NUMO
原子力発電環境整備機構

NUMO-TR-13-05

Safety of the Geological Disposal Project 2010

Safe Geological Disposal Based on Reliable Technologies

English Summary

July 2013

Nuclear Waste Management Organization of Japan（NUMO）

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1 . Introduction

1.1 Background and objectives of the geological disposal project

In June 2000, the Act on Final Disposal of Specified Radioactive Waste (hereafter the Final Disposal Act) came into force. The Final Disposal Act is based on the policy document issued by the Japan Atomic Energy Commission (AEC) in 1998 entitled "Basic Policy for the Disposal of HLW" and the Second Progress Report on Research and Development for the Geological Disposal of HLW in Japan (JNC, 2000a-e; hereafter H12 Report) of the Japan Nuclear Cycle Development Institute (JNC) (now the Japan Atomic Energy Agency (JAEA)); the latter compiles the achievements of R&D conducted over more than 20 years since 1976.

Based on the Final Disposal Act, the Nuclear Waste Management Organization of Japan (NUMO) was established in October 2000 as the implementing organization for geological disposal of high-level radioactive waste (HLW). The Final Disposal Act was revised in 2007 and based on this, some types of long-lived, low heat-generating waste were also included as waste destined for geological disposal and thus fell within the remit of NUMO. These wastes are referred to as TRU waste for geological disposal (hereafter TRU waste).

The site selection process specified in the Final Disposal Act consists of an initial literature survey phase and three subsequent stages: selection of Preliminary Investigation Areas (PIAs), selection of Detailed Investigation Areas (DIAs) and selection of the repository site[1]. In December 2002, NUMO issued a nationwide call for volunteer municipalities to initiate the repository siting process.

Since its establishment in 2000, NUMO has been developing the technologies required for safe implementation of the disposal project and has carried out a range of activities aimed at improving awareness of the project and associated public relations programs. Despite these efforts, however, no application has been received as yet from a volunteer municipality and no literature survey has been initiated for a specific site. Together with the national government, the electricity utilities and other relevant organizations, NUMO is now making its best efforts to obtain public acceptance for starting literature surveys.

In view of this situation, the Policy Evaluation Committee of the Japan Atomic Energy Commission proposed in 2008 that NUMO should publish a report demonstrating the technical feasibility of safe implementation of geological disposal. The report was to be reviewed by external, independent academic institutions and revised and updated periodically to reflect state-of-the-art knowledge

1 In this report the following stage names are used: Literature Survey stage (LS stage) for "selection of Preliminary Investigation Areas (PIAs)" , Preliminary Investigation stage (PI stage) for "selection of Detailed Investigation Areas (DIAs)" Detailed Investigation stage (DI stage) for "selection of the repository site".

(AEC, 2008).

Against this background, NUMO issued a report in September 2011 entitled “Safety of the Geological Disposal Project 2010 - Safe geological disposal based on reliable technologies” (referred to hereafter as the NUMO 2010 Technical Report) (NUMO, 2011e). This summary report presents the major conclusions of the report.

1.2 Structure of the NUMO 2010 Technical Report

The present report effectively has the same structure as the NUMO 2010 Technical Report, with the specific technologies being described in chapters 2 to 8, and is divided into two main parts: project implementation chapters that present the policies for ensuring the safe implementation of the geological disposal project and technology chapters that present the progress made through development of scientific knowledge and the technologies that support the safety concepts for geological disposal since the H12 report, as well as the status of preparations for the implementation of the project (Table 1-1).

Project implementation is described in chapter 2 – ‘background to the geological disposal project’, chapter 3 – ‘strategy for ensuring safety’ and chapter 4, ‘staged project implementation’. Chapter 2 presents basic information on the geological disposal program. Chapter 3 presents the basic strategy and component policies for ensuring the safety of geological disposal, with respect to both long-term post-closure safety and safety during the duration of the project. The strategy is based on staged implementation that allows the risks and uncertainties associated with a long-term undertaking extending over approximately 100 years to be addressed. Chapter 4 presents safety, R&D and confidence-building roadmaps that illustrate how the policies outlined in chapter 3 are realized during staged project implementation.

The technologies developed are described in chapter 5 – ‘investigation and evaluation technologies for the geological environment’, chapter 6 – ‘the technologies for design, construction, operation and closure of the repository’ and chapter 7 ‘the technologies for long-term safety assessment and technical activities during the LS and PI stages.

The technology chapters describe the systematic development of geological disposal technologies for ensuring long-term post-closure safety and safety during each project stage as described in the project implementation chapters, together with specific examples. A description of the technologies required during the LS and PI stages is also provided. In chapter 8, the procedures for safe implementation of the project with coordination and integration of the technologies described in chapters 5, 6 and 7 are presented.

The discussion of the progress in R&D in the technology chapters is focused on HLW. A separate report documents the details for TRU waste (NUMO, 2011a) and thus only key points are addressed in this report.

The Appendix documents the progress of R&D since the H12 report.

Two cases can be envisaged for initiating literature surveys (LS): voluntary application by municipalities or a request made by the national government to municipalities to come forward. Unless otherwise specified, this report assumes that the literature surveys are initiated by an application from a municipality.

The organizations, legal and regulatory framework and reports relevant to the geological disposal project are listed in Table 1-2.

Table 1-1 Structure of the 2010 Technical Report and the present summary report

	Chapters	Title	Content
	1	Introduction	Background, objectives and overall structure of the report
Project implementation	2	Background to the geological disposal project	Goals for ensuring safety and policies/strategies for achieving the goals Policy 1 : Staged and flexible project implementation based on iterative confirmation of safety Policy 2 : Project implementation based on reliable technologies Policy 3: Technical activities for building confidence in NUMO's safety concept
	3	Strategies for ensuring safety	
	4	Staged project implementation	
Technology	5	Investigation and evaluation technologies for the geological environment	Progress in the development of technologies for the investigation/evaluation of the geological environment
	6	Technologies for design, construction, operation and closure of the repository	Progress in the development of technologies for establishing engineering measures
	7	Technology for long-term safety assessment	Progress in the development of technologies for long-term safety assessment
	8	Technical activities during the Literature Survey and Preliminary Investigation stages	Technical activities to be conducted during the LS and PI stages
	9	Conclusions	Overall summary

Table 1-2 Organizations, legislation and regulations and reports relevant to the geological disposal project

	Full name	Acronym
Organizations (domestic)	Nuclear Waste Management Organization of Japan	NUMO
	Japan Atomic Energy Agency (formerly the Japan Nuclear Cycle Development Institute)	JAEA (JNC)
	Radioactive Waste Management Funding and Research Center	RWMC
	Central Research Institute of Electric Power Industry	CRIEPI
	National Institute of Advanced Industrial Science and Technology	AIST
	National Institute of Radiological Sciences	NIRS
	Federation of Electric Power Companies of Japan	FEPC
	Coordination Executive for Fundamental R&D on Geological Disposal	Coordination Executive
	Atomic Energy Commission of Japan	AEC
Organizations (overseas)	International Atomic Energy Agency	IAEA
	International Commission on Radiological Protection	ICRP
	Organisation for Economic Cooperation and Development / Nuclear Energy Agency	OECD/NEA
	Svensk Kärnbränslehantering AB (Sweden)	SKB
	National Cooperative for the Disposal of Radioactive Waste (Switzerland)	Nagra
	Agence Nationale pour la Gestion des Déchets Radioactifs (France)	ANDRA
	Nuclear Waste Management Organization (Canada)	NWMO
Laws & regulations	Act on Final Disposal of Specified Radioactive Waste	Final Disposal Act
	Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Nuclear Reactors	Nuclear Reactor Act
	Final Disposal Plan for Specified Waste	Final Disposal Plan
Reports	Second Progress Report on Research and Development for the Geological Disposal of HLW in Japan (JNC, 2000a to e)	H12 Report
	Second Progress Report on Research and Development for TRU Waste Disposal in Japan (FEPC and JNC, 2005b)	Second TRU Report

2 . Background to the geological disposal project

This chapter aims to improve the understanding of the need for geological disposal and awareness of NUMO's geological disposal program by providing a brief explanation of the relevant radioactive wastes, how the waste will be disposed of, the unique nature of the geological disposal program in Japan and activities ongoing in other countries.

2.1 Radioactive wastes destined for geological disposal

Geological disposal ensures long-term safety through a system of multiple engineered barriers constructed in a stable geological environment (natural barrier) at a sufficient distance from the human environment. Based on the AEC report "Basic Policy on the Disposal of HLW" (AEC, 1998) and JAEA's H12 Report, the Final Disposal Act entered into force in June 2000 and specifies systematic measures for the promotion of geological disposal of HLW. The Final Disposal Act was revised in 2007 to include TRU waste. A brief description of the radioactive wastes destined for geological disposal as specified in the Final Disposal Act is provided below.

2.1.1 High-level radioactive waste (HLW)

The reprocessing of spent fuel involves dissolving the fuel with nitric acid and extracting the uranium and plutonium using an organic solvent (tributyl phosphate or TBP), leaving highly radioactive residues containing mainly fission products and transuranic nuclides as waste (referred to as high-level radioactive liquid waste). The highly radioactive waste is mixed with glass, melted at high temperature, poured into stainless steel canisters and cooled to form vitrified HLW (see left-hand side in Figure 2-1).

2.1.2 Low-level radioactive waste for geological disposal (TRU waste)

TRU waste is low-level radioactive waste generated by the operation and decommissioning of reprocessing and MOX (mixed oxide fuel) fuel fabrication plants, containing long-lived nuclides above specific concentrations.

NUMO is responsible for TRU waste for geological disposal. Typical TRU waste packages are shown on the right-hand side of Figure 2-1; TRU waste groups and their characteristics are presented in Figure 2-2.

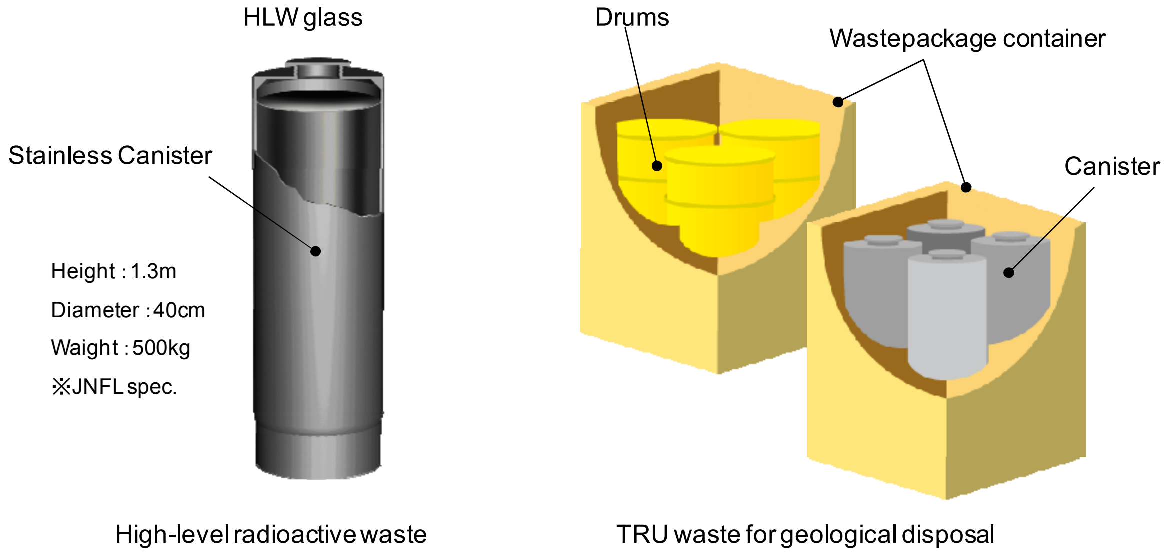


Figure 2-1 HLW and TRU waste forms

Description	**Iodine adsorbent** Silver adsorbent Effluent Intake Adsorbent to remove radioactive iodine	**Hull&endpieces** Hull Sectioning & compression	**Concentrated solution, etc.** Nitric acid solution waste Mortar, etc. Pellet Dried pellet	**Organic waste** Rubber gloves (incineration / compression) **Non-combustible waste** Tools Metal pipes
Waste package image(e.g.)				
Features	• Radioactive iodine (I-129) is included • Cemented waste form	• Relatively high heat power • Radioactive carbon (C-14) is included	• Nitrate is contained • Solidified waste with e.g., mother or bitumen	• Incineration ash or non-combustibles • Solidified waste with cement, etc.
Group	1	2	3	4

Figure 2-2 TRU waste groups and their characteristics
(based on the report by the Advisory Committee for Natural Resources and Energy)

2.2 Specific features of the geological disposal program in Japan

Since 2000, when NUMO was established, the circumstances surrounding the geological disposal project have changed, including revisions made to the Final Disposal Act and the Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors (hereafter the Nuclear

Reactor Act). In line with these changes, the specific features of the geological disposal program in Japan are discussed in this section.

2.2.1 Three-stage site selection process and volunteer approach to siting

The site selection process consists of three stages: selection of Preliminary Investigation Areas (PIAs), selection of Detailed Investigation Areas (DIAs) and selection of the repository site, as defined in the Final Disposal Act (Figure 2-3).

Before initiating literature surveys (LS) for the selection of PIAs, NUMO has been soliciting volunteer municipalities nationwide as potential areas for carrying out investigations for final repository sites since 2002 and has been involved in a range of activities aimed at encouraging volunteer applications. This approach recognizes the importance of independent judgment by local communities in the context of the public nature of the geological disposal project and the project duration extending over approximately 100 years.

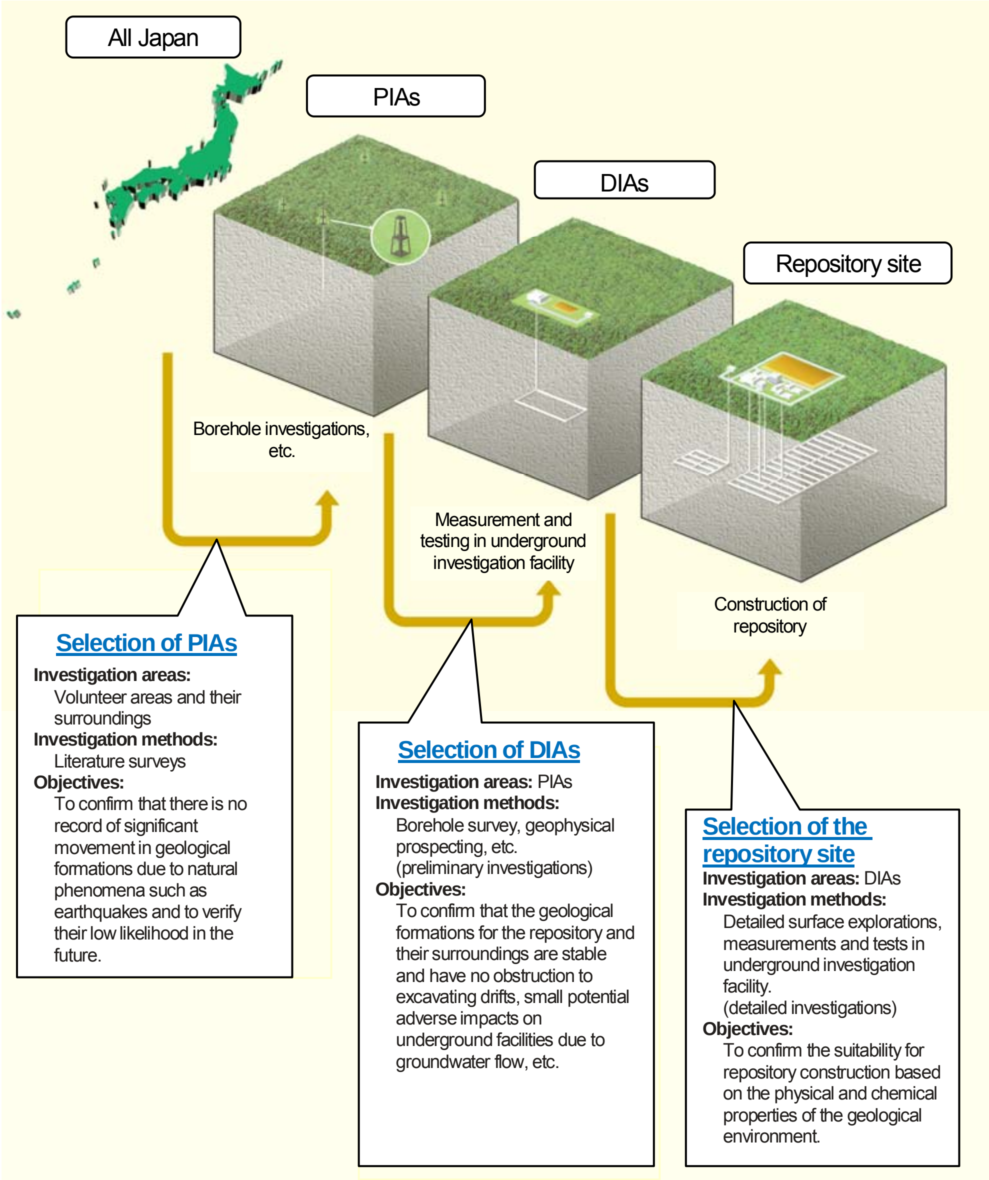


Figure 2-3 Three-stage site selection process (NUMO, 2009b)

NUMO modified the solicitation process to include both HLW and TRU waste[2] in 2008 (NUMO, 2009a-d). Applicants may choose to apply as a potential disposal site for either or both of these waste types.

In accordance with the recommendations made in the Interim Report of the Sub-committee for the Safety of Radioactive Waste Disposal published in November 2007 (Advisory Committe for Energy, 2007), the national government was permitted to request municipalities to come forward for the implementation of literature surveys.

[2] Disposal of HLW and TRU waste at the same site is termed "co-disposal."

2.2.2 Repository dimensions and engineered barriers

According to the Final Disposal Plan (METI, 2008), the size of the repository has been set assuming the number of vitrified HLW containers for emplacement to be 40,000, which corresponds to the accumulated nuclear power generation up to around 2020. The HLW containers will be emplaced with sufficient spacing to avoid any significant impact on the disposal system from high heat generation, particularly during the period shortly after emplacement, although the heat generation from the waste will decay with time. The area of the repository is expected to be 5-6 km^2, but it may be larger depending on the geological conditions at the selected site.

For TRU waste, the repository size has been set assuming the total volume of waste packages to be 19,000 m^3, considering the operation and decommissioning plans for spent fuel reprocessing plants and other relevant facilities. Since TRU waste includes a variety of waste forms and properties with low heat generation for the majority of the waste, it will be emplaced in large cross-section disposal vaults, resulting in a smaller repository area of approximately 0.25 km^2.

Figure 2-4 shows images of the underground facilities for co-disposal of HLW and TRU waste constructed at coastal and inland sites.

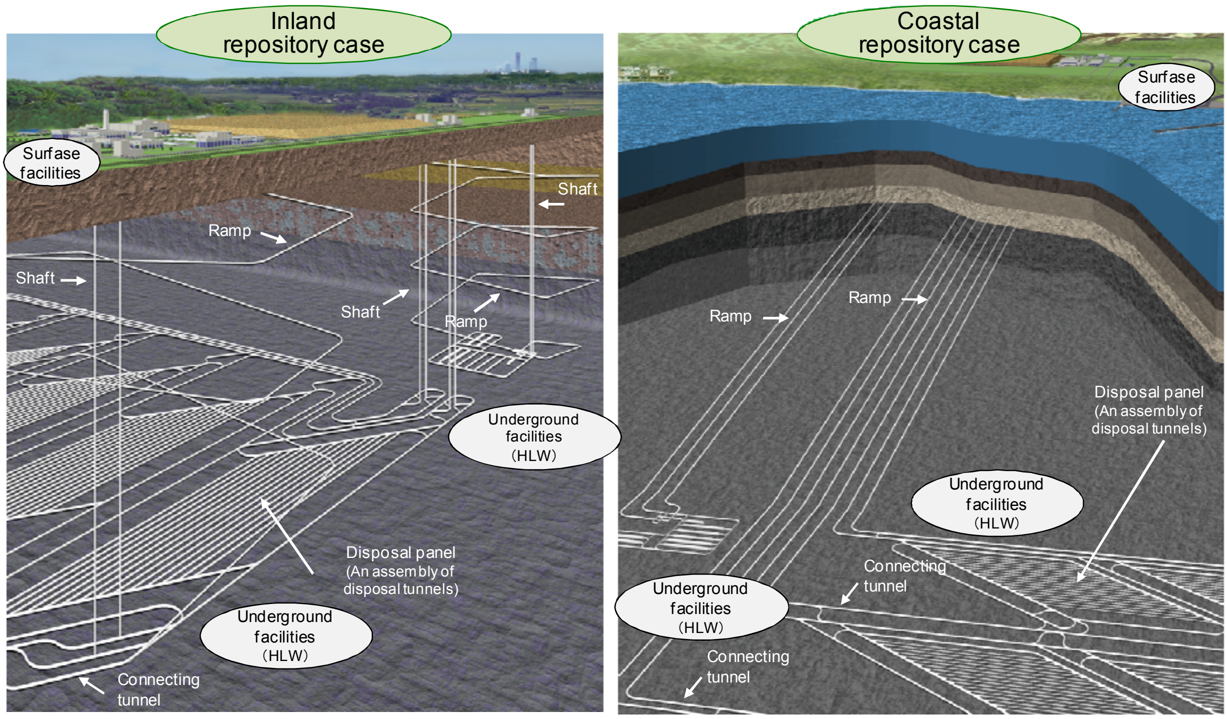


Figure 2-4 Examples of underground facilities for co-disposal of HLW and TRU (NUMO, 2009a)

The basic configuration of the engineered barriers for geological disposal is shown in Figure 2-5 and Figure 2-6 for HLW and TRU waste respectively. For the disposal of HLW, the vitrified waste is sealed in an overpack (metal container) and surrounded with a buffer consisting mainly of natural bentonite. For the TRU waste, the engineered barriers are designed differently for each of the four groups depending on the characteristics of the waste. The basic configuration consists of the waste form, buffer and backfill for Groups 1 and 2 and waste form and backfill for Groups 3 and 4 (see Figure 2-2 for a description of the waste groups).

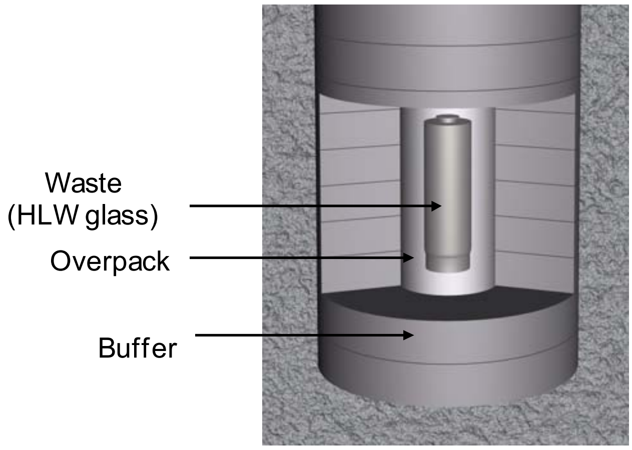
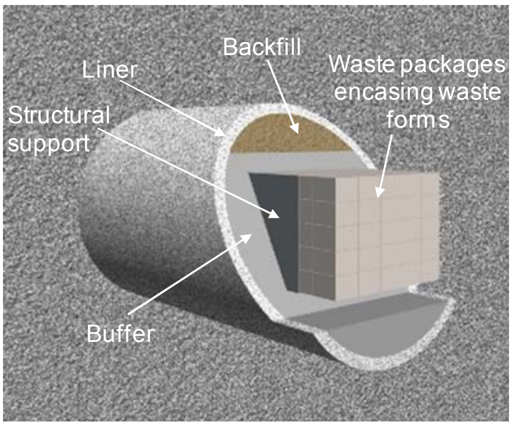
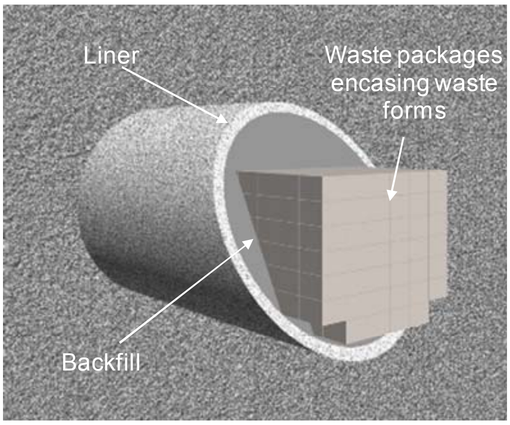


Figure 2-5 Basic engineered barrier system for the disposal of HLW



(a) Group 1 & 2



(b) Group 3 & 4

Figure 2-6 Basic engineered barrier system for the disposal of TRU waste

2.3 Activities in other countries

In countries with nuclear energy programs, geological disposal has also been identified as the best option for management of high-level waste and the projects are at different stages.

As of July 2013, Finland and Sweden have both selected a repository site each. In Finland, Olkiluoto has been selected and the application for a construction license was submitted in December 2012. In Sweden, a potential repository site was selected at Forsmark in June 2009 and an application for the siting and construction of the repository was submitted in March 2011. In France, a potential repository site has been identified in an area near Bure, where the underground rock laboratory (URL) is located. In addition to these programs, preliminary siting procedures are underway in Switzerland, the UK and Canada.

Table 2-1shows the status of geological disposal programs in foreign countries.

Table 2-1 Status of geological disposal programs in foreign countries (adapted from METI, 2011)

Country	Status
Finland	In 2000, Olkiluoto was selected as the final repository site. Construction of an underground investigation facility began in June 2004 and the subsurface geological environment is being evaluated. The license application for repository construction was submitted in December 2012.
Sweden	SKB has been performing a feasibility study in six municipalities since 1995 and selected three of these in 2000 as candidates for further site investigation. After Oskarshamn and Östhammar accepted the project, site investigations and environmental impact assessments were performed at these sites. Based on the investigation results, SKB selected Forsmark in Östhammar as the repository site in June 2009. In March 2011, a licensing application for repository construction was filed.
USA	The Yucca Mountain Site in Nevada was previously selected as the repository site and safety assessments were carried out from 2008 with the aim of obtaining a construction license. However, the Obama administration, which came into power in January 2009, decided to abandon the disposal plan for the Yucca Mountain Site and applied for its revocation in March 2010. Following this, the Blue Ribbon Commission was established in accordance with the US Federal Advisory Committee Act to discuss how spent fuel should be dealt with. The Waste Isolation Pilot Plant (WIPP) for TRU waste started operation in March 1999.
France	Since 2000, ANDRA has constructed a URL at Bure and has been performing various underground tests. Based on the 2006 Planning Act on the Sustainable Management of Radioactive Materials and Waste, an additional investigation program has been underway since 2006 in an area of 250 km^2 (including Bure) for a "reversible" repository; a license will be applied for, with the goal of starting operation in 2025. Based on the investigation results, ANDRA narrowed the area down to 30 km^2 at the end of 2009. If the siting plan is approved via open round-table discussions, an application for a waste emplacement license will be filed around 2014.
Switzerland	Based on the Sectoral Plan for Deep Geological Repositories established in 2008, Nagra proposed three potential candidate regions for the HLW repository site in October 2008. Following a three-stage selection process defined in the Sectoral Plan, the final site will be decided in 2018.
UK	The UK government published a white paper on managing radioactive waste in June 2008 in order to solicit municipalities interested in accommodating the repository. By January 2009, two cities and one county had expressed an interest; these are currently being screened for initial siting criteria.
Canada	The federal government decided to pursue an "Adaptive Phased Management" strategy that starts with on-site and centralized waste storage followed by geological disposal. NWMO formulated a nine-step site selection process for the repository and initiated an "Expression of Interest" phase and site selection plan as the first step. By September 2010, four regions had expressed an interest in receiving information from NWMO.
Germany	The site characterization program at Gorleben has been halted since 2000. The second Merkel administration, however, agreed to lift the moratorium and resume investigations in October 2009.
Spain	The site selection process was interrupted in 1998 and the decision on how the waste will be disposed of has not yet been made. However, geological disposal is considered as a feasible option.
Belgium	An interim report on the safety and feasibility of geological disposal has been published and the R&D program has reached its final stage. A license application for repository construction will be filed around 2020.

3 . Strategies for ensuring safety

This chapter describes NUMO's strategies and policies aimed at achieving safe geological disposal (see Figure 3-1).

3.1 Safety goals

3.1.1 Context and safety goals

The ultimate goal of geological disposal is to prevent harmful effect of the radioactive waste on humans and the environment at any time in the future after the closure of the repository, as well as on residents and workers during each project stage before the facility is closed. NUMO's policies are based on the recognition that safe geological disposal requires the following goals to be achieved:

− Ensuring long-term post-closure safety
− Ensuring safety during project implementation.

3.1.2 Long-term post-closure safety

In order to ensure long-term safety after closure of the repository, the disposal system will be designed based on the principles of containment[3] in the deep underground and isolation[4] from the human environment. Specifically, the waste will be emplaced in a stable underground rock formation with a multi-barrier system consisting of natural and engineered barriers that provide the containment and isolation functions.

The H12 report concluded that long-term post-closure safety could be assured by the following three safety measures:

(1) Selection of a geological environment suitable for disposal and confirmation of its safety-relevant characteristics throughout the siting, construction and operational phases (selection and confirmation of suitable sites),
(2) Appropriate design and construction of the repository, using engineered barriers suitable for the selected geological environment (appropriate engineering for repository design and construction) and
(3) Safety assessment of the post-closure performance of the geological disposal system

3 Containment is based on restricting the release of radionuclides into the groundwater by limiting the leaching rate of radionuclides from the waste and minimizing the transport of radioactive materials by restricting the migration of leached radionuclides (retardation).
4 Isolation involves protecting the repository from geomorphological changes such as erosion by emplacing the waste in a stable deep rock formation and reducing the likelihood of inadvertent human intrusion by making it difficult to access to the waste without special technologies.

(evaluation of long-term safety).

The validity of the conclusions reached has been confirmed by AEC (AEC 2000). The three safety measures are consistent with the safety principles issued by the Nuclear Safety Commission (NSC 2000).

3.1.3 Safety during the project implementation

NUMO will ensure radiological and conventional industrial safety for the general public and workers in each stage by taking appropriate safety measures, starting from site selection through to termination of the project. To ensure that the safety measures are applied appropriately, NUMO will analyze different risks assumed during the project implementation and will reflect the results in planning investigation/construction programs and in the formulation of the safety regulations. Different impacts on the surrounding environment from the large-scale civil engineering work associated with the geological disposal project, such as excavation of tunnels and temporary storage of the excavated soil/rock, will be avoided or mitigated.

3.2 NUMO's policies for ensuring safety

3.2.1 Establishment of safety policies

In order to achieve the safety goals described above, the project needs to be implemented taking into consideration issues relevant to geological disposal and the conditions specific to Japan.

For the long-term safety of geological disposal following repository closure, an element of uncertainty remains due to the extremely long timescales to be considered and the heterogeneous nature of deep geological formations. It is necessary to reduce these uncertainties as far as possible through detailed investigations and evaluations so that safety is assured more reliably. Since it is not possible to directly demonstrate that the facility will be safe for the extremely long time periods involved, it is effective to use the safety case concept, where the focus is on uncertainty management, in order to establish social understanding/agreement. The safety case is a structured set of arguments into which all the information and knowledge on safety and reliability are integrated based on various facts, understanding and experience on safety. The safety case also plays an important role in demonstrating that geological disposal is safe. Owing to the long project timescales (typically around 100 years) between site selection and closure of the facility it is not unlikely that there will be change in social conditions.

In order to achieve the goals of such a complex project, it is important to adopt stepwise and flexible implementation of the individual task phases over the entire project duration. Through this process, the necessary confidence will be acquired in each phase to allow the project to move forward, adjust to the changes in the social environment and strengthen the reliability of the project. Particularly regarding the demonstration of safety, iterative assessment of safety based on the information obtained in each stage and providing the results to the local community and the public will help to acquire more understanding for the project.

NUMO's first policy for assuring safety is therefore defined as:
Policy 1: Staged and flexible project implementation based on iterative confirmation of safety

As noted above, safety over tens of thousands of years after the closure of the facility cannot be assured using conventional methods. Modeling based on state-of-the-art scientific and technological understanding as well as behavior prediction methods based on observed data is therefore used. In order to improve the reliability of the predictive evaluations, it is necessary to adopt highly reliable methodologies for site characterization and the associated engineering strategies. It is crucial to use the best technology available for assessing safety and scientific/engineering measures.

Using the best technologies possible is the responsibility of our generation in order to protect the environment and human health into the far future.

NUMO therefore defines its second policy for assuring safety as:
Policy 2: Project implementation based on reliable technologies

For successful implemetation of the geological disposal project, it is essential that the affected local community/municipality and the public understand and accept the safety that has been demonstrated through technical investigations. Confidence-building towards safety is one of the essential aspects of the geological disposal project. In order to accomplish this, it is necessary to ensure broad understanding by a wide range of stakeholders, which is underpinned by scientifically well-supported evidence.

Therefore, NUMO defines its third policy for assuring safety as:
Policy 3: Technical activities for building confidence in NUMO's safety concept

Figure 3-1 shows the relationships between NUMO's safety goals, policies for ensuring safety and policy components, each of which will be discussed below in more detail.

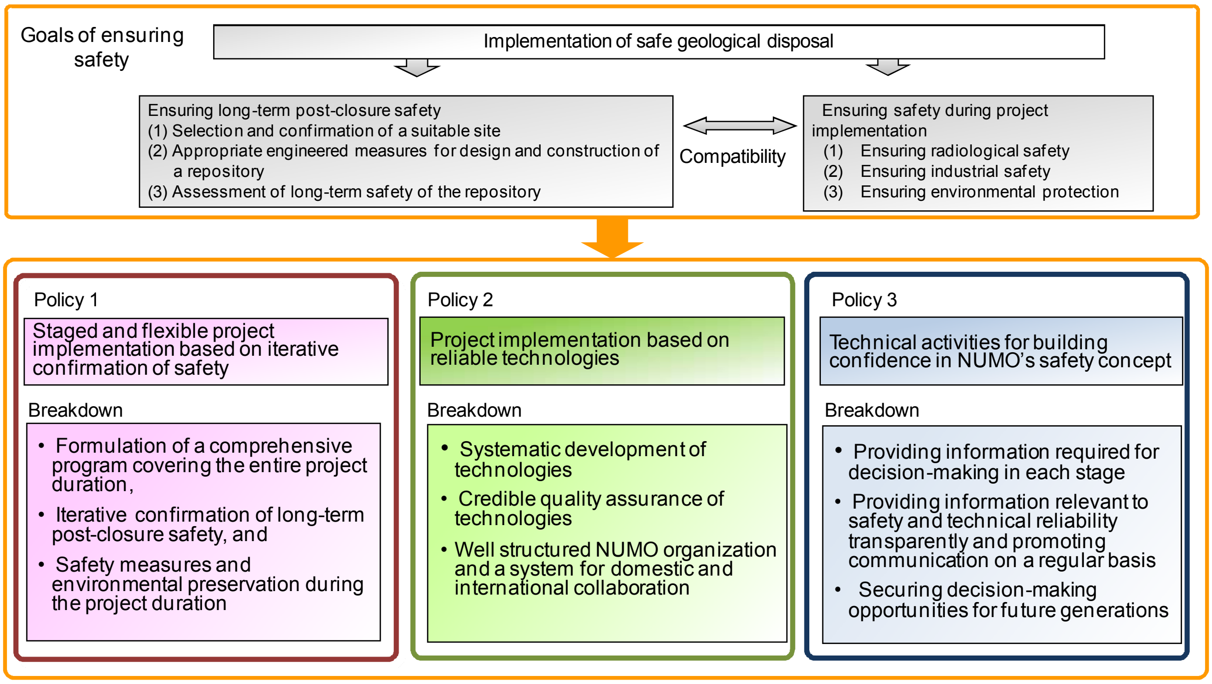


Figure 3-1 Overall structure of the policies for ensuring safety

3.2.2 Policy 1: Staged and flexible project implementation based on iterative confirmation of safety

In order to ensure long-term safety of the repository during its operation and after closure, NUMO has formulated a comprehensive program extending over the entire duration of the geological disposal project. Specifically, Policy 1can be broken down into:

(1) Formulation of a comprehensive program covering the entire project duration,
(2) Iterative confirmation of long-term post-closure safety, and
(3) Safety measures and environmental preservation during the project duration.

Firstly, the formulation of a comprehensive program covering the entire project duration is described. For the smooth implementation of the project, which extends over a long period of time, the program should be established from the perspective of the entire project and implemented in a stepwise and flexible manner. This will allow continuous improvement of the arguments related to safety, development of appropriate responses to changes in the social environment and stepwise improvement of confidence in the project.

To formulate a program covering the entire project duration, NUMO has developed a safety roadmap. This separates the project into 10 stages, extending from literature surveys to project termination, and specifies project goals, safety goals, requirements for achieving the safety goals and the actions in each stage.
For iterative confirmation of long-term post-closure safety, NUMO will continuously improve the

reliability of the safety of geological disposal by iterative confirmation at key milestones based on close linking of the three safety measures (selection and confirmation of a suitable site, appropriate engineering measures for design and construction of a repository and assessment of long-term safety of the repository) and integration of the information obtained.

An approach that has been adopted in several national programs in recent years involves developing supporting arguments for the reliability of the long-term safety of geological disposal based on alternative performance indicators and presenting results from a wider perspective.

Figure 3-2 shows the components of NUMO's safety case and their respective roles. The safety case will be progressively updated and refined throughout the three-stage site selection process, licensing, construction, operation and closure.

The issue of uncertainty is important in the safety case. It is important to recognize and reduce or mitigate the effect of uncertainties in the information to be included in the safety assessment associated with the investigation/evaluation of the geological environment as well as in the design of the repository.

Secondly, safety measures and environmental preservation during the project duration can be explained as follows: During the project, both industrial and radiological safety measures will be implemented. Their impacts on the barrier function of the geological disposal system will be evaluated continuously to ensure that the safety goals are met both during the project and post-closure.

During the site selection and construction stages, the emphasis will be on ensuring conventional industrial safety because no radioactive waste is involved in these stages. The data on the geological environment required for this will be compiled through site characterization conducted during the site investigation and construction stages.

During the stages of operation and closure of the repository, measures for ensuring radiological safety will also be required in addition to those described above as radioactive waste will be present. These stages involve handling of radioactive materials in the deep underground environment, for which there is no experience. Considering the unique nature of the task, the most reliable technologies available at these stages will be utilized in the design and construction of the system.

With a view to establishing a sustainable social structure and achieving common prosperity with the local communities, NUMO will conduct environmental impact assessments and continue activities aimed at preserving the environment. The actions for environmental preservation that NUMO plans to implement are collectively termed environmental considerations here.

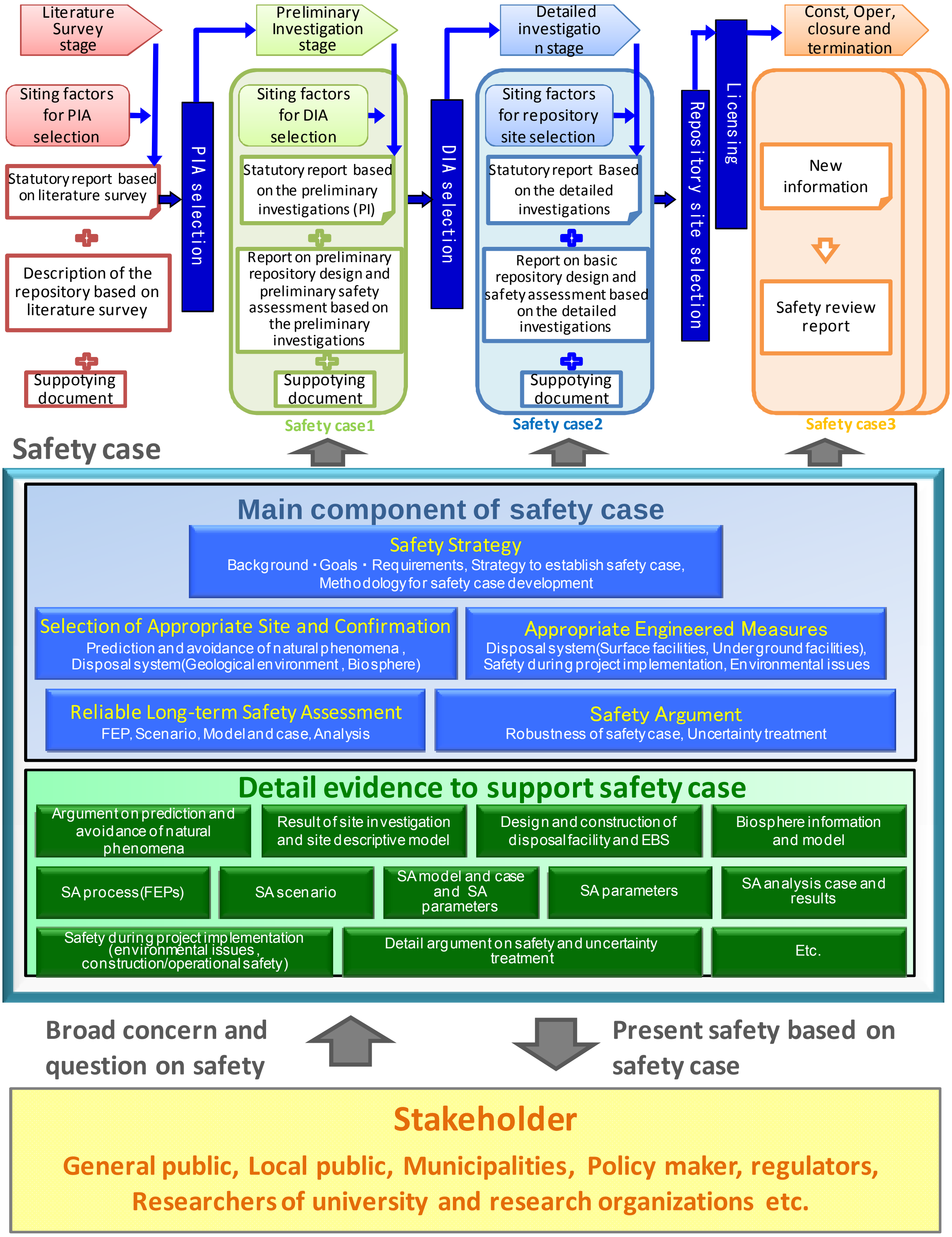


Figure 3-2 Components of NUMO's safety case and their respective roles

3.2.3 Policy 2: Project implementation based on reliable technologies

NUMO will use the best available technologies based on up-to-date knowledge to ensure safety with sufficient reliability. These technologies[5] have been developed and validated in other conventional and/or nuclear industries in terms of their reliability and economic efficiency with quality assurance to a certain level.

Although many of the technologies used in the geological disposal project have been developed in other fields, there are some that have been developed specifically for geological disposal. For these, it is necessary to perform R&D activities based on a well defined plan and the applicability of each technology must be verified. Therefore, NUMO's R&D program will follow a well defined schedule. Furthermore, NUMO places significant emphasis on a structured training plan for its staff members in order to create a highly reliable scheme for implementing the required activities.

Specifically, Policy 2 can be broken down into:

(1) Systematic development of technologies
(2) Credible quality assurance of technologies
(3) Well structured NUMO organization and a system for domestic and international collaboration

Firstly, systematic development of technologies is described. The Framework for Nuclear Energy Policy (AEC, 2005) states that NUMO should be responsible for the development of technologies aimed at safe implementation of geological disposal in a cost-effective and efficient manner, while fundamental R&D organizations will be responsible for geoscientific research, improving the reliability of geological disposal technologies and improving safety assessment methodologies using underground research laboratories and other research facilities. NUMO has been conducting R&D within the framework of this role-sharing structure.

A "Coordination Executive" was established by the Government to outline for the fundamental R&D organizations the technologies required by NUMO and the regulatory body to ensure that the R&D results will address their specific needs (ANRE/JAEA, 2010). As a member of the Coordination Executive, NUMO is able to express its needs in this respect and to evaluate and confirm the R&D results of the fundamental R&D organizations for application in the geological disposal project (NUMO, 2010).

Figure 3-3 shows the key milestones in the geological disposal project and the relationship with the development of technologies and fundamental R&D contributing to these milestones.

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5 The term "technologies" includes engineering knowledge (expertise), methodologies and tools.

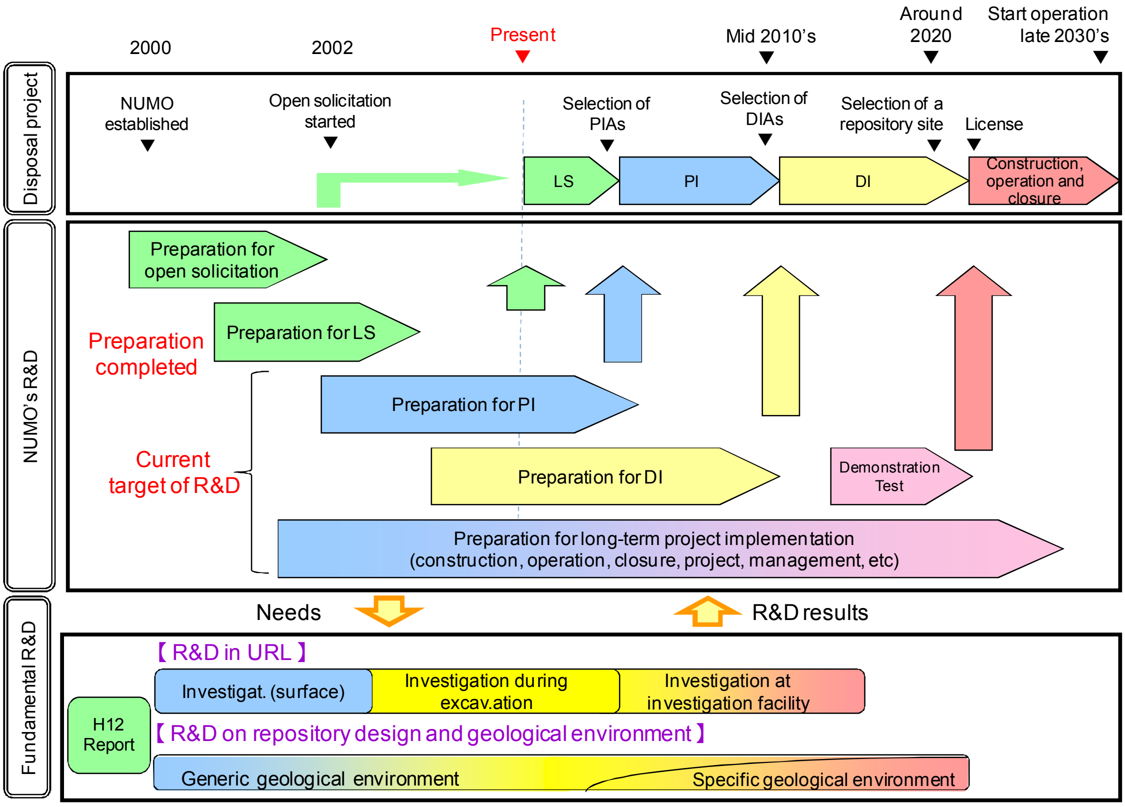


Figure 3-3 Relationship between disposal project, R&D milestones and fundamental R&D

NUMO will check the progress of the fundamental R&D to ensure that it is consistent with the needs that evolve with the progress of the project. The results of the fundamental R&D will be reviewed by NUMO in terms of technical reliability and applicability to the project and, if required, additional studies will be conducted.

The most effective way to demonstrate the applicability of the developed technologies will be to actually apply them. Demonstration of technologies involves verifying the technologies or components thereof by testing their operability under conditions simulating actual conditions. It also includes resolving problems associated with the technologies and improving applicability and reliability.

For technologies specific to geological disposal in particular, such as remote waste emplacement techniques, applicability and reliability will be confirmed through demonstration tests and modifications made if necessary. Even for established technologies in other industrial areas, such as borehole investigations and transport of waste packages, applicability will be evaluated for the specific conditions of geological disposal and the special restrictions it imposes and reliability will be improved through demonstration tests as appropriate.

Secondly, a description of credible quality assurance of technologies is provided below. NUMO has established and implemented a quality management system (QMS) for documentation (preparing technical reports), which is the primary task in the early stages, in accordance with ISO 9001: 2000. The QMS is applied for controlling documentation and its management with quality levels commensurate with the significance of the information contained in the different technical documents, applying consistent principles

Thirdly, the well structured NUMO organization and a system for domestic and international collaboration is explained. NUMO will secure the human resources required for steady implementation of the geological disposal project in Japan. As the geological disposal project extends over approximately 100 years, it will be important to secure the human resources required to support the project and take account of the potential evolution of the project during the entire period. The number of experts required is estimated to be 100 or more at peak times; they will come from different fields including geology, civil engineering and nuclear engineering. The organizational structure of NUMO in the future has also been studied based on estimated manpower requirements and the tasks and expertise required in each project stage.

NUMO will conduct R&D within the framework of the role-sharing structure in collaboration with domestic organizations. This collaboration is essential as NUMO cannot claim to possess all the knowledge required; a wide spectrum of knowledge from different disciplines, where part of the technical knowledge is owned/managed by the relevant domestic organizations, is required for effective implementation of the geological disposal project.

3.2.4 Policy 3: Technical activities for building confidence in NUMO’s safety concept

The geological disposal project involves extremely long time periods during which consideration of safety will be required and ethical issues solved between current and future generations. The project will therefore be implemented stepwise, gaining acceptance by local residents at key milestones in each stage from site selection to decommissioning after closure of the repository.

Specifically, Policy 3 can be broken down into:

(1) Providing information required for decision-making in each stage
(2) Providing information relevant to safety and technical reliability transparently and promoting communication on a regular basis
(3) Securing decision-making opportunities for future generations

Regarding providing information required for decision-making in each stage, numerous decisions will require to be made during the period from site selection to closure of the repository. For the smooth implementation of the stepwise decision-making process, it will be necessary for the implementing organization to provide the information required for making these decisions to all of the concerned parties and to provide clear explanations to facilitate understanding.

Secondly, providing information relevant to safety and technical reliability transparently and promoting communication on a regular basis is described as follows. Achieving confidence in the safety of geological disposal and the reliability of the technologies used is essential for effective decision-making in each stage. NUMO will therefore provide relevant and transparent information to the public on a regular basis. With regard to concerns or questions about the safety of geological disposal raised by the local and general public, it will be important to conduct extensive analyses and studies and to continue confidence-building activities based on the results of these studies. A system for analyzing such aspects based on social science methodologies will be established to provide feedback to the confidence-building activities.

Thirdly, securing decision-making opportunities for future generations ensures that certain decision-making opportunities are reserved for future generations under the conditions prevailing at the time, rather than the current generation attempting to determine matters 100 years into the future based on their own assumptions.

Potentially the most important decision that will require the involvement of future generations will be on closure of the repository. The repository is designed to ensure that safety is based as far as possible on passive measures. NUMO will take all the steps required for ensuring safety before closure of the repository with the aim of eliminating the need for active human control.

3.3 NUMO's strategy for addressing particular issues relevant to the geological disposal project

Geological disposal involves utilization of the natural geological environment with its heterogeneity and large spatial extent, as well as a project extending over approximately 100 years that will almost certainly be accompanied by changes in the circumstances surrounding the project. To ensure an appropriate response to these changes, a risk management approach will be applied for project management.

Since the ultimate goal of the geological disposal project is to ensure passive safety based on a multi-barrier system, for the closure of the repository a decision will have to be made on the timing of the shift of the safety mode from dependence on active administrative control to reliance on the multi-barrier system. The decision on shifting to the passive safety mode is equivalent to deciding to initiate decommissioning of the repository. This will require a review of the information obtained up to that time in the stages of site investigation, construction and operation in order to comprehensively assess compliance with the requirement of passive safety. A key point for such decision-making is how to deal with issues such as reversibility, retrievability and closure.

In this section, NUMO's approach to the following issues will be discussed. It should be noted that specific measures in the areas described below have to be developed considering progress in the establishment of a legal framework relevant to the geological disposal project in Japan and international trends on these issues.

- Risk management during the project duration
- Monitoring
- Reversibility and retrievability
- Closure of the repository

3.3.1 Risk management during the project

In the geological disposal project, it is required to address uncertainties associated with technological and societal aspects. Activities for ensuring safety involve assuming unsafe conditions and making provisions to prevent the occurrence of these conditions or to minimize their consequences in the event of occurrence. Many of the activities associated with assuring safety during the phases before and after closure are common to risk management as practised in other industries: risk identification, risk analysis, risk evaluation and taking measures to prevent/minimize risk.

The aforementioned activities encompassing the risk management approach can be applied to ensure the long-term safety of geological disposal by appropriate implementation of conventional safety measures. On the other hand, for safety during the project, various risks including occupational injuries associated with investigation and construction activities, occupational radiation exposure due to failure of waste packages during operation and closure will be identified and their likelihood and consequences evaluated; based on this, the design of the repository and the safety assessment system will be improved. The risk management approach based on ISO 31000 will be applied to such activities. How NUMO will develop a risk management system based on ISO 31000 is an important issue to be studied in the future.

3.3.2 Monitoring

The geological disposal project employs different types of monitoring for confirming safety or protecting the environment in each stage from site selection to repository closure. Monitoring is also important for verifying that the project has been conducted properly. Disclosing the monitoring data to the general public and local residents will be essential for improving confidence in the project. Monitoring may be carried out as appropriate during the period from confirmation of repository closure to project termination, but passive safety without reliance on active control including monitoring will be necessary for closure of the repository. The monitoring that will be conducted by NUMO can be categorized into the following four types:

- Monitoring for confirming long-term post-closure safety
- Monitoring for confirming radiological safety
- Monitoring for confirming industrial safety
- Monitoring for confirming environmental preservation

Regarding the assurance of long-term safety after closure, due to the extremely long timescales to be considered it is not possible to directly confirm, with the monitoring described above, the accuracy of the overall scenario when assessing safety for the licensing application. Therefore, monitoring will be used to evaluate selected individual phenomena assumed in scenarios (e.g. the saturation process in the buffer material). Quantifying the reliability of predicted physical behavior (e.g. groundwater variation) included in the hydrogeological model complements the reliability of the safety assessment (Kurikami et al., 2010).

The parameters to be monitored will be determined after the site conditions have been set, considering site-specific characteristics and requirements from the viewpoint of safety assessment. After key parameters that may affect safety have been identified, it will be determined whether or not these are to be monitored during site investigation or their variation with time needs to be monitored.

3.3.3 Reversibility and retrievability

Reversibility means the ability to reverse one of a series of steps taken in a repository project. Retrievability is a special case of reversibility, meaning that it is possible to recover emplaced waste packages.

During the period before the repository closure plan is authorized, NUMO will maintain retrievability of the waste packages and, after obtaining authorization, will implement closure according to the approved plan. Closure involves backfilling all underground spaces such as access tunnels, shafts and ramps and installation of plugs as required (Figure 3-4).

Figure 3-5 shows an overview of NUMO's basic policy on retrievability/reversibility and monitoring. Monitoring required for judging whether or not to implement closure of the repository will continue until completion of operations. When closure has been authorized, i.e. the passive safety of the repository has been established, monitoring and retrievability need not be maintained from the viewpoint of ensuring long-term post-closure safety. If closure steps have not been taken and safety measures are required to ensure passive safety, then monitoring for implementing safe closure should be undertaken. In order to confirm that closure has been successfully completed, monitoring will be continued as required.

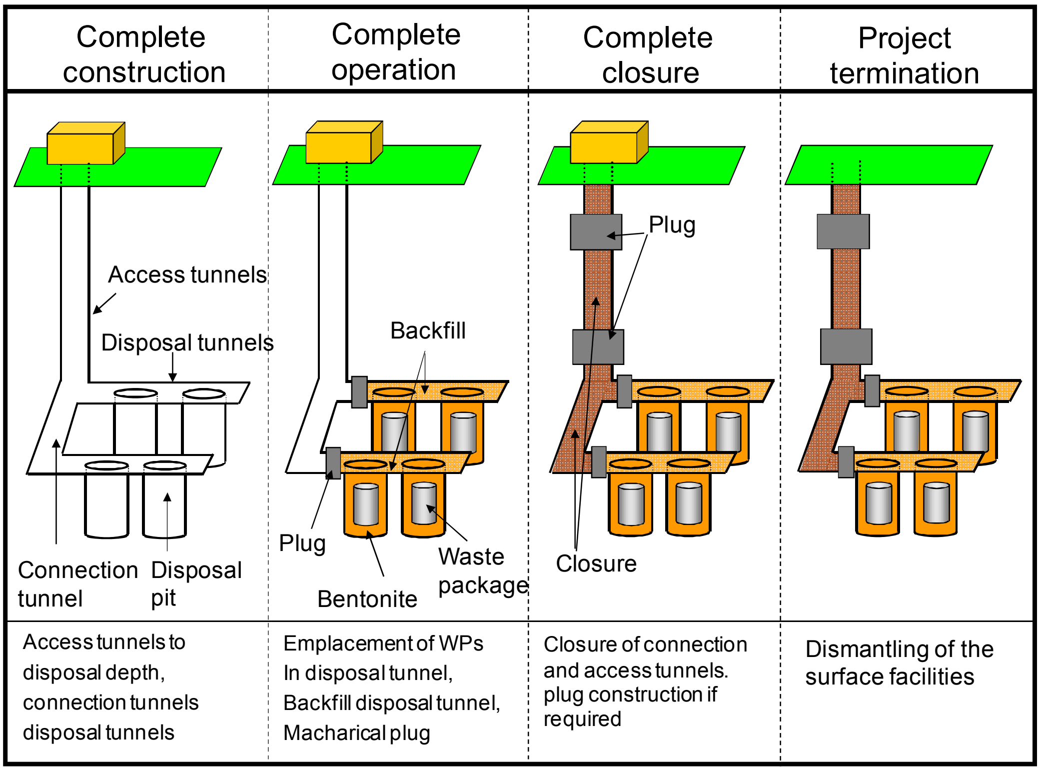


Figure 3-4 NUMO's stepwise closure concept

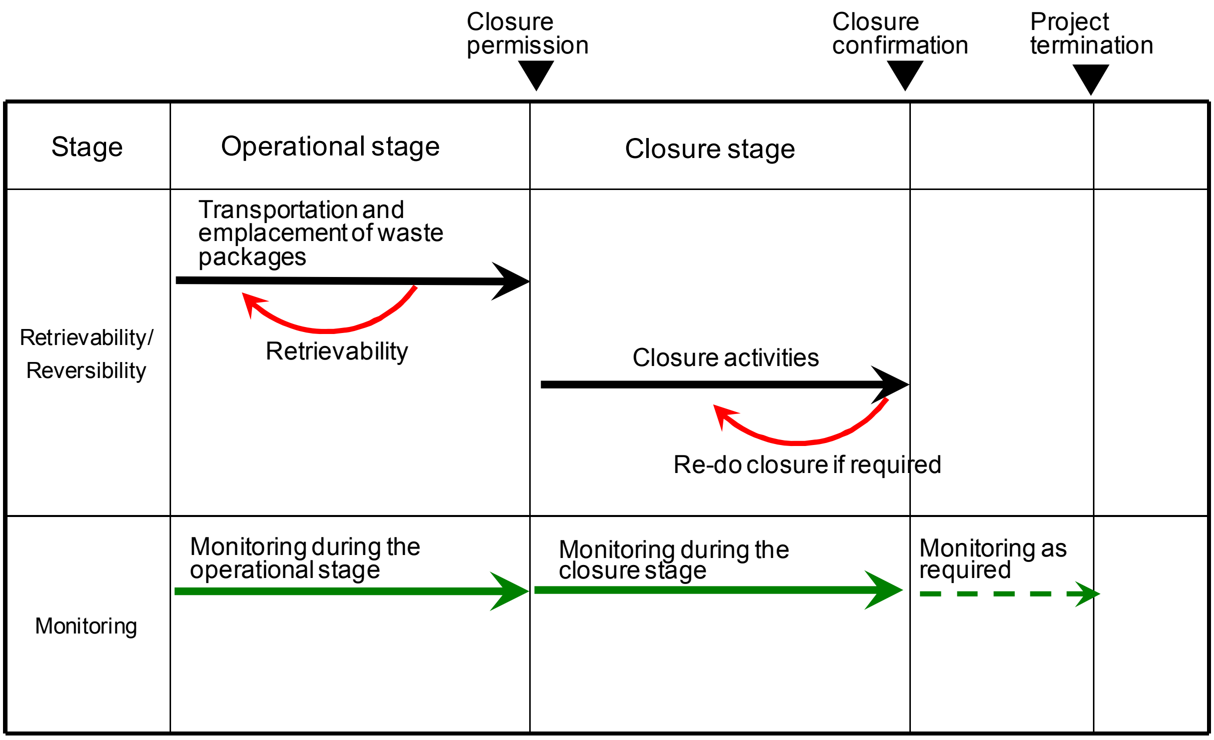


Figure 3-5 NUMO's concept for retrievability/reversibility and monitoring

3.3.4 Closure of the repository

Closure of the repository means actions taken to move from the stage where ensuring safety depends on active administrative control during the project duration to the stage where passive long-term safety is assured without administrative control (IAEA, 2006).

The Nuclear Reactor Act, which was revised in 2007, specifies that a closure plan application should be prepared and submitted by the implementing organization to the national government for authorization. The government is required to confirm long-term post-closure safety based on a final safety review by NUMO.

Recognizing the unique features relevant to ensuring the safety of the geological disposal system, NUMO identifies the closure measures as an important milestone of the project and will start preparing for taking appropriate actions from the current stage of the project.

4 . Staged project implementation

This chapter describes the implementation in practice of the policies discussed in chapter 3 using roadmaps.

Policy 1: Staged and flexible project implementation based on iterative confirmation of safety
Policy 2: Project implementation based on reliable technologies
Policy 3: Technical activities for building confidence in NUMO's safety concept

4.1 Basic approach

4.1.1 Staged project implementation and major milestones

NUMO has a staged project implementation program extending from initial literature surveys to project termination as shown in Figure 4-1 (NUMO, 2009a). With the goal of ensuring passive safety, NUMO will take the required measures during the project, with iterative confirmation of safety from site selection through to the post-closure stage.

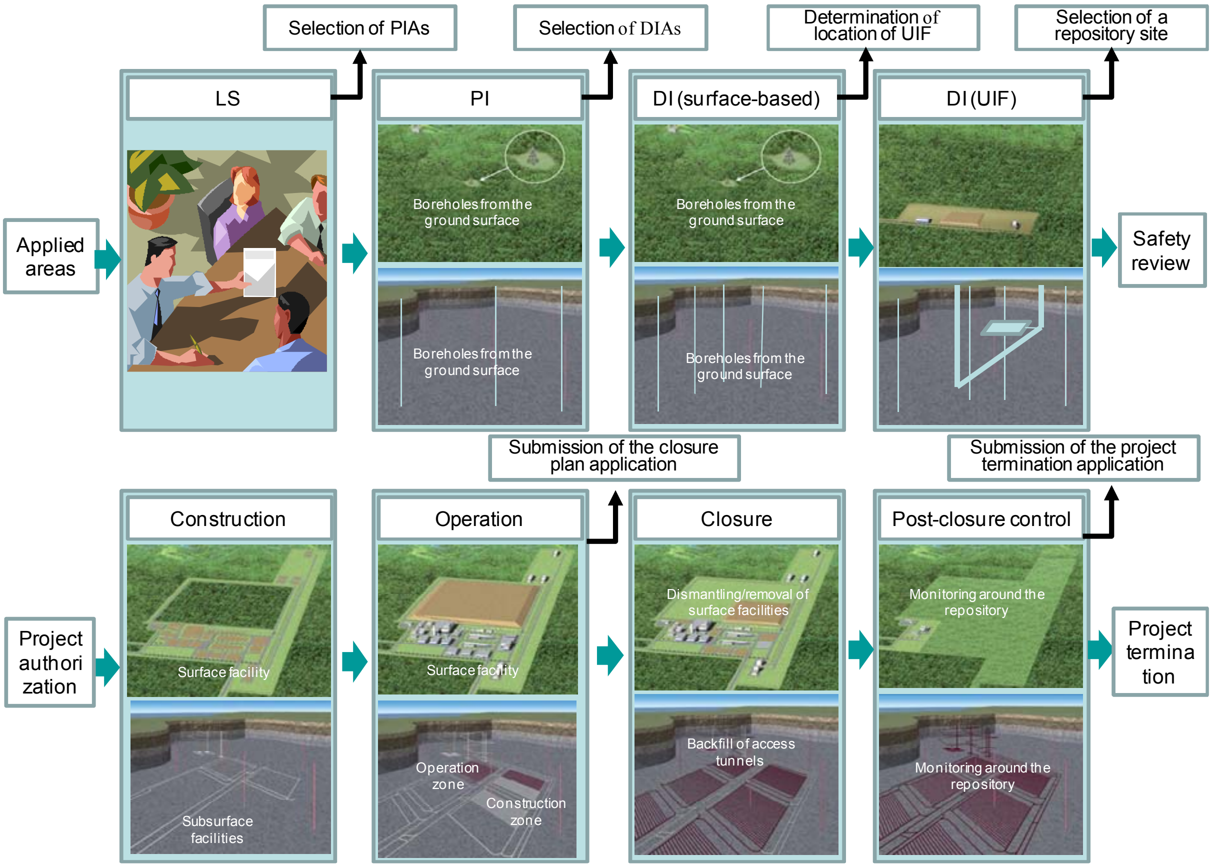


Figure 4-1 Staged implementation of the geological disposal project (NUMO 2009a, partly revised)

4.1.2 Implementation of the geological disposal project and coordination among different technology fields

In the geological disposal project, as noted earlier, the following three safety measures will be implemented in a stepwise manner: selection and confirmation of suitable sites, appropriate engineering for design and construction and evaluation of long-term safety. The three technology fields associated with these measures (site investigation/evaluation, engineering and safety assessment) should be coordinated and integrated to support decision-making at each stage (Figure 4-2). In addition, activities supporting post-closure safety should be integrated with those required to ensure safety at all stages prior to closure.

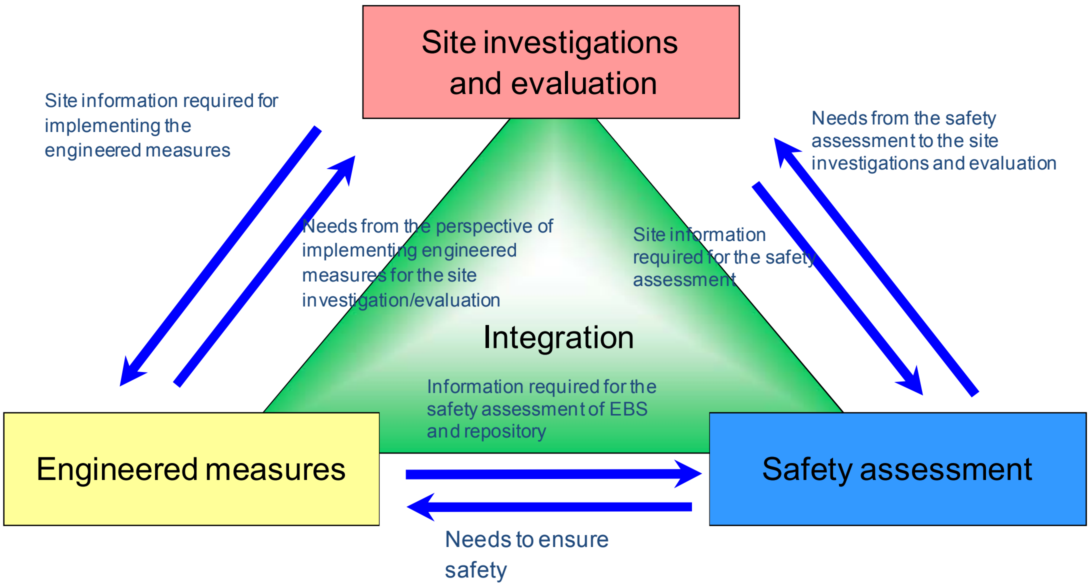


Figure 4-2 Integration of the three safety measures

In identifying sites to be investigated in the site selection stage, justification of the selection has to be made. Before starting the investigations in each stage, NUMO plans to establish and open to the public so-called siting factors for the selection of investigation areas. The siting factors for the selection of PIAs have already been published. The siting factors for the selection of DIAs will be published before initiating the DIA selection stage (preliminary investigation stage) based on discussions on the selection of DIAs with the national goverament. Details will be discussed in chapter 8.

4.2 Implementation of policies (roadmaps)

4.2.1 Approach to the implementation of Policy 1: Staged and flexible project implementation based on iterative confirmation of safety (safety roadmap)

The safety roadmap is divided into the stages shown below considering the entire project duration. For each stage, milestones, requirements, activities and the resulting main documents are shown. The ultimate goal of safe geological disposal will be achieved by reaching the milestones defined for each stage (Figure 4-3).

- Literature Survey stage
- Preliminary Investigation stage
- Detailed Investigation stage – surface-based investigations
- Detailed Investigations stage – investigations in the UIF
- Safety review stage

- Construction stage
- Operational stage – during operation
- Operational stage – end of operation / closure plan
- Closure stage
- Post-closure to project termination stage

In general, in the early stages of site investigations the emphasis is on avoiding natural phenomena with significant impacts, such as volcanic/igneous activity and seismic/fault activity; this then shifts to characterization of the geological environment, design and safety confirmation of the repository and, finally, the safety review for the license application. After granting of the license, the focus will shift to engineering activities such as construction, operation and closure of the repository.

4.2.2 Approach to the implementation of Policy 2: Project implementation based on reliable technologies (R&D roadmap)

This section summarizes how required R&D can be planned in advance based on R&D roadmaps that compare current technology and understanding with the level required to reach the milestones set for each project implementation stage (Figure 4-4). The technologies shown in the roadmap are those required for achieving the goals set out in the safety roadmap, but are considered as still requiring further development and demonstration based on an analysis of their current technology level.

The R&D addressed in this roadmap includes manufacturing technologies, methodologies or scientific/engineering knowledge required for integrated analysis of investigation data, design and safety assessment, together with associated databases and research results. The R&D roadmap also addresses how to compile research results from various organizations and integrate knowledge and technologies to the level of quality required at each project stage. NUMO will use this approach for R&D management.

4.2.3 Approach to the implementation of Policy 3: Technical activities for building confidence in NUMO's safety concept (confidence-building roadmap)

Since geological disposal deals with issues that may be difficult to understand for many stakeholders, such as those associated with deep geological environments, extremely long timescales and radiological effects, extensive and continuous communication efforts are required in order to build confidence in safety among stakeholders who are not experts in the field of nuclear engineering. This report presents the activities to be addressed for building confidence in technical aspects of safety in the form of a confidence-building roadmap (Figure 4-5).

The confidence-building roadmap is prepared in line with the three policy breakdowns described in chapter 3: (1) providing information required for decision-making in each stage; (2) providing information relevant to safety and technical reliability transparently and promoting communication on a regular basis and (3) securing decision-making opportunities for future generations.

Stages	Literature Survey stage	Preliminary Investigation stage	Detailed investigation stage: Surface-based investigations	Detailed investigation stage: Investigations in the UIF	Safety review stage	Construction stage	Operational stage: During operation	Operational stage: End of operation /closure plan	Closure stage	Post-closure to project termination stage
	ca. 20 years					ca.10 years	ca. 50 years		ca. 10 years	
Goals in each stage	Selection of PIAs	Selection of DIAs	Determining the basic repository layout	Selection of the repository site	Granting of a project license	Repository construction	Operation of the repository	Authorization of closure plan	Implementation of closure	Project termination
Safety goals in each stage	･Avoid significant impacts from natural phenomena (avoiding areas that are clearly disqualified)	･Avoid significant impacts from natural phenomena ･Ensuring long-term safety ･Ensuring safety during implementation	･Confirming that significant impacts from natural phenomena have been avoided ･Ensuring long-term safety ･Ensuring safety during implementation	･Confirm that significant impacts from natural phenomena are avoided ･Confirm long-term safety ･Confirm safety during implementation safety	･Assuring long-term safety ･Assuring safety during implementation	･Iterative confirmation of long-term safety based on updated information ･Ensuring construction safety	･Confirming long-term safety based on updated information ･Safety assurance during operation	･Demonstrate long-term safety through integration of all information	･Confirming safety in the closure stage	･Confirmation of long-term safety based on updated information ･Confirmation of safety assurance after closure
Requirements for the goals	Compliance with legal requirements Compliance with environmental requirements Compliance with NUMO working standards	Compliance with legal requirements Compliance with environmental factors for selecting DIAs Compliance with basic guidelines for locensing Compliance with NUMO working standards	Compliance with the legal requirements Compliance with repository site selection environmental factors Compliance with the basic guidelines for licensing Compliance with NUMO working standards	Compliance with the legal requirements Compliance with the environmental requirements for the selection of a repository site Compliance with the guidelines for licensing Compliance with NUMO working standard	Compliance with the safety review guidelines	Compliance with technical standards Compliance with NUMO working standards	Compliance with technical standards Compliance with NUMO working standard	Compliance with standards for the authorization of closure plan	Compliance with authorized closure plan Compliance with NUMO working standards	Compliance with decommissioning authorization standards Compliance with standards for project termination
Activities in each project stage / Long-term post-closure safety / Appropriate site selection and confirmation / Avoid significant impacts from natural phenomena (active faults, volcanoes and uplift/subsidence)	Avoid based on literature information	Avoid based on field investigations	Confirm avoidance using obtained information							
Activities in each project stage / Long-term post-closure safety / Appropriate site selection and confirmation / Characterization of the geological environment	Develop the site descriptive model	Update the site descriptive model	Update the site descriptive model	Develop site descriptive model to be used for licensing		Update the site descriptive model				
Activities in each project stage / Long-term post-closure safety / Appropriate engineering measures provided by design and construction of repository / Subsurface facilities	Generic design	Define basic layout and preliminary design	Define basic layout and basic design	Basic design	Detailed design	Construction	Operation	Fix specifications for closure	Closure	
Activities in each project stage / Long-term post-closure safety / Appropriate engineering measures provided by design and construction of repository / EBS		Preliminary design	Fix specifications Demonstrate fabrication/construction			Construction of EBS fabrication system	Fabrication/transportation /emplacement	Check process		
Activities in each project stage / Long-term post-closure safety / Evaluation of long-term stability of the geological system	Qualitative assessment	Preliminary quantitative assessment	Qualitative assessment for licensing		Supplementary evaluation	Safety assessment based on the information obtained during construction	Safety assessment based on the information obtained during operation	Total assessment for closure	Safety confirmation based on the information obtained during closure	
Activities in each project stage / Safety in each project stag / Industrial safety	Information collection and evolution	Plan measures (surface/subsurface facilities)		Basic design	Detailed design	Application	Application/supervision			
Activities in each project stage / Safety in each project stag / Radiological safety	Generic design	Preliminary design		Basic design	Detailed design		Application/ supervision		Supervision	
Activities in each project stage / Safety in each project stag / Preservation of surrounding environment	Survey boundary conditions	Preliminary impact assessment		Impact assessment and preservation measures	Supplementary study	Preservation measures and supervision (additional measures)				
Main safety documents	Statutory report based on literature survey Description of the repository based on literature survey	Statutory report based on the preliminary investigations (PI) Report on preliminary repository design and preliminary safety assessment based on the preliminary investigations	Report on basic repository design and safety assessment based on the detailed investigations Environmental Impact Assessment Report	Statutory report Based on the detailed investigations Report on basic repository design and safety assessment based on the detailed investigations	License application documents Environmental impact assessment report	Application document for approval of design and construction method Application document for facility inspection Application document for pre-operational inspection Safety review report	General license application Waste package handling license application Safety review report	Closure application documents Safety review report	Closure confirmation application	Decommissioning plan authorization application Safety review report Project termination confirmation application

Legends: (pink): Activities very important for ensuring safety; (yellow): Activities important for ensuring safety

Figure 4-3 Safety roadmap

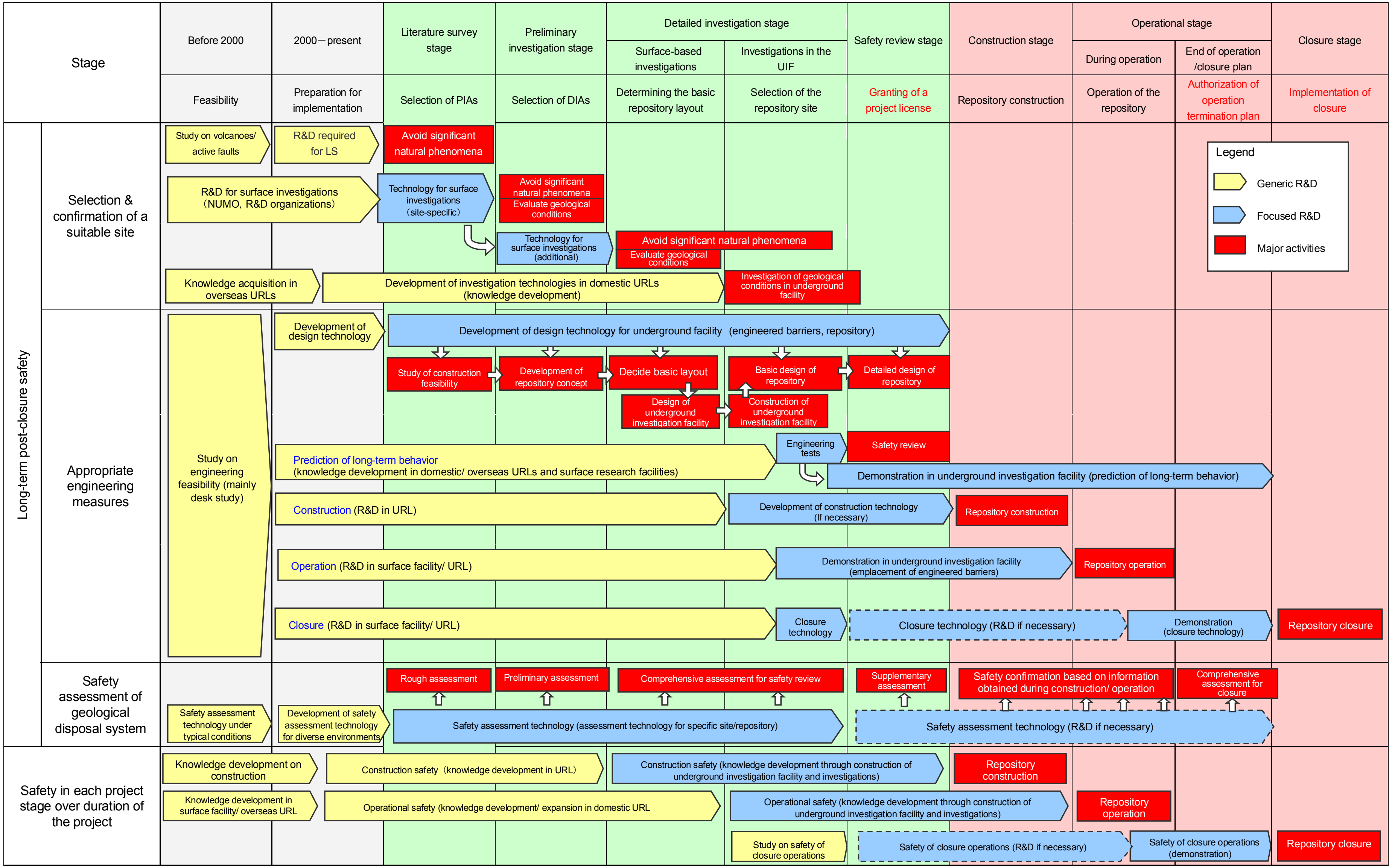


Figure 4-4 R&D roadmap

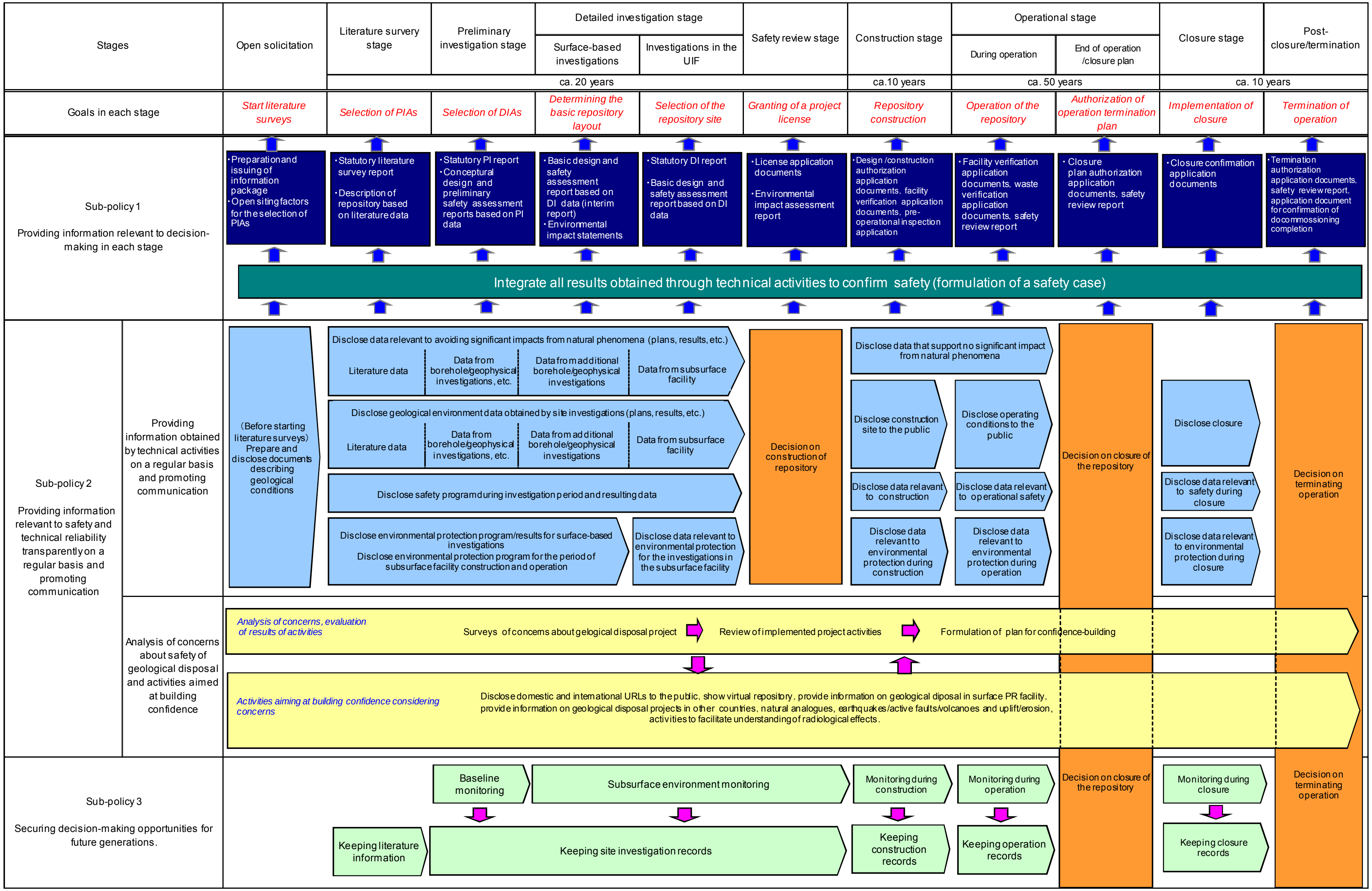


Figure 4-5 Confidence-building roadmap

4.3 Activities in each stage of the project

4.3.1 Site selection and safety review stage

(1) Literature Survey stage

・Goal of this stage	: Selection of PIAs
・Safety goals	: Avoid significant impacts from natural phenomena (avoiding areas that are clearly disqualified)
・Requirements	: Compliance with legal requirements[6] Compliance with environmental requirements Compliance with NUMO working standards
・Main documents	: Statutory report based on literature survey Description of the repository based on literature survey

The goal of this stage is to select PIAs based on literature surveys of volunteer areas. In order to ensure safety, areas that have any significant impact from natural phenomena will be avoided. The requirements for achieving the goal include "Compliance with statutory requirements", "Compliance with environmental requirements for PIA selection" and "Compliance with NUMO working standards" (include siting factors for PIA selection (NUMO, 2009b)).

Overall evaluation and relative comparison will be carried out using favorable factors which are included in the siting factors for PIA selection, as required.

Initially, prior confirmation of geological conditions will be carried out to decide whether or not a volunteer site will be suitable as a literature survey area. As already published (NUMO, 2009b), prior confirmation of geological conditions is based on evaluations of seismic and volcanic activity throughout Japan. Only after a volunteer site fulfills the siting factors will the literature survey start.

Information will initially be collected from databases, relevant institutions and other available sources. Documents will relate to natural phenomena and geological conditions of the target area(s). The collected information will be structured and managed using a geoenvironment data management system.

Based on the evaluation factors for qualification - namely impacts from natural phenomena such as seismicity/active faulting, volcanism/igneous activity, uplift and erosion - areas with significant impacts from natural phenomena will be excluded. Finally, based on an evaluation of unconsolidated Quaternary sediments and mineral resources, PIAs will be selected and a statutory report based on

[6] The siting factors for selection of PIAs consist of factors relating to legal requirements (evaluation factors for qualification (EFQ)) and favorable factors (FF) that are not part of legal requirements. The EFQ include earthquake and fault activity, igneous activity, uplift and erosion, unconsolidated Quaternary sediments and mineral resources.

literature survey will be produced.

In parallel, a regional site descriptive model (SDM) will be produced and, depending on the geological conditions of the area, an outline design of the repository will be developed. Based on this, a preliminary assessment will be made of the long-term post-closure safety of the repository. From these outline safety assessments, a general layout of the surface and subsurface facilities will be developed and documented in a report describing the the outline repository. This will then be reflected in the planning of the subsequent stage.

At the same time, safety will be examined in terms of industrial (operational) safety, radiological safety measures and preservation of the surrounding environment. For industrial safety, a risk assessment will be carried out for the construction and operational phases, looking at potential risks from natural phenomena and the seismic resistance of the underground structures. Radiological safety measures will be evaluated both for workers and the general public for the period when waste packages are being transported to the surface facility and handling of the waste packages in the surface facility. Surveys will be carried out concerning preservation and protection of the surrounding environment. The results for project safety will be documented in a report entitled 'A Description of the repository based on the literature survey.'

(2) Preliminary Investigation stage

・Goal of this stage	: Selection of DIAs
・Safety goals	: Avoid significant impacts from natural phenomena Ensuring long-term safety Ensuring safety during implementation
・Requirements	: Compliance with legal requirements Compliance with environmental factors for selecting DIAs Compliance with basic guidelines for licensing Compliance with NUMO working standards
・Main documents	: Statutory report based on the preliminary investigations (PI) Report on preliminary repository design and preliminary safety assessment based on the preliminary investigations

The goal of this stage is to select areas for detailed investigation. Safety goals in this stage include "Avoiding significant impacts from natual phenomena", "Ensuring long-term safety "and "Ensuring safety during implementation". The requirements for reaching the overall target are compliance with the evaluation factors for qualification, compliance with environmental requirements for DIAs, compliance with the guidelines for the safety review and compliance with NUMO working standards. Taking these safety goals and requirements into account, NUMO will carry out the following activities in order to achieve the goal of this stage.

As part of the preliminary investigations, surface explorations, geophysical surveys and borehole investigations will be carried out in order to obtain regional-scale geological data. From this, it will be shown that areas with significant impacts from active faults, volcanism, uplift and erosion can be avoided. The geological data will also be used to update the site descriptive model produced in the previous stage and a more detailed model will be prepared on a scale that is sufficient for the DIA. Additionally, the basic layout of the surface and underground facilities will be developed from the updated site descriptive model and preliminary assessments will be made of long-term safety and the feasibility of constructing the engineered barrier system (EBS). A reference repository design will also be developed taking into account the specific geological environmental conditions, safety and socio-economic aspects.

Safety will be examined in terms of industrial safety, radiological safety measures and preservation of the surrounding environment, as in the previous stage. In this stage, a more detailed evaluation will be possible using the information on the site obtained from surface explorations, geophysical surveys, trench surveys and borehole investigations. Attention will be paid to the surrounding environment as well as worker safety when carrying out the surveys.

Based on the above activities, DIAs will be selected and a report documenting the surveys carried out in the detailed investigation areas will be produced according to the Final Disposal Act. Also, an evaluation of the repository design and long-term safety will be documented in a report on repository design based on the preliminary investigations and preliminary safety assessments.

(3) Detailed Investigation stage

It is expected that the detailed investigation stage will be divided into two stages in practice: (i) surface-based investigations and (ii) investigations in the underground investigation facility (UIF).

(i) Surface-based investigations

・Goal of this stage	: Determining the basic repository layout
・Safety goals	: Confirming that significant impacts from natural phenomena have been avoided Ensuring long-term safety Ensuring safety during imprimentation
・Requirements	: Compliance with legal requirements Compliance with repository site selection environmental factors Compliance with the basic guidelines for licensing Compliance with NUMO working standards
・Main documents	: Report on basic repository design and safety assessment based on the detailed investigations Environmental Impact Assessment Report

The goal of this stage is to determine the basic repository layout. The orientation and configuration of the repository layout will depend on the information obtained on the geological environment.

The goals for demonstrating safety in this stage include confirming that significant impacts from natural phenomena can be avoided, ensuring long-term safety and ensuring safety during imprimentation. The requirements for achieving these goals are compliance with the evaluation factors for qualification, compliance with repository site selection environmental factors, compliance with the safety review guidelines and compliance with NUMO working standards. In order to achieve the project milestone while maintaining the goals and requirements above, the following activities will be carried out.

The surface-based investigations will involve confirming the geological information obtained from the preliminary investigations in the previous stage, with special focus on obtaining information on the underground environment in the vicinity of the candidate repository site. The site descriptive model will again be updated using new datasets for the geological environment and, based on the revised site descriptive model, the design of the EBS and the repository panel layout will be modified. Next, the basic layout of the repository will be determined taking into account assessments of long-term safety and transport and emplacement of the waste packages and EBS materials. These results will be documented in an interim report on the description of the repository design based on detailed investigation data and preliminary safety assessments.

Additionally, a preliminary environmental impact assessment starting from construction of the underground facility will be carried out and appropriate measures for preserving the environment will be taken. These results will be documented in an environmental impact statement (EIS) report.

(ii) Investigations in the UIF

・Goal of this stage	: Selection of the repository site
・Safety goals	: Confirm that significant impacts from natural phenomena are avoided Confirm long-term safety Confirm safety during implementation
・Requirements	: Compliance with legal requirements Compliance with the environmental requirements for the selection of a repository site Compliance with the guidelines for licensing Compliance with NUMO working standards
・Main documents	: Statutory report based on the detailed investigations Report on basic repository design and safety assessment based on the detailed investigations (interim report)

The goal of this stage is to select a site for construction of the repository. In this stage, the goals for ensuring safety are: confirming that significant impacts from natural phenomena are avoided, confirming long-term safety and confirming safety during implementation. The requirements for reaching these goals are compliance with evaluation factors for qualification, compliance with the environmental requirements for the selection of a repository site, compliance with the guidelines for licensing and compliance with NUMO working standards.

In this stage, the suitability of the host rock will be evaluated through tunnel excavation and investigation of the target rock formation at repository depth, including performing in-situ experiments. Additionally, demonstration experiments will be carried out in the UIF to develop the necessary technologies for repository construction and operation.

(4) Safety review stage

・Goal of this stage	: Granting of a project license
・Safety goals	: Assuring long-term safety Assuring safety during implementation
・Requirements	: Compliance with the safety review guidelines
・Main documents	: License application documents Environmental impact assessment report

In this stage, a project license application will be submitted to the government and an environmental impact assessment report will be produced, describing environmental preservation measures and findings from preliminary assessements of impacts on the surrounding environment due to construction and operation of the repository. In parallel, supplementary investigations and evaluations will be carried out as needed for preparation of the application documents for authorization of the design and construction methods.

4.3.2 Construction stage through project termination stage

(1) Construction stage

・Goal of this stage	: Repository construction
・Safety goals	: Iterative confirmation of long-term safety based on updated information Ensuring construction safety
・Requirements	: Compliance with technical standards Compliance with NUMO working standards
・Main documents	: Application document for approval of design and

	construction method Application document for facility inspection Application document for pre-operational inspection Safety review report

After obtaining a license from the government, preparatory work will be initiated for repository construction. A construction license application will be submitted and, after authorization, construction of the surface facility, including the waste package reception and storage facilities, will start in parallel with construction of the underground facilities. Construction of the surface and underground facilities will proceed in accordance with the license application and the repository design presented in the application documents for authorization of the design and construction methods and following appropriate quality control procedures. After construction, the government will carry out a pre-operational inspection to confirm that the facility has been constructed as designed.

During construction, the safety of the repository will be verified by carrying out further safety assessments using new geological information and a range of monitoring data. The results will then be published in a safety review report.

If necessary, the locations of the disposal tunnels and emplacement positions of the waste packages will be modified within the framework of the Final Disposal Act to improve safety based on the actual geological findings obtained during repository construction.

(2) Operational stage (during operation)

・Goal of this stage	: Operation of the repository
・Safety goals	: Confirming long-term safety based on updated information Safety assurance during operation
・Requirements	: Compliance with technical standards Compliance with NUMO working standards
・Main documents	: General license application Waste package handling license application Safety review report

This stage will involve activities such as encapsulation of the vitrified waste into the overpack in the waste reception facility, followed by transport and emplacement of the waste packages in the underground facility. As well as confirming compliance with the different standards and guidelines, the government will carry out inspections of the waste reception facility to ensure that all safety and radiological protection regulations are being strictly adhered to. Repository safety will be re-confirmed using additional data and scientific knowledge obtained through monitoring and the results will be documented as safety review reports that will be published on a regular basis.

The results of long-term EBS experiments carried out after the DI stage and tests demonstrating the technical feasibility of repository closure will also be published.

As the next stage approaches, overall repository safety will be assessed based on the results of the demonstration experiments and the iterative safety confirmations carried out in each stage and the closure plan for the repository will be produced.

(3) Operational stage (end of operation/ closure plan)

・Goal of this stage	: Authorization of closure plan
・Safety goals	: Demonstrate long-term safety through integration of all information
・Requirements	: Compliance with standards for the authorization of closure plan
・Main documents	: Closure application documents Safety review report

In this stage, repository operation will be completed and the safety case will be revised by carrying out safety assessments based on all the information obtained from the site selection stage to the end of repository operation. Based on this, safety will be confirmed and a safety report will be published in order to obtain acceptance for repository closure.

Under the Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Nuclear Reactors (hereafter the Nuclear Reactor Regulation Act) and related regulations, in order to close the repository NUMO will have to prepare a closure plan and obtain authorization from the Ministry of Economy, Trade and Industry (METI) by submitting a formal closure application. Before the closure plan is authorized, NUMO will maintain the option to retrieve waste packages.

(4) Closure stage

・Goal of this stage	: Implementation of closure
・Safety goals	: Confirming safety in the closure stage
・Requirements	: Compliance with authorized closure plan Compliance with NUMO working standards
・Main documents	: Closure confirmation application

In this stage, in order to fulfil the quality standards according to the regulations based on the Nuclear Reactor Reguation Act, the repository will be closed by backfilling the connecting and access tunnels, etc. When repository closure has been completed, a closure confirmation application including details relating to topography, geology and groundwater conditions prior to and after closure will be submitted to METI. Once the repository is closed, authorization also has to be granted by METI, stating that the condition of the repository complies with the standards prescribed in the Final Disposal Act. NUMO must also submit all repository records to METI for permanent archiving.

(5) Post-closure to project termination stage

・Goal of this stage	: Project termination
・Safety goals	: Confirmation of long-term safety based on updated information Confirmation of safety assurance after closure
・Requirements	: Compliance with decommissioning authorization standards Compliance with standards for project termination
・Main documents	: Decommissioning plan authorization application Safety review report Project termination confirmation application

In this stage, as the project moves towards termination, an overall assessment of long-term safety will be carried out and the safety case revised. Based on this, a safety review report will be published and a decommissioning plan authorization application will be submitted. Based on the authorized decommissioning plan, decommissioning of the surface facility will be implemented in line with the required quality controls. When decommissioning is complete, a project termination confirmation application will be submitted to the government. Once project termination is officially authorized by the government, the disposal project is no longer covered by the terms of the nuclear legislation.

After repository closure, NUMO will be responsible for managing the area covering the repository footprint until NUMO is disbanded (within the framework of the Final Disposal Act, a new law will be established for this).

Also, depending on the Final Disposal Act, if NUMO deems it necessary to protect the area above the repository footprint and surrounding areas, on receiving an application from NUMO the government can designate these areas as protected areas. Within the protected areas, any type of excavation would be forbidden without the authorization of METI. At present, it is planned that a separate law will be enacted for handling the repository after NUMO has been disbanded, when it is expected that the responsibility for managing and assuring repository safety will lie with the national government.

5 . Investigation and evaluation technologies for the geological environment

This chapter describes how the technologies required for selection and confirmation of suitable sites - one of the three policies that support long-term post-closure safety - have been developed steadily, focusing on literature survey stage and preliminary investigation stage. In addition, NUMO's approach to the investigation/evaluation of the geological environment is outlined and the progress in the required technologies over the the past ten years is then described.

5.1 Approach to investigation/evaluation of the geological environment of Japan

Due to the fact that the islands of Japan are located in a tectonically active zone, potential impacts due to disruptive natural phenomena such as volcanic/igneous activity, seismic/fault activity and uplift/erosion need to be evaluated (Table 5-1). In this context, sites where significant impacts of future natural phenomena could be avoided will be selected in the first step. The long-term evolution of the geological environment at the potential repository sites will then be forecasted, with the site for repository construction being selected from the perspectives of designing and constructing a repository and ensuring its long-term post-closure safety.

5.1.1 Forecast of natural phenomena in the future

There is a consensus in Japan that forecast of natural phenomena up to approximately one hundred thousand years into the future is justifiable based on geological records of stability over the past several hundreds of thousands of years (e.g. AEC 1997; JNC 2000b; JSCE 2001; NUMO 2004b). Based on this, NUMO has formulated a basic concept for predicting natural phenomena in the future as follows.

The forecast of future natural phenomena will be conducted by extrapolation, taking into account the volume and accuracy of information and geotectonic history that differ by area and by phenomenon, with clear statement of the assumptions made. The periods for forecasting natural phenomena from the view poin of site investigation/evaluation are defined as follows depending on the uncertainties associated with the forecast:

Period A: period when forecast by extrapolation is justified, with reliable geomorphological/ geological data for a sufficiently longer period in the past than the timescale of forecast;
Period B: period when forecast is justified using certain assumptions but with larger uncertainties;

Period C: period for which forecast by extrapolation or any other method is difficult to justify (Table 5-2).

In the safety assessment, scenarios will be developed with a reasonable understanding of degree of uncertainties for these periods.

Table 5-1Natural phenomena to be taken into account in Japan, their potential impacts on the geological disposal system and their treatment in the site selection process

Natural phenomena	Potential impacts on the geological disposal system and surface facility	Potential consequences	Treatment in the site selection process
Volcanic/igneous activity	･Direct destruction of the repository by intrusion/ eruption of magma	･Release of radionuclides to the ground surface	･Avoid areas with evidence of Quaternary volcanism based on the literature or field investigations and those where such activity can be anticipated within relevant time periods based on trends of past volcanic activity.
	･Increase in rock temperature due to heat convection or alteration in surrounding rocks. ･Convection of hot water and associated enhancement of nuclide migration. ･Change in groundwater flow and groundwater chemistry due to introduction of hot water/volcanic gas into the groundwater.	･Impacts such as a significant decrease in geological disposal system performance.	
	･Change in topography and associated groundwater flow conditions due to large-scale eruption of magma or pyroclastic flow.	･Groundwater flow conditions could vary depending on the scale of the topographic change due to volcanic activity.	･Assuming the scale and location of the change in topography based on literature information and site measurements to be considered as one of the factors of long-term evolution.
	･Destruction or loss of safety functions of the surface facility due to ash fall, volcanic mudflow or pyroclastic flow.	･Could endanger safety functions of the surface facility during operation.	･Evaluate volcanic events, their scale, arrival time at the site and impacts on the surface facility based on literature information and site measurements and develop a method for avoidance or countermeasures depending on their level. (Guidelines or standards as defined for the design of reactor facilities have not yet been developed.)
Earthquake/fault activity	･Destruction of subsurface facilities due to seismic ground motion	･Only small ground motions have been observed at relevant depths. Significant ground motion is thus unlikely.	･Evaluate and confirm that seismic design can withstand credible ground motions, using literature information and site measurements
	･Change in groundwater level and groundwater pressure due to change in crustal strain before and after an earthquake	･Recovery in several weeks to several months has been measured. Permanent effects on groundwater flow are thus unlikely.	･Evaluate such occurrences and consequences based on literature information and site measurements.
	･Direct destruction of repository and/ or waste packages due to movement/ fracturing of rocks	･A newly formed fracture zone may become a preferential pathway for migration of radionuclides from subsurface facilities to the ground surface.	･Avoid areas where active faulting is evident based on literature information and field investigations.
	･Mechanical perturbations due to fracturing and/or rock displacement ･Change in hydraulic properties in surrounding rocks due to generation of small fault and joints.	･The level of impacts would not be so large as to have significant impacts on the disposal facility, but will only open the fractures, causing changes in the rock conditions.	･Evaluate the extent where strain, small faults or joints are formed around the fault and characterize them based on literature information and site measurements as part of characterization of the geological environment.
	･Destruction or loss of safety functions of subsurface facilities due to seismic ground motion	･Could endanger safety functions of the surface facility during operation.	･Evaluate and confirm that seismic design can withstand credible ground motions, using literature information and site measurements.
Uplift/erosion	･Approach of repository to the ground surface and associated changes in groundwater flow and chemistry	･Significant impacts may be caused such as shifting of the underground facility to an oxidizing environment and increase in groundwater flow rate and flux if extent of uplift/erosion is significant compared to the disposal depth.	･Areas with significant uplift are assumed to have associated high erosion and should be avoided.

(Adapted from e.g. JSCE, 2001, 2006; NUMO, 2004b etc)

Table 5-2 Definition of periods for forecasting natural phenomena from the viewpoint of site investigation/evaluation

Periods for forecasting future geological evolution		Period A	Period B	Period C
		Forecast by extrapolation is justified with sufficient information from the past.	Forecast by extrapolation is justified, but associated with larger uncertainties.	Forecast by extrapolation is not justifiable.
Approach to the forecast of future geological evolution		・Forecast will be possible with reliable data (e.g. trends of evolution, mechanisms and driving forces) for a sufficiently longer period in the past than the timescale of the forecast. ・Although there may be several theories explaining trends in tectonic evolution, their differences are considered to be small.	・Forecast will be based on data (e.g. trends of evolution, mechanisms and driving force) covering a shorter time period in the past than the timescale of the forecast. ・Several theories explaining trends in tectonic evolution need to be postulated due to insufficient data and knowledge or their variability. This will increase uncertainties.	・Uncertainties in the forecast will be large because changes in the trend of tectonic evolution cannot be ruled out or no trend in the past can be identified. ・Phenomena that could occur after the evolution need to be assumed.
Uncertainties in the forecast	Relative degree	Small	Medium	Large
	Type	Uncertainties associated with data	Uncertainties associated with conceptualization and data	Uncertainties associated with conceptualization
	Note for parameter setting	・Take into consideration intrinsic variability of phenomena and observation errors during the investigation.	・Take into consideration both uncertainties by postulating several theories explaining trends in tectonic evolution and intrinsic variability of phenomena and observation errors during the investigation.	・Interpretation of the trend of tectonic evolution involves large uncertainties. ・Phenomena that could occur after the evolution should be assumed based on the information in other areas under similar conditions, and appropriate parameters should then be set.
Example of uncertainties to be taken into account	Volcanic/ igneous activity	e.g. Distribution of volcanoes and evolution and fluctuation of location of the volcanic front		e.g. Generation of new conduits
	Earthquake/ fault activity	e.g. Spatial distribution, activity, range of deformed zone, branching/extension of faults		e.g. Reactivation of geological faults, generation of faults
	Uplift/ erosion	e.g. Error in the estimation of uplift/erosion rate	e.g. In addition to error estimation of uplift/erosion rate, changes in modes of motion	e.g. Trends in uplift/erosion and rapid change in the mode of motion.

5.1.2 Consideration of a wide range of geological environment in Japan

Geological environment in Japan can generally be represented by combinations of crystalline rocks (hard fractured media) or sedimentary rocks (soft porous media) and fresh or saline groundwater in terms of transport of groundwater and solutes. Investigation/evaluation technologies for coastal regions where fresh and saline water come into contact are partly different from those for inland settings. These investigation/evaluation technologies have been developed mainly by fundamental R&D organizations. NUMO will utilize the evaluation results described in later in section 5.4.2 to investigate and evaluate the geological environment suitable for the repository site.

5.2 Approach to literature surveys and preliminary investigations

5.2.1 Stepwise investigation and evaluation

The geological environment extending over several square kilometers for a potential repository has a wide range of characteristics. The long-term safety assessment covering a period of several tens of thousands of years or longer after repository closure will also inevitably contain spatial and temporal uncertainties. In order to efficiently evaluate the geological environment with its inherent uncertainties, including its long-term stability, it will therefore be important to demonstrate stepwise the ability of the geological disposal system to ensure safety (Figure 5-1). This is done using an approach in which investigation/evaluation results are checked against safety goals in each step; elements with higher uncertainty and key significance for each milestone are identified and prioritized in terms of data acquisition in subsequent stages. To this end, information from characterization of specific sites will be integrated into site descriptive models (SDM) and its reliability will be confirmed and uncertainty factors will be identified. Furthermore, based on the results from evaluation and investigation of the geological environment, uncertainty factors with high priority will be identified and reflected in the investigation plan in the next step. Stepwise evaluation and investigation is effective for incorporating new scientific/technical findings and know-how into the investigations in each step and for optimizing the evaluation/investigation plans.

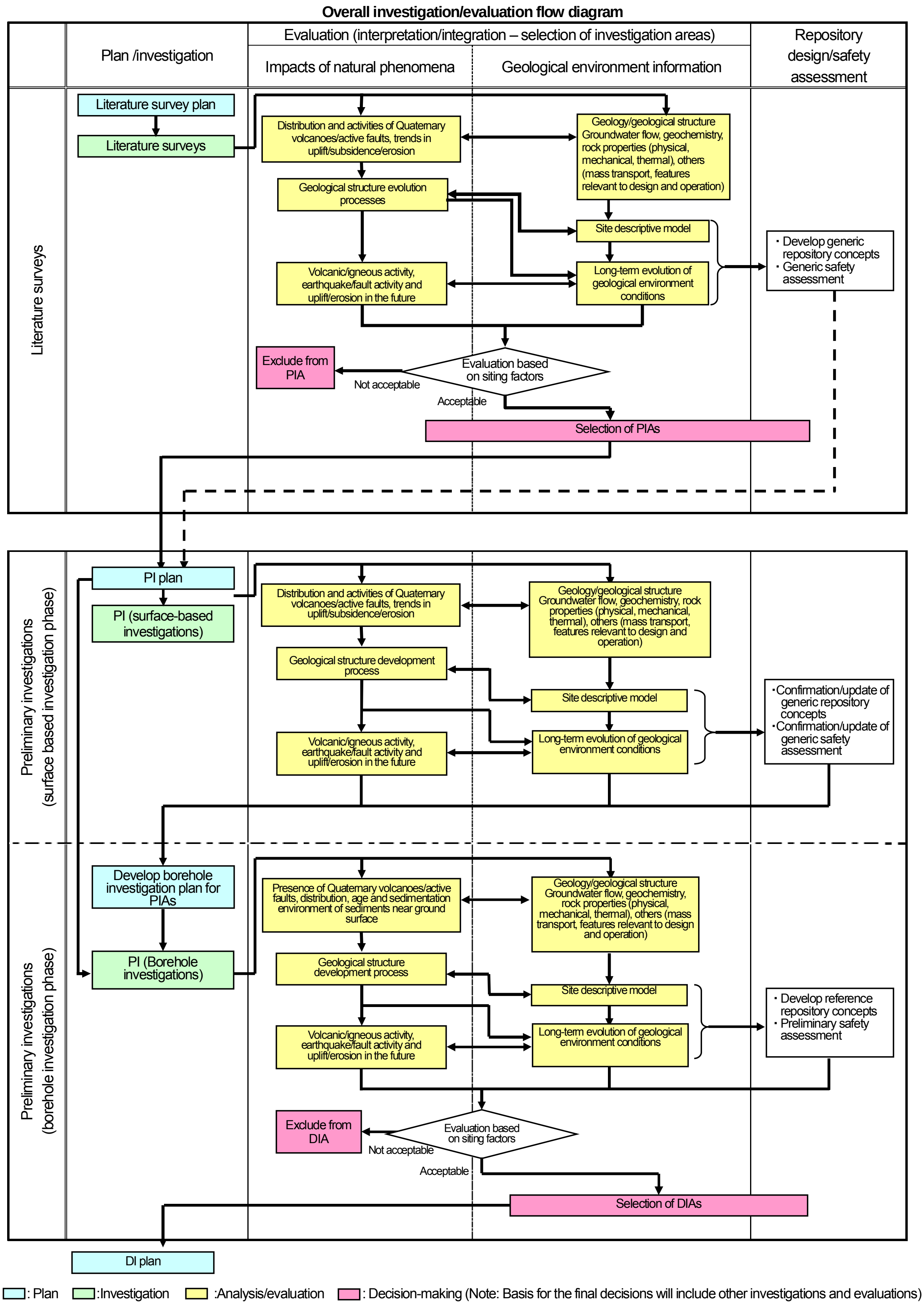


Figure 5-1 Flow diagram for literature surveys and preliminary investigations: An example of coordination and sharing of investigations and information

The steps from the acquisition of common information to selection of each investigation site in the highly variable geological environment in Japan are presented. In order to perform site investigations and evaluations efficiently, geological/geostructural investigations will be optimally planned and information will be shared.

5.2.2 Uncertainties in investigaton and evaluation

Uncertainties in the data and in conceptualization are associated with investigation and evaluation of the geological environment. Uncertainties in the data are contained in data obtained through various measurements as well as datasets into which data from multiple sources are integrated (e.g. dataset for the SDM) and result from different factors such as measurement errors and measurement accuracy (spatial resolution, frequency). Uncertainties in conceptualization result from temporal/spatial data interpretation and cannot be avoided in predicting future natural events and understanding ongoing processes at the site.

Data obtained in the literature survey stage relate to the near-surface environment and information about the deep underground environment is limited. This leads to a large element of uncertainty in the SDM at this stage. For example, only the surface distribution and dip are known for faults; their shape and distribution deeper underground will have to be estimated and extrapolated from measurements made at the surface, which will contain inherent uncertainties. In addition, in the preliminary investigation stage the SDM will have to be constructed based on an insufficient amount of information in order to model the geostructure, geological environment and other phenomena. In such a case, the level of understanding of the geological environment based on the available information, information on the type and degree of uncertainty in the interpretation and forecast will have to be reported to the facility design and safety assessment groups. Furthermore, through engineering strategies and safety assessment based on the dataset, important structural/environmental features that might affect the feasibility of the disposal facility and post-closure safety assurance will be identified. The results will be reflected in the investigation plan for the next step and the uncertainties will be reduced.

5.2.3 Applicability of investigation and evaluation technologies

In order to assure safety with sufficient reliability, NUMO will implement the project using state-of-the-art technologies based on the latest findings. When applying such technologies, optimization of the project, including economic aspects, will be considered. For the investigation and evaluation of the geological environment, technologies that have been verified in various fields such as natural science, resource exploration, civil engineering and nuclear facility construction as well as technologies developed by NUMO and fundamental R&D organizations will be used.

Regarding the investigation and evaluation technologies for natural phenomena, NUMO is compiling existing research examples and evaluating the results with respect to applicability to the geological disposal project. For example, NUMO has been hosting an International Tectonics Meeting (ITM; Chapman et al., 2009a) in recent years. As part of this project, natural processes such as volcanic/igneous activity, seismicity and faulting as well as uplift/erosion have been evaluated and it was concluded that the existing investigation/evaluation technologies are basically applicable to the geological disposal project in Japan.

In addition, for investigation and evaluation of the characteristics of the geological environment, through collaborative research with CRIEPI (Kondo et al., 2011) NUMO is currently examining the applicability of different technologies such as drilling as well as systematic investigation methods (which integrate multiple methods).

The process of confirmation of the investigation and evaluation technologies described above is one of the key elements of building a safety case and will be continued further.

5.3 Literature surveys and preliminary investigations

5.3.1 Literature surveys

According to the Final Disposal Act, literature surveys (LS) are conducted to exclude clearly unsuitable areas where significant natural phenomena cannot be avoided and to select areas for preliminary investigations by further avoiding locations where constructing the repository would be difficult and where human intrusion, such as mining activities, is highly likely. Information is to be collected on topography, geology, geological structure, groundwater flow and chemistry, rock characteristics (mechanical and thermal) and solute transport. Using the information, a preliminary evaluation of the underground facility and the EBS, as well as a preliminary safety assessment (sensitivity analysis), will be performed. Based on the evaluation results, information to be obtained with high priority to reduce uncertainties for future safety assessments will be identified and reflected in the planning of the next investigation step. Literature surveys will be performed as follows (Figure 5-2).

(1) Planning of literature surveys

The area to be covered by the literature surveys will be determined and an LS plan prepared, including the list of literature to be collected. Information to be compiled will be used to evaluate the appropriateness of the volunteer region, i.e. not only the volunteer municipality but also the surrounding areas. The content will be categorized into information that is legally required and additional information necessary to evaluate the siting factors for selecting the PIAs. The former includes earthquake and fault activity, volcanic/igneous activity, uplift/erosion, unconsolidated Quaternary sediments and occurrence of mineral resources. The latter includes rock formation properties, groundwater properties, difficulty of investigation/evaluation, natural disasters, acquisition of land and transportation routing.

(2) Collection and management of literature information

Collection of literature information will be performed by three methods: database search, visiting relevant organizations/authorities and collecting information from the public. All collected information will be managed in the data management system developed by NUMO in order to ensure transparency and traceability of the information on the preliminary investigation area selection process.

(3) Analysis and evaluation of the literature information (geosynthesis)

In the geosynthesis, information on topography, geology, structure, volcanic/igneous activity, earthquake/fault activity and uplift/erosion, mineral resources, properties and characteristics of rock and groundwater, meteorology/surface hydrology and natural disasters will be compiled. If necessary, data from remote sensing and geodetic and geophysical surveys will also be analyzed. The siting factors for selecting the PIAs will then be evaluated. In addition, a SDM for geology/structure, groundwater flow and chemistry and rock properties will be constructed and the characteristics of the geological environment will be evaluated.

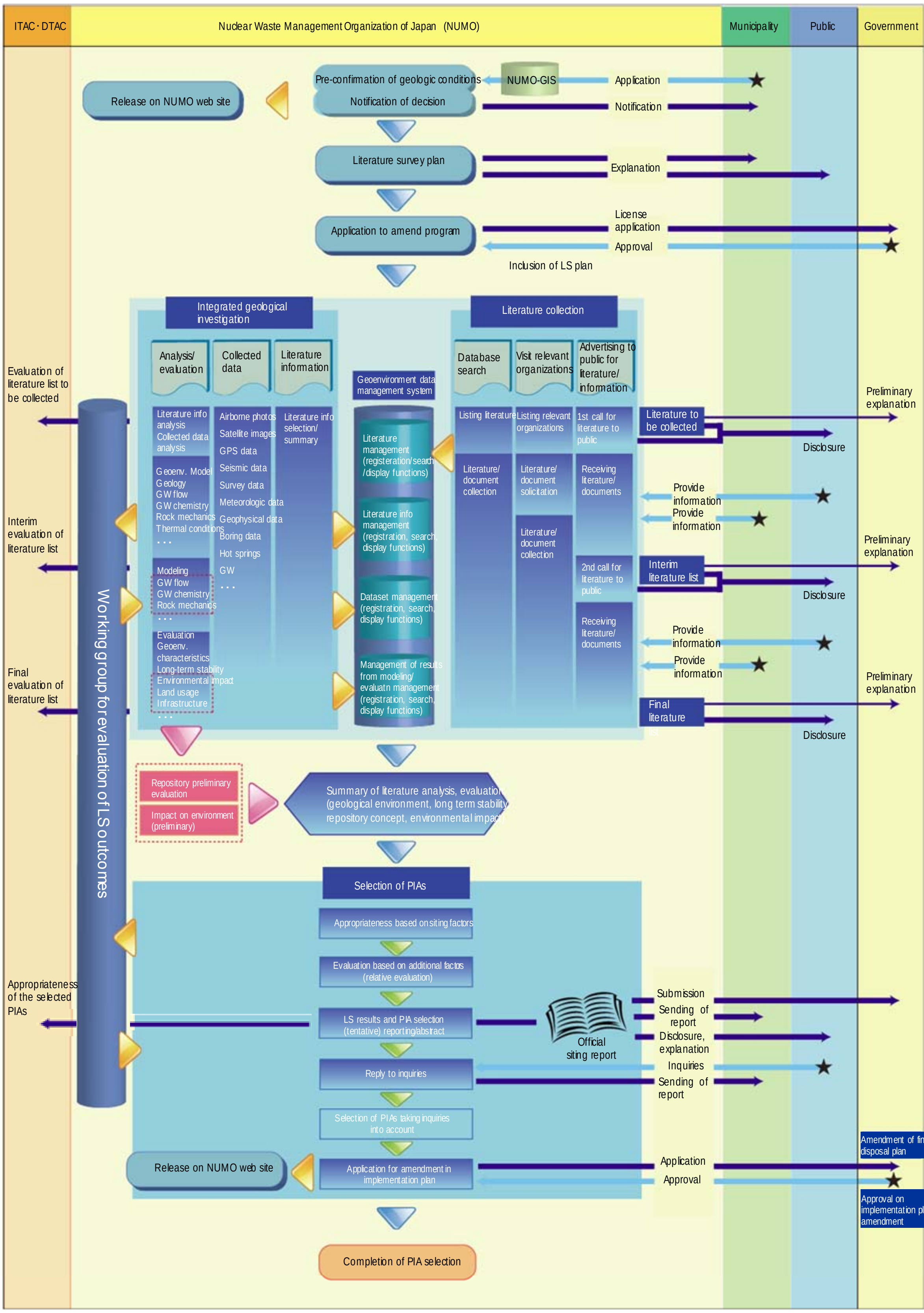


Figure 5-2 Literature survey process flow (example based on volunteer solicitation)

5.3.2 Preliminary investigations

Preliminary investigations are conducted to select DIAs with the prospect of ensuring safety during the project duration as well as long-term post-closure safety. This is done based on investigations from the ground surface, including geophysical surveys and borehole investigations. Applying the evaluation factors for qualification, the selection will be based on confirmation that significant impacts from natural phenomena can be avoided in the area, that there are no difficulties in terms of excavating tunnels and that there would be no adverse impacts of rock temperature or groundwater flow on the repository. In order to achieve this, evaluation of the results based on literature information will be confirmed by directly acquiring site information. The SDM from the previous step will then be updated and the long-term evolution of the site geological environment will be evaluated. Based on this, the preliminary design of the underground facility and the EBS will be prepared and a preliminary safety assessment performed. In the preliminary design, based on the SDM and associated datasets, the location and layout of the underground facility and operational safety will be examined. In the preliminary safety assessment, groundwater modeling, geochemical modeling, mechanical modeling, radionuclide transport modeling and thermo-hydro-mechanical-chemical coupled modeling will be performed. Safety assurance during the operational phase, work efficiency and economic aspects of the project will also be considered and all the results will be evaluated comprehensively. Finally, sites which are more appropriate will be selected for detailed investigations. Information with high priority in terms of reducing uncertainties in the safety assessment will be identified and reflected in the next detailed investigation planning stage. The preliminary investigations will be performed as follows:

(1) Planning preliminary investigations

The preliminary investigation plan is prepared, including the objectives, the investigation area, methods, target results, schedule and implementation framework. The area to be investigated consists of the “preliminary investigation area (PIA)” and “surrounding areas for supplementary investigations”. The preliminary investigation area will be selected from the area including the volunteered site that meets the siting factors for selecting the PIAs. If necessary, areas for supplementary investigations will be selected in order to further investigate the effects of natural processes, such as volcanic/igneous activity, earthquake/fault activity and uplift/erosion, on the geological environment in the PIA.

(2) Implementation of preliminary investigations

In order to acquire the information necessary for evaluating the PIA and surrounding areas, preliminary investigations will be basically performed in two different phases: surface exploration and borehole investigations (Figure 5-3). During the surface investigation phase, surface mapping and geophysical surveys (airborne, ground, off-shore) will be performed and the literature survey evaluation results will be confirmed and improved. Based on these results, the outline of the geological environment will be interpreted and a plan for the subsequent borehole investigation phase will be developed. In the drilling phase, the focus will be on investigations using deep boreholes. These will include core logging, borehole imaging, geophysical logging, hydraulic tests, laboratory tests using core samples and groundwater chemical analyses. Through these investigations, information on the deep underground that was not obtained through the surface investigations, such as geology/geostructure, groundwater (including non-volcanic hydrothermal water) flow and chemical characteristics, rock mass properties (mechanical, thermal) and solute transport, will be obtained.

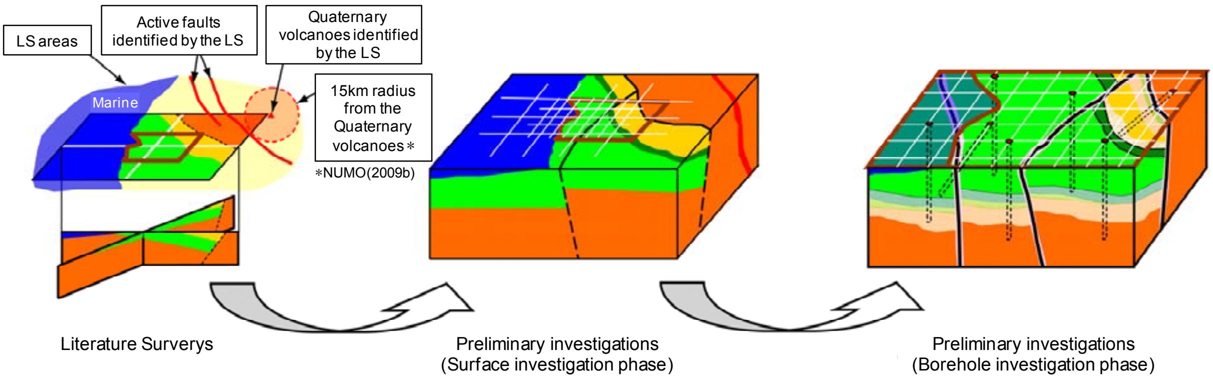


Figure 5-3 Staged approach during preliminary investigations (surface and borehole investigation phases)

(3) Evaluation of preliminary investigations

In the preliminary investigations, it will be evaluated whether or not a PIA is suitable as a detailed investigation area (DIA) based on the siting factors for selecting DIAs to be established in the near future. Regarding natural events, potential impacts of Quaternary volcanic/igneous activity and active faults that were not sufficiently investigated in the literature surveys and volcanic/fault activity identified in the literature surveys will be evaluated. Uplift and erosion identified in the literature surveys will be confirmed and the effects on the safety of the geological disposal system will be evaluated. Regarding the geological environment characteristics, information necessary for repository design and safety assessment, such as fracture distribution, groundwater chemistry, permeability, physical/mechanical properties, thermal properties and groundwater pressure distribution and chemistry, will be obtained. In each investigation phase, the concept of the geological environment developed based on the literature survey will be re-evaluated and reflected in the updated SDM. The long-term evolution of the geological environment will also be evaluated based on the investigation of the effects of natural events. Based on the above, a preliminary design for the underground facility and the EBS as well as a preliminary safety assessment will be conducted.

5.4 Progress in developing the technologies supporting investigation/evaluation activities

Regarding the technologies for evaluating the effects of natural phenomena and the geological environment in the literature surveys and preliminary investigations, the status and open issues at the time of the completion of the H12 report, as well as progress since then, are being summarized. The technologies developed since the H12 report are compiled in Table A.5-1 through Table A.5-8 in Appendix. The evaluation and application of the technologies that NUMO considers to be of particular importance are described below.

5.4.1 Investigation and evaluation technologies related to the effects of natural phenomena

(1) Investigation and evaluation technologies for volcanic/igneous activity

Prior to the completion of the H12 report, and following the progress in dating of volcanic activity, a nationwide distribution of Quaternary volcanoes in Japan (Committee for the Catalogue of Quaternary Volcanoes in Japan 1999) was compiled. It was shown that there is a heterogeneous distribution of Quaternary volcanoes in active regions and that changes in volcanic activity over the last 100,000 years can be attributed to expansion/contraction of the active areas. In addition, methods for evaluating the temperature gradient of volcanoes and their impact on groundwater are also well developed in the geothermal field. For example, a nationwide geothermal gradient distribution has already been prepared and the thermal impact and duration of such effects around volcanoes and magma chambers have already been studied.

In the H12 report, it was recommended to further investigate the likelihood of new volcano formation on the backarc side and in the monogenetic volcanic fields of south-west Japan and to evaluate high temperature anomalies in non-volcanic regions.

With regard to progress since the H12 report, with the advances in deep geological analysis techniques such as seismic tomography, the reliability of evaluation methods has improved to the extent that it is possible to evaluate the generation of new volcanoes and movement of magma and to evaluate deep heat sources (e.g. Kondo, 2009; Umeda, 2009, Table A.5-3 in Appendix). In addition, a method for evaluating deep geothermal waters based on geochemical methods has been developed, leading to identification of thermal waters originating from sources other than magma (e.g. Umeda et al., 2009). As an alternative approach to these deterministic methods, probalilistic methods for estimating new volcano formation were developed based on the probabilistic methods applied in other countries. Their applicability in evaluating regional areas and monogenetic volcanic fields in

Japanhave been confirmed (Chapman et al., 2009b; Martin et al., 2004). Based on the above developments, data on the distribution of Quaternary volcanoes and records of past volcanic activity could be obtained and future activity be forecasted using current technologies.

(2) Investigation and evaluation technologies for earthquake/fault activity

Prior to the completion of the H12 report, methods for investigating the distribution of major active faults and characteristics of groundwater around active faults had been developed by combining interpretation of aerial photographs, geophysical surveys, surface mapping and trench investigations. This led to the production of a 1:2,000,000 map of active faults in Japan (Nakata and Imaizumi, 2002). It was also demonstrated that major earthquake/fault activity has shown similar temporal recurrences over the last 100,000 years, although the spatial distribution is not uniform in that active fault type and activity vary depending on region.

In the H12 report, evaluation of the effects of fault activity and detection methods for faults that do not have clear surface expression were listed as future open issues for further investigation.

Since the H12 report, investigation of earthquakes that have caused damage in inland areas where active faults have not been identified at the surface raised issues such as the relationship between earthquake source faults and active faults, identification of concealed active faults and immature faults, and the adequacy of existing active fault maps. Methods that have been employed to address these issues, such as evaluation of active faults not associated with clear displacement at the surface, have used a combination of GPS, geomorphology, structural geology, geophysics, and geochemistry (Aoyagi and Abe, 2009; Umeda et al., 2010, Table A.5-4 in Appendix). For the evaluation of zones influenced by faults, an evaluation method that compares the results of numerical analyses based on modeling of fault-related folding (folding with subsurface fault movement) and sandbox experiments with field observations has been developed (e.g. Ueda, 2011). As an alternative to the above deterministic approach, a method for probabilistic evaluation of future fault activity was developed based on strain rates obtained from several measurement methods such as GPS, earthquake and surface deformation and its applicability to regional areas in Japan has been confirmed (Chapman et al., 2009b). Based on the above developments, data on the distribution of Quaternary volcanoes and records of past volcanic activity could be obtained and future activity predicted using current technologies.

(3) Investigation/evaluation technologies for uplift and erosion

Prior to the completion of the H12 report, methods for evaluating past uplift and erosion had been developed based on river terrace deposits, etc. Nationwide uplift/subsidence rates were compiled (Koike and Machida, 2001) and erosion rates in each region were evaluated both in terms of planar and linear erosion. Regarding planar erosion, a nationwide map was developed (Fujiwara et al.,

1999) based on the fact that planar erosion is closely related to surface topography. The rate and extent of linear erosion is investigated from major rivers.

The H12 report recommended that improvements should be made in the methods used to evaluate the reliability of inland uplift and erosion rates and that sea-level change should be taken into account when evaluating the future evolution of surface topography.

Since the H12 report, methods for determining site-specific uplift/subsidence and erosion depths/erosion rates, and for estimating past climate/sea-level changes have been improved (Table A.5-5 in Appendix). With the improved technologies for correlating and dating fluvial terrace deposits, the reliability of estimates of uplift in inland areas over the past hundred thousand years has been improved (e.g. Hataya et al., 2009). Forecast methods and simulation techniques for future geomorphological changes have also been developed based on erosion history and climate/sea-level changes in the past, allowing information to be provided for long-term groundwater flow analysis (e.g. Sanga and Yasue 2008). Based on the above developments, uplift/subsidence, erosion depth/erosion rate and climate/sea-level change can be estimated and future activity predicted using current technologies.

5.4.2 Investigation/evaluation technologies relevant to the characteristics of the geological environment

Prior to the completion of the H12 report, development of tools and methodologies for investigating groundwater flow and solute transport and validation of fundamental tools such as for geophysical surveys had been carried out.

It is the goal of R&D since the H12 report to accumulate sufficient knowledge on the deep geological environment under various conditions and to systematize investigation/evaluation methods for the geological environment.

Based on the above, existing investigaton/evaluation methods for specific targets, e.g. geology/structure, groundwater flow and chemistry, solute transport, issues related to construction and safety and monitoring, have been improved/updated (Table A.5-5 in Appendix).
From the viewpoint of geological disposal, the geological environment in Japan can be divided roughly into crystalline rocks (hard fractured media) and sedimentary rocks (soft porous media), combined with fresh and saline groundwater environments. In addition, near the coastline where freshwater and saline water meet, different technologies and concepts are needed for investigation/evaluation.

In JAEA's program, the geological environments in crystalline rock-freshwater and sedimentary rock-saline water have been studied in two URLs (Saegusa et al., 2007; Ota et al., 2007). These programs are examples of systematic investigation/evaluation, in which a series of tasks ranging from data acquisition to model development during the first investigation phase from the surface were conducted iteratively to improve understanding of the geological environment and to reduce uncertainties. With regard to coastal areas, technologies for characterization of active faults based on literature data, geophysical surveys from the surface and the sea floor, identification of the saline/freshwater interface geometry, surveying groundwater discharge at the sea floor and investigations using controlled drilling technology have been developed. This will allow continuous investigation/evaluation straddling the inland and off-shore areas (e.g. AIST, 2010). Other than R&D in the geological disposal field, similar underground exploration is being conducted in fields such as resource exploration, active fault investigations and some test methods in civil engineering projects. Findings from these developments will also be incorporated into the geological disposal project.

NUMO has also conducted demonstration studies at CRIEPI's Yokosuka site as part of a NUMO-CRIEPI collaborative project with the objective of confirming the investigation/evaluation technologies developed by fundamental R&D organizations and developing an investigation management strategy (Kondo et al., 2011). Through stepwise data acquisition via literature surveys, geophysical surveys and borehole investigations, interpretation of data and updating of the site descriptive model, systematic investigation/evaluation technologies to be used in the preliminary investigation phase have been developed. The effectiveness of the methodologies for appropriate and rational decision-making on schedule, quality controls and safety management were confirmed by conducting a series of tasks from planning of investigation programs through evaluation of the results.

5.5 Conclusions of chapter 5

The H12 report indicated that geological environments that meet the requirements for safe geological disposal are widely distributed in Japan and that whether or not such requirements are met can be judged using investigation/evaluation technologies available at the time. Since the completion of the H12 report, NUMO has been synthesizing the technologies developed to investigate/evaluate the impacts of natural phenomena and geological environment characteristics for use in the selection of PIAs and DIAs. In parallel, NUMO and fundamental R&D organizations have collected data on the geological environment and have improved and refined various methodologies that may be required for site characterization. As a result of the efforts described above, NUMO is prepared for carrying out the literature surveys and preliminary investigations as well as evaluations for site selection when there are applications or acceptance of governmental nomination from a municipality. Furthermore, new scientific findings and advances in investigation/evaluation technologies will continuously be incorporated in order to improve the reliability of investigation/evaluation technologies for the geological disposal project.

6 . Technologies for design, construction, operation and closure of the repository

This chapter describes the technologies required for implementing the policy on appropriate engineering for design and construction of the repository.

Since the completion of the H12 report, the understanding of the long-term behavior of, and interaction among the engineered barriers has improved and technologies for transporting and emplacing the engineered barriers have made significant progress. Based on this, NUMO has systematically formulated technical requirements for the design of the repository and demonstrated combinations of waste package emplacement methods and operating technologies suitable for a range of geological environments.

6.1 Basic design policy for the geological disposal project

6.1.1 Staged design implementation

Information on the geological environment of potential sites will be accumulated progressively throughout the three-stage site selection process. NUMO will iterate the design of the surface and subsurface facilities that make up the repository in line with accumulated understanding and development of technologies towards more detailed and refined design.

The ultimate goal of geological disposal is to ensure long-term post-closure safety and the design of the subsurface facilities, including the engineered barriers, therefore requires consideration of factors that can cause changes in barrier performance associated with the long project timescales.

Therefore, R&D on engineered barrier materials such as bentonite-based materials, cement-based materials and metallic materials will be carried out in cooperation with fundamental R&D organizations and up-to-date knowledge on the engineered barriers will also be accumulated within and outside Japan. In addition, development of technologies for achieving safe and effective operating systems will continue and progress will be reflected in the selection of construction, operation and closure technologies.

Based on the stepwise improvement of the information on the geological environment outlined above, advancement of technologies and validation of these in the underground investigation facility (UIF) during the DI phase, design specifications appropriate for the site conditions will be determined and the reliability and practicality of the design will be improved.

6.1.2 Handling uncertainties in the design

Uncertainties associated with information obtained through geological investigations will exist because of the spatial extent and heterogeneity of the host rocks where the repository is to be constructed. In structural design, large tolerances are generally allowed in the design specification for components with uncertainties, which will also be applicable in the design of the repository. Uncertainties associated with the geological environment will be accommodated by selecting a suitable area of potential host rock to locate the underground facility, considering areas that may be unfavorable for emplacing waste packages. The size of the repository footprint may change depending on the host rock properties, but the accuracy of the size estimation should increase with time because more reliable data on the mechanical and thermal properties of the host rock will be available.

For ensuring long-term post-closure safety, consideration will have to be given to factors that could compromise safety from a long-term perspective in the design of the underground facility and the engineered barriers. The performance of the engineered barriers will evolve with time and uncertainties will increase. Factors that could cause changes in the engineered barrier performance and lead to increased uncertainty will be taken into account in the design to assure basic performance when the engineered barriers are constructed using current technologies, based on the results of the safety assessment and long-term behavior analysis.

6.2 Safety functions and technical requirements for the repository

The technical requirements for long-term post-closure safety have been considered based on the development of international criteria (IAEA, 2006, 2011) and advances in technologies since the H12 report. Specifically, based on the principles for ensuring safety, i.e. isolation and post-closure confinement, technical requirements are systematically defined for each repository component such that these components will achieve their safety functions. With the progress of investigation/evaluation of the geological environment, the technical requirements for each investigation area will be clarified and reflected in the design.

Figure 6-1 shows the relationship between the basic concept for ensuring radiological safety and the different project stages. During the period from reception of the waste packages to closure of the repository, the focus will be on safety in each prior project stage and the principal safety measures will therefore consist of confinement during operation and radiation shielding, as well as control of radiation exposure. During the period after closure, the focus will shift to isolation and containment. These measures will be applied to both HLW and TRU waste. The relationship between isolation and containment after closure of the repository and the safety functions is shown in Table 6-1.

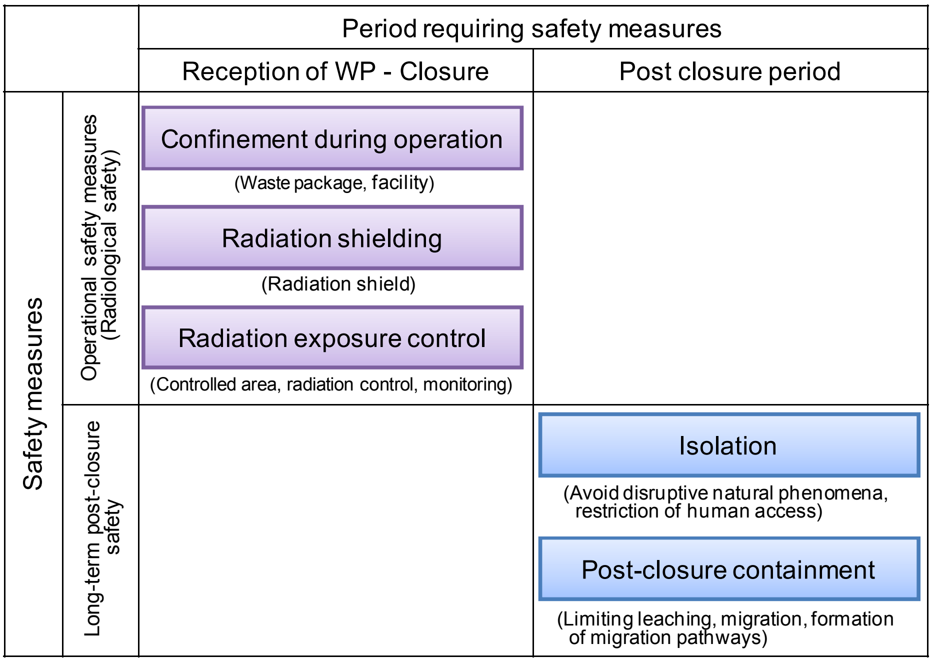


Figure 6-1 Relationship between the basic concept for ensuring safety and the different project stages

Table 6-1 Basic concept for ensuring long-term post-closure safety and safety functions

Basic concept	Safety functions	Description of the safety functions
Isolation	Protection from long-term geological evolution	Emplace waste packages deep underground, isolated from the human environment to protect them from topographic changes such as erosion.
	Limiting human intrusion	Make the access to the waste packages difficult without special technologies in order to reduce the likelihood of inadvertent human intrusion.
Containment	Reducing leaching of radionuclides	Reduce the nuclide release rate to the groundwater by restricting the leaching rate of radionuclides from the waste.
	Retardation of nuclide migration	Reduce radioactive material migration rate by retardation of nuclide migration.

Engineered measures that ensure isolation and containment after closure complement those that reduce subsequent radiological impacts on the human environment; this is the basis of the multi-barrier system. With regard to the relationship between the safety functions for the repository and the multi-barrier system components, the natural barrier will be responsible for the functions "protection against long-term geological evolution" and "restriction of human intrusion", the waste package and overpack for the safety function "restriction of leaching of radionuclides" and the buffer, backfill, plug and natural barrier for the safety function "retardation of nuclide migration".

Three types of technical requirements will be set: those for securing basic barrier performance, those for maintaining long-term barrier integrity and those for ensuring engineering feasibility. The basic barrier performance relates directly to the safety functions and is essential for ensuring safety. The long-term integrity of the barriers refers to the situation where basic barrier performance can be maintained even if the barrier properties have been subjected to change during the long post-closure period. The technical requirements will be set in such a way that the barrier performance required for ensuring safety will not fail due to changes in material properties such as alteration due to heat generation from the waste packages. Ensuring engineering feasibility means that the production, manufacture and cost of the engineered barriers will not be unrealistic. The technical requirements for maintaining the long-term integrity of the engineered barriers and ensuring engineering feasibility will be subordinate to the requirement of basic barrier performance. The technical requirements for basic barrier performance specified in accordance with the concept described above are shown in Table 6-2 through Table 6-4.

Table 6-2 Technical requirements for the overpack (ensuring basic barrier functions)

Safety functions		Technical requirements	Description of the technical requirements	Design items
Restriction of leaching of radionuclides	Preventing contact with groundwater during the period when the heat generation rate is significant	Corrosion resistance	Safety functions should not be endangered due to corrosion for a defined period	Overpack design (material, configuration and thickness)
		Structural integrity	Maintain structural integrity against mechanical loading after emplacement	Overpack design (material, configuration and thickness)
		Corrosion resistance of the weld and structural integrity	Achieve mechanical strength and corrosion resistance of the weld comparable to those of the base metal	Overpack design (material, lid structure, welding method and welding conditions)

Table 6-3 Technical requirements for the buffer (ensuring basic barrier functions)

Safety functions		Technical requirements	Description of the technical requirements	Design items
Retardation of nuclide migration	Restriction of migration by advection	Low permeability	Restrict groundwater flow (advection) in the buffer to restrict the migration of radionuclides	Buffer design (material, configuration, thickness)
	Prevention and restriction of colloid migration	Colloid filtration	Restrict colloidal migration of radionuclides	Buffer design (material, configuration, thickness)
	Retardation of nuclide migration by sorption	Sorption capability	Retard migration of radioactive materials leached from the glass by sorption	Buffer design (material)

Table 6-4 Technical requirements for the backfill and plug (ensuring basic barrier functions)

Safety functions		Technical requirements	Description of the technical requirements	Design items
Retardation of nuclide migration	Preventing the access tunnel and rocks around the tunnel from functioning as a preferential migration path	Restriction of formation of migration paths along the tunnel	Restrict formation of preferential groundwater flow paths along the tunnel	Backfill design (material design), sealing plug design (material, layout), mechanical plug design (material, layout)

The concept for radiological safety measures is described below. Safety measures based on the radiation protection concept for the repository are: containment of radionuclides during operation, radiation shielding and radiation exposure control. They are shown in Table 6-5 together with the associated measures. The concept of safety measures against abnormal events is described below.

Abnormal events are those which could cause deviation from normal operating conditions in the surface or subsurface facilities. Examples include dropping, falling or collision of waste packages in the surface or subsurface facilities. An accident is an event which causes radioactive materials to be released from the facility under extended abnormal conditions. To be extended to an accident triggered by abnormal events, such as earthquake, fire, tsunami and loss of power, a combination of several events will be required, such as dropping the waste package, failure of the waste package and dispersal of released radioactive materials.

In the case of an abnormal event, measures to prevent the spread of the contamination by, for example, installing a ventilation system with a decontamination function such as filters will be required to prevent dispersal of radioactive materials. If the situation should extend to accident conditions, actions to mitigate the consequences, e.g. decontamination, should be taken.

Table 6-5 Basic safety measures for radiation protection

Concept	Safety measures	Description
Confinement during operation	Prevention of release of radioactive materials from the waste packages	Prevent leakage of radioactive materials from waste packages during operation
	Prevention of excessive release of radioactive materials from the facilities to the environment	Prevent excessive release of radioactive materials from handling facilities during operation (on reception of waste packages)
Radiation Shielding	Shielding of radiation	Reduce air dose rate by shielding radiation from the waste package
Radiation exposure control	Setting radiation controlled areas	Limit access to radiation controlled areas
	Monitoring/radiation exposure control	Control radiation exposure to workers and monitor radiation controlled areas and areas around the site

6.3 Repository design

6.3.1 Design procedures

The repository design, including the specifications of the surface and underground facilities and the EBS in order to ensure safety during each phase of the geological disposal project, is clarified depending on the progress of site investigation and evaluation.

The basic approach and procedure for designing the EBS, the underground facility and the surface facility are outlined in Figure 6-2. The repository will be designed with sufficient safety and to satisfy corresponding technical requirements.

Firstly, the characteristics of the geological environment such as the thermal environment, the mechanical and hydrological regimes, the geochemical environment and the extent of the host rock will be evaluated. Based on the results, the maximum tunnel depth determined largely by mechanical stability around the tunnels and the waste thermal characteristics, regions with longer radionuclide transport times and pathways and repository dimensions determined by the volume of waste will be considered and the depth and location of the underground facility will be specified.

Based on the characteristics of the host rock at the repository location, the overpack and buffer material components of the EBS will be designed and the specifications of the EBS such as the material, shape and thickness of the overpack and buffer will be determined.

An access route will then be considered and the tunnel cross-sections and waste emplacement specifications in the disposal tunnels will be determined. Once tunnel dimensions sufficient for accommodating the waste and the EBS have been determined, the support measures necessary for maintaining these dimensions will be calculated based on evaluation results of tunnel mechanical stability. Heat generation from the waste will then be quantified and waste package spacing determined such that no significant temperature increase in the EBS will occur.

Based on the tunnel cross-sections and waste emplacement density, repository panel dimensions and configurations, main/connecting tunnel layouts and the number of access tunnels and their locations will be determined and the layout of the entire underground facility will be specified. The tunnel backfilling and plug specifications and their positions will then be designed.

Regarding the surface facility, a potential site will be selected based on natural and social environmental conditions and transport infrastructure. The entrance location will then be decided based on the position of the underground facility. Radiation controlled areas and transport of construction materials and machinery will be considered in deciding on the configuration of other required facilities.

After confirming that the safety performance of the geological disposal system is sufficient, all of the above will form the repository concept. NUMO will further improve the accuracy and reliability of these procedures through iterative updating of information, technologies and know-how in each step of the project.

The above description of the design flow process is relatively one-way. The actual design will be carried out with more flexibility by feeding back the results for the EBS, underground facilities, surface facilities and investigation and evaluation results into decisions for adjusting parameters and re-designing repository components.

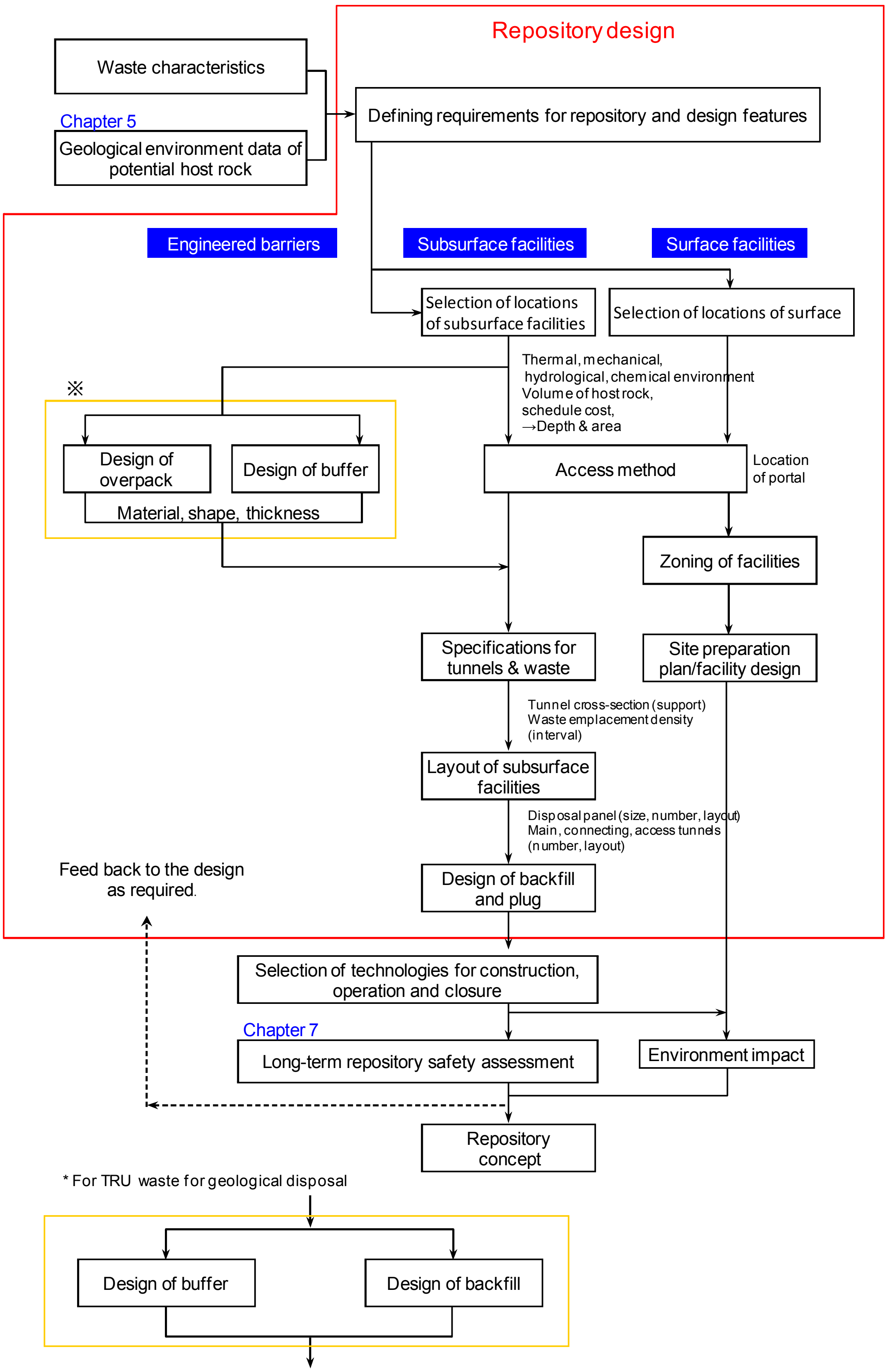


Figure 6-2 Sequence of repository design

6.3.2 Design of the engineered barriers

The engineered barriers for the HLW repository consist of the vitrified waste, the overpack and the buffer material, while those for TRU waste consist of backfilling and buffer materials. In this section, the design procedure for the engineered barriers based on the technical requirements is described. The production of the vitrified waste is excluded as this is done during reprocessing.

(1) Design of the overpack

The safety function of the overpack is to prevent radionuclide leaching; in particular, the overpack must not be in contact with groundwater during the high heat generation period. Considering the vitrified waste and its thermal properties, this period is expected to be the first 1,000 years after emplacement. The technical requirements for the overpack to ensure fundamental performance and the behavior of the intact base material as well as welded sections should show sufficient resistance to corrosion and structural strength to withstand loading. Based on this, the design of the overpack involves determining its material, shape and thickness. Carbon steel is currently considered as the best candidate material due to its good workability. An example of the design procedure for a carbon steel overpack with a lifetime of 1,000 years is shown in Figure 6-3.

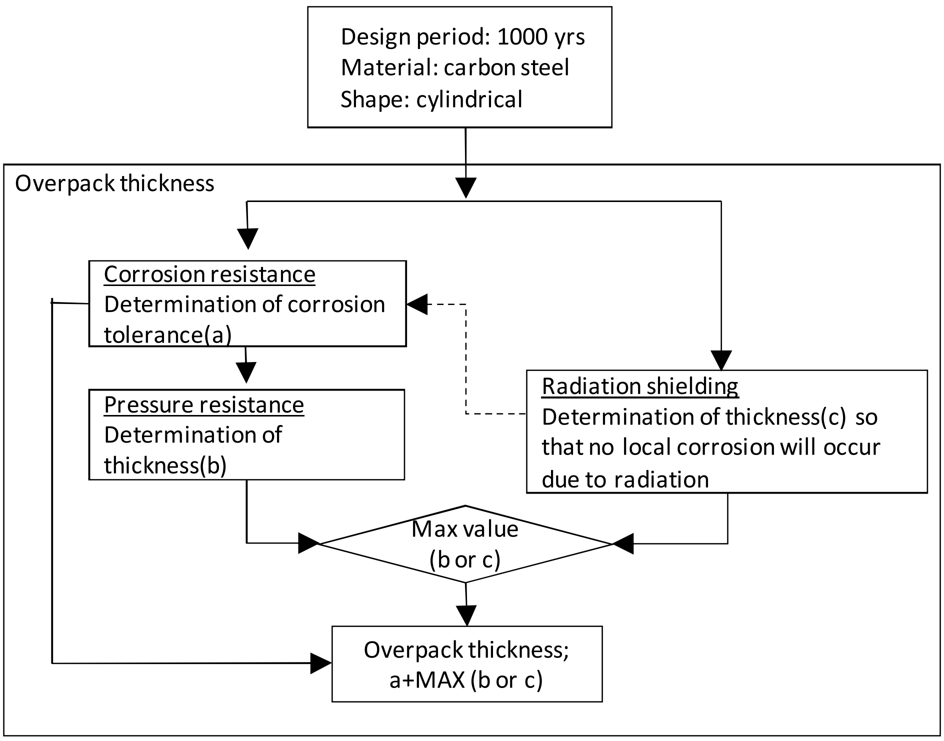


Figure 6-3 Example of the overpack design procedure (JNC, 2000b)

Since the NUMO 2010 report, the technologies for evaluating the corrosion behavior of carbon steel have been further developed and the conservativeness of the above design example and its feasibility were confirmed. For example, the results from a carbon steel corrosion test in a radiation field with an intensity that is expected in the repository showed that there was a negligible effect on the properties of the carbon steel. Therefore, it is possible to reduce the overpack thickness by re-evaluating such effects.

(2) Design of the buffer material

The safety function of the buffer material is to prevent radionuclide transport, in particular advective transport, and colloid migration and to retard radionuclide migration via sorption. For these safety functions, the technical requirements for assuring fundamental buffer performance are low permeability, colloid filtration and sorption capacity. Figure 6-4 shows a design flow for the buffer material. In order for the technical requirements for assuring fundamental barrier performance, maintaining long-term stability and engineering feasibility to be satisfied, a range of buffer material specifications is considered. The final buffer material specifications, shape and dimensions will be determined taking into account quality control procedures and economic aspects depending on the buffer fabrication, transportation and emplacement methods. Once the buffer material specifications have been determined, the long-term stability of the material will be evaluated. If long-term stability is found to be insufficient, the design specifications will be modified by, e.g., increasing the buffer thickness or dry density.

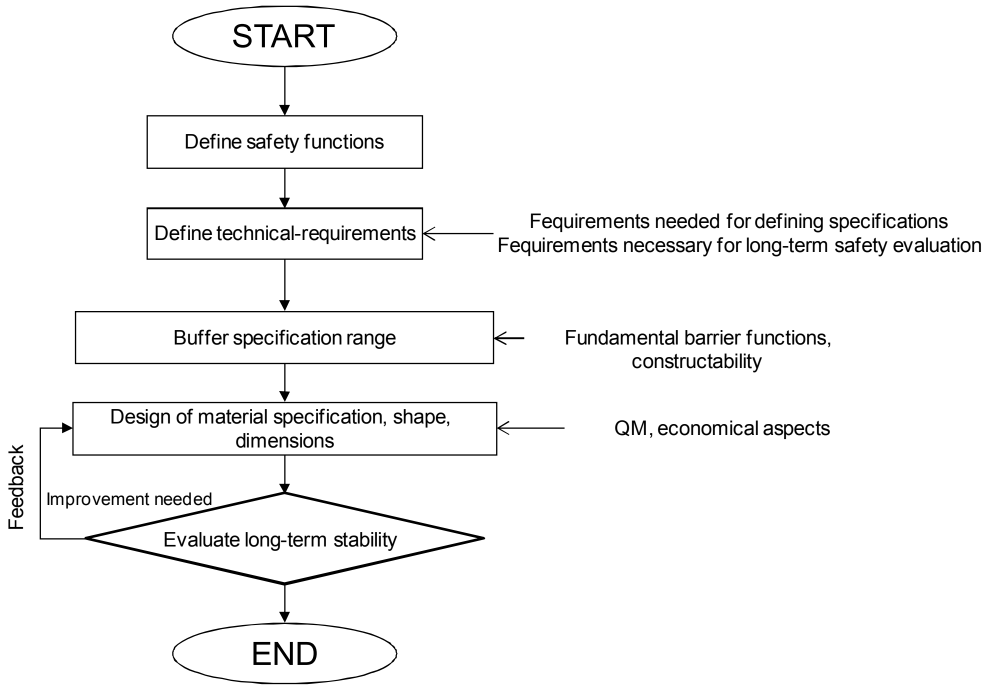


Figure 6-4 Design flow for buffer material (NUMO, 2011a)

Since the NUMO 2010 report, more data on buffer material fundamental characteristics and on scientific understanding of long-term stability have been obtained. For example, the reduction in swelling pressure due to salinity is now better understood and such information can be used to evaluate self-sealing. Concrete supports and grouts are expected to be used for the construction of the underground facilities. Therefore, experimental investigations and development of modeling methods for the interaction between cement-based and bentonite-based materials are being advanced. The results will be reflected in future evaluation of long-term buffer stability.

6.3.3 Design of the underground facilities

The design of the underground facilities will be performed in the order 1) selecting the location of the underground facilities, 2) tunnel specifications and waste emplacement configuration, 3) underground facility layout and 4) backfill and plug design.

(1) Location of the underground facilities

Table 6-6 shows examples of the criteria to be evaluated in determining the location of the undeground facilities. These criteria include the extent of the host rock and other aspects such as schedule and economic feasibility, in addition to geoenvironmental characteristics such as thermal, hydraulic, mechanical and chemical properties.

From the viewpoint of the thermal environment, since the rock temperature increases with depth, the maximum depth of the repository location will be determined considering the working environment and thermal restrictions on the engineered barriers. From a mechanical viewpoint, tunnel diameter at a depth of 300 m or more (one of the evaluation factors for qualification) will be determined by the relationship between rock strength and ground pressure applied to the tunnel. The general trend is for ground pressure to increase with depth, leading to mechanical instability of the tunnels. The maximum depth where mechanical stability can be maintained should therefore be determined.

Considering the hydrogeological regime, groundwater flow characteristics in the host rock and groundwater flow paths and flow rates in potential disposal areas and depths will be evaluated and more promising areas from the viewpoint of radioactive material transport, e.g. areas that have longer groundwater migration paths and slower groundwater flow rates, are selected based on mechanical and thermal feasibility.

Table 6-6 Evaluation criteria for defining the location of the underground facilities

Factors to be evaluated	Evaluation indicators (example)	Information required for the evaluation
[Thermal environment] Low post-closure temperature of the repository	Waste emplacement area based on thermal output of the waste packages and rock properties and evolution of the repository temperature with time	Layout of waste packages and evolution of temperature calculated using models incorporating thermal output of waste packages and rock properties
[Mechanical field] Ensuring mechanical stability of tunnels Post-closure mechanical field in and around the repository appropriate to ensuring stability of engineered barriers	Spacing of disposal tunnels and specification of tunnel support based on rock properties	Rock property model, initial lithostatic load, lateral pressure, rock mechanical properties , competence factor, etc.
[Hydraulic field] Low post-closure groundwater flux and velocity in and around the repository	Groundwater migration path length, groundwater travel time, etc.	Hydrogeological model, long-term evolution of the geological environment, hydraulic gradient, geothermal gradient, groundwater chemistry, hydraulic conductivity, effective porosity, groundwater flow direction, etc.
[Chemical environment] Chemical environment in and around the repository that keeps the solubility of nuclides low and is appropriate for barrier material stability	Long-term behavior of engineered barriers based on groundwater chemistry	Groundwater chemistry model, redox potential, pH, groundwater chemistry, rock mineralogy, etc.
[Extent of rock body] Sufficiently large area (volume) that permits layout of the repository and configuration that allows effective arrangement of disposal panels	Repository-scale, number and configuration of disposal panels	Site descriptive model, spatial extent of host rock, distribution of fault/fracture zones, etc.
[Schedule, economics, etc.] Good prospect for keeping schedules and efficient construction processes	Construction and operation schedules, rough estimate of construction costs, etc.	Length of access tunnels, disposal concept, disposal tunnel cross-section

(2) Tunnel and waste emplacement specifications

When determining tunnel specifications, the cross-sectional dimensions and the tunnel shape and support are the main items. For HLW emplacement, determining the waste package spacing (waste emplacement density) is the major item from the viewpoint of the thermal environment.

The tunnel specifications will be determined based on the space required for emplacing the buffer and the waste and constraints associated with the facilities for buffer and waste transport and emplacement (i.e. minimum dimensions needed to accommodate such facilities). The shape of the tunnel cross-section has to ensure sufficient mechanical stability (small deformation), good workability and economic advantages (as small as possible, while maintaining the required volume).

The tunnel support measures will be evaluated based on the results of the mechanical stability assessment of the tunnel cross-section. The pitch between the emplacement tunnels and the waste packages is determined from the viewpoint of mechanical effects and thermal effects due to the heat from the waste, given the temperature constraint in the EBS after backfilling. In particular, the waste emplacement density will be set in such a way that the buffer material will not be altered by the rise in temperature due to the heat from the waste. The temperature evolution with time in the near-field after the waste is emplaced will thus be evaluated numerically and the emplacement tunnel and waste package spacing will be determined such that the maximum temperature in the buffer material will not exceed a predetermined threshold value.

For TRU wastes disposal, the tunnel specification design approach will be the same as that for the HLW. Tunnels with a higher waste emplacement density are economically preferable. TRU wastes generate less heat than the HLW and a larger number of waste packages can thus be emplaced in a large cross-section tunnel (NUMO 2011a). Tunnels with a large cross-section are typically excavated in steps to ensure mechanical stability and safety. The mechanical stability of the tunnels is evaluated via numerical simulations incorporating the actual excavation steps.

(3) Underground facility layout

For the underground facility layout, the size and number of disposal panels and the orientation of the tunnel groups are determined. The main tunnels and access shaft/ramp connecting with the surface facility are then determined. For the orientation/configuration of the tunnel groups, in addition to assuring safety during the construction, operation and closure phases and smooth transport of materials, geoenvironmental characteristics such as the direction of principal stresses and groundwater flow in the rock mass will be considered.

Orienting the tunnels in the direction of the maximum principal stress within the horizontal plane is the most efficient way to reduce rock deformation and ensure stability. By aligning the short side of the underground facility perpendicular to the groundwater flow, the amount of groundwater seeping into the facility is minimized. This is efficient from the viewpoint of radionuclide transport. The longest tunnel will be determined based on the fracture conditions in the rock mass that can affect the mechanical and hydraulic fields.

(4) Design of backfill and plugs

The backfill material and sealing plugs are expected to prevent radionuclide transport due to advective groundwater flow after closure. The mechanical plug is expected to reduce swelling that would result in a decrease in buffer density. In particular, the remaining voids in the tunnels are backfilled and the excavation damaged zones (EDZ) are separated with sealing plugs as needed. Mechanical plugs are installed at the end of the emplacement tunnels to prevent buffer movement and buffer erosion. The design will be evaluated not in terms of individual elements such as backfill or plug, but as an isolation system into which all the elements are integrated.

6.3.4 Design of the surface facility

The design procedure for the surface facility consists of 1) zoning for the surface facility, 2) access to the underground facility, 3) zoning for other facilities and 4) construction plan for the surface facility.

Zoning of the surface facility will be performed considering natural environmental conditions in the volunteer area, the risk of natural disasters such as landslides or tsunami and the socio-economic environment, such as adjacent land use. The depth and location of the underground facility and access routing from the surface to the underground facility, i.e. vertical shaft, ramp or a combination of these, will be determined. The waste treatment facility, operational materials facility, other facilities for construction/closure and the site management facility will be located such that each can function with optimum efficiency. For the construction plan for the surface facility, measures will be taken to reduce the spreading of excavated soil due to wind and rain. Each component of the surface facility will be designed to meet the requirements specifically set for that facility.

6.4 Repository construction, operation and closure

6.4.1 Repository construction

Repository construction starts with preparing the land, building roads, providing the infrastructure for power and water as well as site management facilities. Following installation of a ventilation system and a drainage water processing plant, construction of the underground facility will start. For constructing the surface facilities, existing technologies used for conventional industrial or nuclear facilities can be used, paying sufficient attention to protecting the surrounding environment.

Construction of the underfround facility is done in such a way as to ensure safety and a safe working environment at all times, including emergency evacuation routes and ventilation shafts/tunnels. The construction methods will be determined based on the rock mass conditions and other factors. For excavating vertical shafts, ramp and horizontal tunnels, the most appropriate methods will be selected from those used in similar geotechnical projects, taking into account the geoenvironmental conditions, safety and working efficiency as well as reduction of the EDZ around the tunnels. For example, at the Mizunami and Horonobe URLs (Nakayama et al., 2008, Figure 6-5), the short-step method is employed for excavation of the vertical shafts.

NUMO has analyzed the issues to be resolved for implementing the construction process (approximately ten years from the start of construction to the start of repository operation) and the operation schedule (approximately 1000 canisters of vitrified HLW will be disposed of per year). For example, excavation of disposal vaults and disposal of the excavated rock will be a critical factor that can significantly influence the project schedule and, to this end, effective construction technologies have been developed.

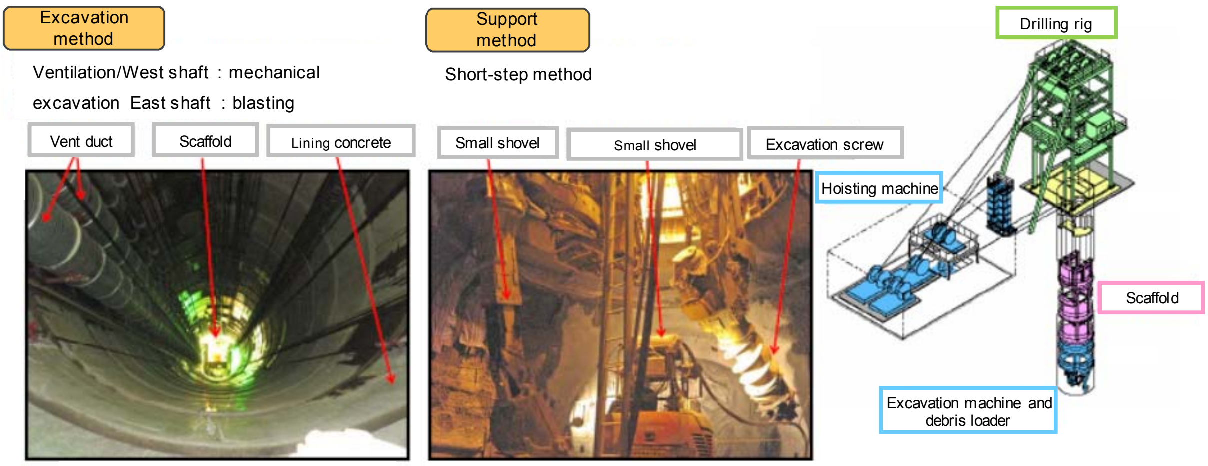


Figure 6-5 Excavation of vertical shafts using the short-step method (Nakayama et al., 2008)

6.4.2 Repository operation

Repository operation consists of receiving, encapsulating and inspecting the vitrified high-level waste in the surface facility, transport to the underground facilities and emplacement in the disposal tunnels.

The vitrified waste (in transport containers) will be transported to the HLW reception/ encapsulation/ inspection facility using a special vehicle. The waste will be inspected for any potential damage to the container and the vitrified waste caused during transporation before encapsulation in the overpack. Vitrified waste that passes the inspection will be transported to the underground facilities after 1) encapsulation in the overpack, 2) welding of the overpack lid and 3) inspection of the welded section. Figure 6-6 illustrates the waste production process based on welding of the overpack and inspection of the welded section using ultrasonic damage detection.

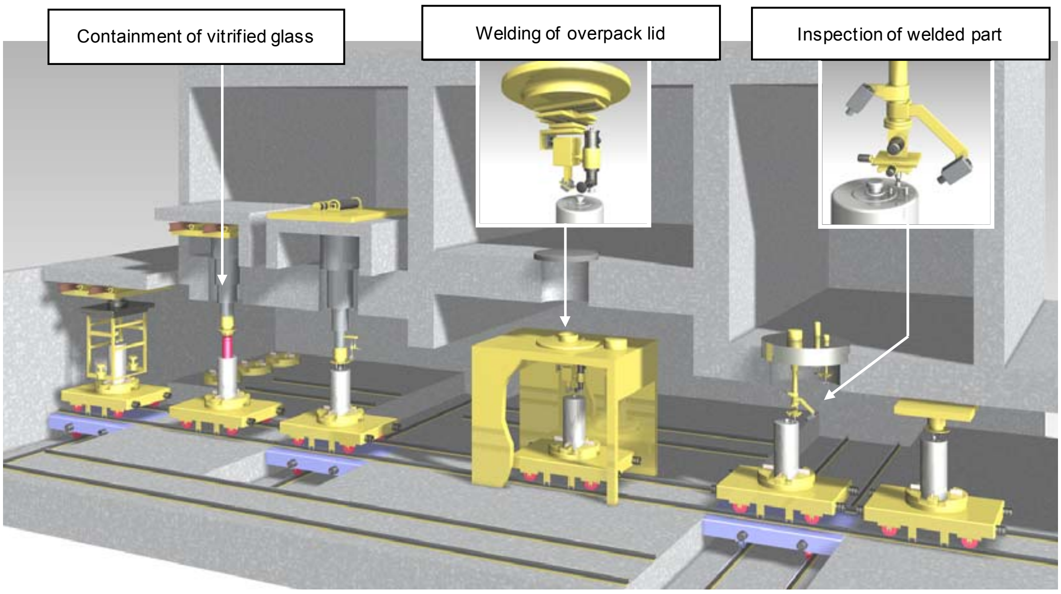


Figure 6-6 Schematic process for remote-controlled waste encapsulation in the overpack (carbon steel single overpack) (NUMO, 2002)

NUMO has investigated methods for improving the reliability of the quality of the engineered barriers and reducing underground work (transport and emplacement). As part of this, the Prefabricated Engineered barrier system Module (PEM) method was selected as a promising technique together with conventional in-situ construction and emplacement methods. In the PEM case, the engineered barriers are prefabricated as an integrated module and then transported and emplaced underground. A schematic illustration of the PEM method is shown in Figure 6-7.

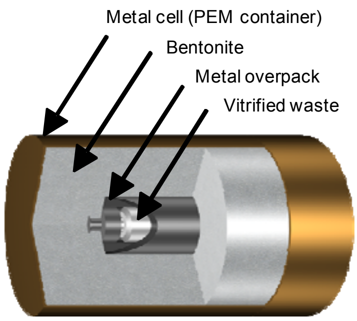


Figure 6-7 Schematic illustration of the PEM method

The most obvious advantages of the PEM method are improved quality and efficient transport because the module is assembled at the surface. On the other hand, considering its heavy weight (total of about 35 tons, including waste package, buffer and steel shell), R&D has been conducted by fundamental R&D organizations on horizontal transport/emplacement techniques in the tunnel with its spatial constraints and backfilling the gap between the PEM container and the disposal tunnel.

6.4.3 Repository closure

When closing the repository, the access and connecting tunnels as well as any boreholes will be backfilled to isolate the underground facilities from the surface facilities. On completion of the operational phase, the surface facilities will be dismantled and removed as soon as they are no longer required. Backfilling of the tunnels and plugging the entrance will be defined as the "closure plan" and closure processes will be initiated after the plan has been approved by the Ministry of the Environment, Trade and Industry (METI). Figure 6-8 shows an image of the repository before submitting the closure plan. The brown parts are those that have already been backfilled during the operational phase and the white parts are those to be backfilled during the closure phase. As noted in chapter 3, R&D will continue until the closure plan is approved.

Closure of the horizontal tunnels will be done using in-situ methods such as emplacing bentonite blocks, compacting the backfill material or shotcreting. For vertical shafts, it will be more efficient to repeat cycles of backfilling and compacting from the bottom. More flexibility will be needed in the compacting methods when backfilling in ramp.

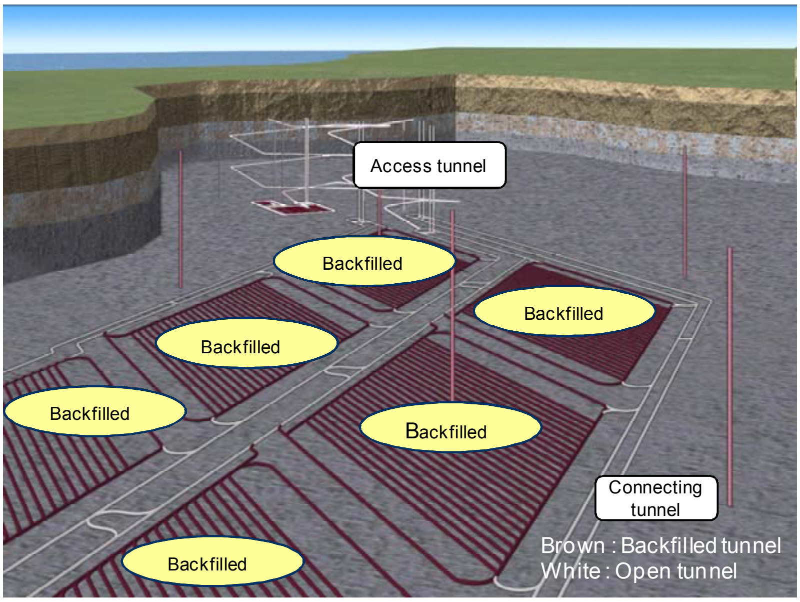


Figure 6-8 Image of the repository before submitting the closure plan

6.4.4 Approach for operational safety

During the operational phase, radioactive waste will be transported to the repository and the fundamental safety strategy for avoiding exposure to radiation will be confinement during operation, radiation shielding and radiation exposure control. These are the same as the strategies adopted for other nuclear facilities. Efforts will be made to design and construct reliable facilities, develop technologies and assure safety considering the unique aspects of deep geological disposal of radioactive waste, with a view to minimizing dose to the public and to workers.

For example, as part of radiation exposure control, radiation controlled areas will be set up within the repository according to the Nuclear Reactor Act. In the access tunnels and other underground transport routes that are outside the radiation controlled areas, the HLW will be contained in a shielding container and transported using special vehicles with a view to achieving confinement during operation and radiation shielding. In addition, tasks in the surface facilities such as encapsulation of the vitrified waste in overpacks and then the shielding container, removal of the waste packages from the shielding containers and emplacement underground will be done remotely in radiation controlled areas.

NUMO selected various abnormal events, considered their effects and developed countermeasures based on multiple safety measures consisting of the following steps: (a) identifying abnormal events, (b) taking measures to prevent these (abnormal event prevention measures), (c) identifying abnormal events that could occur even if such measures are taken, (d) preparing automatic response systems in the case of an abnormal event, (e) providing multiple lines of preventive measures in the case of non-activation of such systems (prevention of propagation of abnormal events) and (f) taking mitigation measures in the case of release of radioactive materials outside the facility (mitigation measures).

6.4.5 Analysis of the compatibility of pre-closure safety and long-term post-closure safety

Operational safety measures that will not endanger long-term post-closure safety have been studied by considering factors that could influence them.

Activities during the construction, operation and closure stages could alter the deep underground environment conditions to varying degrees. For the safe implementation of work procedures, materials other than those for the engineered barriers (mainly man-made materials) need to be introduced underground. Specifically, tunnel support will be required to ensure mechanical stability (steel or cement-based materials) and grouting using cement-based materials may be required to restrict seepage during tunnel excavation. Many of these materials will be left in the subsurface facilities or surrounding rock.

Construction, operation and closure could have two types of effect on the functions expected for the natural and engineered barriers in terms of ensuring post-closure safety: changes in deep geological environment conditions and the presence of materials other than engineered barrier materials.

The effects on long-term post-closure safety will be determined based on research results on the interaction between materials other than engineered barriers materials and groundwater, rock and the engineered barriers.

If it is considered that there will be impacts on long-term post closure safety and that these will be significant, materials that can be removed from the repository will be removed. Materials that will not have a significant impact on the barrier functions but may be left in large quantities and thus have an impact that cannot be ignored fundamentally consist of cement-based and organic materials. Low-pH cement has been developed as an alternative and its applicability in construction of the repository has been tested. For other materials that may have adverse impacts but cannot be removed or substituted, or whose effects are not clear, their impact should be analyzed before establishing an operating plan to ensure that appropriate safety measures can be implemented to avoid compromising long-term post-closure safety.

6.5 Design and operation technologies accounting for the variability of the geological environment

6.5.1 Design considerations specific to coastal areas

NUMO has developed technologies for repository design, construction, operation and closure considering the range of geological environments in Japan.

Given that Japan is surrounded by sea, design features and considerations were listed from the viewpoint of groundwater flow regime and groundwater chemistry in coastal areas in addition to inland areas which were the focus of the H12 report. Specifically, an approach was developed for determining the location of the underground facility, taking into account the change in groundwater flow patterns associated with changing sea-level.

The long-term characteristics of the geological environment in coastal areas will depend on the shift of the saline/freshwater interface associated with periodic sea-level change. Therefore, for radionuclide migration, the effects of periodic changes in groundwater flow rate, discharge points and groundwater salinity (solubility and distribution coefficients of radioactive materials) on migration should be evaluated.

The swelling properties of bentonite, which is one of the key components of the buffer/backfill materials, are affected by salinity. For regions with saline water offshore from the freshwater/saline water interface, it is necessary to determine specifications for the buffer/backfill materials (i.e.

materials, composition) considering the effect of saline water on the bentonite properties. Since the H12 report, new findings have been made on the effect of salinity on the EBS material characteristics. Based on these findings, the specifications of the buffer/backfill materials will be evaluated and changes in groundwater chemistry, such as salinity changes, may lead to different buffer/backfill material specifications being selected.

Another important issue in coastal regions is the design of the access tunnels. In particular, when placing the underground facilities beneath the seabed, the surface facilities cannot be positioned directly above. Consequently, the access tunnels will be longer compared to surface facilities that lie directly above the underground facilities. As the length of the access tunnels increases, construction will take longer and ventilation and drainage systems will need higher capacities. For access tunnels longer than 10 km, it will be necessary either to increase the number of tunnels or increase the cross-section.

6.5.2 Repository concepts/technologies that that take into account the variability of the geological environment

Based on state-of-the-art technologies, NUMO has developed a range of options for waste package emplacement concepts and operating techniques that can be adapted assuming a range of operating environments. The emplacement concepts and operating techniques are defined here as a combination of waste package emplacement method, emplacement tunnel dimensions and operating technologies. The emplacement concept can be divided into vertical emplacement and horizontal emplacement.

For these emplacement concepts, considering the conditions assumed in the underground environment (groundwater seepage, high humidity, locally weak mechanical rock strength), techniques considered to be promising were selected for both vertical and horizontal emplacement options taking into account the level of technology development and the prospect of improving working efficiency: vertical emplacement/block emplacement, horizontal emplacement/spraying, horizontal emplacement/PEM. Images of these three emplacement concepts are shown in Figure 6-9, Figure 6-10 and Figure 6-11.

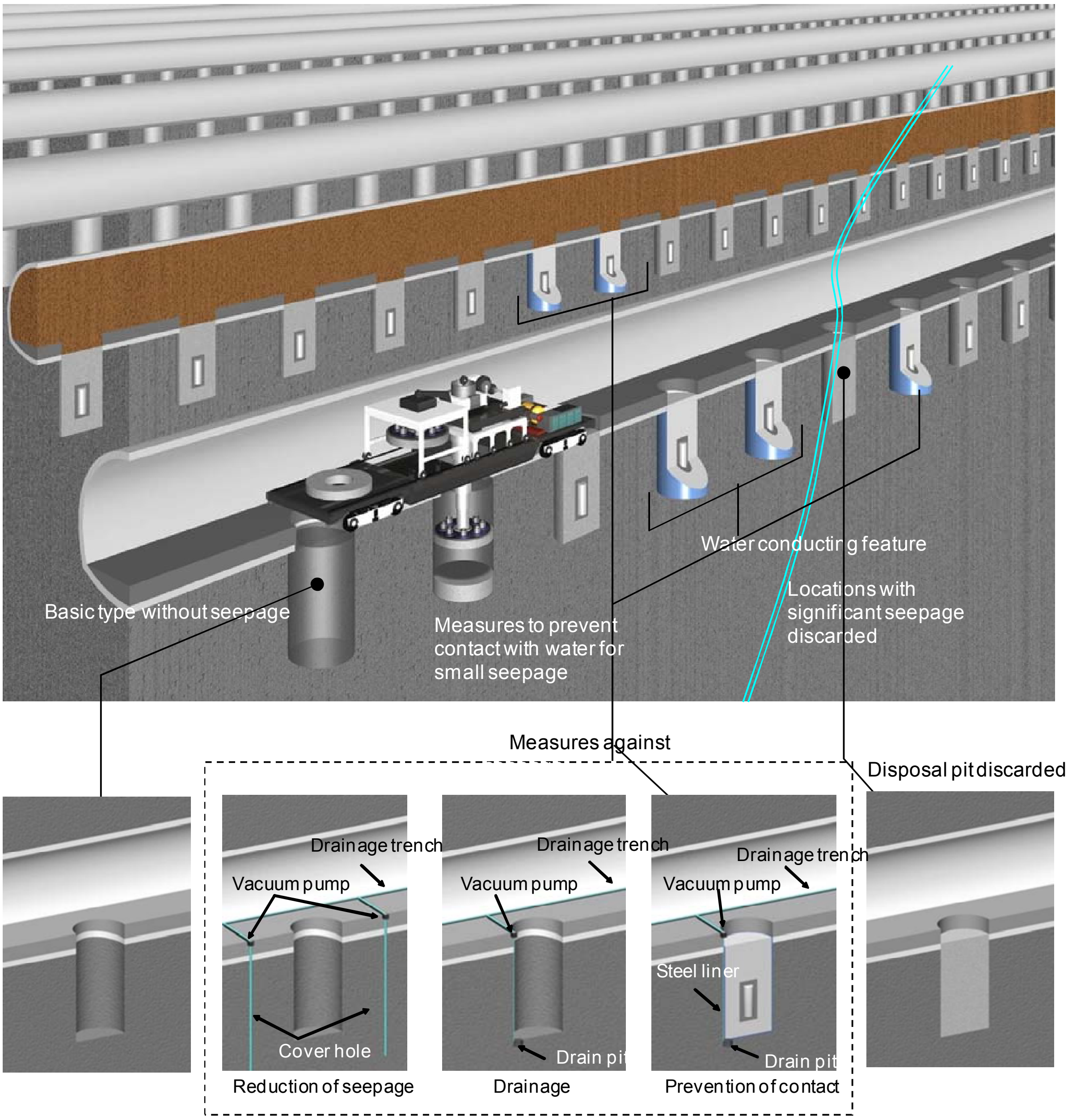


Figure 6-9 Emplacement option considering assumed underground conditions (vertical emplacement/block emplacement)

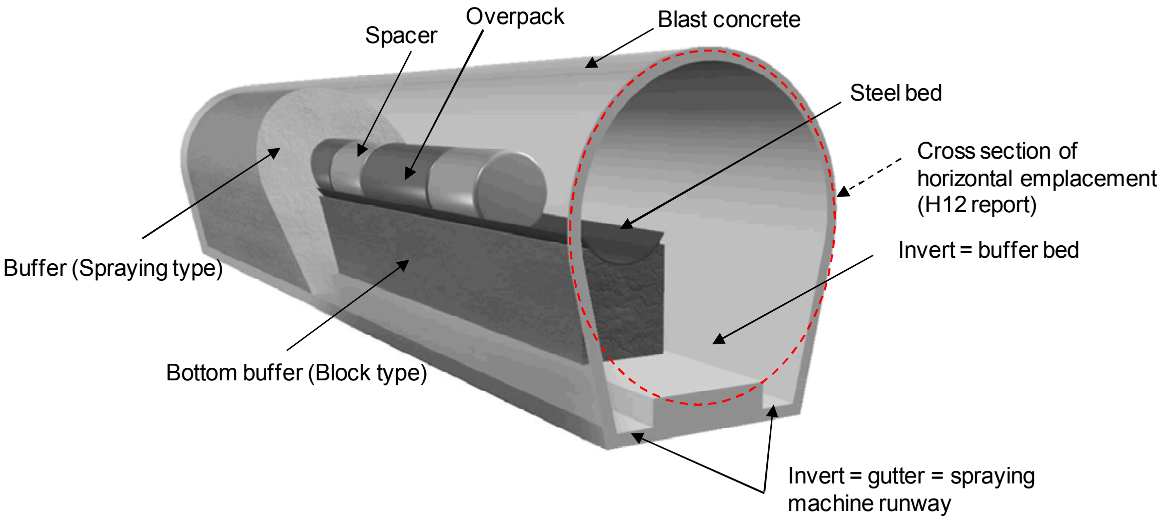


Figure 6-10 Emplacement option considering assumed underground conditions (horizontal emplacement/in-situ construction)

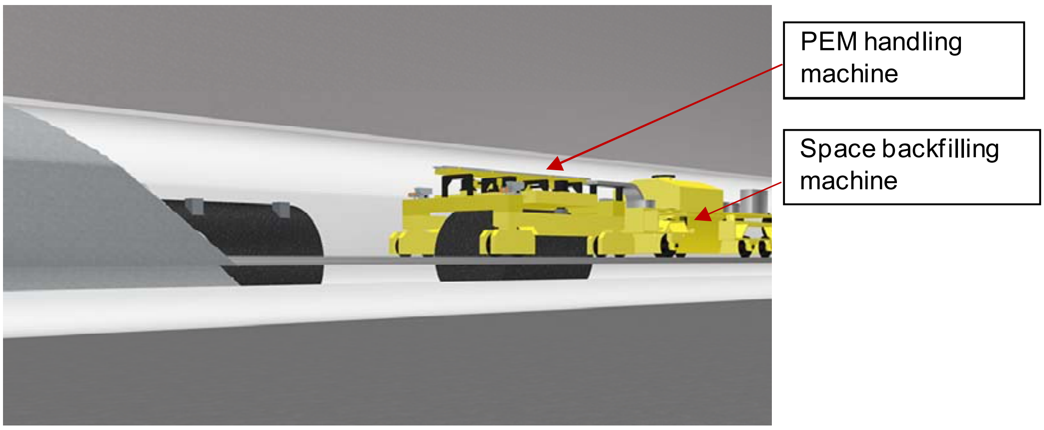


Figure 6-11 Emplacement option considering assumed underground conditions (horizontal emplacement/PEM type)

The above options are compared below based on design features that were applied as evaluation factors in the development of repository concepts (NUMO, 2004a), particularly for technical feasibility. Although the comparison is only qualitative because the repository site has not yet been selected, the features of the three proposed disposal concepts and technical options based on the design objectives have been analyzed. Engineering feasibility was evaluated from the viewpoint of schedule, workability, efficiency and adaptability to the underground environment. The weighting of the criteria and evaluation indicators will depend on the volume/quality of geological environment data and the level of technology development at the time. With the progress of site selection, narrowing-down of the repository concept/technology options will be carried out based on a comprehensive comparison of these features.

6.6 Development of technologies that support engineered measures

Since the H12 report, the understanding of the phenomena relevant to the long-term behavior of, and interaction among, the engineered barriers has progressed and technologies for transporting and emplacing the engineered barriers have developed significantly. Focusing on the results of R&D, the current status of the following technologies is described.

- Technologies for evaluating basic properties and long-term behavior of the engineered barriers
  - Long-term behavior of the vitrified waste
  - Long-term behavior of the overpack
  - Interaction between buffer properties and long-term behavior
- Evaluation of seismic resistance of the geological disposal facility
- Construction/operation technologies
  - Applicability of low-pH cement
  - Remote welding of overpack and inspection
  - Buffer production, transportation and emplacement technologies
- Retrieval of wastes

6.6.1 Technologies for evaluating basic properties and long-term behavior of the engineered barriers

The engineered barriers will be designed such that their integrity will be maintained over a long period of time based on an understanding of the phenomena expected in the near-field. In this context, the fundamental R&D organizations have studied overpack corrosion and the effects of radiation on the overpack, the properties of the buffer material under saline conditions and the interaction between the buffer material and cement or iron. These results have been compiled as fundamental data to be reflected in the design and safety assessment.

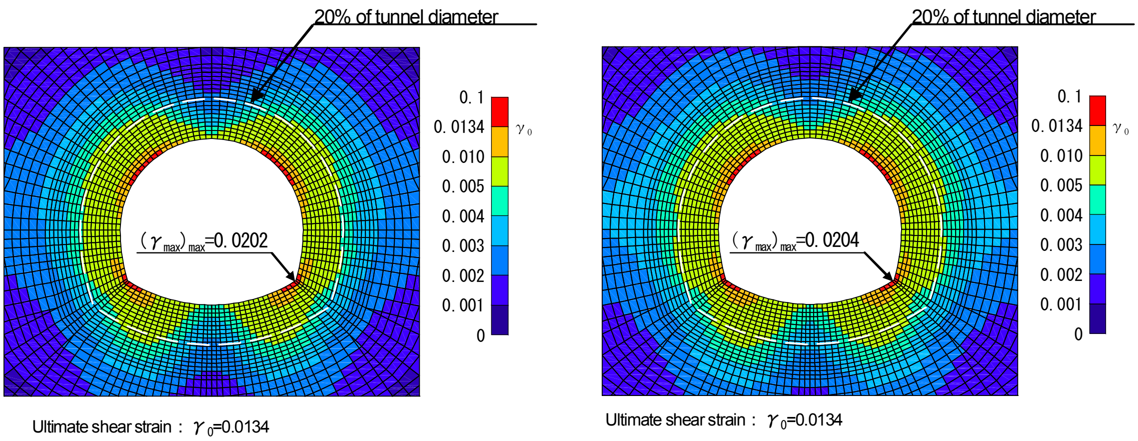
In the H12 report, the dissolution rate of glass was found to decrease with time. From the viewpoint of conservative numerical evaluation, however, the rate of dissolution of radioactive substances from the vitrified waste was assumed to be constant over time. In order to advance the understanding of glass dissolution and further improve the models, dependence of dissolution on pH is being investigated (Inagaki et al., 2009, 2010).

Table A.6-1 in Appendix summarizes the current status of scientific understanding of corrosion behavior of the overpack base metal and weld. Basic properties, long-term behavior and interaction with buffer materials, including behavior under saline conditions and interactions between buffer and cement or iron, are summarized in Table A.6-2and Table A.6-3 in Appendix.

6.6.2 Seismic resistance of the geological disposal facility

The repository is unique in that it will be constructed deep underground, has large tunnel cross-sections and is interconnected with large-scale connecting tunnels; its safety must also be assured even after the facility is closed. In Japan, where seismic activity is very high, the safety of the facility in the event of an earthquake is extremely important.

Therefore, NUMO evaluated the seismic resistance of the repository tunnels during the operational phase using a rock mass model that is similar to that used in the 2010 report. More specifically, the stress field when the tunnel is excavated was obtained using a two-dimensional FEM analysis. Assuming that the stress field is that under normal conditions, incremental stress induced by the hypothetical earthquake was computed using a dynamic FEM simulation (horizontal and vertical movements considered simultaneously). By adding these two results, the seismic resistance (safety) was evaluated. Figure 6-12 shows an example of the simulation results. It was confirmed that the maximum shear strain during normal and earthquake conditions was about the same and that the effects of an earthquake on the repository tunnels would be insignificant.



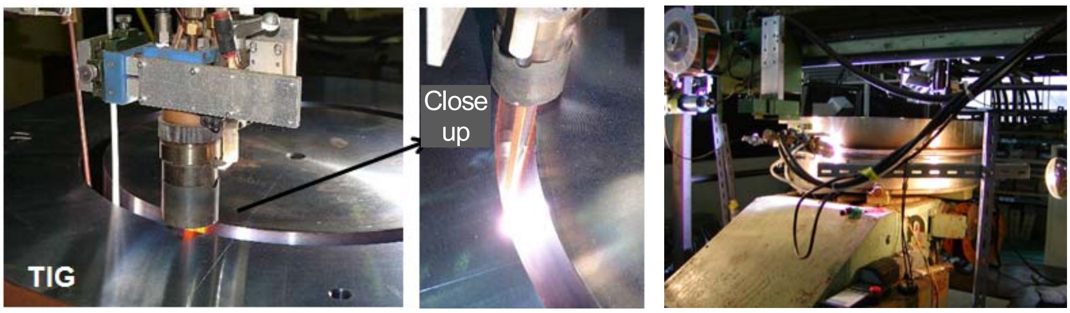
(normal) (earthquake)

Figure 6-12 Maximum shear strain around the tunnel (HLW repository tunnel) (NUMO, 2011d)

6.6.3 Construction and operation technologies

In the repository, it is expected that cement-based materials will be widely used to ensure sufficient structural strength. However, it is suspected that the dissolution of the cement will lead to generation of highly alkaline components, resulting in a reduction of the swelling capacity of the buffer material or alteration of the rock mass (natural barrier). In order to avoid/reduce such effects, low-pH cement was developed as an alternative material and its characteristics are being investigated (Iriya and Mihara, 2003). To verify the applicability of the low pH cement under practical conditions, some tests, including shotcreting tests, were performed. The results confirmed reasonable workability as well as strength (Nakayama et al., 2009).

Welding tests on the overpack have been conducted for electron beam welding (typical high energy welding technique with a high rating in the H12 report) and TIG welding (Tangsten Inert Gas Welding) (Figure 6-13) and MAG welding (Metal Active Gas Welding) techniques (representative arc welding techniques) using full-scale lid structures. Welding technologies have been evaluated in terms of technical aspects such as applicability to the overpack (including lid structure) and welding conditions （RWMC, 2009a）



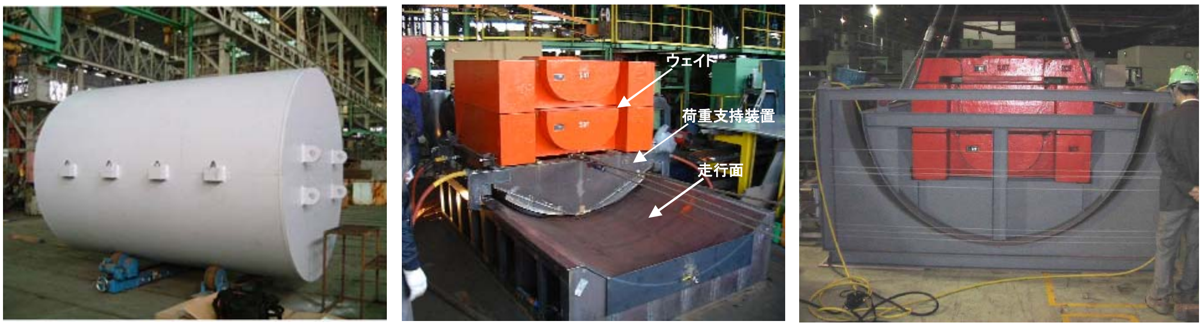
(a): Vertical (b): Horizontal

Figure 6-13 TIG welding of the overpack

(a) From RWMC (2009a), (b) From RWMC (2003)

For operating technologies and the buffer transport/emplacement technology, fabrication of blocks, in-situ compaction, pellet backfilling, shotcreting and PEM are being developed. Each of these has been tested in 1:1 scale validation tests and confirmed to have reasonable workability as well as sufficient density.

The PEM test includes fabrication of a full-scale PEM, determination of the difference in the tunnel floor level that the air bearing tramsportation can clear during horizontal transfer and a PEM lifting test with an air jack (Figure 6-14) (RWMC, 2009b).



(a) Full-scale PEM container (b) Air bearing transportation test (c) Lifting up & down of PEM using an air jack

Figure 6-14 Tests of the PEM-type EBS

(from RWMC (2009b) for (a) and (c) and RWMC (2004) for (b))

As part of fundamental R&D, gap filling tests have also been conducted using pelletized buffers for a simulated full-scale disposal tunnel (horizontal emplacement type) (RWMC, 2008). Parameters include shape and dimensions of the pellets, the effect of using a mixture of pellets with different sizes, gap filling density and pellet feed rate. Based on a quantitative evaluation, the feasibility and application conditions of the technique for filling gaps with pelletized buffer using pressurized air were established.

A bentonite spraying method using a supersonic nozzle was demonstrated as being able to achieve a suitable dry density, even using bentonite only (RWMC, 2010). It was confirmed that buffer with a homogeneous density distribution could be constructed with the spraying method.

Regarding waste retrievability, retrieval methods before and after backfilling of the repository tunnels are being developed. One possible method is shown in Figure 6-15. This is based on the overcoring technology typically used for cutting rocks and concrete.

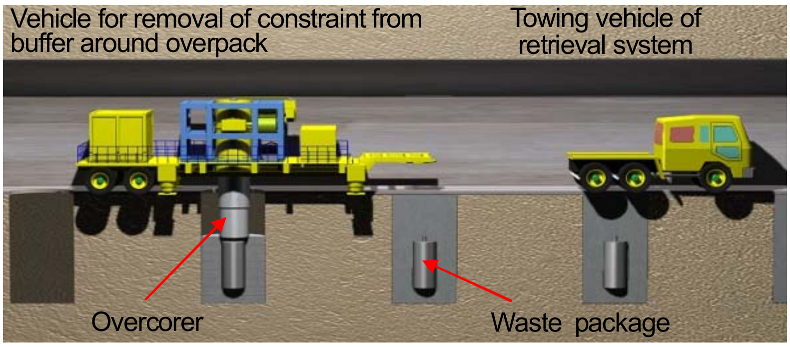


Figure 6-15 Example of waste retrieval technology

6.7 Conclusions of chapter 6

As described above, technologies for repository design and operating technologies applicable to a variety of geological environments have been developed considering the long-term behavior of the engineered barriers.

Since the H12 report, there has been a significant improvement in the safety and reliability of the technologies for repository design and engineering technologies such as construction and transportation and emplacement of the engineered barriers.

In close collaboration with fundamental R&D organizations, NUMO will continue its efforts towards reliable implementation of the engineered measures for long-term post-closure safety and measures for ensuring safety in each project stage.

7 . Technology for long-term safety assessment

This chapter describes the technologies required for evaluating long-term safety which is one of NUMO's three policies for assuring safety.

In the H12 report and the second TRU report, a basic methodology was demonstrated for evaluating the long-term safety of geological disposal under generic geological environment conditions. Since the H12 report, NUMO has developed a program of staged safety evaluation of the geological disposal system for each of the site selection stages. In parallel with this, NUMO and fundamental R&D organizations have been improving the individual technologies aimed at evaluating the safety of the disposal system for a range of geological environments and more practical design options. The progress in evaluating the safety of the geological disposal system is described below.

7.1 Basic strategy for safety assessment

7.1.1 Procedures for safety assessment

An important and unique difference between the safety assessment of the geological disposal system and that for conventional engineering systems is that the former involves extremely long time periods compared to other nuclear facilities such as nuclear reactors; it also has to consider a heterogeneous and huge natural spatial environment, i.e. geology. This means that is not possible to apply the approach used in conventional engineering, i.e. optimization and demonstration through the process of constructing actual objects, checking their behavior and feeding back the results to the design (OECD/NEA, 1983).

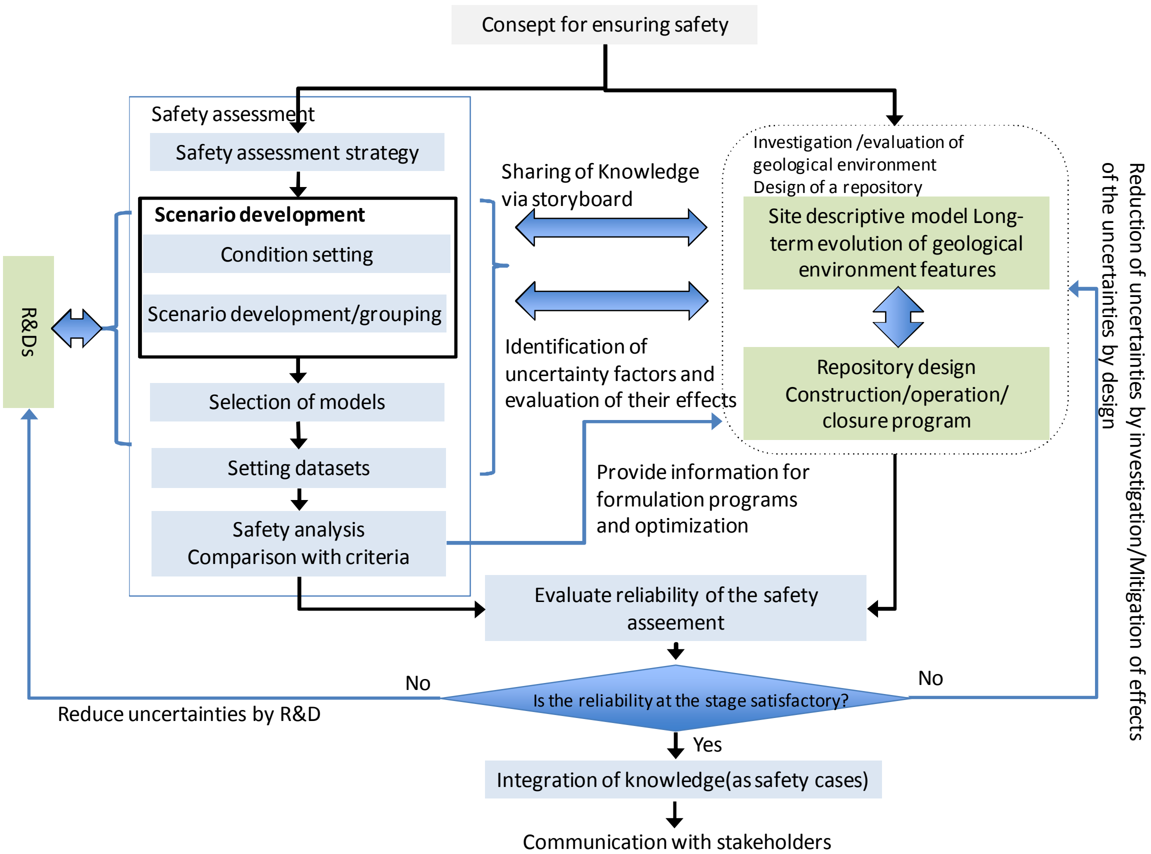


Figure 7-1 Basic procedures for safety assessment

In projects run by international organizations, there is a consensus that a reference methodology has been established to a satisfactory level (OECD/NEA, 1991b, 1997) through discussion based on research and experience in different countries (e.g. OECD/NEA, 1991a and 1991b). The generic approach involves scenario development, selection of models, defining datasets, safety analysis and comparison of the analysis results with relevant safety criteria. As described in section 3.2, the safety assessment is generally incorporated into the framework of the safety case that demonstrates long-term safety from multiple aspects, including investigation/evaluation of the geological environment, repository design, uncertainties and their treatment and use of alternative safety indicators. Based on the above, basic procedures for evaluating long-term safety were established (Figure 7-1). Although the fundamental procedures are common to each stage, the focal points will differ in different stages depending on the major actions to be carried out and the availability of information.

During the literature survey stage, the availability of geographical, geomorphological, geostructural and geoenvironmental information is generally limited. There is therefore a relatively large degree of uncertainty associated with the performance assessment of the host rock as the natural barrier. ,which leads to a rather conservative EBS design. Therefore, the focus of the safety assessment at this stage is not to systematically evaluate whether or not the geological disposal system has the required safety performance, but to identify important factors that can affect the safety assessment in the later stages and effectively reduce the uncertainties.

In the preliminary investigation stage, in addition to the information obtained through the literature survey, information on geoenvironmental characteristics as well as findings on long-term stability of the rock mass will be enhanced through surface investigations, geophysical investigations and borehole investigations. The selection of the host rock and the preliminary design of the underground facilities and the EBS will be performed based on these findings. Therefore, the safety assessment will mainly focus on confirming the appropriateness of the repository design, comparing possible options, developing the safety case and planning the detailed investigations.

During the detailed investigation stage, more tunnel-scale findings will be obtained through investigations in the underground investigation facility. Based on the repository design developed in the previous stage, specifications for the underground facility and the EBS will be determined and a plan for construction/operation/closure will be prepared. The safety assessment in this stage will mainly focus on a generic assessment of safety based on reconsideration of the prerequisites relating to the geological environment and repository design, confirmation of safety for the license application, preparation of the license application and updating of the safety case.

7.1.2 Approach to dealing with uncertainties

As discussed in section 3.2.2, handling of uncertainties is an important issue in the safety case. The uncertainties will be reduced as far as possible by performing stepwise geological investigations/evaluations, with more detail being incorporated as the project proceeds. The repository is then designed conservatively by considering the remaining uncertainties, such that the effects of the uncertainties will be further reduced. Although uncertainties cannot be eliminated completely, in the safety assessment they will be addressed through an iterative process of identifying uncertainties, classification of their effects/importance, reduction of their effects and reflection in the safety assessment (Figure 7-2). During the iterative process, not all potential uncertainties and their combinations are considered, but effectively only those that are essential for the safety assessment as follows:

- Combinations of uncertainties that are too conservative for investigation and evaluation of the geological environment and repository design will not be considered. For optimizing the repository design and demonstrating its performance, impractical assumptions, such as a certain safety performance being lost, may need to be considered.
- For uncertainties that can significantly affect safety based on expert judgement or sensitivity analyses, if their effects cannot be eliminated they will be handled in such a way that a reasonable level of conservativeness will be added to the design.
- Comprehensiveness (effects of one event are included/emcompassed in those due to another event) will be considered.

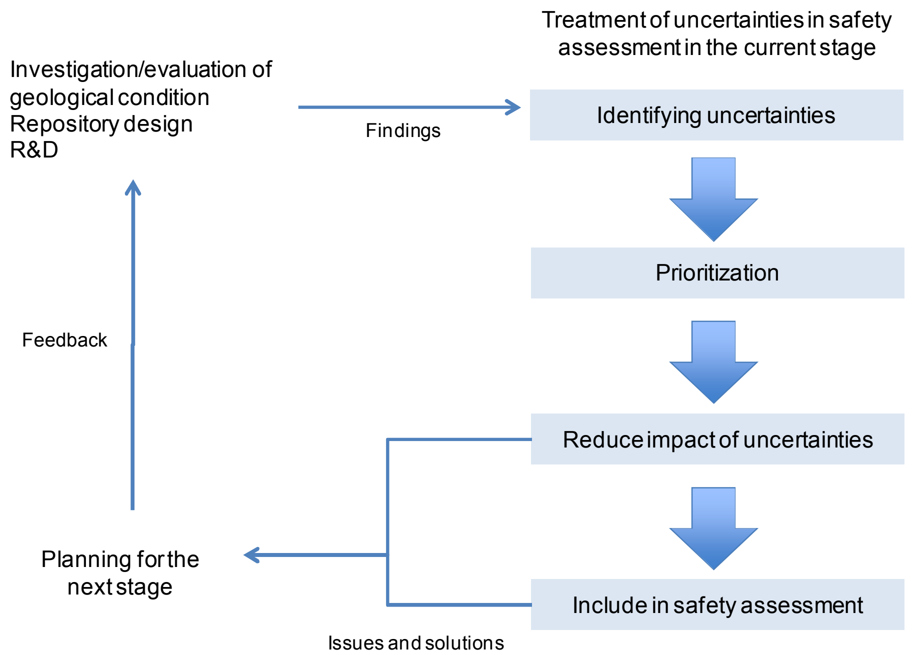


Figure 7-2 Handling of uncertainties in the safety assessment

7.2 Development of the safety assessment

7.2.1 Construction of scenarios

Scenarios for safety assessment provide the framework for model development and parameter determination by describing the future evolution of the geological disposal system, allowing a systematic evaluation of disposal system safety. Scenarios will also need to be developed depending on the uncertainties associated with predicting the distant future. When developing scenarios, the features of the geological disposal system, events that can affect the features and processes in the future evolution of the system, collectively referred to as FEPs, have been the main focus. Recent trends are based on the safety functions rather than conventional FEP-based scenario development (e.g. ONDRAF/NIRAS, 2001; Nagra, 2002; ANDRA, 2005; SKB, 2006; Ebashi et al., 2010). This approach emphasizes what features of the geological disposal system contribute to the safety functions and how the safety functions will be affected by the future evolution of the system. It allows the scope of the key phenomena to be defined and is thus expected to lead to a much clearer definition of the scenario development process and effective development of scenarios. Therefore, NUMO will develop scenarios using both FEP-based and safety function-based approaches. In predicting the future evolution of the geological disposal system, storyboards (Figure 7-3) will be used as a tool for knowledge-sharing across different disciplines. Because the future evolution of the system will involve different phenomena that will evolve in different ways, it will be difficult to clearly understand and represent all of them accurately. Therefore, the phenomena to be included in the scenarios have to be selected based on international FEP lists and existing FEP lists and from the viewpoint of conservativeness in the safety assessment.

7.2.2 Model selection

Models to be used in the safety assessment will be selected based on additional information/understanding of the features of the geological disposal system and the objectives of the safety assessment, both of which evolve as the project stages progress.It should be recognized that detailed modeling of the complex behavior of the actual geological disposal system will be difficult due to the variability of relevant phenomena, the heterogeneous geological environment and length of the assessment duration. Therefore, two types of models will be used complementarily: system performance assessment models that are simplified and focused on safety functions and phenomenological analysis models used for realistic evaluation of individual phenomena and barrier components (Figure 7-4). The simplification in the system performance assessment models will be tested to the extent possible using phenomenological models, while key uncertainties will be covered by conservatism, supported by system understanding (NUMO, 2004a).

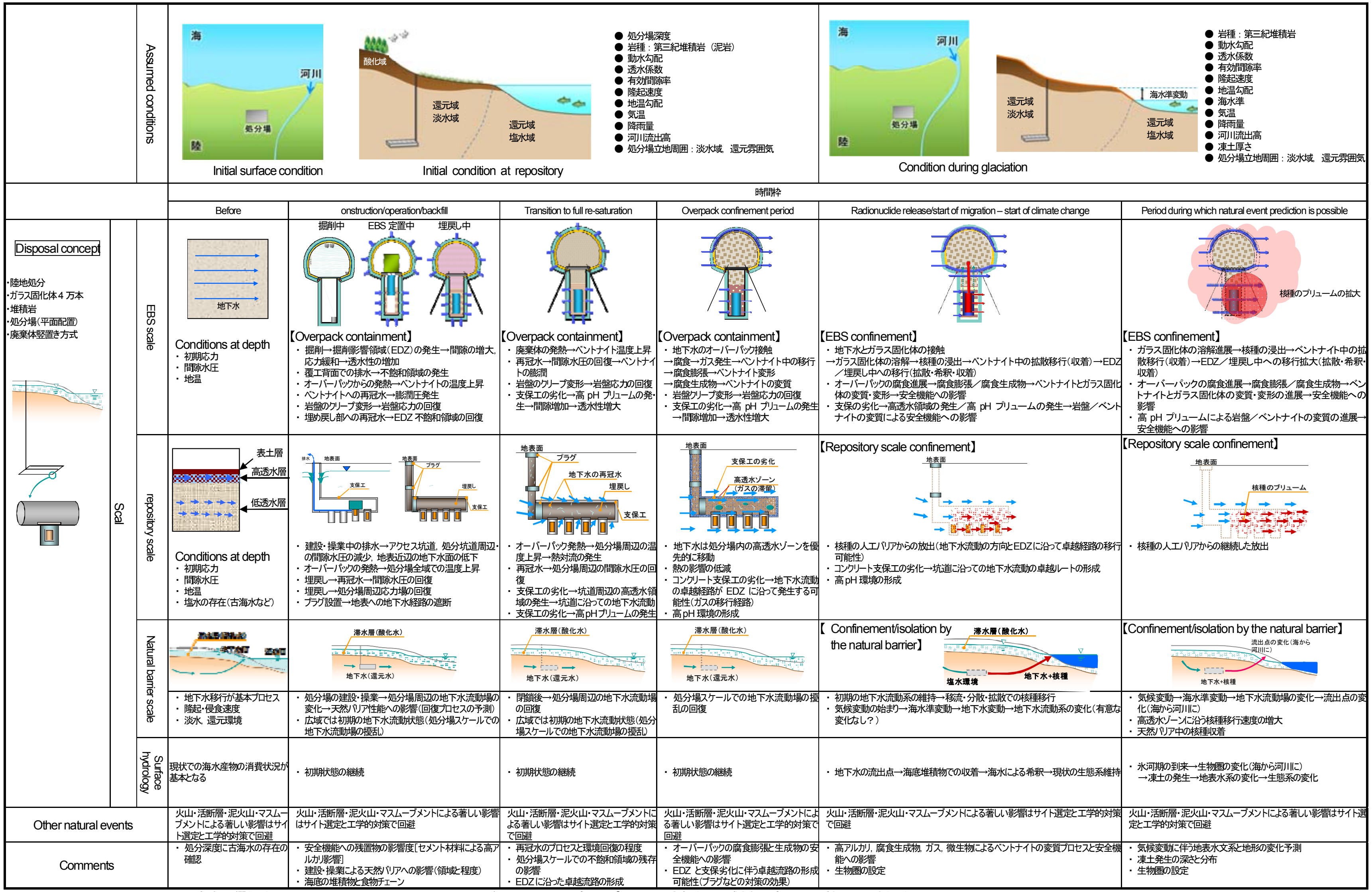
Therefore, options, for safety assessment models need to be shown and the influence of the model selection on the safety assessment must be understood considering the degree of process understanding for modeling, and the level of conservativeness and simplification.

7.2.3 Dataset selection

Information on a specific site will be limited in the early stages of the project. Therefore, datasets will be prepared by selecting data similar to those for the potential target site. With the progress of the investigation/evaluation of the geological environment, newly obtained site-specific data (e.g. sorption data using rock samples and groundwater sampled at the site of interest) will be reflected in the datasets. Furthermore credibility of the dataset will be increased by comparison with existing database. Different uncertainties associated with datasets and the interpretation of data will be covered by appropriate values or ranges of values that assure appropriate conservatism.

7.2.4 Safety analysis

The safety analysis uses scenarios, models and datasets. It will be mainly deterministic, with a single value being explicitly assigned to a parameter, complemented using statistical methods as appropriate. Safety indicators will be radiological dose and other performance or supplementary indicators. Regarding uncertainties, variations will be considered for the scenarios, models and datasets to check the compliance of the safety assessment results for different analysis cases with the safety criteria. The effects of the uncertainties will be evaluated and a comparison of different design options will also be conducted and reflected in the formulation of the investigation program and optimization of the repository design for the subsequent stages.



EDZ：Excavated Disturbed Zone（掘削影響領域），EBS：Engineered Barrier System（人工バリアシステム），高 pH プリューム：岩盤中に形成される高アルカリ性の地下水領域

Figure 7-3 Storyboard for the disposal of HLW (Example)

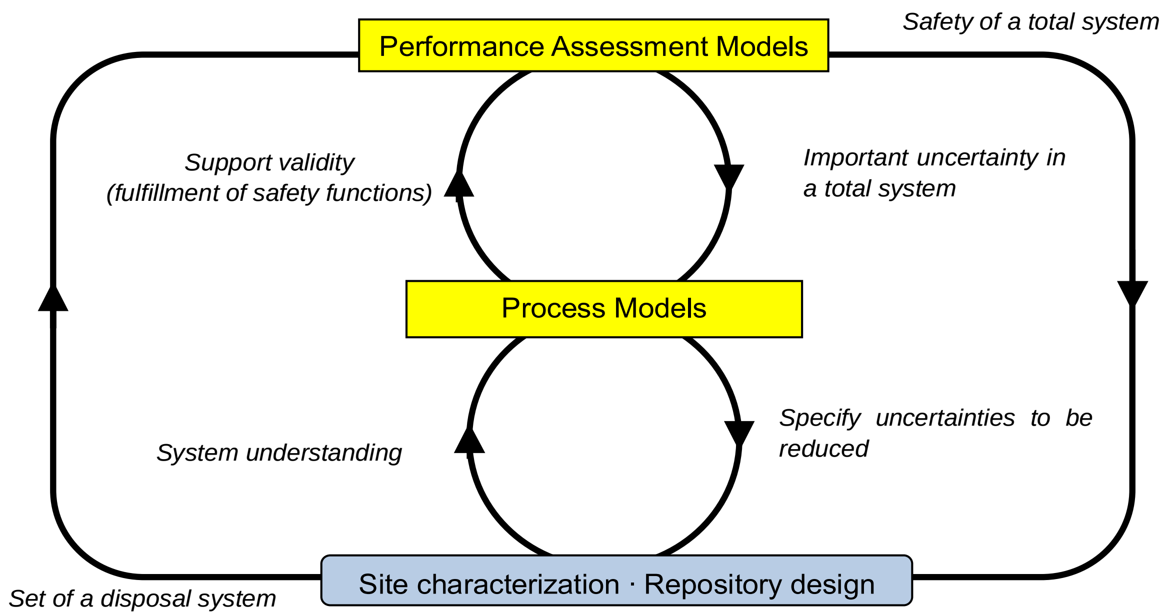


Figure 7-4 Complementary use of performance assessment models and process models (from Ishiguro et al., 2007, partly modified)

7.2.5 Evaluation of safety assessment reliability and integration of findings

On completion of the safety analysis, the long-term reliability will be evaluated, e.g. based on alternative indicators other than dose as proposed by the OECD/NEA (2002) (Table 7-1). When sufficient long-term reliability has been confirmed for each stage, the results of the safety analysis, open issues for the next step and solutions will be integrated into the safety case. If the long-term reliability is insufficient, on the other hand, issues where a further reduction of uncertainty is necessary have to be clarified and reliability will be improved through information feedback to the geological environment investigations, repository design and the R&D program.

Table 7-1 Major discussion points for constructing a safety case (OECD/NEA, 2002)

Category	Arguments
Confidence in the proposed disposal system	・ Intrinsic robustness of the multi-barrier system ・ "What if?" scenarios and calculations ・ Comparisons with familiar examples and natural analogues
Confidence in the data and knowledge of the disposal system	・ Quality of the research programme and site investigations ・ Quality assurance procedures ・ Data from a variety of sources and methods of acquisition ・ Use of formal data tracking techniques
Confidence in the assessment approach	・ Logical, clear, systematic assessment approach ・ Assessment conducted within an auditable framework ・ Building understanding through an iterative approach ・ Independent peer review of approach
Confidence in the IPA models	・ Explaining why results are intuitive ・ Consideration of alternative conceptual models and modeling approaches – simple and complex ・ Testing of models against experiments and observations of nature ・ Model comparison exercises ・ Comparisons with natural analogues ・ Independent evidence such as paleohydrogeological information
Confidence in the safety case and the IPA analyses	・ Clear statements and justifications of assumptions ・ Demonstrate that assumptions are representative or conservative ・ Sensitivity studies ・ Clear strategy for managing and handling uncertainty ・ Multiple safety indicators ・ Multiple lines of reasoning
Confidence via feedback to design and site characterisation	・ Support for any disposal concept design changes ・ Overall quality and safety of the disposal system

7.3 Development of technologies that support the safety assessment

Since 2000, NUMO and fundamental R&D organizations have been leading R&D programs necessary to implement the project and allow the following:

(1) Handling of the variability of the geological environment and its long-term evolution
(2) Analysis of different design options
(3) Incorporation of updated knowledge into the safety assessment and

(4) Evaluation of significant impacts from natural phenomena.

The progress of R&D on safety assessment technologies by NUMO and fundamental R&D organizations since the H12 report is summarized in the Table A.7-1through Table A.7-4 in Appendix. Major technologies relevant to the above four points are discussed below.

7.3.1 Scenario development technologies

The geological environment will be affected over long periods of time by uplift/erosion and changes in climate and sea-level. In coastal areas, consideration will have to be given to the effects of saline water and the long-term evolution of the saline/freshwater interface. NUMO has developed a method for identifying the conditions of the geological disposal system to allow the effects of saline water and long-term evolution of the saline/freshwater interface to be handled realistically (NUMO, 2011b).

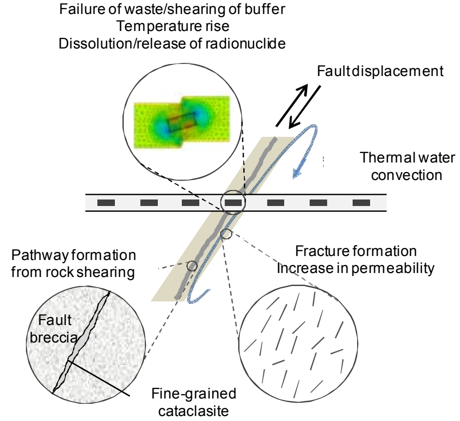
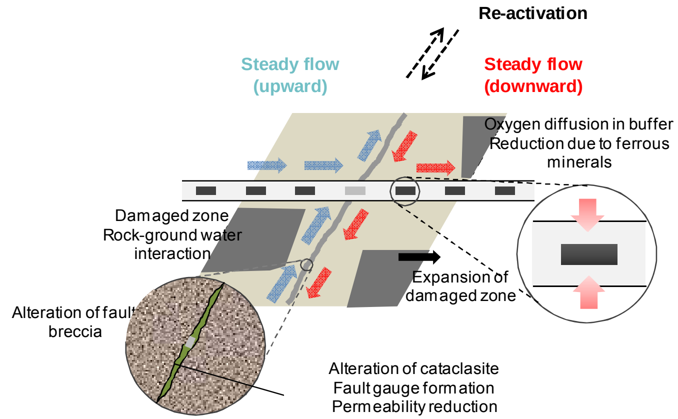
Knowledge relevant to geological disposal will be accumulated in a stepwise manner through R&D and other research and it will be important for NUMO to incorporate it into the safety assessment to meet defined milestones. The near-field environment has the important barrier function of restricting nuclide migration. The performance of the near-field is less dependent on the site-specific geological environment than the natural barrier. Development of technologies relevant to the near-field can therefore be carried out now before a specific site has been selected to provide a starting-point for incorporating the features of specific sites. NUMO has therefore developed a scenario development methodology for the long-term evolution of the near-field, based on knowledge on long-term evolution of the geological disposal system, focusing on its safety functions (NUMO, 2011b).

The FEP information that will form the basis for the scenario development has been compiled as a FEP database by the fundamental R&D organizations (Kanzaki et al., 2009). For TRU waste, the FEP information used in the second TRU report has been compiled as a comprehensive FEP list (FEPC/JNC, 2005a).

Significant impacts from natural phenomena should, in principle, be avoided by selecting a suitable site. However, due to the extremely long timescales involved, the uncertainties associated with the time and frequency of their occurrence need to be taken into account. NUMO and the fundamental R&D organizations are developing scenarios for the impacts from earthquakes and faults (Table 7-2), as well as methods for evaluating their effects (NUMO, 2011b; Miyahara et al., 2008).

Based on these results, fundamental technologies and information databases for scenario development were improved.

Table 7-2 Example of potential changes in safety assessment when a new fault intersecting the repository is formed (NUMO, 2011b)

		Immediate effects after new fault formation	Gradual transition after new fault formation
			
Scenario 1 (Rise of reducing deep groundwater)	Waste intersected by fault	T: Temp. rise to > 300°C due to fault friction-induced heat (several minutes) H: Hot water convection and degradation of buffer sealing due to heat generation M: Failure of waste, shear in buffer C: Dissolution of radionuclides and release through EBS	T: Temp. rise during re-activation H: Hot water convection due to heat generation M: Repeated shear in buffer C: Radionuclides completely released
	Other waste	T: Slight temp. rise (short-term) H: Transitional flow due to porewater pressure changes M: Seismic motion C: -	T: - H: Flow increase due to increase in permeability in deformation area M: Seismic motion C: Radionuclide migration under reducing condition
Scenario 2 (Entrapment of oxidizing surface water)	Waste intersected by fault	T: Temp. rise to > 300°C due to fault friction-induced heat (several minutes) H: Hot water convection and degradation of buffer sealing due to heat generation M: Failure of waste, shear in buffer C: Dissolution of radionuclides and release through EBS	T: Temp. rise during re-activation H: Hot water convection due to heat generation M: Repeated shear in buffer C: Radionuclides completely released
	Other waste	T: Slight temp. rise (short-term) H: Transitional flow due to porewater pressure changes M: Seismic motion C: -	T: - H: Flow increase due to increase in permeability in wide deformation area M: Seismic motion C: Oxidation of groundwater, reduction due to iron minerals in buffer

T: Thermal effects, H: Hydraulic effects, M: Mechanical effects, C: Chemical effects

7.3.2 Development of modeling technologies

Features in coastal areas include changes in groundwater chemistry, flow direction and flow rate due to the shift of the saline/freshwater interface around the repository, as well as changes in the geosphere-biosphere interface (GBI, locations at ground surface which can be reached by radioactive substances) and environmental conditions with time. This necessitates nuclide migration analyses considering the specific features of coastal areas in addition to analysis of preferential flow paths in heterogeneous host rock. With the aim of developing a method for realistically incorporating the features of coastal areas, a modeling methodology was developed to evaluate nuclide migration in the natural barrier and biosphere, considering the evolution of groundwater flow and groundwater chemistry (NUMO, 2011c).

In the staged geological disposal project, multiple design options (e.g. panel/tunnel arrangement and waste package emplacement method) will be developed in order to respond to different uncertainties and constraints. Narrowing down the design option will require evaluation of differences among the options from different viewpoints such as safety and economic efficiency. In identifying differences among the design options from the safety assessment point of view, a quantitative differentiation is difficult when a one-dimensional model is used because the 3D configuration of the engineered barriers and subsurface facilities and the heterogeneity of the surrounding rock are conservatively simplified. Therefore, 3D modeling tools were developed to allow more realistic analysis (Wakasugi et al., 2008; NUMO, 2011c). Among the developed tools, the solute transport model was applied to two types of rock heterogeneities (Figure 7-5). The colors in Figure 7-5 indicate the particle velocity at the time step shown. For type 1, the particles show random movement within the buffer and backfill materials via diffusion. For type 2, on the other hand, the drift intersects with a highly permeable fault at the midpoint; particle movement is thus locally enhanced along the fault. This type of information is important when determining the configuration of the emplacement drifts. These results have contributed to updating and expanding the technology bases to respond to the safety assessment needs, expanding technical options in the selection of safety assessment models.

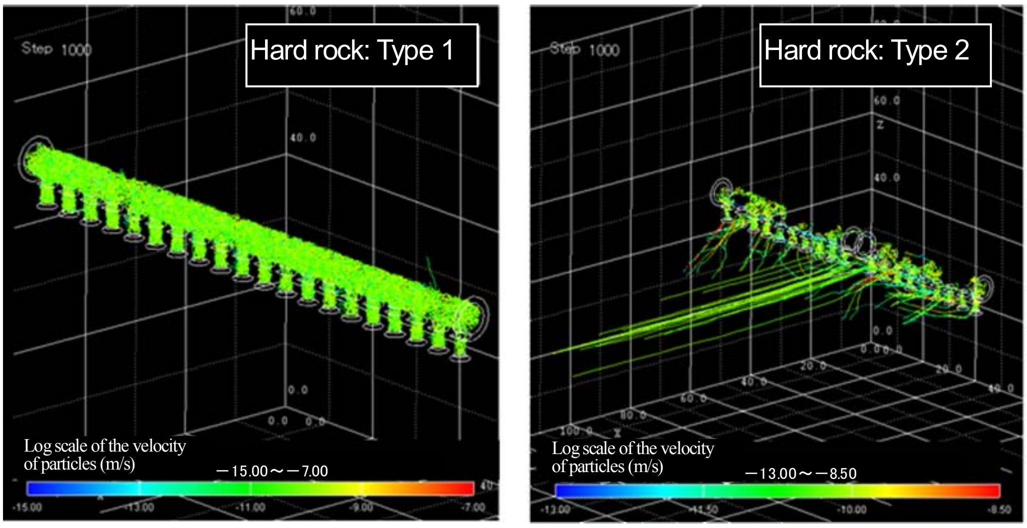


Figure 7-5 Example of particle tracking analysis for one hundred thousand years (NUMO, 2011c) (Hard rock 1: Low permeability and random distribution of factures with low frequency; Hard rock 2: Highly permeable factures as well as permeable faults)

7.3.3 Development of datasets

Preparing appropriate datasets is important for building confidence in the long-term safety assessment. Since the H12 report, the fundamental R&D organizations have published databases and research data on parameters relevant to nuclide migration analysis as follows:

- Thermodynamic database (JAEA-TDB): Modified thermodynamic database on radioactive elements and geochemical elements compiled in a format that can be used for different geochemical codes (e.g. PHREEQC) (Kitamura et al., 2010)
- Sorption database (JAEA-SDB): Data on distribution coefficients for bentonite and rock compiled from domestic and international literature. It is equipped with functions of data retrieval that match assigned conditions and conducting regression analysis for a data group (Tachi et al., 2009).
- Diffusion database (JAEA-DDB): Data on effective diffusion coefficients for different rocks found in Japan compiled from the literature (Tochigi & Tachi, 2009, 2010).
- Glass dissolution database (GlassDB): Data on glass composition, test methods, solution chemistry, co-emplaced material and constituents, alteration products, testing conditions, test results, etc. compiled from the literature (Hayashi et al., 2005).
- Environmental migration data: Collection of parameters on the mobility of nuclides in rice fields and soil (Kd) and the fractions of nuclides that are transferred to agricultural products (TF) (NIRS 2008, 2009, 2010).

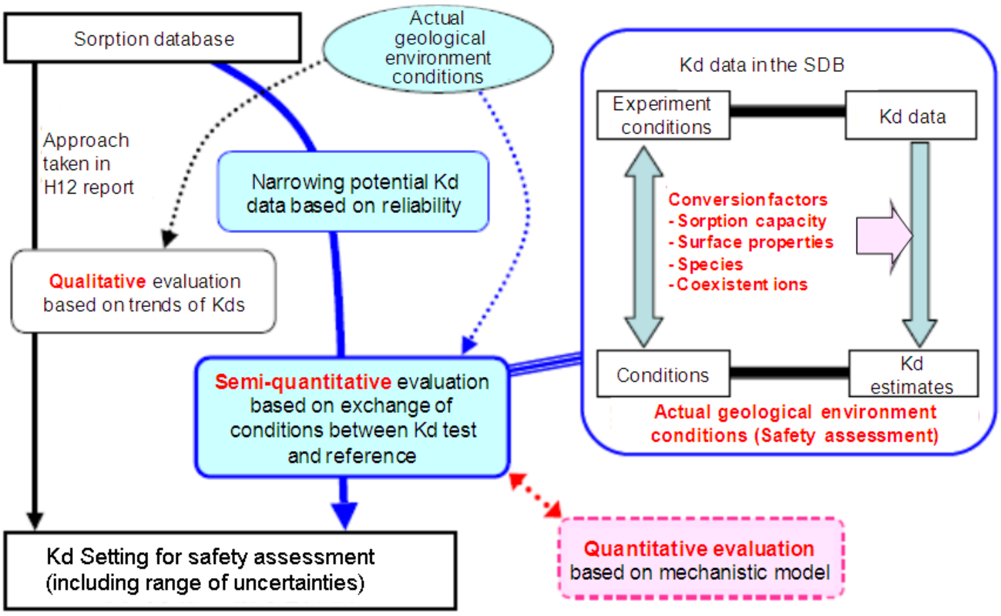


Figure 7-6 Application of sorption database (SDB) for setting Kd value (from Tachi et al., 2009)

Sorption and diffusion databases are derived systematically, taking into account the assessment of data of differing quality in terms of experimental conditions, traceability and the reliability (Ochs et al., 2008). Guidelines consisting of multiple decision criteria were established for evaluating reliability.

Studies were also conducted on how to define parameters using the developed databases. Since the H12 report, in order to improve the reliability of parameter settings, a method for correcting the data for different environmental conditions has also been developed. For example, after extracting data on distribution coefficients with a certain level of reliability, data are corrected based on the difference between the experimental conditions when the data were obtained and the geological environment conditions assumed in the safety assessment. Such a correction method has been validated for sorption behavior of Cs in sedimentary rocks; Cs is one of the major radionuclides for safety assessment. It was shown that, based on a correction considering illite content and Na ions, the results were roughly consistent with the experiments (Ochs et al., 2008).

For TRU waste, sorption distribution coefficients are defined for different alteration zones in the cement-based materials for a range of pH values (Mihara & Sasaki 2005). With regard to the effect of nitrate on backfill and buffer materials, the second TRU report defined sorption distribution coefficients for relevant nuclides, considering the nitrate reduction process by mineral and microbial influence on the nitrate transformation scheme. It is appropriate to consider such effects as those described in the report (NUMO, 2011a).

Based on these results, fundamental information for preparing datasets for analyzing radionuclide transport was improved.

7.4 Conclusions of chapter 7

This chapter described the basic strategy for stepwise assessment of the long-term safety of the geological disposal system at an actual site. It also presented the different technologies that NUMO and fundamental R&D organizations have developed aimed at realistic evaluation of a range of geological environments and design options from the perspective of long-term safety since the H12 report. Based on these activities, the reliability of the technologies that support the long-term safety assessment has been improved further in terms of response to the variability and long-term evolution of the geological environment, to different design options and incorporation of updated knowledge. In close coordination with R&D ongoing in fundamental R&D organizations, NUMO will continue its effort to improve the reliability of the long-term safety assessment technologies.

8 . Technical activities during the Literature Survey and Preliminary Investigation stages

This chapter summarizes the descriptions provided in the previous chapters. The procedures for the Literature Survey (LS) stage and the Preliminary Investigation (PI) stage, as well as the methodologies required in these stages, will be described.

Figure 8-1 shows how the chapters in this report are structured.

Two cases are expected for initiating the LS stage: a volunteer application from a municipality or a request made by the national government to municipalities to come forward. Although the two cases may be different before initiating the LS, the technical procedures thereafter will be the same. This report assumes an application made by a municipality, if not specifically mentioned otherwise.

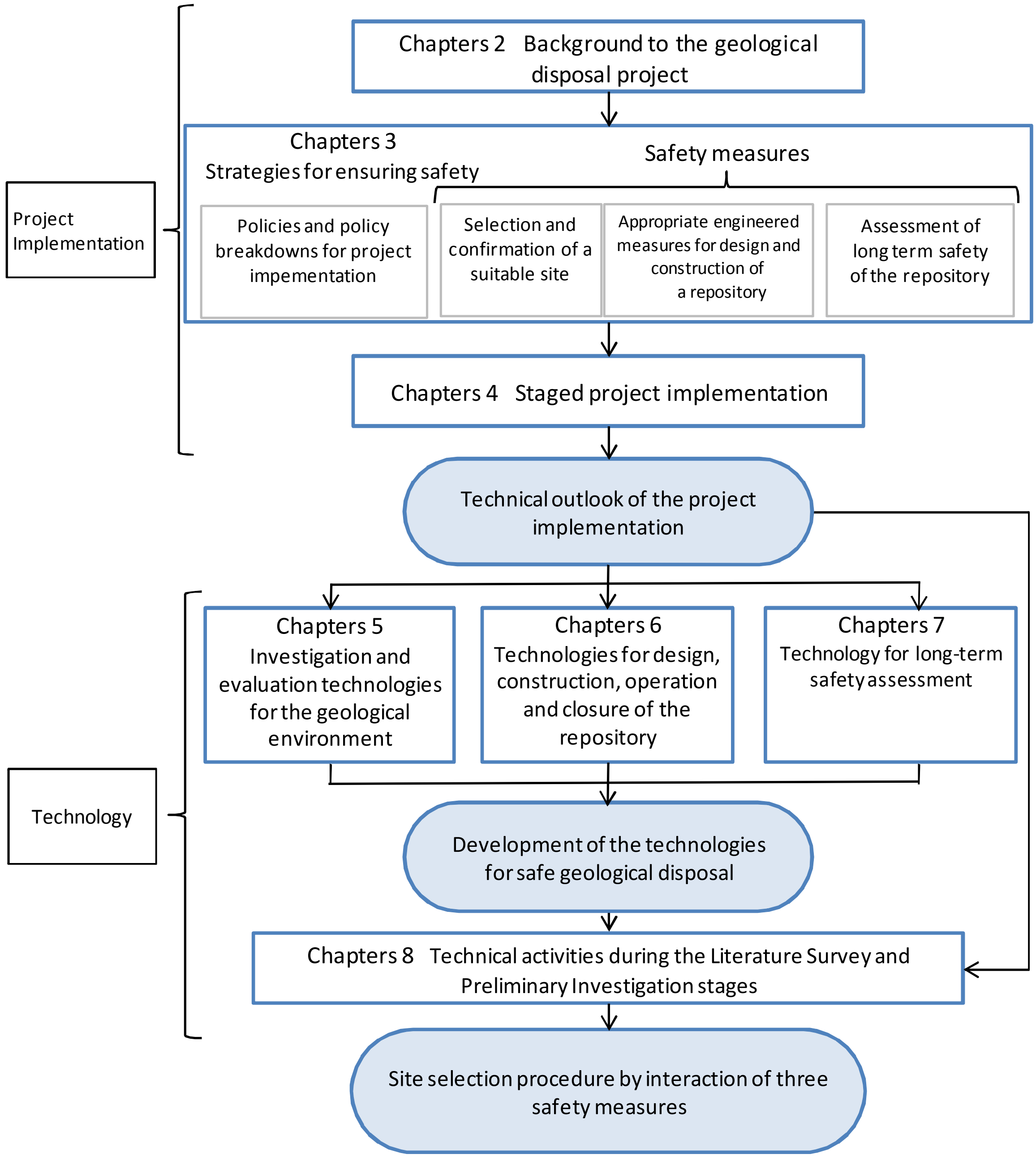


Figure 8-1 Structuring of the chapters in this report

8.1 Site selection process from public solicitation and start of the LS to the selection of DIAs

The key milestones during the project are the three steps for site selection (LS stage, PI stage and DI stage) and the subsequent project licensing. The sequence of project activities and technical activities in the stages from public solicitation to the PI stage are shown in Figure 8-2.

When an application is received, NUMO will check the geological conditions before initiating a literature survey to confirm that:

- No active faults documented in the literature based on a nationwide investigation using interpretation of aerial photographs for inland areas and marine acoustic exploration for marine areas are present and
- No area within 15 km of the center of a Quaternary volcano is included, considering the potential extent of magma activity tens of thousands of years in the future.

The results of the advance check will be sent to the mayor of the applying municipality. A literature survey will not be conducted for areas that do not meet the above confirmation points.

After explainng the LS plan to the relevant municipality, the LS will be initiated to check whether or not the area satisfies the basic criteria for selecting PIAs. If the criteria are not met, the area will not be considered as a PIA. If they are met, statutory reports compiling the investigation results will be published in each site selection stage and submitted to the mayors of the applicant municipalities and the relevant prefectural governor for inspection. Briefing sessions will also be held and NUMO will respond to comments or questions submitted on these occasions. Based on these procedures, NUMO will select investigation areas for the subsequent stage and submit an application for the modified implementation plan to METI. METI will collect opinions from the prefectural governor and mayors of the municipalities. Respecting their opinions, and consulting with the Japan Atomic Energy Commission (AEC) and the Nuclear Safety Commission (NSC), METI will determine the revision of the final disposal program; this will be finalized in a cabinet meeting. The modification of the implementation plan will be authorized via the process mentioned above and the first stage of the site selection process will be completed. In parallel with this, NUMO will prepare a plan for the next preliminary investigation (PI) stage.
In the PI stage, DIAs will be selected following a similar procedure and an application for the modified implementation plan will be submitted to METI. METI will collect opinions from the prefectural governor and mayors of the municipalities. Again respecting their opinions, and consulting with AEC and NSC, METI will determine the revision of the final disposal program which will then be finalized in a cabinet meeting. The modification of the implementation plan will be authorized via the process mentioned above and the site selection process will be completed. In parallel with this, NUMO will prepare a plan for the next DI stage.
The processes in the DI stage will be similar.

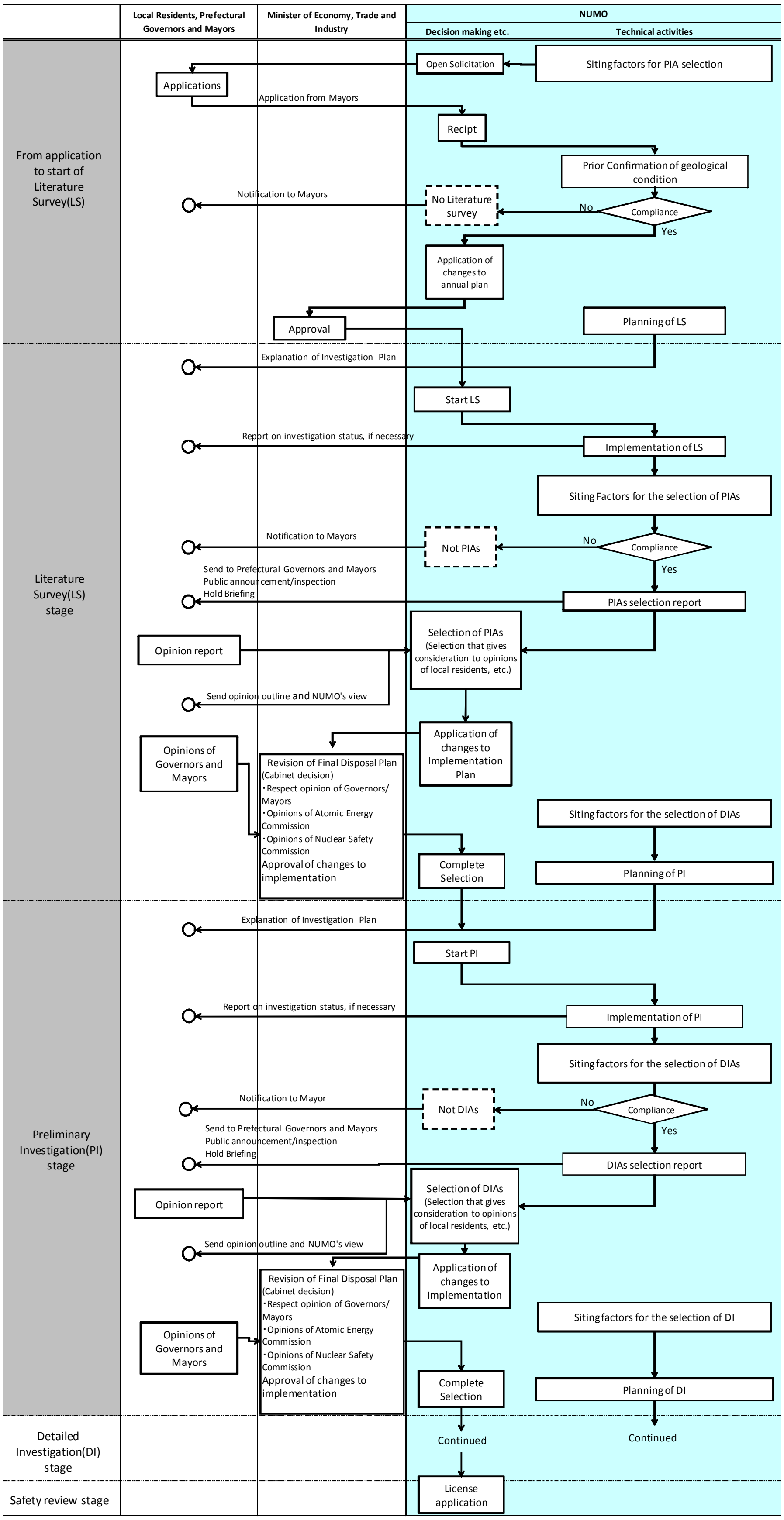


Figure 8-2 Sequence of activities in the LS and PI stages (for the case of formal volunteering)

8.2 *Literature Survey stage*

8.2.1 Activities in the Literature Survey stage

In the LS stage, the goal is to select PIAs and achieve the goals relevant to safety assurance, such as avoiding significant impacts from natural phenomena (avoiding clearly unsuitable areas: see section 4.3).
In this stage, the area for which the LS will be performed will be determined. If necessary, additional investigation areas around the PIA will be selected to acquire data on volcanic/igneous activity, seismic/fault activity and uplift/erosion in order to evaluate the effects of these natural events and geoenvironmental characteristics on the PIA.

Based on an LS manual, literature and documents are compiled systematically to manage the information on the geological environment and other relevant information. Information to be collected includes that relevant to the impacts of natural phenomena, geological environment characteristics, the natural environment and the social environment.

Determining the impacts of natural phenomena involves investigating volcanic/igneous activity, uplift/erosion, unconsolidated Quaternary sediments and mineral resources.

With regard to the site descriptive models, conceptual models of the geology/geological structure will be developed first based on geological structure development history and then conceptual models of the geological environment characteristics, including hydrology, groundwater chemistry and rock mechanical properties, will be developed. Based on the conceptual models, the site descriptive model will be developed to quantitatively represent and visualize information on hydrology, groundwater chemistry, rock properties (physical, mechanical and thermal) and mass transport properties.

The evaluation of the long-term evolution of the geological environment characteristics involves analyzing how current geology will evolve within the developed site descriptive model. This will use the results of the investigation/evaluation of impacts from natural phenomena, interpretation of the geological structure development history and assessment of changes in the hydrogeological environment using a paleogeological approach.

Based on the evaluation of the long-term evolution of the geological environment characteristics and the impacts of natural events, information on the potential PIAs is compared to the siting factors for the selection of PIAs and any areas that clearly do not meet these criteria will be excluded. The results will be compiled as a statutory report on site selection.

During the preliminary review of the repository concept, the applicability of the design of the engineered barriers and the repository as a whole will be assessed based on the site descriptive model. In addition, in order to reflect this in the PI program and design studies in the subsequent stage, the engineering feasibility, economic efficiency and construction schedule for the project will also be comprehensively evaluated to identify investigation parameters and design issues for the subsequent stage.

In the preliminary review of safety, based on the limited volume of information on the geological environment obtained during the LS, the performance of the host rock as a natural barrier will be evaluated based on a preliminary safety assessment of the design, emphasizing the conservativeness of the engineered barriers.

The preliminary development of repository concepts will be compiled in the form of an overview of the repository based on literature information, based on the preliminary review of the repository and preliminary review of safety.

The statutory report on the LS and the description of the repository based on LS will be made public and will be available for inspection in the affected areas; briefing sessions will also be held in the relevant prefectures. Comments on the report will be compiled and NUMO will respond to these. Figure 8-3 shows the flow of the processes in the LS stage.

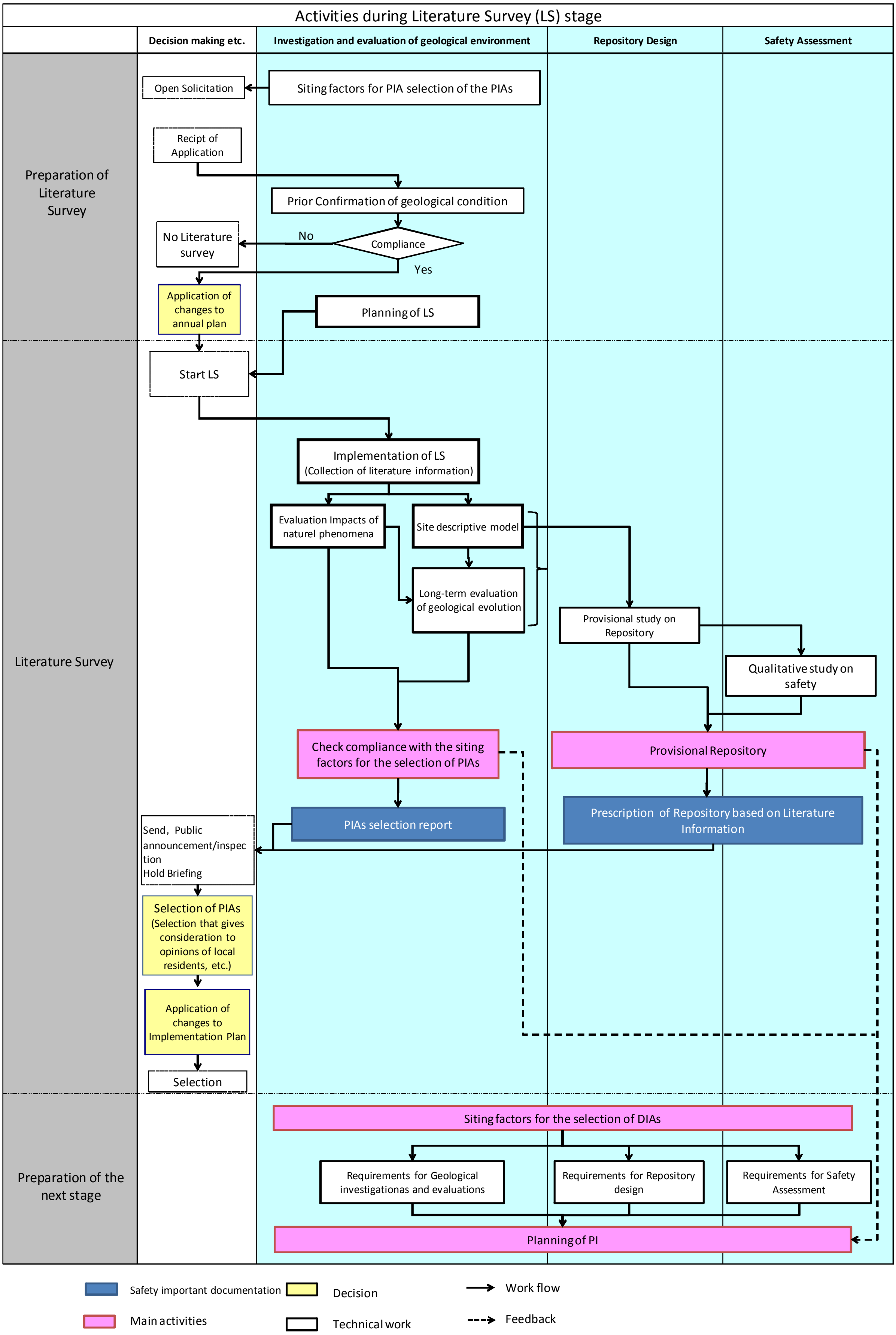


Figure 8-3 Sequence of activities in the LS stage (for the case of volunteer application)

In the PIA (bounded by the dotted/dashed line in Figure 8-4), investigation and evaluation of the geoenvironmental characteristics will be the main tasks. In the supplementary investigation area (bounded by the dotted line), impacts due to natural events, particularly volcanic/igneous activity, seismic/fault activity and uplift/erosion, and evolution of the regional geological structure will be investigated. Figure 8-4 shows the schematic setting of a PIA and the supplementary investigation areas.

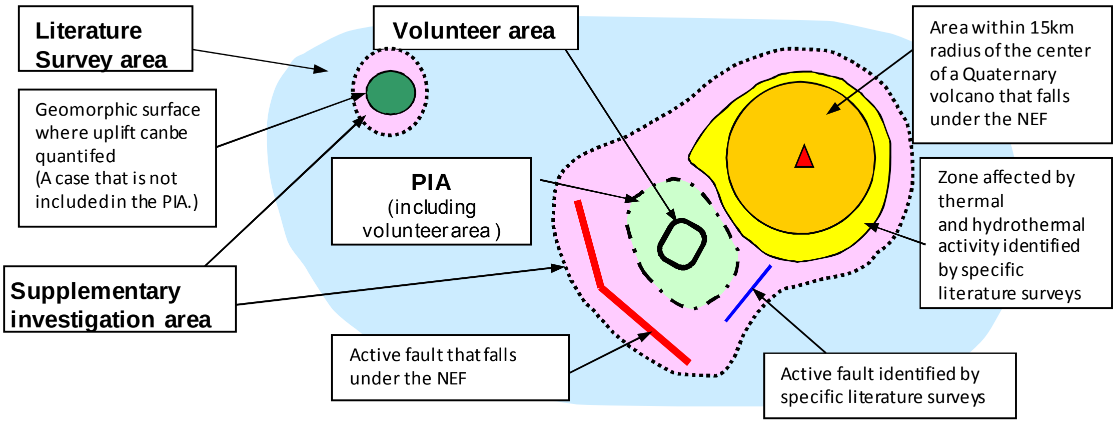


Figure 8-4 Setting of PIAs and supplementary investigation areas (for the case of volunteer application) (from NUMO, 2004b)

- PIAs will be selected via the process discussed below: Areas where active faults or igneous activity as defined in the evaluation factors for qualification (see below) are found will be excluded from potential PIAs.
- Potential PIAs may be larger than the volunteer area, depending on the relative location of active faults or igneous activity zones, but the area not included in the volunteer area will be subjected only to preliminary investigation. NUMO will not select anywhere outside the PIA as a repository site
- The area around PIAs may be investigated for more detailed characterization of the PIAs.

8.2.2 Siting factors for the selection of PIAs

The siting factors for the selection of PIAs are factors to be evaluated in selecting PIAs based on the Final Disposal Act considering the guideline "Environmental Factors to be Evaluated in Selecting Preliminary Investigation Areas for the Disposal of HLW" (NSC, 2002).

The siting factors for the selection of PIAs consist of evaluation factors for qualification (EFQ) and favorable factors (FF).

EFQ define the conditions of areas to be excluded as PIAs. The suitability of areas that apply as PIAs will be evaluated in terms of factors related to earthquake/fault activity, uplift/erosion, unconsolidated Quaternary sediments and mineral resources, based on the LS for each applicant area and their surrounding areas.

Specifically, the evaluation factors for qualification for this stage are:

- No record of significant tectonic movement due to natural phenomena such as earthquakes
- Low likelihood of significant movement due to natural phenomena such as earthquakes far into the future
- No record of unconsolidated Quaternary sediments in the potential repository area (to be specified by ministerial ordinance of METI)
- No record of valuable mineral resources in the potential repository area (to be specified by ministerial ordinance of METI)

Favorable factors were also defined for areas not excluded from selection as PIAs based on the EFQ, in accordance with the requirement that NUMO should also consider the economic and operational efficiency of the project on the premise that safety has been assured (MITI, 2000). Areas where compliance with the EFQ is confirmed will be compared with each other in terms of factors related to (1) properties and characteristics of the geology, (2) groundwater characteristics, (3) investigation/evaluation of the geological environment, (4) potential natural hazards during construction and operation, (5) land acquisition and (6) transportation.

8.3 Preliminary Investigation stage

8.3.1 Activities in the Preliminary Investigation stage

For the PI stage, the goal is to select DIAs and meet the goals relevant to assuring safety, such as avoiding significant impacts from natural phenomena, the prospect of ensuring long-term safety and the prospect of ensuring safety during the project duration (avoiding clearly unsuitable areas: see section 4.3).

The PIs are conducted in two phases: surface investigations and borehole investigations.

The implementation of surface investigations includes confirmation of LS results at the sites to roughly understand the geological environment of the PIAs and investigation of topography and geology from the surface by reconnaissance and trench surveys and geophysical exploration (aerial, ground surface and marine) to obtain information for planning of the borehole investigation phase.

Based on the findings from the surface investigations, investigation/evaluation of the impacts of natural events including volcanic/igneous activity, seismic/fault activity and uplift/erosion will be performed. According to rock type, lithofacies, stratigraphy, distribution of fractures, fracture conditions and weathering/alteration level and geostructural elements (rock body, strata, faults and so on) will be categorized, the results from the LS will be evaluated and the geostructural model will be updated. Using the updated model, the geoenvironmental model, including hydrogeological structure, groundwater chemistry and rock mass characteristics, will be updated. The updated geoenvironmental model will provide an understanding of the evolution of the geological structure. Forecast of geoenvironmental evolution based on a paleogeological approach will be used to evaluate the long-term evolution of geoenvironmental conditions.

In the borehole investigation phase, data on the deep underground not available from the surface investigations will be acquired. Based on data from the surface and borehole investigations, volcanic/igneous activity, earthquake/fault activity and uplift/erosion will be investigated and evaluated.

Geological and structural elements (rock bodies, strata and structural discontinuities such as faults) are classified and characterized based on information such as rock types, rock facies, stratigraphy, fracture distribution, deformation, degrees of weathering and alteration obtained from the surface and borehole investigations. These are compared with of the information from the Literature Survey stage to update the geological model. The hydrogeological model, hydrochemical model and rock mechanical model are also revised based on the updated geological model and the results of hydrological, hydrochemical and rock mechanical investigations.

The evaluation of the long-term evolution of the geological environment characteristics involves analyzing how current geology will evolve within the updated site descriptive model. This will use extended results of the investigation/evaluation of impacts from natural phenomena, interpretation of the geological structure development history and assessment of changes in the hydrogeological environment using a paleogeological approach.

In the confirmation of suitability referring to the siting factors for the selection of DIAs to be described later, it will be checked whether or not unsuitable areas are included in the potential DIAs based on data obtained by the PI. The results will be compiled as the statutory report on PIs.

The selection of potential host rocks involves evaluating suitability based on site descriptive models and data on long-term evolution of the geological environment. Suitability as a host rock will be evaluated in terms of thermal environment, mechanical regime, hydrological regime, chemical environment, size of the rock mass, schedule, economic efficiency, etc. Potential host rocks for the repository site in the subsequent stage will be selected from those determined as being suitable.

Based on the site descriptive model and the characteristics of the host rock, the conceptual design of the repository will be performed. This involves defining the location of the underground facility (depth and area), designing the engineered barriers (e.g. materials and structure), defining the specifications of tunnels (e.g. vault diameter, support and tunnel spacing) and defining the basic layout of the underground facility (e.g. configuration, number and layout of the disposal panels and access method), as well as designing the surface facility. Regarding the disposal concept, technical options will be narrowed down based on the geological environment, the feasibility of the construction schedule and economic aspects.

Based on the site descriptive model and conceptual design of the repository, the preliminary safety assessment involves assessing cases based on scenarios, models and datasets to be developed separately.

The development of a reference repository concept involves compiling the results of the conceptual design of the repository and the preliminary safety assessment and integrating them into a repository concept; this is supported by a report on conceptual design and preliminary safety assessment based on the PI.

As in the case of selection of PIAs, a statutory report based on PI and a report on preliminary repository design and preliminary safety assessment based on the PI will be made public, opened for inspection in affected areas and briefing sessions held in the relevant prefectures. Comments on the report will be compiled and NUMO will respond to them.

Figure 8-5 shows the sequence of activities in the PI stage.

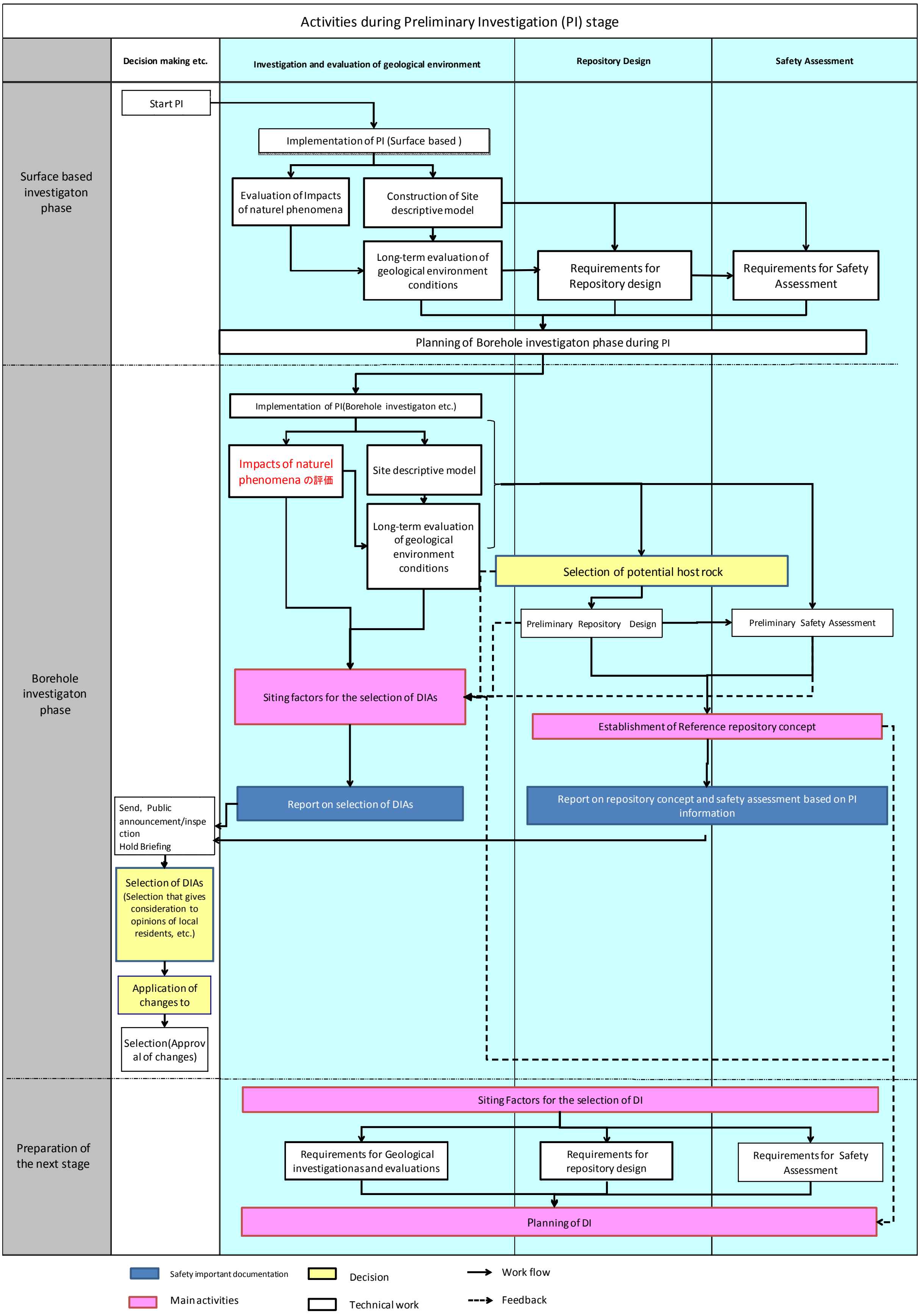


Figure 8-5 Sequence of activities in the PI stage

8.3.2 Siting factors for the selection of DIAs

In selecting DIAs, on the premise of ensuring safety during the project duration, the emphasis in the evaluation will be on compliance with the evaluation factors for qualification as specified in the Final Disposal Act. Since the selection of DIAs is the intermediate stage in the siting process, siting factors for the selection of DIAs should be established considering not only the evaluation factors for qualification for this stage, but also requirements for the subsequent repository site selection stage as specified in the Final Disposal Act.

Evaluation factors for qualification for this stage are:

- No significant tectonic activity due to natural phenomena such as earthquakes has occurred in the geology of concern for a long period of time
- There are no difficulties in terms of excavation in the geology of interest
- Any active fault, fracture zone or groundwater flow found in the geology of interest is unlikely to have adverse impacts on tunnels or other subsurface facilities
- Other requirements as specified in a ministerial ordinance of METI

Tectonic activity, including earthquake/fault activity, volcanic/igneous activity and uplift/erosion will be evaluated. Regarding difficulties in tunnel excavation, the requirements for judging feasibility will be evaluated from the perspective of ensuring safety during each project stage.

If there are highly permeable zones (water flowpaths) such as large-scale fracture zones, shallow or deep groundwater could reach the repository location via these flowpaths, with the result that groundwater flow characteristics, geochemistry and thermal properties could have a significant impact on the barrier functions of the underground facility. Therefore, compliance with the evaluation factors for qualification for DIAs will be evaluated from the point of view of impacts of groundwater flow on the underground facility.

Detailed investigations, including construction of the underground investigation facility, require a large investment of time and money. From the implementer’s point of view, it is therefore necessary to ensure that the DIA selection process is not only safe but also feasible in terms of project implementation. Regarding the characteristics of the DIAs from various viewpoints such as post-closure safety, feasibility of construction and safety assurance during operation, reduction of adverse impacts on the environment, acquisition of the land, securing of financial aspects and schedule, factors that are not required by the law (geoenvironmental characteristics, natural environment, and social environment) will be evaluated. This allows confirmation of compliance with the requirements and an assessment of the feasibility of geological disposal.

The siting factors for the selection of DIAs will be specified and published before starting the DIA selection stage, taking into account discussions in committees within AEC.

8.4 Conclusions of chapter 8

This chapter describes the LS stage and the PI stage stages as shown below, indicating that preparations for implementing these stages have been achieved from a technical viewpoint:

- The goals and activities for implementing LS and PI have been clarified
- Fundamental implementation procedures for selecting PIAs and DIAs have been prepared by coordinating investigation/evaluation technologies for the geological environment, technologies for design, construction, operation and closure of the repository and technologies for long-term safety assessment
- The applicability of the technologies presented in chapters 5 through 7 has been checked in accordance with the implementation procedure in each stage.

9 . Conclusions

Important issues in implementing the geological disposal project are to ensure both long-term safety after closure of the repository as well as safety during the project duration. NUMO therefore established two goals, namely ensuring long-term post-closure safety and ensuring safety during the project implementation.

The activity of the waste inventory will decay with time, but its potential effect on the environment will remain for a very long period of time. It therefore has to be confirmed that there will be no harmful effect on future generations during tens of thousands of years following completion of the project. This will require detailed investigations during site selection, to ensure that a stable geological environment is selected and to confirm that the radioactive materials are safely confined and isolated using a multi-barrier system consisting of engineered and natural barriers. In implementing the project, both safety during the project implementation and long-term post-closure safety will be checked iteratively in each of the construction, operational and closure stages. Implementation of the geological disposal project will extend over approximately 100 years. Such a long project duration requires provisions to allow modification of the project plan as appropriate in order to reflect advances in technologies and social changes.

NUMO will implement the project in accordance with three policies for ensuring safety: Policy 1: Staged and flexible project implementation based on iterative confirmation of safety; Policy 2: Project implementation based on reliable technologies and Policy 3: Technical activities for building confidence in NUMO’s safety concept. NUMO has established specific measures for implementing each policy; these are described in the roadmaps for appropriate implementation in each stage of the project.

With regard to the technologies that support safe geological disposal, it is important to use the best available technologies at the time in each stage. NUMO has been systematically developing technologies in collaboration with fundamental R&D organizations since its establishment in 2000, so that these will be available when required. NUMO will continue to develop technologies aimed at achieving safe geological disposal, as well as improving the economy and efficiency of implementation and integrating the results of both NUMO and fundamental R&D organizations to establish systematic technologies required for the project.

The NUMO 2010 Technical Report and this report describe the up-to-date results of R&D on technologies that support safe geological disposal carried out with the support of organizations such as the Japan Atomic Energy Agency (JAEA), the Radioactive Waste Management Funding and Research Center (RWMC), the National Institute of Advanced Industrial Science and Technology

(AIST), the Central Research Institute of Electric Power Industry (CRIEPI), the National Institute of Radiological Science (NIRS), the Federation of Electric Power Companies of Japan (FEPC) and Japan Nuclear Fuel Limited (JNFL).

The H12 report demonstrated that the technical basis for the safe implementation of the geological disposal project has been established. On this basis, technologies for the implementation of the project have made steady progress in the following areas since NUMO's establishment:

(1) Technologies that allow more realistic investigation /design /safety assessment
(2) Practical technologies for systematic site selection
(3) Technologies that allow response to a range of geological environments during investigation /design /safety assessment

The progress of these technologies has contributed to improving the technical reliability of the implementation of the project and specific technologies for the LS stage and subsequent PI stage have been prepared. Technologies for implementing the repository site selection stage and subsequent stages have also been developed. In close cooperation with the fundamental R&D organizations, NUMO will continue its efforts in this area, focusing on site-specific issues and technologies required in the stages after the PI stage, with the aim of further improving reliability.

The key content of the NUMO 2010 Technical Report is summarized in this report. In preparing this report, constructive comments and input were provided by many experts and organizations, including NUMO's Technical Advisory Committee and fundamental R&D organizations. The report was also reviewed by third parties such as the Atomic Energy Society of Japan and experts from other countries. This report was finalized to reflect the review comments.

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APPENDIX

Table A.5-1 Summary of investigation/evaluation technologies for volcanic/igneous activity (1/2)

Evaluation items		Description	Relevant stage		
			LS	PI	DI
Database		Nationwide databases include Quaternary volcanoes in Japan, a new version of the tephra atlas, a borehole temperature database, a hot springs chemistry database and hydrothermal deposit atlas of Japan	○		
Volcanic evolution		For eject samples from Quaternary volcanoes for which it is difficult to apply the radioactive dating technique, different methods were developed such as the RIPL method that identifies tephra-origin subvisible materials or tephra ashfall horizons, techniques using chemical compositions of trace elements, chemical composition of major components of the glass inclusion in volcanic ash origin quartz and refraction index of the plagioclase phenocryst.		○	
Intrusion and eruption of magma	Generation of new volcanoes	A volcano generation forecast method was developed for the North-east Japan Arc based on relationships among volcanoes and topography/tectonic structure, distribution of low velocity seismic waves and plate movement. With regard to caldera and large-scale pyroclastic flow, a correlation between caldera formation and tectonics was identified, which led to the proposal of a working hypothesis for the evaluation of caldera-forming eruptions.	○	○	
	Migration of magma from existing volcanoes	A method for evaluating horizontal magma migration has been proposed. It uses the results of studies of migration of craters that reveal a relationship between the chemical composition of magma and direction of conduit distribution.	○	○	
	Deep heat source	A method was developed for evaluating underground magma conditions and thermal effects of the magma based on evaluation of deep heat sources in areas where no volcanoes are distributed in the back arc of North-east Japan by combining seismic velocity structure from seismic tomography, distribution of microseismicity, resistivity structure by the MT method and geochemical data ($^{3}He/^{4}He$). In the Noto Peninsula, in order to identify the heat source of non-volcanic hot springs, isotope analysis of noble gases in the hot spring gas and 3D resistivity structural analyses were conducted.	○	○	
	Deep geological structure	New technologies for evaluating intrusion/eruption of magma were developed, such as the double difference tomography and seismic wave analysis techniques using the receiver function or following wave, which contributed to improving the accuracy of the evaluation of the presence of magma in the deep underground and the ascending process of the magma.	○	○	

○: Most relevant stage

Table A.5-2 Summary of investigation/evaluation technologies for volcanic/igneous activity (2/2)

Evaluation items		Description	Relevant stage		
			LS	PI	DI
Geothermal activity	Comprehensive thermal/geothermal evaluation	As a basis for evaluation, thermal/hydrothermal abnormal areas were identified by overlapping geological and geophysical data and areas with high temperature zones were categorized. Based on this categorization, methods were developed such as the geothermal distribution evaluation method using the geothermal simulator, a thermal anomaly identification/characterization method and an alteration zone analysis method. An analysis technique for groundwater formation processes based on fluid/rock reactions was also developed. Development of an evaluation method for deep hot water has been conducted based on a geochemical approach.	○	○	○
	Thermal history	Development of evaluation methods has been conducted, including methods for hydrothermal alteration history around non-volcanic high temperature hot springs based on a method similar to the thermal age determination method that couples several radioactive dating techniques and an analysis method that extrapolates the thermal effects of large-scale pyroclastic flow on the deep underground by applying thermal history analysis based on the fission tracking method. The (U-Th)/He dating technique has been applied to the analysis of low temperature (> 70 ºC) thermal history.		○	○
	Effects from heat source/volcanoes	Development has been conducted on a method to evaluate thermal flux and fluid velocity using a 1D heat transport model and 3D hydrothermal simulation method using Magma 2002, an analysis code for calculating heat and hydrology around the magma chamber.	○	○	○
Probabilistic evaluation		R&D being conducted includes a method for predicting generation of volcanoes in the next one hundred thousand years using a probabilistic model based on temporal and spatial distribution of volcanoes and geophysical information, a probabilistic evaluation method for independent monogenetic volcanoes and a method using a multiple inference model that incorporates geophysical information on the Japan island scale into the probabilistic model using the Bayesian technique.	○	○	

○: Most relevant stage

Table A.5-3 Summary of investigation/evaluation technologies for earthquake/fault activity (1/2)

Evaluation items		Description	Relevant stage		
			LS	PI	DI
Existence of active faults	Database	The nationwide database developed after the H12 report includes geological structures in the marine area around Japan, a detailed active fault digital map, active fault database, Quaternary reverse fault atlas and active faults in urban areas. An earthquake monitoring network (NIED) and GPS monitoring network (GEONET; GSI) have been established and are used to locate active faults.	○		
	Geodetic technologies (SAR,GPS)	High resolution topographic change analysis using the PALSAR system mounted with earth observation satellites and GPS continuous analysis revealed the presence of strain concentration zones. They also allowed simplified monitoring of strain accumulation at plate boundaries.	○		
	Geomorphic technologies (tectonic relief)	Airborne radar surveys have been used to find faults in vegetation-covered areas and identification of faults based on analysis of minor displacement topography. For areas where faults are clearly found at the ground surface, a lineament identification method has been proposed. Methods for finding and characterizing the activity of concealed active faults have been proposed, based on the distribution of uplift level estimated from terrace distribution.	○	○	
	Geotectonic methodologies (geotectonic analysis, age determination)	Methodologies developed include evaluating activity based on the progress of fracturing, deformation and alteration around the fault or color of the fault gouge and based on the gouge age determination method that evaluates activity directly from materials that constitute the fault (fault rock). A method for evaluating activity history was developed based on the tectonic history, including investigations to determine thermal age. An earthquake occurrence frequency analysis method has been developed based on detailed analysis of turbidite on the sea bottom.		○	○
	Geophysical technologies (reflection survey, electromagnetic survey, seismic tomography)	Applicability of the reflection survey method has been expanded and demonstrated, including development of the 2D technique, application of the 3D technique in exploration of mineral resources, geotectonic analysis and investigation of active faults, deposits and topography in marine areas and investigation of geology and ground in inland areas (small-scale faults). The multi-channel sonic survey system has been developed to accurately determine tectonic structure in marine areas and has been applied in the investigation of active faults. A marine electromagnetic exploration system for application in the foreshore at a depth of 200 m or less (expected to be used complementarily to acoustic exploration) has been developed and improved. In order to survey areas extending from coastal areas to marine areas, combination of the marine electromagnetic exploration system and other electromagnetic exploration systems has been developed. The gravity exploration method has been considered for determining the length of active faults. A method for identifying faults in active fold zones has been proposed, in which an earthquake source fault is estimated based on distribution of corrected seismic sources and the estimated earthquake source fault is compared with the tectonic structure using simulated movement analysis based on finite element analysis. For the evaluation of the seismic source fault model, analysis of seismic waves such as tomography has been considered.		○	○

○: Most relevant stage

Table A.5-4 Summary of investigation/evaluation technologies for earthquake/fault activity (2/2)

Evaluation items		Description	Relevant stage		
			LS	PI	DI
Existence of actie faults	Geochemical approach (H_2, He)	Development of a method to locate and characterize faults by measuring H_2 gas generated due to fracturing of rocks and He isotopes in groundwater, hot springs and gas in the soil has been conducted.		○	
Existence of actie faults	Comprehensive methodology	A method to evaluate active structures of the seismic source fault was proposed for areas where clear evidence of seismic faulting has not been observed at the ground surface; this is based on an analysis of micro-seismicity, airborne radar surveys and reflection surveys.	○	○	
Definition of deformation zone and affected region around active faults	Determination of deformation zone (e.g. active fold)	Fault-related fold analysis (e.g. growth strata) coupled with acoustic survey data was effective in identifying fault structures in marine areas with sediments. Studies of formation mechanisms and categorization of active folds in Japan have been conducted. Development processes of active fold/reverse fault zones and associated affected zones have been evaluated by model experiments and evaluations based on the concept of fault-related folds have been conducted using existing geological data and the balanced cross-section method. Evaluation methods validated for their effectiveness for reverse and strike-slip faults include the method applying the balanced cross-section based on geological investigation data and the method applying a numerical analysis program to estimate deformation zones of rocks and topographic deformation in area around the fault.	○	○	
Definition of deformation zone and affected region around active faults	Development and extent of faulting	An evaluation method for reverse faults has been developed based on an analysis of their development process using model experiments. Evaluation of strike-slip faults has been conducted by comparing development levels of major faults in the Chugoku and Chubu areas as well as experiments/simulations.	○	○	
Definition of deformation zone and affected region around active faults	Characterization of fault fracture zones	Studies conducted include geological evaluation of damaged and process zones associated with faults that are relevant to changes in groundwater flow and the underground environment and evaluation of the extent of the damaged zone based on resistivity obtained by MT surveys.	○	○	○
Evaluation of reactivation of active faults		Fault activities in recent destructive earthquakes such as the 2003 Miyagi earthquake and the 2008 Iwate-Miyagi Inland Earthquake and the Tachikawa fault in the southern part of Kanto area suggest potential reactivation of existing geological faults. The reactivation of geological faults has been studied by model experiments and numerical analyses.	○	○	
Probabilistic evaluation of fault activities		A fault generation forecast method extending approximately one hundred thousand years into the future has been developed based on strain velocity distribution and probability of exceeding the annual strain rate obtained from topographic change such as active faulting/uplift, GPS data and historical earthquake data. Probabilistic seismic hazard analysis has been applied in forecast several tens of years into the future in the disaster prevention areas.	○	○	

○: Most relevant stage

Table A.5-5 Summary of investigation/evaluation technologies related to uplift/erosion (climate/sea-level change)

Evaluation items		Description	Relevant stage LS	Relevant stage PI	Relevant stage DI
Database		Nationwide database including the marine terrace atlas for Japan, uplift/subsidence distribution in the last 100,000 years, uplift rate distribution in the last 100,000 years and landslide topography distribution in Japan on a scale of 1 to 2 million.	○		
Investigation/evaluation of uplift/subsidence	Terrace correlation/ chronology	A comprehensive approach for terrace correlation/chronology emphasizing topographic sequence, geological sequence and age information was proposed to avoid erroneous interpretation of age data, which was validated using a detailed volcanic ash analysis method. Technologies that support the approach include quantification of terrace surfaces using DEM and its application to terrace correlation. The index of weathering for the cover and terrace gravel layer that constitute the terrace was revised. This contributed to improving the reliability of the identification of terraces formed in the last stage of the marine oxygen isotope stage six (approximately 140,000 years ago) used for evaluating uplift in inland areas.	○	○	
	Evaluation of uplift level in inland areas based on river terraces	The applicability of the uplift estimation method of river terraces to inland areas was reviewed and causes of errors were identified. The estimate of uplift based on river terraces was verified by the balanced uplift between that estimated based on the throw of the active faults and the uplift difference on both sides of the fault obtained from the relative height of the terrace.	○	○	
	Representation of uplift/subsidence based on deposits	Developed methodologies include estimating uplift/subsidence rates during the period from the past to present by comparing depth of the formation (whose age is clear) when it was aggraded and current distribution elevation/sea-level and clarifying the paleogeography and development process of inland basins using the sequence sedimentary facies analysis method.		○	
Evaluation of erosion volume and rate	Forecast of topographic change, topographic change model	R&D being conducted includes topographic change forecast based on estimates of past erosion history and erosion depth obtained by comparing erosion topography on new and old marine terraces, combined with change in the climate/sea-level and that based on simulation of topographic change using diffusion equations. In addition, a method was proposed in which depth and volume of dissected valleys on the marine terrace formed during one cycle of glacial-interglacial periods are estimated using DEM and, using these values, incision rate and average erosion rate for the entire terrace are obtained.	○	○	
	Evaluation of long-term erosion (removal) level using age determination method	Developed methods include estimating uplift/erosion rate of the geology during a period of several million years based on the relationship between the closure temperature and burial depth of minerals and using age determination technology to estimate uplift/erosion rate of sediment layers based on thermal alteration of minerals and organics (e.g. transformation of silica minerals), aggraded depth and age and estimated geothermal gradient at the time of aggradation.		○	○
	Measurement of erosion rate using cosmogenic nuclides	A method to estimate denudation duration and erosion rate has been developed based on the type of in-situ cosmogenic nuclides generated by the reaction between materials on the earth and cosmic rays and their generation rate in a year.		○	
Representation of climate and sea-level change		Analysis of regional climate change and representation of evolution of vegetation have been conducted through the analysis of eolic deposits on terraces, analysis of sediment obtained by coring in inland basins and analysis of pollen.		○	○

○: Most relevant stage

Table A.5-6 Summary of investigation/evaluation technologies for geological environment characteristics (1/3)

Evaluation items			Description	Relevant stage LS	Relevant stage PI	Relevant stage DI
Geology/ geological structure	Geophysical exploration		For the reflection survey method (acoustic survey in the marine areas), the 2D data processing method has been improved. The reflection survey technique has been used for resource exploration (3D method), geotectonic structure analysis, investigation of active faults, sediments and topography in marine areas, investigation of geology/ground in inland areas (small faults with a throw of approximately 5 m). A multi-channel acoustic survey system for accurate investigation of the tectonic structure in shallow marine areas has been developed. The marine electromagnetic exploration system for the foreshore at a depth of 200 m or less (expected to be used complementarily to acoustic exploration) has been developed. Technologies for surveying areas extending from coastal areas to marine areas and 3D analysis methods have been developed. The stacking method has also been developed; this is important for obtaining high quality data required for the analysis of the MT technique.		○	○
	Borehole drilling		A system that allows control of drilling direction and angle, core sampling and borehole logging was developed and has been used for the drilling in coastal areas.		○	○
	Fracture analysis for crystalline rocks		R&D has been conducted on a method for estimating the spatial distribution of fracture density taking into account the relationship between fractures in the borehole and topography/fault of the bedrock for granitic rock and the multi-scale fracture distribution simulation technology that allows consideration of regularity/correlation of fracture distribution on different scales.		○	○
	Fracture analysis for sedimentary rocks (3D structure)		The methodologies for analyzing 3D distribution of permeable features such as faults that are the basis for the hydrological analysis were developed for different scales. Also developed was an analytical fracture characterization method and site descriptive model development method based on borehole investigation data, an investigation/analysis method for spatial distribution of highly permeable structures based on rock mechanical stress calculations considering fault development mechanisms and an investigation/analysis method for the time when the development of the anticline started based on diagenesis of silica minerals.		○	○
Groundwater hydrology	Hydrology	Hydrology in deep rocks	A series of methodologies have been developed for analysis of hydrological parameters such as permeability as part of the development of sequential hydrological testing methods for deep underground rocks and a testing unit was developed for use for groundwater conditions with dissolved gases in sedimentary rocks.		○	○
		Permeable fractures/water conduits	Methodologies developed include a method for identifying intake and outflowing water locations in the borehole with high sensitivity flowmeter logging, a method to identify/estimate permeable fractures with electrical conductivity logging and a water channel estimation method using optical fiber temperature logging assuming the locations where flow velocity changes as locations where intake or outflowing of water occurs.		○	○
	Groundwater flow direction /flow rate		A flow direction /flow rate measurement method for extremely low flow rates was developed that allows measurement of flow direction /flow rate of 10^{-9} m/s by tracing the migration tracks of solid particles with ultrasonic sensors.		○	○

○: Most relevant stage

Table A.5-7 Summary of investigation/evaluation technologies for geological environment characteristics (2/3)

Evaluation items			Description	Relevant stage		
				LS	PI	DI
Groundwater hydrology	structure model/groundwater flow	Crystalline rock	Development of the GEOMASS system that integrates processes from the development of numerical models to evaluate groundwater flow in the rock to groundwater flow analysis has been conducted.		○	○
		Sedimentary rock	Synthesis of data obtained by investigations from the ground surface using groundwater flow analysis, analysis for sedimentary rock areas where saline groundwater with dissolved gases is distributed and modeling of the stability of groundwater depending of the bonding level (pF) of the groundwater in the pores of rocks have been conducted.		○	○
		Modeling of long-term evolution	For coastal areas where sedimentary rocks are distributed, long-term groundwater flow evaluation considering long-term evolution of the climate and sea-level as temporal evolution boundary conditions[27] and groundwater flow analysis during the period from the past to present using paleotopographic distribution models have been conducted.		○	○
Groundwater chemistry	Water chemistry, age determination		Surveys of technologies for sampling and analysis of groundwater were conducted. A method for identifying fossil seawater based on groundwater age determined using ^{36}Cl generated in underground rocks and data on stable isotopes are proposed.		○	○
	Groundwater chemistry model		This includes M3 analysis (Multivariate Mixing and Mass balance modeling analysis) that combines primary element analysis and mixing/mass balance calculations to evaluate the range and extent of the temporal evolution of the groundwater chemistry and determination of ion concentration in the porewater extracted from rock cores to analyze the correlation with groundwater flow.			○
Rock properties	Mechanical properties		The rock evaluation method using three factors (uniaxial compressive strength, ROQ and fracture condition) as indices was proposed. With regard to rock pressure measurement methods, the overcoring method for measuring stress in soft rocks and the downward compact conical-ended borehole overcoring technique for in-situ rock stress in deep boreholes have been developed. The difference in uniaxial compressive strength due to the difference in mineral composition in granite samples has been analyzed and mechanical characteristics of the granite have been compiled in terms of mechanical and rock properties. Rock stress measurement methods are being studied based on change in tangential Young's modulus. In the Mizunami URL, boreholes have been drilled from the ground surface to develop a mechanical conceptual model of rocks.		○	○
	Thermal properties		Data on rock properties (physical, mechanical, hydraulic and thermal) under high and low temperatures were collected based on literature surveys and compiled into a database[44]. Mechanical properties of sedimentary rocks (soft rock) in a high temperature environment (temperature dependence of three axial compressive strength and creep characteristics) have been shown.		○	○
	Evaluation of difficult constructions		By compiling existing data, criteria for evaluating extrusion of the ground and a design guide for tunnel construction methods based on geological information obtained in advance were presented and a method for evaluating the likelihood of encountering difficult construction conditions based on information obtained up to the PI stage was proposed. Safe construction methods against failure of the liner that is likely to occur during shaft construction in fault/ fracture zones have been proposed.		○	○

○: Most relevant stage

Table A.5-8 Summary of investigation/evaluation technologies for geological environment characteristics (3/3)

Evaluation items		Description	Relevant stage		
			LS	PI	DI
Mass transport properties		Thermodynamic, sorption and diffusion databases have been developed. Studies have been conducted on processes and field structures that control migration or retardation of radionuclides in permeable fractures in crystalline rocks and in-situ testing methods and modeling methodologies have been developed.		○	○
Others	Mud volcanoes	It is known that fluid that causes eruption of mud volcanoes ascends from a depth of 2,000 m and dehydration of clay minerals plays a key role in the formation of the fluid; the fluid contains hydrocarbons generated by decomposition of biogenic organics. Data on activation period and volume of ejecta for mud volcanoes have been collected from cases in other countries. Underground structures and distribution/scale have been estimated based on geodetic or geophysical techniques. Mechanisms of volcano formation and its scale have been studied based on knowledge of Miocene mud diapirs.		○	
	Mass movement	A method for predicting potential large collapse in the Mino Terrain was developed, in which frequency of the collapse is estimated based on age determination (based on ^{14}C) of the sediments in a dammed lake formed by large-scale collapse of Mt. Ibuki. Large-scale landslides during earthquakes are also reported.		○	
Monitoring		Measurements of groundwater pressure and long-term monitoring of water chemistry have been conducted using boreholes in the Mizunami and Horonobe URLs. At JAEA Tokai, development of technologies and verification of their applicability have been conducted to monitor the performance of the engineered barriers. Other R&D includes preparing technology options (technology menu) for data transmission, sensors and measurement technologies.		○	○

○: Most relevant stage

Table A.6-1 Current status of scientific knowledge on corrosion behavior of the base metal and weld

Behaviors		Description
Base metal	General corrosion behavior	Data on corrosion rate were accumulated. Decrease of the corrosion rate in a long-term perspective was shown by experiments.
	Local corrosion, passivation	It was shown that the passivation could be prevented by the pH buffering effect of the buffer materials or by using of low-pH cement. Test data on local corrosion were accumulated, which indicates that the local corrosion would not be significant as to affect to the corrosion life.
	Effects of radiolysis products on corrosion resistance	Insignificant effects of radiolysis product of groundwater (e.g. hydrogen peroxide) due to γ-ray from HLW glass was validated by tests, indicating conservativeness of the radiation shielding allowance of 150 mm that has been taken into account in the design to prevent local corrosions.
	Microbiological effect on corrosion	Reduction of activities of sulfate-reducing microbes with the increase of bentonite/water ratio was validated by laboratory tests. Effects of microbes such as sulfate reducing microbes are considered to be small because migration of the microbes will be prevented by the filtration effect of the compacted bentonite, restricting their inhabitation or activities.
Weld	General corrosion	Preferential corrosion was observed under oxidizing conditions; however, there is a prospect that it could be solved by changing welding materials. It was also shown that the corrosion resistance of the weld is equivalent to or better than the base metal.
	SCC, hydrogen embrittlement	Sensitivity to SCC was tested in the carbonate solution and sensitivity to hydrogen embrittlement evaluated under simulated saline water, showing less sensitivity than the base metal.

Table A.6-2 Current status of scientific knowledge on basic properties, long-term behavior and interaction of buffer materials (1/2)

Behaviors		Description
Effects of saline water		The swelling pressures decreases with the increase of salinity, but its difference from that under fresh water is not significant at the effective density of $1.5Mg/m^3$ or higher. The volume swelling ratio increases with the increase of effective density of the clay but it is less with the increase of the salinity.
Cement-bentonite interaction	Transformation to Ca-bentonite of clay minerals in the buffer	The groundwater passing through the concrete support or plug could become Ca ion rich composition. Studies have been conducted on potential alteration of Na-smectite to Ca- smectite by ion exchange, resulting increase of permeability and decrease of swelling pressure, when it contact with the buffer material.
	Dissolution of clay minerals in the buffer	It is a phenomenon that the smectite, a main mineral that constitutes the buffer material, dissolves into the groundwater, as reported in literatures. Formulation the phenomenon has been conducted using pH and temperature as parameters.
	Sedimentation of secondary minerals	It is a phenomenon that the smectite, a main mineral that constitutes the buffer material, forms secondary minerals and is replaced with it, which could result in change in swelling properties and permeability. This phenomenon could be significant under the condition where the smectite becomes mineralogically unstable.
	Cementation	It is a phenomenon that could occur around the cement-bentonite interface where secondary minerals precipitate and fill the pores in both materials. This could cause change in swelling properties and permeability.

Table A.6-2 Current status of scientific knowledge on basic properties, long-term behavior and interaction of buffer materials (2/2)

Behaviors		Description
Interaction between carbon steel corrosion products and bentonite	Exchange of exchangeable interlayer cation with Fe-ion	Exchangeable interlayer cation (Na^{+}) in the smectite could be exchanged with Fe^{2+} ion, which could result in change of swelling properties, permeability and sorption capability of the bentonite.
	Chemical alteration of minerals	At the increased portion of Fe^{2+}, minerals such as pseudo chlorite/Fe-chlorite, berthierine, nontronite, Fe-saponite could be formed. Alteration to pseudo chlorite/Fe-chlorite and berthierine that do not have welling capability could cause change of swelling properties, permeability and sorption capability of the bentonite.
	Cementation by corrosion products	Sedimentation of the iron corrosion product or chemical reaction of minerals could cause secondary sedimentation of other minerals, resulting closure of pores. It could cause change in swelling properties, permeability and sorption capability.
Illitization		It is proven that the illitization could not occur below the temperature of 130 ^{o}C, thus has insignificant impact to the safety functions of the buffer.
Erosion of buffer material		Erosion is the phenomenon that need to be noted under the fresh groundwater condition, but it is proven that, under the saline groundwater condition, it effect is insignificant. Under the fresh groundwater condition, appropriate measure will be required based on the analysis of effects of fractures contacting with the buffer on the erosion behavior of the buffer material.

Table A.7-1 Progress of R&D relevant to safety assessment since the H12 report (1/4)

R&D area		Description	Relevant technology area		
			EBS	NB	BIO
Scenario development	Effective scenario development methodology	Development of a scenario development methodology based on safety functions and on FEPs.	○	○	
		Development of methodology to improve completeness and efficiency, based on hierarchical relationships between FEPs and safety functions. Development of a tool to express correlations between FEPs in a matrix.	○	○	
		Development of a concept for revising scenarios in the light of advances in R&D and preparation for application cases.	○	○	
		Development of a concept for classifying events based on the significance of their consequences by analysis of links between safety functions and nuclide migration parameters.	○	○	
	FEP-based scenario development methodology and compilation of FEP information	Compilation of knowledge in a FEP list based on literature information (for engineered barriers and groundwater transport scenarios for geological environments typical of Japan). From correlations between FEPs, judgment on whether or not to include in key scenarios. Compilation of FEP data for the safety assessment of the geological disposal of TRU waste.	○	○	
	Determination of system conditions and scenario development methodology considering long-term evolution	Development of a methodology for determining system conditions taking into account the long-term evolution of the coastal geological environment.	○	○	
		Development of a scenario development methodology taking into account long-term evolution of the near-field environment.	○	○	
		Development of a methodology for defining nuclide migration analysis model parameters by compiling geoscientific knowledge on features of relevant phenomena, focusing on changes in thermal / hydrogeological / mechanical / chemical conditions.	○	○	
	Scenario development methodology for disruptive natural phenomena	Development of a methodology for handling "what if?" scenarios for events that should be avoided by site selection or EBS design.	○	○	
		Development of a methodology for evaluating potentially significant natural events.	○	○	

[Relevant technology areas] EBS: Engineered barriers, NB: Host rock (natural barrier), BIO: Biosphere

Table A.7-2 Progress of R&D relevant to safety assessment since the H12 report (2/4)

R&D area		Description	Relevant technology area		
			EBS	NB	BIO
Model development	Improvement of nuclide migration analysis methods taking into account the heterogeneity of host rocks and design options	Development of a 2D model for evaluation of nuclide migration and retardation in the EDZ.	○		
		Development of a 3D nuclide migration model for evaluation of the effects of heterogeneity of host rocks and design options.	○	○	
		Development of an approach to optimize repository layout (maximize number of waste packages emplaced, use of better quality rock), based on spatial distribution of geological characteristics.	○	○	
		Development of an approach to improve performance of the repository by laying out the repository in better quality rock.	○	○	
		Development of a methodology for incorporating information on heterogeneous migration pathways obtained by groundwater flow analysis into the nuclide migration analysis models.			
	Improvement of nuclide migration analysis methods taking into account long-term evolution of the surface environment and geological environment	Development of a biosphere evaluation model and related dose conversion factors addressing the effect of climate change by focusing on the reduction of precipitationb in cool temperate and cold desert zones, changing parameters such as irrigation water volume, penetration/run-off rate and ingestion of foodstuffs.			○
		Development of a model development methodology for incorporating hydrology/mass transport at the geosphere / biosphere interface.			○
		Development of a methodology for incorporating features of the geological environment in coastal regions together with their long-term evolution into nuclide migration models.		○	○
	Development of effective calculation methods for nuclide migration analysis	Improvement of groundwater analysis code (FEGM) and nuclide migration code (FERM) and their application in groundwater analysis/chloride ion concentration analysis at the Äspö URL.		○	
		Development of a statistical nuclide migration analysis model using GoldSim.	○	○	
		Development of effective nuclide migration analysis tools considering temporal evolution of parameters.	○	○	
		Derivation of approximation solutions that facilitate obtaining the response of thegeological disposal system.	○		
Development of datasets	Compilation data	Construction of a glass dissolution database Construction of a thermodynamic database Construction of a sorption database Construction of a diffusion database	○		

[Relevant technology areas]　EBS: Engineered barriers,　NB: Host rock (natural barrier),　BIO: Biosphere

Table A.7-3 Progress of R&D relevant to safety assessment since the H12 report (3/4)

R&D area		Description	Relevant technology area		
			EBS	NB	BIO
Development of safety assessment datasets	Data compilation	Review of dose conversion factors for radionuclides selected for biosphere evaluation in the current regulations, reflecting ICRP Recommendation 1990 (for HLW and TRU waste).			○
		Standardization of measurement methodologies for sorption and diffusion data.	○	○	
		Compilation of nuclide migration data in the natural environment.			○
	Compilation of datasets	Tentative setting of sorption distribution coefficients for actual geological environments and development of methodology for using the JAEA sorption database.		○	
		Establishment of a procedure for defining biosphere parameters considering the significance of the parameters, significance, progress of database construction and availability of data.			○
		Formulation of strategies for collecting knowledge and parameter setting for parameters relevant to civil engineering from those used in the groundwater scenario for the safety assessment of geological disposal.	○	○	
		Tentative compilation of a dataset using actually obtained geological environment data (porewater chemistry, distribution coefficients).	○	○	
		Development of datasets for the safety assessment of the geological disposal of TRU waste.			
Safety analysis	Sensitivity analysis methodology	Identification and quantification of parameters that have significant effects on the evaluation results.	○	○	
		Compilation of uncertainty factors for the geosphere-biosphere interface that impact on biosphere evaluation. Development of a methodology for identifying important parameters in biosphere evaluation.		○	○
	Complementary indicators	Development of a methodology for reducing uncertainties associated with dilution by comparing the radionuclide flux at groundwater discharge points from fault fracture zones with natural fluxes. Collection and compilation of data on concentration and flux of natural origin radionuclides and development of calculation methods for natural origin radionuclides focusing on drainage basins.		○	○

[Relevant technology areas] EBS: Engineered barriers, NB: Host rock (natural barrier), BIO: Biosphere

Table A.7-4 Progress of R&D relevant to safety assessment since the H12 report (4/4)

R&D area	Description	Relevant technology area		
		EBS	NB	BIO
Coordination with other technology areas	Presentation of procedures/methods leading from investigation/evaluation of the geological environment to nuclide migration analysis to be applied for specific sites.	○	○	
	Development of a safety assessment methodology considering uncertainties conducted as part of the Horonobe URL project.		○	
Comprehensive safety assessment (including methodologies)	Comprehensive safety assessment of the geological disposal of TRU waste for geological disposal under generic geological environment conditions in Japan.	○	○	○
	Evaluation of the robustness and feasibility of the geological disposal system based on analysis of issues proposed in the 2nd TRU report and using additionally obtained data.	○	○	○

[Relevant technology areas] EBS: Engineered barriers, NB: Host rock (natural barrier), BIO: Biosphere