly the traceability of the information. However, there is no specific description of what kind of feedback was obtained on the site descriptive models from the areas of repository design and safety assessment. The Review Committee suggests that additional explanations will be necessary.

Probabilistic evaluation technique for assessment of natural phenomena and associated evolution of the geological environment

NUMO has developed a method called ITM (International Tectonics Meeting)-TOPAZ (Tectonics of Potential Assessment Zone) for long-term safety assessment for a period exceeding about 100,000 years in the future. Using this method, NUMO addressed a probabilistic evaluation of the possibility of natural phenomena such as volcanic/igneous activity, earthquake/fault activity, etc. that could significantly affect the safety functions of the repository.

The Review Committee places a high value on the ITM-TOPAZ method as a new attempt to objectively clarify long-term uncertainties relating to natural phenomena that will be important in the tectonically active geological environment of Japan. This method is an advanced approach that makes full use of the latest geoscientific knowledge and mathematical methods obtained through the cooperation of foreign experts. It also serves as a platform that unifies information on natural phenomena and expert opinions in an integrated manner, taking time and space into account. The Review Committee suggests that domestic experts familiar with the geological environment of Japan should participate in future efforts. The Committee also suggests specifically addressing the policy and method for collaboration with persons with a modeling background for long-term evolution of the geological environment characteristics and safety assessment of geological disposal systems in Chapter 6 of the NUMO Safety Case. In addition to volcanic and igneous activity that has been reported so far, the Review Committee hopes that more examples of the application of this method will be accumulated for earthquake/fault activity and uplift/erosion.

It should be noted that, in the NUMO Safety Case, the title is “Probabilistic evaluation method for evolution of the state of the geological environment due to the occurrence of natural phenomena”. However, the Review Committee thinks this title needs to be corrected because, from the original title, the method may be misunderstood to apply to evolution in the state of the geological environment rather than to the occurrence of natural phenomena.

3.1.3 Status of development of site descriptive models integrating information on the geological environment

NUMO has been developing a methodology for comprehensively evaluating the suitability of a site through the design of the repository and the safety assessment mainly by developing a site descriptive model with various geological features such as faults and fractures in order to investigate, evaluate, and select sites with the geological conditions necessary for isolating and confining radioactive waste on the long term.

According to this methodology, the geological environment is investigated in each stage through literature surveys, preliminary investigations and detailed investigations. The geological environment data are interpreted/integrated into a site characterization model describing the geological environment (geological structure model, hydrogeological structure model, hydraulic model, rock mechanics model) so that the

geological structures that define the geological environment and the thermal, hydraulic, mechanical, and chemical conditions are consistent with each other. The siting environment information obtained from these models is used to design the repository while evaluating the engineering feasibility and the safety assessment is then performed based on the geological information on the siting environment and the provisional design. Repeating this series of studies, the level of detail of investigations and of evaluation and reliability will be improved by reducing uncertainties.

In order to show that such a site descriptive model can be specifically developed for various geological environments in Japan, NUMO selected the examples of plutonic rocks, Neogene sedimentary rocks and Pre-Neogene sedimentary rocks as representative geologies that should be considered in the repository site selection. The potential host rocks were set for these geologies. NUMO developed a geological model and a hydrogeological model considering geological information observed for each rock type, such as the scales of rock bodies and strata, the dominant orientation, length and distribution density of faults and fractures in the rock. In addition, it considered parameters such as the hydraulic conductivity of the matrix and the faults and fractures in the bedrock. The level of detail of the models was set according to hierarchical spatial scales (i.e. regional scale, repository scale, panel scale).

Considering that the geological environment of Japan was summarized in the H12 Report, the Review Committee places a high value on the three types of potential rocks that were selected as representative in the NUMO Safety Case and appropriate consideration being given to the geological characteristics of Japan. The Review Committee believes that, for these three types of host rocks, a series of processes should be integrated as a site descriptive model that will serve as the basis for repository design and safety assessment, and the investigation and evaluation technologies used in each stage of site selection should be systematically compiled as universally as possible.

The NUMO Safety Case compiles and analyzes a wide range of relevant scientific knowledge, establishes the standards for quality assurance and categorizes the potential rock types into plutonic rocks, Neogene sedimentary rocks, and Pre-Neogene sedimentary rocks under current conditions when no site has been identified. Compared with the H12 Report, this is considered to have advanced to a more realistic approach based on the geological conditions of Japan. In particular, the site descriptive model of Pre-Neogene sedimentary rock, which is estimated to occupy nearly half of Japan's surface, had been established in the absence of a pre-existing synthesis. This was an important result for examining the practicality of the technologies to be applied to the complex geological structures caused by thrust faulting in accretionary prisms and fold structures in accretionary complexes. On the other hand, no actual field survey was described to test modeling methods based on the regularity of fault and fracture distribution. The Review Committee suggests considering other cases, such as Sweden and Finland, that take a similar approach in order to explain the validity of the method more clearly.

The Review Committee considers it highly important that the system presented in the NUMO Safety Case should be an effective approach for selecting a suitable site for geological disposal, even under conditions where the rock physical properties assumed in Japan are heterogeneous and the spatial geological data are

limited. In addition, many of the technologies applied to modeling are consistent with those used in foreign countries such as Finland and Sweden and the Review Committee places a high value on the technical system being the state-of-the-art.

Long-term evolution and the timescales of the geological environment characteristics

In Japan, the location of the repository is not clear. Therefore, NUMO selected geological formations and rock bodies as "potential host rocks for consideration" in which safety functions are expected to be maintained for a long period of time in order to construct a site descriptive model. The potential host rocks under consideration were evaluated to show that long-term evolution of the geological environment would not impair the durability of the safety functions of the repository.

The Review Committee places a high value on current knowledge being compiled and the direction of future efforts shown regarding the long-term evolution of the characteristics of the geological environment. In addition, to evaluate the geological environment of Japan more realistically, appropriate issues have been identified for the next stage. However, the situation that "long-term evolution of topography and geological structure including uplift and subsidence, climate and sea-level changes were not specified" in the description of the "approach" in Chapter 2 of NUMO Safety Case was treated as obvious in Chapter 3 of the report. This may be misleading to readers who refer only to Chapter 3. The Review Committee suggests that NUMO should clarify the precondition again, including the rationale.

NUMO uses the terms "geological timescale", "timescale", and "time change" in the description of the temporal characteristics of the geological environment and the properties of long-term evolution. However, it is not clearly explained what periods these "times" indicate. Improvements are needed to allow a better understanding of the readers. The Review Committee suggests that the time range should be as specific as possible, considering its relevance to the timescale used in the H12 Report.

Handling uncertainty on the geological environment characteristics

For reducing uncertainty using an iterative approach, NUMO confirmed that the effectiveness of this was checked through activities from geological investigation to development of a site descriptive model as part of the research in the deep underground research facilities in Mizunami and Horonobe by the Japan Atomic Energy Agency (JAEA). In addition, in future efforts related to long-term evolution of the geological environment, NUMO plans to develop methodologies such as systematization that allow optimization of modeling and analysis technologies according to temporal and spatial scales and features.

In this way, NUMO explained the concept of uncertainties being caused by the restricted amount of information at each spatial scale shown in the NUMO Safety Case and how to handle this based on examples from Mizunami and Horonobe. NUMO also mentioned the need for such research as part of the systematization of investigation technologies in future efforts. The Review Committee agrees with these

considerations. In the NUMO Safety Case, however, there are no considerations of important issues in the assessment of uncertainty at each stage using the iterative approach, and no example of a foreign country where investigations at an actual disposal (candidate) site have been conducted. The Review Committee considers that supplementary explanations will be necessary regarding the status in Japan and foreign countries.

Radionuclide leaching/retardation function expected for the geological environment

For the requirements of long-term post-closure safety, NUMO described that the geological characteristics of the deep underground will change slowly over the long term, and the possibility of sudden or rapid changes will be small. Considering this range of change, if favorable geological environment characteristics from the viewpoint of geological disposal were maintained, it could be said that the geological environment would be "stable over a long period". The expected period for reduction of the risk presented by the waste due to radioactive decay would be about 100,000 years. Therefore, the possibility of reducing or losing the leaching/retardation function expected in the geological environment would be extremely small even for a long period of time exceeding 100,000 years.

The Review Committee agrees with NUMO that this is very important information in the context of explaining the safety of geological disposal systems. However, to explain this point more clearly, the Review Committee suggests supplementing the knowledge with other information currently cited in the OECD/NEA report [6]. In addition, in Chapter 2 of the NUMO Safety Case, there is a description that, "in the long time period beyond about 100,000 years in the future, the uncertainty of future predictions related to the evolution of the geological environment and the occurrence of natural phenomena increases." It is important that "evolution of the characteristics of the geological environment in a very limited area within the crust" should not be confused with large-scale "evolution in the crust and tectonic plates associated with changes in the location of volcanoes and faults, as well as uplift and erosion". For this reason, the Review Committee suggests improving the description so that the expression is more consistent throughout the report.

How to treat the Darcy flow velocity in the hydrogeological model of fault and groundwater flow analysis

For faults (fault zones) with a scale of several kilometers or more, NUMO has established a hydrogeological structure model with a core zone and a damaged zone around it, based on knowledge of fault morphology and structure, hydraulic characteristics, etc. reported in fault surveys in Japan and overseas.

Recognizing that this hydrogeological model properly reflects the generally accepted hydraulic structure of faults, the Review Committee agrees that NUMO should treat this model as a representative conceptual

model that describes the internal structure of large faults. On the other hand, since asymmetrical fault zones that contain a significant number of fractures have been found in the Houraikyou, Mt. Rokko and the San Andreas faults, from the viewpoint of expanding the usability of this model the Review Committee suggests describing a wider range also referring to this research.

In addition, NUMO calculated Darcy flow velocity as one of the results obtained from groundwater flow analysis using a hydrogeological structure model, and used this for subsequent discussions.

The Review Committee agrees to using the Darcy flow velocity as a measure of groundwater movement at the scale to be analyzed when considering the position and layout of the repository. However, there is no description of the technical meaning of Darcy flow velocity in the NUMO Safety Case. The Committee recognizes that it is necessary to explain the technical meaning in detail. In addition, the Committee suggests that the relationship between the actual flow velocity used in safety assessment and the Darcy flow velocity should also be accurately described in Chapter 3 or Chapter 6 of the NUMO Safety Case.

Influence of high bicarbonate concentration groundwater

The bicarbonate concentration and pH of the groundwater greatly affect complexation for some metal ions and carbon steel corrosion and it can be a very important technical element for ensuring the quality (reliability) of these data for safety assessment. The groundwater sampled from a borehole, however, may be different to the original due to degassing, etc. To solve these problems, NUMO screens water quality data and estimates the concentration of bicarbonate based on charge balance. The Review Committee agrees to NUMO adopting this approach. For groundwater with high sodium ion and chloride ion concentrations, however, it is necessary to be aware that the error of measurement values becomes large when estimating the concentration of bicarbonate from the difference in ion concentration. The Review Committee also agrees that NUMO Safety Case addressed the need for data preparation in future work for sedimentary rocks that contain carbonate / organic matter, especially Pre-Neogene sedimentary rocks (accretionary sedimentary rocks) for which there is little information.

3.2 Design of the repository and engineering technology

3.2.1 Outline of review

In Chapter 4 of the NUMO Safety Case, based on the basic concept for ensuring the safety of geological disposal described in Chapter 2, a design concept for the repository (engineered barriers, surface facilities, underground facilities) system and examples were presented using the results of the site descriptive model examined in Chapter 3. The detailed review of the Review Committee was carried out from the following specific viewpoints, considering the aspects of the "validity of the scientific and engineering basis to which the Safety Case refers" shown in Chapter 1 of this report.

- Is the design of the repository based on the approach specified in the basic safety concept for ensuring the NUMO Safety Case (Chapter 2)?
- Are the performance requirements of the repository established appropriately as a basic framework for selecting a design, and is the design process for satisfying the required performance shown clearly?
- Are the values of material properties for the design and their rationale shown clearly? Are the values appropriate for the stage when no site is selected?
- Does the examination leave room for alternative selections, such as examining two or more activities in parallel, considering future technology developments?
- Are the safety measures for abnormal conditions included, as experienced by the 2011 Great East Japan Earthquake, in addition to normal conditions?
- Has retrievability been examined rationally?

The opinions submitted by each member were collected and compiled based on the above-mentioned viewpoints. The general results of the review are as follows.

- For the three site descriptive models for candidate host rocks (crystalline rock, Neogene sedimentary rock and Pre-Neogene sedimentary rock) discussed in Chapter 3 in the NUMO Safety Case, the methodology and procedures for design, construction, operation and closure of the repository which satisfy the five design factors (operational safety, long-term post-closure safety, retrievability, engineering feasibility and economic viability) were described in detail in Chapter 4 of the NUMO Safety Case. Although there are many indefinite elements at present, the pertinent information needed for the engineering design of the repository was compiled and the contents shown as realistically as possible, so that feasibility of implementation can be reasonably assured.
- The Review Committee places a high value on the current approach, which leaves room for future selection allowing a flexible approach to future uncertainties, for examining alternative approaches

in parallel, such as introducing horizontal emplacement of a PEM system instead of vertical emplacement for vitrified waste, introduction of B-type packages for TRU waste, and rationalization of overpack thickness.

- Although uncertainty is unavoidable in engineering design, the Review Committee suggests that, in addition to considering the uncertainties associated with information/data on the material properties used for the geological characteristics and engineered barriers depicted by the site descriptive model, uncertainties associated with the boundary conditions assumed for the design or the resulting range of design specifications should be considered. Since it is very challenging to maintain the safety of the repository over a very long time period, the implementing organization and the regulatory body are required to ensure safety by assuming as many scenarios as possible after the repository is closed. The Review Committee considers it highly important that issues to be considered in the future are described comprehensively in the NUMO Safety Case. In the actual design, however, technologies related to design, construction, operation and closure are expected to continue to evolve. The Review Committee suggests describing that the main issues must be updated with the latest reliable knowledge.

3.2.2 Design workflow

In Chapter 4 of the NUMO Safety Case, the requirements for design were specified by defining the repository properties and performance required as “design factors”. In addition, design requirements were set to ensure the performance indicated by the defined requirements. The repository was designed based on these requirements to determine the basic specifications (materials, shape, dimensions, etc.). The specific “repository design workflow” was shown as a figure, which includes a sequence of design workflow with feedback during the design and layout of the engineered barriers, surface facilities and underground facilities.

However, regarding the figures shown as "Design workflow based on design factors and design requirements" and " Design workflow of the repository", it was not clear whether the object of the impact assessment and subsequent feedback to determine the validity of the defined specifications was only the repository with engineering design (engineered barriers, surface facilities and underground facilities), the entire geological disposal system including the natural barrier, or whether it includes a review of design factors and design requirements. In addition, the relationship between “impact assessment” in Chapter 4 and “safety assessment” in Chapters 5 and 6 of the NUMO Safety Case was also difficult to understand. It was described in design validation and feedback that there are two processes: a review of the design requirements for the engineering design of the repository and a safety assessment of the entire geological disposal system. An explanation of the relevant figure should be provided in the text. At that time, in the design study of the repository, there were small feedback loops that were handled in engineering

technology and large feedback loops including safety assessment. These should be used properly according to the objectives.

In addition, because the repository is designed to ensure very long-term safety, there is a possibility that trade-offs will occur on the time axis between operational safety and long-term post-closure safety (for example, drainage function of the permeable layer in contact with the mechanical plug and long-term stability of a drained mechanical plug). It is important that the repository design allows for feedback of the results from assessment of the evolution of the repository to allow required changes to repository components and their specifications.

Based on the above, the Review Committee suggests that the description of the design framework should be clearly understandable by describing the feedback concepts and preconditions.

3.2.3 Design factors and requirements

The characteristics and functions required of the repository as an entire geological disposal system were specified as design factors under the assumed geological environment. The basis for this is, however, unclear. Since these settings are also an important design process, the Review Committee suggests adding more detailed explanations.

The current description explaining the design factors is difficult to understand; it explains the content of the requirements for each component of the repository. Together with a figure showing the design workflow, the Review Committee suggests adding an explanation with a description of the requirements at the beginning of Chapter 4 of the NUMO Safety Case.

3.2.4 Concept for ensuring safety in designing the surface facilities

The Review Committee places a high value on considering safety measures for abnormal conditions in addition to normal conditions, which is the specified situation for the development of nuclear facility design in Japan based on the experience of the 2011 Great East Japan Earthquake. On the other hand, specific studies on seismic activity and tsunamis were not conducted on the ground that the conditions of the site geological environment had not been specified. The Review Committee suggests, however, adding evaluation results for scenarios that assume, for example, earthquakes and tsunamis such as caused by the 2011 Great East Japan Earthquake. In addition, the Review Committee suggests ensuring consistency with Chapter 5 “Assessment of operational safety” of the NUMO Safety Case.

3.2.5 Material properties for the design

Establishing geological environment characteristics

In this study, information required for the design in terms of thermal characteristics, mechanical characteristics, hydraulic characteristics and chemical characteristics of the groundwater in the assumed geological environment was derived from the site descriptive models for plutonic rocks, Neogene sedimentary rocks and Pre-Neogene sedimentary rocks specified in Chapter 3 of the NUMO Safety Case. The geological and environmental characteristics in the actual design should utilize in-situ or laboratory tests using rock samples as well as physical tests etc. after site selection. The Review Committee suggests describing that the geological and environmental characteristics for design were selected tentatively considering variations in the three potential host rocks, and that the characteristics of the geological environment used in the actual design will have to be determined with sufficient accuracy through future field investigations and tests.

Establishing material properties for the engineered barriers

The values for the material properties used in the design of the overpack, waste package, and buffer material that make up the engineered barriers are taken from the literature and test results, in addition to the site descriptive model in Chapter 3 of the NUMO Safety Case. For example, the pH and chemical composition of the pore water in the buffer material in contact with the overpack were calculated based on the water quality model in Chapter 3. The Review Committee suggests describing that the values used will have to be updated with the latest reliable knowledge during the actual design, although they are meaningful as representative values to be used for the design studies at the present time. Moreover, the Review Committee suggests describing the need to carefully consider whether the assumed boundary conditions will be maintained over the long term, since some of the estimated numerical values are based on these.

3.2.6 TRU and other waste characteristics and their disposal concepts

In discussing the characteristics of the waste package as a design basis, there are some remaining problems, especially for the TRU waste. The percentage distribution of the nuclides in each waste package will be determined by reprocessing in the future. Regarding the inventory of individual radionuclides contained in each TRU waste package, the relevant supporting report shows the values selected, the basis for the selection and their validity. However, since these are important for safety assessment, the Review Committee suggests describing these values in the main report. The waste properties include chemical composition, leaching properties, heat resistance, etc. As the characteristics of waste such as TRU are very

variable, the Review Committee suggests clarifying and describing the characteristics of the waste packages as a design condition.

The disposal of vitrified waste, one of the wastes for co-disposal with waste such as TRU, and the starting-point for examining disposal is already well documented in the H12 Report, including repository concept catalogs and design options. A future task will be to proceed with the same design options for TRU waste disposal.

In the design of the engineered barriers for a TRU waste repository, the description of the specifications for waste package type A was omitted based on the premise of the Second TRU Report. The Review Committee suggests adding an explanation of the difference between the specifications of waste package types A and B. In addition, regarding removal of pore water to suppress hydrogen gas generation due to radiolysis in filled mortar, the Review Committee suggests describing the effects of mortar shrinkage due to drying together with the differences in the functions required of fillers in waste package types A and B.

3.2.7 Design of the underground facility layout

The layout-determining features (LDF) are defined as the characteristics that determine the layout of the underground facilities as given by the site descriptive model at the repository scale. The emplacement position determining features (EDF) are defined as properties that determine the emplacement position of the vitrified waste packages (hydraulic properties of faults and fractures less than 1 km in length) as given by the site descriptive model at the panel scale. The Review Committee places a high value on clearly describing the approach for defining these features. The explanation of LDF and EDF, however, is limited to an explanation of the abbreviations in footnotes. The Review Committee suggests properly explaining the concept in the main report as an important design issue.

3.2.8 Retrievability

The NUMO Safety Case discusses the impact of maintaining retrievability before closing the repository to investigate the engineering feasibility of waste retrieval technology. In the NUMO Safety Case, three conditions were specified according to the difficulty of retrieval. Impacts on the geological environment of the near-field, the engineered barriers, and required maintenance of tunnels were considered for the case when ease of retrieval is maintained. For these three conditions, the applicability of the retrieval technology was considered only for conditions where the impact was intermediate.

In the report [7] on “Reversibility and retrievability (R & R) for deep geological disposal of high-level radioactive waste and spent fuel” published by the OECD/NEA in 2011, it is described that retrievability is not part of the basic concept for the long-term safety of the repository, but retrievability has to be

considered in each stage of the waste life cycle in terms of ease of retrieval, passive safety and active management, because retrievability facilitates safety arguments and could be desirable for reasons other than safety. Following the "Internationally agreed staged classification of retrievability (R scale)" proposed by the OECD/NEA, the Review Committee suggests describing the impact not only for the intermediate case but also for the other cases in the NUMO Safety Case.

3.3 Safety assessment for the operational phase

3.3.1 Outline of review

In Chapter 5 of the NUMO Safety Case, and based on the basic concept for ensuring the safety of geological disposal described in Chapter 2, scenario development, impact assessment based on abnormal scenarios and examples of responses after accidents, etc. were presented for a site descriptive model and repository design based on it in a pre-closure safety assessment. The Review Committee has conducted a detailed technical review from the following specific viewpoints related to "relevance of scientific and technological foundations relied on by the Safety Case", as described in Chapter 1 of this review report.

- Is the safety assessment performed according to the approach defined in the basic concept for ensuring safety in the NUMO Safety Case (Chapter 2)?
- Is the basis for setting the scenarios for operational safety assessment consistent with international standards?
- Are the scenarios and analysis cases assumed in the safety assessment sufficiently comprehensive?
- Is the scientific basis supporting the safety assessment methodology, models and codes adequately outlined?

Based on the above viewpoints, the opinions submitted by each member were collected and compiled as review results. The general findings of the review are as follows.

- In Chapter 5 of the NUMO Safety Case, safety assessment prior to closure was discussed from the viewpoint of radiological protection and general occupational safety. In accordance with the safety case and safety assessment guidelines issued by the IAEA, normal-state scenarios and abnormal-state (accident) scenarios were developed and studied. As accident scenarios, dropping a waste package, fire within the facility, loss of external power supply and other equipment failure were assumed. The possibility of mechanical and/or thermal damage to the overpacks and waste packages in which vitrified materials are encapsulated that could cause a release of radioactive material was also evaluated. The Review Committee concludes that the overall evaluation framework and basic concept including abnormal condition (accident) scenarios are appropriate.
- The events in the accident scenarios, on the other hand, are not necessarily sufficient. Because of the large degree of site dependence, important scenarios were set only for internal initiating events without considering external initiating events. The Review Committee suggests establishing and evaluating scenarios for external initiating events that could be assumed even at the generic stage of the project.

3.4 Assessment of long-term post-closure safety

3.4.1 Outline of review

In Chapter 6 of the NUMO Safety Case, based on the basic concept for ensuring the safety of geological disposal described as a long-term post-closure safety assessment technology in Chapter 2 of the report, scenario development, nuclide migration analysis models and the development of datasets, a series of methodologies up to dose evaluation and analysis techniques were shown for a site descriptive model and the design of repository. The Review Committee conducted a detailed technical review based on the specific viewpoints described below, related to "relevance of scientific and technological foundations relied on by the Safety Case", as described in Chapter 1 of the report.

- Is the safety assessment performed according to the approach defined in the basic concept for ensuring safety in the NUMO Safety Case (Chapter 2)?
- Is the basis for specifying the post-closure safety assessment framework (scenario classification, evaluation period, application of stylization, etc.) consistent with international standards?
- Are the disturbances expected during construction/operation and maintenance of retrievability properly taken into account in the safety assessment?
- Is the post-closure safety assessment model properly constructed in line with the site descriptive model and the design of the repository?
- Are the safety functions of the individual barriers in the geological disposal system properly described considering the timescale, and is safety assured by multiple safety functions over the long term considered?
- Are the scenarios and analysis cases assumed in the safety assessment sufficiently comprehensive?
- Are scientific bases for supporting safety assessment methodologies, models and codes shown?
- Are the features, events and processes affecting the evolution of the disposal system clearly documented and sufficiently comprehensive compared to the international FEP database?

Based on the above specific viewpoints, the opinions submitted by each member were collected and compiled as review results. The general findings of the review are as follows:

- The system for long-term post-closure safety assessment presented in Chapter 6 of the NUMO Safety Case is consistent with international guidelines and methodologies in other countries, and is reasonable as an approach that quantitatively demonstrates the safety of geological disposal in a situation where no specific site has been identified. The Review Committee places a high value on, in particular, efforts in the NUMO Safety Case to conduct an evaluation using site-specific information rather than a generic evaluation that demonstrates the technical feasibility of geological

disposal and the preparations for the safety assessment technology being established to consider more realistically the geological environment and disposal system characteristics in Japan.

- The Review Committee acknowledges that significant progress has been made in the following aspects based on the results since the H12 Report and the Second TRU Report:
  - Adopting a risk-based approach and a disaggregated dose/probability approach considering the likelihood of scenario occurrence
  - Utilizing integrated methods and storyboards that combine a bottom-up approach using FEPs and a top-down approach based on safety functions in developing scenarios
  - Introducing (more) practical methods to handle the characteristics of the specific site descriptive model constructed in Chapter 3 and the geological disposal system developed and designed in Chapter 4 of the NUMO Safety Case (including remaining artifacts introduced during construction and operation)
  - Utilization of the latest database for data selection for nuclide migration
  - Establishing a safety assessment system considering the co-disposal of vitrified waste and TRU waste, and
  - Evaluation of biosphere incorporating the latest knowledge.
- From the viewpoint of improving the reliability of long-term post-closure safety assessment, there is still room for improvement regarding the following points;
  - Clarification of the positions, roles, and relationships of a series of tools and analysis methods (storyboards, FEPs, attribute analysis, etc.) used for scenario development
  - Reinforcement of information on quality assurance for mathematical models, codes, data and analysis of nuclide migration processes
  - Clarification that the uncertainties to be included in the safety assessment are considered comprehensively
  - Clarification of relevance to the evaluation of possible perturbations of the underground environment before closure, retrievability, accidents during construction and operation, and
  - Discussion of differences by comparing the safety assessment results with previous results.

In the following sections, the results of the Review Committee are compiled on issues raised by the comments submitted in the Committee regarding safety assessment concepts, scenarios, models, data and assessment based on nuclide migration analysis.

3.4.2 Concept for safety assessment

Evaluation period

A logical approach is to classify the state of the disposal system after closure into four timeframes (T1-T4) and to define the FEPs related to the safety functions for each time section. At the current stage when no site is specified, however, it is considered difficult to define the FEPs, including the possibility of changes in the geological environment over a long timescale. In this sense, care needs to be taken in handling T4. For example, although T3 is defined as "the period when it is considered that the characteristics of the current geological environment will not change significantly after the start of radionuclide migration", based on this definition it was necessary for T4 to consider changes in the geological environment. On the other hand, in the evaluation of the reference scenario, it was assumed that the characteristics of the geological environment would not change significantly during the evaluation period up to the occurrence of the maximum dose. The Review Committee suggests that, after clarifying the concept of T4 in the reference scenario and handling of changes in the geological environment, from the viewpoint of consistency with the long-term evolution of the geological environment in Chapter 3 of the NUMO Safety Case, the description should be changed for ease of understanding of the relationship between the evaluation timeframes and the scenario categories.

Relationships between uncertainties

The uncertainties in scenarios, models and data described in Chapter 2 of the NUMO Safety Case are consistent with the classification and definition of uncertainties in domestic and international safety assessments. In the long-term post-closure safety assessment, however, since it is necessary to appropriately evaluate a range of uncertainties, a careful description is required of the policy for dealing with uncertainties and specific approaches. In particular, as it was difficult to understand the relationship between the uncertainties handled in each scenario classification derived from the reference scenario and the uncertainties in scenarios/model/data, it was difficult to appreciate that the uncertainties to be considered in the safety assessment are comprehensively evaluated. For example, the uncertainties in data for the reference scenario were handled in the form of scenario uncertainties with alternative scenarios. Regarding the relationship between the uncertainties in scenarios/models/data and the scenario categories, the Review Committee suggests revising the description so that readers can easily understand that the impacts of uncertainties are comprehensively and rationally evaluated.

3.4.3 Scenarios

Storyboard

A method for depicting the evolution of the safety functions and the state of the disposal system using storyboards that describe it from the period from closure in several temporal and spatial frames was consistent and appropriate with the latest scenario development methodology, while the basic procedure for safety assessment was illustrated. Since the storyboard appears to be positioned at the upper level in scenario development, readers may be led to misunderstand that scenarios are determined a priori. The evolution of the system state presented in the storyboard was in fact to be clarified through attribute analysis and impact analysis, and the content of the storyboard should have been updated based on these analyses. This concern is related to the fact that the storyboard development method is not clearly described. There are also some descriptions in the main report to the effect that a storyboard was developed, and scenarios were derived based on this storyboard. Therefore, the Review Committee suggests that explanations should be provided to avoid the above misunderstandings.

Based on the above, the Review Committee suggests clarifying the objectives of introducing the storyboard concept in safety assessment, and the methods for its development and application, as well as the position of the storyboard in the assessment. The validity of the figure showing the flow of basic procedures for safety assessment (especially the relationship between the storyboard and attribute analysis/impact analysis) should also be reconsidered.

Development of scenarios

The Review Committee places a high value on scenarios being developed using scenario development technologies based on the method used in the H12 Report and according to latest scenario development technology in Japan, and the FEP list necessary for scenario development being structured to improve the comprehensiveness of the scenarios. On the other hand, it is difficult to understand, as described later, how to develop a scenario based on attribute analysis, impact analysis and storyboards in the explanation of the basic procedure for safety assessment shown in the figure. The Review Committee suggests adding an explanation to improve the transparency of the process related to scenario development.

In addition, the Review Committee considers it important that the introduction of the new integrated FEP list, which is a reduced version of the previous FEP list (NUMO FEP list) for scenario development, should be seen as an attempt to improve the complexity of presenting correlations using many FEP lists. For example, there are some merits because using an integrated FEP list in the attribute analysis diagram is simpler than using the NUMO FEP list. On the other hand, the Review Committee points out that there is still reluctance to use the integrated FEP list in the subsequent scenario development from the

viewpoint of comprehensiveness. The NUMO FEP list and the integrated FEP list should be mutually complementary from the viewpoint of comprehensiveness and practicality. In this regard, the Review Committee suggests supplementing the description, including examples of application, of how the newly introduced FEP list will be effective.

Attribute analysis/Impact analysis

The Review Committee considers it appropriate that attribute analysis and impact analysis are introduced as methods for analyzing the impact on safety functions, which are key in scenario development, and comprehensive evaluation of the factors that may impact safety functions through state variables. On the other hand, since it is difficult to understand how scenarios are developed based on attribute analysis and impact analysis, the Review Committee suggests adding an explanation. While the safety functions and state variables were explained using buffer material as an example in the attribute analysis, the Review Committee suggests explaining them with a list rather than an example, since the attribute analysis is important for deriving scenarios. Furthermore, the Review Committee suggests clarifying the basis for selecting the phenomena in the impact analysis and the process for deriving scenarios through associated evaluation. Regarding the perturbation of the geological environment due to construction and operation, the effect of maintaining retrievability, and the impact of accident conditions during construction and operation on long-term safety, as discussed in Chapter 5, only a scenario in which the original state is recovered is considered although, in reality, they may affect the initial conditions of long-term safety assessment. The Review Committee suggests adding a more careful explanation of this as well as referring to the relationships with Chapter 5. It should be noted that, although not directly covered in this review, the Committee considers it extremely important to expand the information on various FEP lists in order to improve the comprehensiveness of attribute analysis and impact analysis, and, in particular, to continue research and analysis for FEPs considered to have a significant impact on safety functions.

Scenario categories

The Review Committee acknowledges that it is appropriate to classify scenario categories according to the likelihood of occurrence of events based on a risk-based assessment method, and this scenario classification is recognized as one of approaches to responding to uncertainties in the scenarios. In general, models and data are set based on a scenario, and uncertainties in models and data in the reference scenario are evaluated within the reference scenario category. Uncertainties are handled in the different scenario categories (alternative scenarios) in the NUMO Safety Case, which describes that “an alternative scenario includes variants, reflecting the uncertainties that should be considered based on scientific rationality with respect to the state of evolution of the repository and the evaluation models

and data set in the reference scenario". The Review Committee agrees with the concept in the NUMO Safety Case, however it is difficult to understand what uncertainty is handled in which scenario category. As a result, it is difficult to confirm whether the scenario categories developed in the NUMO Safety Case sufficiently cover the uncertainties to be considered. The Review Committee suggests restructuring the relationship between scenario classification and handling of various uncertainties from the viewpoint of consistency and adding explanations to the main report as necessary.

Reference scenario

The Review Committee places a high value on the reference scenario being set by combining conservative assumptions based on technological progress after the H12 and Second TRU Reports, aiming to represent the phenomena in the disposal system more reliably in a highly probable scenario. The Review Committee suggests, however, adding supplementary explanations and a rational basis for the following points related to the setting of the reference scenario.

- Assumption that perturbations considered to be caused by construction/operation and maintaining retrievability will not significantly affect the initial state for the long-term safety assessment
- Assumption that the effects of cement leaching of the mechanical plug together with that in the associated permeable layer can be ignored, although the NUMO Safety Case described that the cement leaching of the mechanical plug will occur and the cement component is likely to diminish
- Assumption that hydrogen gas generated due to corrosion of overpacks and PEMs will not significantly affect the safety functions
- Assumption that the initial state of the EDZ would be maintained over a long time period, while the state of EDZ is thought to evolve due to various processes such as cement interaction with tunnel support, Fe interaction with the PEM, and stresses resulting from buffer material swelling and overpack corrosion, and
- Handling of uplift and erosion in the reference scenario (in particular, the effect of uplift and erosion was not considered in T4).

Alternative scenarios

In the derivation of alternative scenarios, uncertainty factors, which were defined for each component of the disposal system, were difficult to understand in terms of their effect on the safety functions. The

Review Committee suggests adding an explanation as to why this structure has been selected. In addition, the NUMO Safety Case describes that a case combined alternative cases that was not considered because the probability of occurrence was very small; however, there are cases where the relevance cannot be completely ruled out depending on the process (for example, the effect of overpack corrosion products on glass dissolution rate and on sorption performance of the buffer material). The Review Committee suggests confirming again that these scenarios that should not be considered in the reference scenario and should be considered as alternative scenarios are sufficiently comprehensive in the NUMO Safety Case and expanding the explanation. In addition, while handling of analysis cases corresponding to the alternative scenarios is shown in the table, the Review Committee suggests, from the viewpoint of traceability/transparency, referring to the supporting reports that are the basis for the uncertainties such as “not considered” or “included in the base case” in the table.

Unlikely event scenarios

Although there is an explanation that unlikely event scenarios consider events that are very unlikely in assessing system robustness, the Review Committee suggests clarifying the screening criteria for the events in this scenario category because these are ambiguous. In addition, in the discussion of the latest regulatory standards for intermediate depth disposal, the unlikely event scenario category was not introduced and all scenarios other than the reference scenario were treated as alternative scenarios, which may have some influence on geological disposal. Given that a longer evaluation timescale is required for geological disposal, it is obvious that some kind of evaluation is necessary for unlikely external events. Therefore, the Review Committee suggests clarifying the difference from the alternative scenario category and adding an explanation to avoid misunderstanding.

3.4.4 Models

Nuclide migration analysis model

The nuclide migration analysis model in the NUMO Safety Case considers the effects of multiple faults and fractures in the site descriptive model and the geometry of the repository more realistically, which is significant progress from the previous generic safety assessment model. The Review Committee recognizes, however, that more detailed explanations are necessary regarding the differences from the model in the H12 Report and the Second TRU Report. In particular, the Review Committee suggests describing clearly the concept of selecting specific processes for handling flow field heterogeneity, the use of fundamental solutions, simplification with one-dimensional models and the connection between different scales, etc., as well as the entire workflow of safety assessment analysis.

Since nuclide migration in the engineered barriers and in the near-field (the host rock around the engineered barriers) was modeled on the same near-field scale, the amount of nuclides confined in the engineered barrier region (waste, container, buffer material) could not be distinguished from the amount of nuclides migrating within the near-field geological environment or panel-scale area. In order to show that most of the relatively short-lived radionuclides decay within the engineered barriers, the Review Committee suggests using the engineered barrier region as the minimum unit of spatial scale, and indicating the transfer rate from the engineered barrier region to the near-field scale as the "release term".

Regarding the nuclide migration analysis model using the particle tracking analysis method and multi-channel model, the Review Committee suggests adding explanations of the following items in order to improve reliability.

- Process of conducting nuclide migration analysis based on the results of particle tracking analysis (including processes for optimizing hydraulic transmissivities)
- Verification cases for the phenomenological model of mass transport (nuclide migration between fractures and matrix, mutual diffusion between media) set for the Neogene sedimentary rocks
- Objective of simplifying the nuclide migration model using the multi-channel model (reducing computational load, ensuring conservativeness, etc.)
- Explanation why the calculated flow velocity (transmissivity coefficient) is smaller than that obtained only by the fracture network model when the pressure head information obtained using the equivalent porous model is converted to the fracture network model.

The Review Committee suggests adding an explanation for the following aspects related to the nuclide migration analysis model.

- Definition of "release rate" in the dissolution of glass
- Nuclide migration process within the EDZ
- Relationship with the assumption that parallel plate models are used for all rocks and the micro-permeability conceptual model types constructed for each of the potential host rocks plutonic rocks, Neogene sedimentary rocks and Pre-Neogene sedimentary rocks shown in Chapter 3.

In the regional-scale model, it was described that ignoring fault migration resistance gave a robust safety assessment for long-term uncertainties related to the depth of the underground facility and changes in

fault/fracture length due to uplift and erosion. However, assuming that the repository approaches the ground surface due to uplift and erosion, the dose obviously becomes higher than that based on the above setting. The Review Committee suggests re-examining the dose, because there will be a change in the chemical environment around the repository, acceleration of nuclide migration in the engineered barriers due to increased groundwater flow and increased exposure due to stripping of contaminated soil.

Biosphere evaluation model

Regarding the evaluation of biosphere, the Review Committee acknowledges the appropriateness of conducting the evaluation based on global standards such as the IAEA coordinated research project BIOMASS. In addition, the latest dose conversion factors and migration parameters were used to determine the conversion factors to dose. The Review Committee places a high value on properly considering progress since the H12 Report and the Second TRU report. However, the Committee suggests describing this in the main report, because the basic conditions for biosphere evaluation described in the supporting reports (evaluation objectives, evaluation indicators, evaluation concept, disposal system, site conditions, source term and GBI, evaluation period, society, etc.), the concept of setting compartments and the process for deriving the conversion factors to dose represent core information that underpins the biosphere assessment.

3.4.5 Data

Nuclides for evaluation and radioactivity inventory

When selecting the nuclides for evaluation, the selections made in other countries are used as the basis. Fundamentally, however, it is necessary to provide a reasonable explanation based on the waste streams in Japan, and it is necessary to describe the calculation conditions in a traceable form when calculating the inventories. The inventories are calculated by a nuclide generation/decay calculation code, but it is necessary to show into which streams and to what extent they are distributed during the reprocessing process. Although these are described in the supporting reports, the Review Committee suggests that they be described in the main report because these parameters contribute significantly to the evaluation results, in particular for those in which significant conservative assumptions are made about the distribution of I-129 and Cl-36.

Nuclide migration data

The nuclide migration data adopted in the NUMO Safety Case are selected appropriately using the latest scientific knowledge and databases since the H12 Report. It should be noted that large values for both

the permeability and the diffusion coefficient (of some elements) of the buffer mass are used in the reference scenario because they are conservative. Since conservativeness of the parameters depends on the scenario, however, it is necessary to carefully explain how to handle this in the alternative scenarios for parameters where conservative values have already been set in the reference scenario.

Multi-channel model data

In the nuclide migration analysis in the NUMO Safety Case, an approximation method with a one-dimensional multi-channel model is used based on the results of mass transport analysis using three-dimensional particle tracking. The calculation method for the transmissivity assigned to each channel and the transmissivity data, however, are not described in the main report, nor in the supporting reports. The Review Committee suggests adding this information from the viewpoint of traceability of the nuclide migration analysis.

3.4.6 Assessment based on analysis of nuclide migration

Analysis results

As described in Section 3.4.4, in order to quantitatively demonstrate the performance of the engineered barrier system, the Review Committee recommends adding the migration rate (Bq/y) through the engineered barrier (buffer material) (or a value derived using the conversion coefficient to dose in the biosphere) in the dose rate evaluation results.

In this analysis, although likely processes and data were used based on the risk-based theory, more conservative values were set considering their uncertainty. There is a possibility that the peak of the total dose appears earlier than the period expected from the intrinsic performance of the geological disposal system. At the current stage when no site is specified, the Review Committee agrees to adopting such a method for dealing with uncertainty, however, it would like to point out also that the conservative setting of one scenario does not necessarily mean that it is conservative in other scenarios. This is particularly important for the case considering uplift and erosion, which was not covered in the NUMO Safety Case.

While the NUMO Safety Case resulted in U-233, a Np-237 daughter nuclide, giving a relatively high dose due to complexation because of the high bicarbonate concentration in sedimentary rock pore water, the Review Committee suggests explaining that the results were based on the assumption of high bicarbonate concentrations maintained in all of the migration paths, and that even a geological environment with such bicarbonate concentration yields a negligible dose no larger than 10 μSv/y.

The dose evaluation results for the alternative cases show quantitatively that they are sufficiently low compared to the dose guideline set in the NUMO Safety Case. However, it is necessary to avoid misunderstandings in interpretation. For example, fluctuation of the effective diffusion coefficient of the buffer material in the alternative cases has a small impact on the dose evaluation results. This indicates the robustness of the geological disposal system but does not mean that the low diffusivity of the buffer material is unnecessary.

It was explained that there is robustness in ensuring safety in the NUMO Safety Case since the analysis results for unlikely scenarios gave 1-20 mSv or less, which may be misleading for the reader. For example, it could be interpreted that safety would be ensured even if a volcano directly affected the repository, which may even raise doubts about the reliability of the entire analysis. The Review Committee suggests, in addition to clarifying the meaning of robustness, explaining carefully that the analyses were made very conservatively for events that have a very low likelihood of occurrence. Also, although it was a major premise that such events should be avoided in the site selection process, the reference dose value used for comparison with the goal of the implementation body was weighted by the probability of occurrence, and it should be noted that future efforts will be important for building a robust system that minimizes the impact of unlikely events over the long term. The same applies to the summary of the human intrusion results.

Comparison with previous safety assessments

The Review Committee places a high value on updating the nuclide migration analysis and dose evaluation based on the H12 Report and the Second TRU report as the technological basis for the long-term post-closure safety assessment in the NUMO Safety Case, referring to the latest research and development results and the progress of science and technology. On the other hand, the dose evaluation results presented in the NUMO Safety Case are clearly different from the previous results. In particular, in the dose assessment for the reference scenario for vitrified waste, there is a notable difference in that the NUMO Safety Case shows that Se-79 (plutonic rock), I-129 (Neogene sedimentary rock with low Cl^- concentration groundwater) and U-233 (Neogene sedimentary rock with high Cl^- concentration groundwater) are dominant, while the dominant nuclide in the H12 Report was Cs-135. There was also a difference in the time when the maximum dose would occur in the reference scenario in both cases. The Review Committee suggests analyzing the reasons for the differences from previous safety assessments and clarifying changes compared to previous assessments and related uncertainties.

Safety assessment towards stepwise site selection

The NUMO Safety Case discusses the investigation and evaluation of the geological environment, repository design and prospects for safety assessment in the current situation where no site is specified. In the future, once a site has been identified, the safety assessment will be performed using the basic information and evaluation technologies indicated in the NUMO Safety Case. However, further considerations will be necessary in the future regarding how the safety assessment will be performed using the information refined through stepwise investigations, to what extent the safety assessment will be achieved based on the quality, quantity and uncertainty of the information obtained at each investigation step, and how to optimize safety in cooperation with geological investigations and engineering design.

In addition, the dose evaluation in the NUMO Safety Case resulted in values below the dose criteria in all scenarios. From this, it was considered that existing processes and natural phenomena have an extremely low possibility of compromising the safety of geological disposal. However, the demonstration of the safety of geological disposal is not established based on this evaluation. Rather, to improve the reliability of future NUMO safety cases, it is necessary to deepen the understanding of the safety functions that should be further strengthened, to identify processes and parameters that contribute to safety, and to clarify issues for reducing and minimizing uncertainty.

The Review Committee suggests that the above points should be considered and that the core messages of the safety assessment should be described more clearly based on the role of safety assessment in future site selection.

4. Reliability as a safety case

4.1 Outline of review

In the Review Committee, the detailed technical review of " reliability as a safety case" presented in Chapter 7 of the NUMO Safety Case, from the specific viewpoints described below, related to "the validity as an entire safety case" presented in Chapter 1 of this report:

- Consistency of the context: Is each chapter consistently developed based on the basic concept for ensuring safety (Chapter 2) specified for the Safety Case, and are the general conclusions of the Safety Case properly derived in Chapter 7 based on the conclusions of each chapter?
- Validity of the descriptions: Are the progress and differences from the H12 Report and the Second TRU Report evaluated and is the technical basis specified? Are there any omissions of important elements required for a safety case at the present stage, considering the characteristics and situation of Japan? Furthermore, is the applicability as a basic form of the safety case after site selection demonstrated?
- Recognition of future tasks: Is there a clear distinction between site-independent universal issues and site-specific issues, and is the research and development to be implemented in the future described?
- Compatibility within Japan and abroad: Is the intent behind preparing the NUMO Safety Case consistent with the government's basic policy on final disposal, is it consistent with international standards and similar precedents in other countries, is the technical terminology consistent with international definitions, and is the report written in Japanese that can be understood correctly?
- Integration as a report: Are the main conclusions of the NUMO Safety Case presented in the main report clear and intelligible, is the basis for the conclusions traceable and objective?

Based on these viewpoints, the Review Committee considered the opinions submitted by each member regarding reliability as a safety case. The results of the review are compiled as “reliability as a safety case at the current stage” and “relevance as a basic form of safety case after site identification[1]”. Furthermore, the tasks until site identification and the long-term R&D up to and after site identification are compiled as “Future tasks and R&D for the next stage”.

The general view of the Review Committee is as follows:

- The Review Committee confirms the following: the NUMO Safety Case is structured to properly lead to the general conclusions reached, and is consistent with the defined context: considering the geological characteristics and social conditions of Japan, there were no omissions of

[1] “After site identification” refers to the stage after a specific site including the literature survey area has been identified.

important issues required for a safety case to be developed at the present time. The report is consistent with Japan's basic policy on final disposal and refers to international standards and similar precedents in other countries. The technical terminology is consistent with international definitions, and the Japanese can be understood correctly. In addition, the main conclusions of the report are presented clearly and, considering the supporting reports, there is traceability and objectivity in the basis for the conclusions. There is also a clear distinction between site-independent and site-specific aspects, and the research and development to be conducted in the future is described.

- Following the above confirmation, the Review Committee agrees that the NUMO Safety Case is reliable as a safety case at the current stage and relevant as a basic form for a safety case after site identification, with consideration of various siting environment conditions. Furthermore, to assure gradual improvement of the reliability of future safety cases, required R&D from a long-term perspective is covered in “future tasks and R&D for the next stage”.

4.2 Reliability as a safety case at the present stage

· The NUMO Safety Case describes the technical reliability as a safety case at the present stage from the following five viewpoints;

1) Demonstrating technologies for constructing a repository that satisfy the required safety functions

2) Ensuring the safety of geological disposal in Japan's geological environment

3) Ensuring reliability as a safety case

4) Making clear future efforts to improve reliability, and

5) Showing the possibility of using the NUMO Safety Case as a basic form of safety case to be updated after a site has been specified.

· The descriptions are in accordance with “basic concept for ensuring safety” presented in Chapter 2 of the NUMO Safety Case, which outlined the assessment basis for the safety case. The site descriptive model, design/construction/operation technologies for the repository, and safety assessment before and after closure are summarized in Chapters 3 to 6 of the NUMO Safety Case. Also described are the progress since the H12 Report and the Second TRU Report, ensuring retrievability, and efforts to improve reliability in the future. These were described here again.

· In the NUMO Safety Case, the basic concept for site selection in Japan is shown as a three-stage siting process, and requirements for the geological environment were described for each investigation stage. In addition, the basic policy for site selection requirements and standards and factors affecting the safety functions are presented. In other words, the basic concept of NUMO is presented

concerning selection requirements (statutory requirements) for the three stages of investigation stipulated in the Final Disposal Act, as well as the requirements for clarifying unfavorable and preferable areas shown in the "Nationwide map of scientific features for geological disposal".

- In addition, the NUMO Safety Case describes current efforts to ensure reliability as a safety case, how to ensure quality and how to deal with uncertainty by applying NUMO's quality management system. Furthermore, in the safety assessment of disposal systems, in addition to evaluation using dose as an indicator, multi-faceted studies are also conducted using natural analogues and complementary indicators such as concentration, time and flux. The importance of natural analogues and complementary indicators is agreed internationally. The evaluation based on these various indicators in the development of the safety case could be used as objective and user-friendly information for decision-making to advance to the next stage in a long-term geological disposal project. The Review Committee acknowledges that it is also the preferred approach in terms of ensuring the safety of geological disposal.

- The Review Committee acknowledges that the NUMO Safety Case is structured appropriately to lead to the general conclusions of the Safety Case with contextual consistency and that, considering the geological characteristics and social conditions of Japan, there is no omission of important issues required for a safety case at the present time.

- In addition, the Review Committee acknowledges that the NUMO Safety Case is consistent with Japan's basic policy on final disposal and refers to international standards and similar precedents in other countries. The Review Committee confirms that the technical terminology is consistent with international definitions, and that the Safety Case is written in understandable Japanese. In addition, the main conclusions are shown clearly, and the supporting reports provide traceability and objectivity as the basis for the conclusions.

- On the other hand, the term "long-term" is an issue that is interpreted differently by experts in the context of geological disposal. In the report, there is a description that makes it easy to understand a timescale of "long-term over 100,000 years in the future"; however, there are many descriptions in which the timescale is vague, such as "long term after closure", "over a long term", "long-term evolution of the geological environment". The Review Committee suggests rewriting the descriptions to respond to the question of how long does "long-term" mean so that readers can understand the concept, while maintaining logical consistency between each chapter in the NUMO Safety Case.

- The NUMO Safety Case also describes the development of technology for integrating information into the site descriptive model. It is described that, by repeating the investigation and evaluation processes in the geological investigations, the uncertainty associated with understanding the distribution of spatially inhomogeneous characteristics such as faults and fractures is gradually reduced. Therefore, the Review Committee suggests providing a careful description from a higher-level viewpoint since stepwise reduction of such uncertainties is important for improving the reliability of the NUMO Safety Case.

- For dealing with uncertainties associated with the site descriptive model, it was shown that the data used for setting the site descriptive model were derived from an open database in such a way as to ensure the quality of the input data for design and safety assessment. The Review Committee acknowledges that management to ensure the traceability is important for the quality assurance of handled data, covering the original data referred to in the development of the database, information such as specific conditions regarding the process for developing the database, and the data after processing.

- In order to demonstrate the reliability of the Safety Case, with reference to legal requirements and requirements/criteria related to scientific characteristics as criteria for determining site suitability, NUMO provided "criteria for judging suitability" in selecting preliminary investigation areas. The Review Committee recognizes that this basic concept is important and suggests describing it more clearly.

- The Review Committee considers it desirable to describe the concept of retrievability clearly from the viewpoint of the reliability of the Safety Case.

- The Review Committee considers it desirable to confirm the meaning and effectiveness of supplementary indicators such as concentration, time, and flux which complement dose evaluation and to explain carefully the relationship with related parameters such as biosphere concentrations and flux.

4.3 Validity as a basic form for a safety case after site identification

- In the NUMO Safety Case, the basic concept for site selection is shown as a three-stage site investigation process. The report provides the proposed content to be included in the safety case for each stage by clarifying which investigation stage each requirement for the geological environment corresponds to. Therefore, the Review Committee agrees that the NUMO Safety Case, which considers various site environmental conditions, could be used as a basic form of safety case following site identification.

- The NUMO Safety Case raises the issue of developing technologies for modeling geological environment characteristics because the geological environment of Japan is located in a tectonically active zone which evolves over time. It describes that, in the future, it is planned to improve the reliability of modeling technology for long-term evolution of geological environment characteristics. Furthermore, it was pointed out that there is not much information about Pre-Neogene sedimentary rocks. Accordingly, the Review Committee suggests describing these issues in the summary with the aim of being able to say "basic technology is in place".

- NUMO proposed issues to be addressed in the future to improve reliability. The Review Committee considers that, in order to clarify the objectives and goals, it is important to indicate by which site

investigation stage each problem and issue should be solved. This is also linked to when the safety case will need to be updated. The Review Committee also points out that there was an unsupported step to the current statement that “the items to be included in the NUMO Safety Case are clear” in the summary.

· The Review Committee suggests that the relationship between the basic form of the safety case and the development of a safety case at each stage of site selection should be described more clearly. For example, describing how the "rough safety assessment" in the literature survey stage will be performed by developing the basic form of the safety case is important because it explains how to customize the basic form according to the quality and quantity of information obtained at that stage. Such a viewpoint is considered to contribute to clarifying the relationship between the basic form of the safety case shown in the NUMO Safety Case and the safety case at each stage of site selection.

4.4 Issues to be solved in the next stage and future research and development

· The Review Committee acknowledges that, in the NUMO Safety Case, a distinction is made between site-independent issues and site-specific issues, and the research and development to be conducted in the future is outlined.

· Improving the reliability of the safety case should continue in the future, and NUMO is in a position to lead research and development to be carried out in this respect. In terms of objectives, it is important, together with clarifying the distinction between generic and site-specific aspects, to identify the research and development activities to be addressed in the future and to prepare the infrastructure for conducting the research. In addition, after a site has been identified, the NUMO Safety Case will need to be continuously updated based on scientific knowledge from appropriate site investigations and evaluations. The Review Committee confirms that the NUMO Safety Case was prepared on the basis of the current technical foundation and with future efforts in mind.

· As a future issue, it is also important to identify what is currently lacking in the safety case for the stage where there will be narrowing down to actual sites. From this point of view, the NUMO Safety Case showed that plutonic rocks and Neogene sedimentary rocks had been systematically investigated in URLs (Mizunami Underground Research Laboratory and Horonobe Underground Research Center), but that the information on Pre-Neogene sedimentary rocks that make up accretionary complexes was limited. According to the “Nationwide map of scientific features for geological disposal”, Pre-Neogene sedimentary rocks may have favorable characteristics and there is a possibility that they may be distributed in coastal areas which are considered preferable in terms of transportation. For this reason, the NUMO Safety Case recognizes the need to acquire data for model construction in the future. The Review Committee agrees that this recognition is an urgent issue for improving the reliability of future safety cases. It should be noted that, since it is thought that there are specific problems associated with the case of constructing the repository beneath the seabed near

the coast, the Review Committee suggests adding this case from the viewpoint of repository design and engineering technology.

- The NUMO Safety Case did not consider that safety is a site-dependent issue as a basic stance. However, concerning operational safety before the repository is closed, there is safety independent of the site and that dependent on the site. For example, securing the distance from the facility to the site boundary is site-dependent, but accident scenarios such as equipment failure and fire are events independent of the site. Such a viewpoint contributes to understanding the uncertainties even at the present stage when a site is not specified. Considering that the operational period of the geological disposal project will be longer than normal experience of developing tunnels and mines, it will be more important in the future to improve the reliability of the safety case by considering the site-independent and site-dependent issues from the above viewpoint.

- Generally, in dealing with uncertainty in the development of the site descriptive model, the uncertainty in investigation and assessment of a geological environment is dependent on the geological environment itself and on measurement techniques, etc. At the present stage, it is difficult to deal with the mutual uncertainties uniformly and representative characteristic values were conservatively set for each potential host rock. In order to improve the reliability of the safety case, the Review Committee suggests examining how to deal with the uncertainty in site characterization and evaluation methods. In addition, to improve the reliability of models and evaluations, it will be necessary to continue R&D according to the type of uncertainty.

- A site descriptive model developed by probabilistically generating faults and fractures is considered applicable for evaluating the feasibility of geological disposal or to proceed to the next stage of the site selection investigations. For the final safety assessment, however, the location and size of large faults and fractures must be determined by investigations up to that point. In addition, when using a model based on probabilistically generated faults and fractures in the final safety assessment, it is necessary to confirm the sufficiency of the data for developing the model and the effectiveness of the model for safety assessment. Such handling of faults and fractures will be an important issue in the future when site selection is conducted based on the results of safety assessment using a site descriptive model developed for the site. The Review Committee agrees that the NUMO Safety Case considers these approaches. However, the Review Committee suggests adding a description of what kind of future investigations will reduce uncertainty regarding the distribution of faults and fractures in different stages.

5. Concluding statement

The Review Committee reviewed the technical reliability of the descriptions in the NUMO Safety Case compiled as a safety case at a time when no site has been specified, and summarizes the results in this review report.

In the NUMO Safety Case, the comprehensive technical results are compiled based on information acquired from R&D in the underground research laboratories, etc. since the H12 Report and the Second TRU Report.

In its Safety Case, NUMO describes the following: the technical basis for acquiring geological environment information required for site selection has been established; the site descriptive model reflecting the characteristics of the deep underground environment in Japan is presented; the technical basis for designing a repository that meets requirements is established, and the technical basis for conducting safety assessments before and after repository closure is established.

Overall, the NUMO Safety Case is presented with a sufficient level of scientific and technical reliability as a safety case for the generic stage of site selection, and is consistent with the international framework. The Review Committee agrees that NUMO has appropriate and sufficient technical capabilities and methodologies for investigating site characteristics, engineering design and safety assessment to be conducted in each stage of the site selection process in the future, and is an organization with technical reliability.

In order to select a site with the geological conditions required to isolate and confine radioactive waste over long times, NUMO has developed a site descriptive model unique to Japan, reflecting the characteristics of the geological structures of the Japanese archipelago which is located at the convergence boundary of multiple tectonic plates. In the current stage, before selecting sites by integrating the geological environment information obtained from investigations in the future, and the prospect of design/construction and ensuring safety based on this information, the establishment of the above-mentioned site descriptive model unique to Japan by NUMO is an important achievement worthy of special mention.

The Review Committee hopes that the results of this review will contribute considerably to improving the scientific and technical reliability of the NUMO Safety Case. At the same time, it is hoped that the NUMO Safety Case will promote trust in NUMO among the public, and will encourage discussions on geological disposal.

For future developments, the Review Committee is concerned with how to make the general public aware of the NUMO Safety Case. In terms of public awareness, it is considered that the descriptions in the report should be communicated by NUMO to experts in geological disposal, then to general scientists and then to the general public through the media.

In considering such communication, it is necessary to recognize that the NUMO Safety Case is has been prepared for experts with some knowledge of geological disposal. For traceability, the report is structured as an overview, main report and supporting reports, and all references are easily searchable and linked to subordinate information. It can be said that a very effective approach has been taken in the documentation of the Safety Case, which has enormous amount of information. Regarding transparency, the descriptions in the report are structured in the form of safety case and are logically clear. Therefore, for experts in geological disposal, the NUMO Safety Case is sufficiently transparent and traceable.

However, it should be remembered that a document that is transparent to experts in geological disposal does not necessarily become a document that is transparent to general scientists and engineers. This is the fate of professional technical reports.

Transparency in a safety case refers to attributes such as being written clearly and being understandable to the intended reader. From this perspective, the NUMO Safety Case can be considered sufficient for the geological disposal community, but will not necessarily be appropriate for the general scientific and technical community. Even in the Review Committee, which included experts considered to be involved in geological disposal, there were often discussions where there was no consensus.

One reason for this is that geological disposal is a technical undertaking that requires the integration of a wide variety of technical fields and the underlying methodology and terminology are different in these fields. The second reason is that geological disposal is based on unique concepts.

For example, in the disposal project, the concept is that, after the waste is released from active human management by “disposal”, the status becomes passive and the conditions are controlled by the natural environment and the waste can be isolated and confined for a long time. This seems unfamiliar to many people other than disposal experts.

The concept of safety assessment after the repository is closed is unfamiliar to the general public. Predictive methods are the only way to understand the future status of geological disposal systems and radionuclide migration behavior. Thus, there is always uncertainty here, and a complete description is essentially impossible. Recognizing this uncertainty, a scenario that assumes the future state of the system is established, and an analytical model is applied along with this scenario to evaluate the exposure dose. This evaluation method is sufficiently effective for safety assessment, and it is considered that safety is reasonably demonstrated. This way of thinking is unique to the safety assessment of geological disposal.

The detail and reliability of the models will improve as the investigations of the geological environment progress stepwise. The degree of improvement will be determined iteratively by the effectiveness of the repository design and the safety assessment to which the site descriptive model is applied. In addition, while considering the feasibility of the entire disposal system under the assumed geological environment represented in a site descriptive model updated according to the progress of site characterization, the performance required for the repository and the feasibility of design and construction are evaluated. Furthermore, in the safety assessment, the uncertainty in the prospect of ensuring safety with respect to

the geological environment and repository design is reduced at each stage. Such a stepwise approach based on cooperation among the areas of geological investigations, repository design, and safety assessment is unique to geological disposal.

In the future, when using the NUMO Safety Case to promote communication with the scientific and technical community (other than geological disposal experts) and with other people, explaining that the above-mentioned concepts are unique to geological disposal is important.

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