DEVELOPMENT OF THE NUMO SAFETY CASE
- GEOLOGICAL CHARACTERISATION AND SYNTHESIS -

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Any assessment of long-term HLW repository safety will require development of arguments and evidence that demonstrate the persistence of key safety functions of the host geological environment up to several hundred thousand years into the future. NUMO has now been developing a generic safety case (NUMO 2015 Safety Case), which provides arguments and evidence to ensure that the staged identification of a suitable repository site where the key safety functions are adequate will be feasible in Japan. Focus thus concentrates mainly on precluding potentially significant impacts of natural disruptive events/processes on the geological environment and also characterising the long-term stability of the host geological environment. Basic concepts and advanced methodologies are demonstrated in a logical fashion for the preclusion and the characterisation with interaction with repository design and safety assessment on the basis of key evidence from the state-of-the-art geoscientific knowledge. Attempts are made through geosynthesis to develop realistic geological and hydrogeological models that represent the types of potential host rock environments in Japan and take account of the 4D evolution of their boundary conditions. Such models and boundary conditions will serve as bases for subsequent repository design and safety assessment in this safety case.

I. INTRODUCTION

Providing assurance of the long-term stability of the geological environment is a prerequisite for deep geological disposal of high-level radioactive waste (HLW). Key safety functions of containment and isolation of the waste must be provided by the host geological environment for a sufficiently long period of time, despite natural disruptive events/processes. In Japan, a particular concern has focussed on the long-term stability of the geological environment, as earthquakes and volcanic eruptions, for example, frequently occur in relation to tectonic evolution over geological timescales. Selecting a suitable site for a HLW repository is thus one of the biggest challenges in Japan and should be made taking into consideration tectonic mechanisms and their temporal and spatial (or 4D) evolution. Key issues to be addressed during the site selection process involve the likelihood of a new volcano forming in the selected areas, the likelihood of undetected active faults occurring in the selected areas and the likelihood of accumulated impacts of uplift/erosion adversely affecting a repository.

The Nuclear Waste Management Organization of Japan (NUMO) initiated the siting process in 2002 with open solicitation of volunteer host municipalities for the identification of a suitable repository site in three stages: literature survey (LS), preliminary investigation (PI) and detailed investigation (DI) as specified in the Act on Final Disposal of Specified Radioactive Waste (the "Act"). A logical, comprehensive and progressive basis for the siting process has been developed, which involves explicit exclusion criteria (or siting factors), on the basis of geological attributes associated with the dynamic tectonic setting in Japan[1].

On 11th March, 2011, the 2011 off the Pacific coast of Tohoku Earthquake (Mw 9.0) and resulting huge tsunami occurred, which triggered a nuclear accident at the Fukushima Daiichi nuclear power plant. Consequently, these natural and nuclear disasters amplified public scepticism in the feasibility and safety of geological disposal in Japan. The necessity of re-evaluating the technical reliability of safe geological disposal on the basis of the latest scientific knowledge was therefore pointed out by recommendations discussed by the Science Council of Japan[2] and following statements published by the Japan Atomic Energy Commission[3]. In addition, a more active role of the Government in the siting process was recommended as no volunteer host municipalities had come forwards. To this end, the Government established a working group of experts in geosciences and promoted the re-evaluation on the basis of the latest geoscientific information that was assembled nation-wide over the last decade and summarised by NUMO[4]. The previously demonstrated existence of potentially favourable geological environments in Japan was re-confirmed following this appraisal of the new information[5].

Taking such changes in boundary conditions into consideration, NUMO has launched the development of a generic safety case ("the NUMO 2015 Safety Case") that builds on international state-of-the-art scientific and technological knowledge and, in particular, improved understanding of favourable geological environments in Japan, as well as NUMO's technical advances to date[6]. Although the repository concept has not been chosen at the present generic stage but rather is to be tailored to siting environments on the basis of increasingly more detailed, site-specific information, the NUMO 2015 Safety Case will provide arguments and underpinning evidence to demonstrate the technical feasibility and long-term safety of geological disposal in Japan[7].

This paper introduces the context and contents of 'geological characterisation and synthesis' as one of the key elements of the NUMO 2015 Safety Case to a wider audience. Importantly, the development of multiple lines of arguments and evidence is based on the state-of-the-art geoscientific knowledge. Focus thus concentrates on both demonstration of basic concepts and advanced methodologies for the staged identification of a suitable repository site in Japan and also realistic representation of the types of potential host rock environments in Japan.

II. KEY STATEMENTS AND ARGUMENTS

Since the main focus concentrates on the feasibility and long-term safety of geological disposal, the top-level statements are defined as:

- Selecting a suitable repository site in Japan where the key safety functions of the host geological environment will persist for a long period of time would be feasible.
- Models developed by interpreting and synthesising the latest geoscientific information are reasonably representative of the types of potential host rock environments.

The first key statement is underpinned by direct input form the next level of argumentation, which involves:

- Potentially significant impacts of natural disruptive events/processes on the geological environment can be precluded.
- Stable geological environments can be identified and their 4D evolution characterised.

Such argumentation will be sequentially developed further to increasingly more detailed levels as the staged siting process progresses and the depth of understanding enhances so as to tailor this structure to more specific siting environments.

III. CURRENT UNDERSTANDING OF JAPANESE GEOLOGICAL ENVIRONMENTS

The Japanese archipelago lies, at the junction of four major tectonic plates, in tectonically active circum-Pacific Belt. The Pacific and the Philippine Sea oceanic plates are subducted beneath the archipelago and the motion of these oceanic plates against the Eurasian and North American continental plates defines the present tectonic setting around Japan. The trend of crustal deformation such as regional faulting and uplift are directly related to the plate motion and the volcanic arc system is caused by subduction regime for the oceanic plates. The motion of the plate system around Japan has been in steady state since the late Pliocene[8,9]. The present tectonics formed mainly in the Pliocene to the Pleistocene and no significant changes in crustal movements have been recognised for up to one million years to date[10]. On the basis of such geological records of stability, the current uniform mode and rate of crustal movements can be extrapolated over the next hundred thousand years in a reasonable and reliable fashion[5,10].

The geological environment in which a repository is constructed must provide containment and isolation of the waste for a sufficiently long period of time. For ensuring the containment function in particular, the host geological environment is expected to maintain an environment suitable for performance of the engineered barrier system and to function as a natural barrier to limit and retard likely radionuclide migration and to provide sufficient buffering against internal/external perturbations. The favourable characteristics/properties of the geological environment in this context, which have been redefined in terms of thermal, hydrological, mechanical and chemical (THMC) conditions[5], are presented in Table I.

Since the publication of "H12: Project to Establish the Scientific and Technical Basis for HLW Disposal in

TABLE I. Prevalence of Favourable THMC Conditions in Deep Geological Environments

Conditions	Favourable characteristics/properties required	Prevailing characteristics/properties identified since the H12 report
Thermal	Low geothermal gradients for prolonged periods	Geothermal gradients in non-volcanic regions lie generally in the range of 3°C to 5°C per 100 m (Refs. 4 and 11), which demonstrates that areas where target temperatures prevail at a depth greater than 300 m are widely distributed
Hydrological	Slow groundwater movements due to low hydraulic gradients and/or low rock hydraulic conductivities	Values determined for hydraulic gradients in the order of 0.001 to 0.1 and hydraulic conductivities in the order of 10^{-12} to 10^{-6} m/sec (Ref. 4) show that high hydraulic gradients are normally associated with low hydraulic conductivities and vice versa, which indicates the occurrence of slow groundwater movements
Mechanical	Small rock deformation including rock creep	Rock mechanical datasets updated show that the ratios of uniaxial compressive strength to overburden pressure are generally in the range of 1 to 2 (Refs. 4 and 12)
Chemical	Groundwater with near neutral pH, reducing conditions and concentrations of dissolved inorganic carbon (DIC) less than 0.5 mol/dm^3	The common occurrence of deep groundwater with pH values between 6 and 9, more negative Eh values and DIC concentrations of smaller than 0.1 mol/dm^3 (Refs. 4 and 13) demonstrates the prevalence of favourable geochemical conditions

Japan" (the "H12 report")[14] by the Japan Nuclear Cycle Development Institute (currently the Japan Atomic Energy Agency; JAEA) in 1999, geoscientific knowledge has been further expanded by multidisciplinary research programmes; for example, JAEA's underground research laboratory (URL) projects at Mizunami[15] and Horonobe[16]. The state-of-the-art geoscientific knowledge demonstrates more precisely that the favourable THMC conditions most likely prevail in deep geological environments in Japan, as summarised in Table I. A convincing indication worth noting here for slow groundwater movements in particular is that deep groundwater having a very long residence time (2 to 10 million years) has been reported in some sedimentary formations[17-19].

IV. PRECLUSION OF SIGNIFICANT IMPACTS OF NATURAL DISRUPTIVE EVENTS/PROCESSES

IV.A. Natural Disruptive Events/Processes

A wide spectrum of natural events/processes is commonly perceived as having potentially disruptive impacts on the geological environment. As defined in the Act and associated regulations, focus concentrates on igneous activity, earthquake and fault movement and uplift/erosion in Japan[1]. More precisely, natural disruptive events/processes that would appear likely to perturb the favourable characteristics/properties of the geological environment can be specified on the basis of the state-of-the-art geoscientific knowledge[4]. Here the estimated magnitude and extent of such impacts on the geological environment does not remain within the range manageable by currently applicable engineering measures, resulting in the impairment of containment. For physical isolation, the potential likelihood of natural disruptive events/processes that would significantly reduce the geological barrier needs to be taken into consideration[20]. The specified natural disruptive events/processes to be dealt with during the staged identification of a suitable repository site can thus be summarised in Table II.

IV.B. Basic Methodology for Precluding Potentially Significant Impacts

The potentially significant impacts of natural disruptive events/processes shown in Table II are to be precluded, in principle, during the initial LS and the next PI stages. The LS stage involves use of all available information, which includes prior confirmation of geological conditions as initial screening to ensure that a proposed or volunteering area qualifies for further consideration. A comprehensive set of siting factors covering tectonic stability, which has been updated taking account of suggestions from the working group[5], will be applied for exclusion of certain areas owing to increased likelihood of potentially disruptive impacts from nation-wide and site-specific perspectives. Basic concepts for precluding such impacts are presented in Table II. Compliance with legal requirements ensures that any geological environments in excluded areas are obviously unsuitable as repository sites.

The following PI stage concentrates on geological characterisation at the site selected as a preliminary investigation area (PIA). Field-based investigations such as geological, geophysical and geomorphological surveys and borehole investigations will be extensively carried out in order to gain sufficient information to decide whether to preclude conceivable potential impacts. A variety of investigation techniques, the applicability of which has already been ensured[6,21], will be applied to evaluate the degree of such impacts over different 4D scales. If the likelihood of the impacts can neither be ruled out nor precisely evaluated owing to large remaining uncertainties at the end of the PI stage, this area will be rejected from further consideration.

In addition to a deterministic/empirical approach to precluding the potentially significant impacts, a suite of probabilistic approaches will be applied to evaluate the likelihood of disruptive impacts with its uncertainty for longer periods of time into the future, from one hundred thousand to one million years. NUMO has developed to date a methodology for evaluating future low probability,

TABLE II. Basic Concepts for Precluding Natural Disruptive Events/Processes

	Natural disruptive events/processes	Potential adverse impacts	Basic preclusion concepts
Igneous activity	Magma intrusion into and eruption through a repository	Loss of isolation	Exclusion of areas within a 15 km radius circle around the centre of Quaternary volcanoes[1]
	Elevated heat flow and generation of heat sources by geothermal or non-volcanic thermal activity	Impairment of containment by thermal effect	
	Mixing with acid or high DIC groundwater by penetration of a volcanic thermal or deep-seated fluid	Impairment of containment by chemical effect	Exclusion of areas where a low pH, high DIC or high temperature fluid occurs[5]
Earthquake and fault movement	Fracturing and crushing of the host rock by high crustal displacement at a disposal depth	Impairment of containment by mechanical effect	Exclusion of areas transacted by active faults and also crush zones that have a width of about 1/100 of the fault trace length in the vicinity of a fault[1,5]
	Changes in groundwater flow paths by increase in hydraulic conductivity in and around a fault	Impairment of containment by hydrological effect	
	Penetration of oxidising surface water by increase in hydraulic conductivity in and around a fault	Impairment of containment by chemical effect	
Uplift/erosion with climatic/sea-level changes	Significant reduction in the thickness of the geological barrier	Loss of isolation	Exclusion of areas where uplift/erosion amounting to greater than 300 m during the last one hundred thousand years[1,5]

disruptive events/processes on the basis of a couple of internationally acknowledged methods[22]. This methodology allows quantifying uncertainties related to both 4D variability of distribution and intensity of events and also limitations in knowledge of processes whilst taking account of a possible change of the present plate-tectonic conditions. Specifically, scenario logic trees for volcanic activity, rock deformation and uplift/erosion will be developed and qualitative scenario probability assessed by assigning weights to the logic trees on the basis of expert elicitation, thereby providing relevant input such as description of the tectonic situation and a list of impact scenarios for subsequent safety assessment (SA) studies[23].

As an illustration, an advanced basic methodology for precluding the potentially significant impacts of uplift/ erosion and its geoscientific background are presented below.

IV.B.1. Geoscientific Background to Evaluating Uplift/ Erosion

In high altitude regions (e.g. mountains), the activity of crustal movements correlates with the magnitude of erosion[24] and, in particular, more intense tectonic activity causes significant fluvial deepening[25]. Although the mean altitude of the most mountains increases under concurrent tectonics and erosion processes, the rates of uplift and erosion have reached an equilibrium state in some mountains where the current mode and rate of crustal movements established before the Quaternary[10,26]. In coastal regions, the amount of erosion often exceeds that of uplift[27] and estimations of erosion depths are as much as 100 m near the mouth of a major river[6].

Basic concepts derived from improved understanding of tectonic-driven uplift/erosion described above focus rather on quantifying the amount and rate of erosion during the LS and the PI stages, as suggested by the working group[5]. For inland regions, fluvial deepening is the most profound linear erosion process to be primarily evaluated. The amount of erosion can be quantified by assuming that the uplifted surface is proportionally eroded or conservatively that erosion progresses towards a base-level of erosion. For coastal regions, the amount of erosion can be quantified by integrating temporal changes in erosion rates estimated from the height of the surface above sea-level or conservatively by assuming a lowest sea-level (i.e. 150 m lower than the current sea-level).

IV.B.2. Basic Methodology for Precluding the Potentially Significant Impacts of Uplift/Erosion

During the LS stage, relevant information will be assembled and interpreted, which includes the distribution, altitude and age of marine or fluvial terrace, the amount of debris removed by rivers, aerial photo-interpretation, geodetic data, geological evolution, geomorphological evolution models etc. Here, focus needs to concentrate particularly on uplifting inland mountains and co-seismic uplifting coasts where the amount of erosion including the effects of uplift and sea-level drop is greater. On the basis of all available information, areas where there is clear literature evidence of the erosion amounting to greater than 300 m during the last one hundred thousand years will be eliminated as defined as prior-confirmation in the siting guidelines[1]. In addition, areas where the potentially significant impacts of erosion are obvious in the future will be excluded from the PIA.

During the PI stage, geological, geomorphological and geodetic surveys will be conducted along with extensive studies on geomorphological markers such as marine or fluvial terraces, buried valleys and alluvial fans and on terrace sediments and alluvium. The rate and amount of uplift will be determined by assessing temporal changes in uplift rate on the 10^5 to 10^6 year timescale on the basis of geological and geomorphological information and also evaluating the mode and rate of uplift on the 10 to 10^2 year timescale on the basis of geodetic observation. The rate and amount of future erosion will then be estimated by establishing temporal changes in river deepening rate and evaluating the amount of fluvial erosion owing to sea-level fluctuations and the magnitude of lateral erosion and marine abrasion. Consequently, areas that are identified as likely to be significantly affected by uplift/erosion will be a focus for further repository design (RD) studies to redesign the repository.

V. CHARACTERISATION OF THE LONG-TERM STABILITY OF GEOLOGICAL ENVIRONMENTS

V.A. 4D Evolution of the Geological Environment

As already described, the potentially significant impacts of the natural disruptive events/processes can be precluded by applying the siting factors during the LS and the PI stages. However, the potential impacts of other natural events/processes, in particular, gradual processes that develop rather slowly with time over a large spatial scale (e.g. uplift/erosion), cannot be precluded by siting factors. It is thus necessary to ensure that the extent over which the favourable THMC conditions vary with time would have an insignificant impact on the key safety functions of the host geological environment, thereby assuring its long-term stability. In fact, there is convincing evidence that the signatures of palaeohydrogeological evolution in groundwater, rocks and minerals indicate that favourable hydrological and geochemical conditions have been preserved in many rock formations for long periods of time, despite constant uplift/erosion and eustatic sea-level fluctuations[28,29]. To this end, site investigations will focus on quantifying a wide range of key properties and processes currently ongoing in the host geological environment and, as importantly, assessing their 4D evolution over geological timescales by adopting a palaeohydrogeological approach with multidisciplinary expertise in an efficient and logical fashion[30].

V.B. Basic Concepts for Characterising the 4D Evolution of the Host Geological Environment

The PI and the final DI stages involve geological characterisation at the PIA and the selected detailed investigation area (DIA) respectively at a progressively increasing level of detail; from early surface geological and geophysical surveys through borehole investigations to the final more detailed investigations including in situ experiments in an underground investigation facility. A strategy has been well established to date for the stepwise site investigations by employing a variety of state-of-the-art techniques[6]. However, such field-based investigations at any stages (or work steps within an individual stage) have more or less technical constraints on characterising deep geological environments. Of importance is thus that site investigations have sufficient flexibility to respond to the gradually improving understanding of the host geological environment and, in particular, the surprises that inevitably occur during investigations, which could enhance the opportunity to adopt the investigations to the site-specific conditions.

Dealing with uncertainty is one of the critical issues in geological characterisation as they are inherent in natural systems. Uncertainties in conceptualisation and modelling of the geological environment result from data acquisition and its 4D interpretation, which cannot be avoided in understanding currently ongoing processes and predicting natural events/processes in the future at the site. Of great importance is thus to identify factors that are particularly sensitive to site uncertainties and their degree and also to try to reduce them in a stepwise and iterative fashion during site investigations with close interaction with RD and SA[31]. As the extent and quality of the site investigation dataset has an impact on the SA modelling results, it is necessary to rigorously manage quality in data acquisition and interpretation and ensure that such data are traceable.

More detailed descriptions on critical issues to be taken into account in site investigations during the PI and the DI stages are provided below.

V.B.1. Application of Geosynthesis Methodology

As the repository concept is to be tailored to the siting environments, the requirements from RD and SA develop iteratively. To facilitate this, a global integration methodology, termed ‘geosynthesis’, will be applied both to clearly define the goals of individual investigations and also to interpret and synthesise relevant information from the wide diversity of investigations into a consistent 4D site model and associated datasets, as required for RD and SA. Since the geosynthesis methodology is defined as proceeding in several steps from the initial investigation and data acquisition, data interpretation, conceptual model development, numerical modelling and simulation and the final derivation of output (e.g. 4D site model) in an appropriate form, the transparency and traceability of the production of such output can be ensured[31]. More importantly, the impact of limitations in knowledge and uncertainties in data can be explicitly assessed by RD and SA to provide feedback not only at the end of each stage but also in each work step of the stage in order to guide focussing or optimising subsequent investigations.

V.B.2. Adoption of Iterative Approach

During each stage or work step of the stage in the stepwise progress of geological characterisation, based on the output of the preceding stage or step, key aspects to be investigated and the type and degree of uncertainties will be identified, the investigation targets and their priority determined and then a series of field-based investigations with a supporting laboratory programme planned in a strategic fashion following the planning manuals that have been developed to date[32]. The planned investigations in which the entire geosynthesis is incorporated will be carried out in an iterative fashion and finally the investigation results assessed in the light of RD and SA for producing the model and datasets. This strategy ensures not only the efficient improvement of understanding of the site geological environment but also identification of associated uncertainties in the output of geosynthesis. However, this needs to be optimised by taking account of the known site-specific conditions when the PIAs are selected.

V.B.3. Implementation of Quality Management

Of essential importance in site investigations is to warrant confidence in all activities and to ensure that all output fulfils the requirements from RD and SA. Stringent quality management and formalised demonstration of the quality need thus to be implemented in a consistent and transparent fashion by a functional quality management system (QMS)[33]. NUMO has established to date a generic QMS that is represented by document architecture for a suite of conceivable field-based investigations and model development during the PI stage. This QMS needs to be tailored to the site-specific conditions when the PIAs (and later the DIAs) are selected and then applied to quality-critical activities in a comprehensive and consistent fashion so that their quality level can be satisfied in the light of contribution to the safety case. In addition, all relevant information needs to be recorded. More importantly, the QMS will be continuously assessed and optimised so that it can be truly fit-for-purpose.

VI. REPRESENTATION OF POTENTIAL HOST ROCK ENVIRONMENTS

VI.A. Significance of Realistic Model Development

Whilst there has been to date no choice of host rock or site, trial RD and SA will be undertaken in the NUMO 2015 Safety Case to demonstrate the technical feasibility and long-term safety of geological disposal in Japan[7]. Generic RD and SA were performed in the H12 report for two illustrative geological settings, namely crystalline rock and sedimentary rock[14], but geoscientific knowledge has been further expanded since the H12 report. It is thus of great significance to update the previous RD and SA on the basis of the current best understanding of Japanese geological environments. To this end, realistic geological and hydrogeological models of the types of potential host rock environments are developed. Performing RD and SA based on such realistic models with considering the 4D evolution of their boundary conditions would provide underpinning evidence to demonstrate the technical (or engineering) feasibility[34] and the long-term safety[35].

The entire model development process is illustrated in Fig. 1, which is based on the geosynthesis methodology. At the time of writing this paper, work is still ongoing and hence discussions below focus mainly on the stepwise modelling process and key concepts to be adopted.

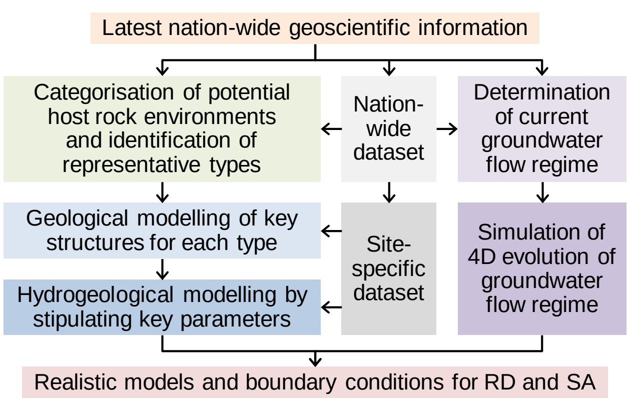

Fig. 1. The process for developing potential host rock environment models

VI.B. Identification of the Types of Potential Host Rock Environments

On the basis of the latest nation-wide geoscientific information that has been assembled to date, a total of 70 combinations of rock types and ages (e.g. Mesozoic granites and Neogene mudstones) that commonly occurs with sufficient spatial extent both on the surface and in the subsurface is specified in a comprehensive fashion. Here the Quaternary sediments and volcanic rocks are excluded because they are defined to be unsuitable as repository host rocks by the siting factors[1]. Each rock type – age combination is then characterised in the light of key geological structural and THMC features – which are of significance to geological disposal – that include potential groundwater pathways, long-term structural stability, thermal conductivity, hydraulic conductivity, uniaxial compressive strength, chemical buffering capacity etc. Eventually, these combinations are categorised focussing on common distinct characteristics/properties into a couple of groups (i.e. the types of potential host rock environments) such as ‘igneous rocks’ and ‘Neogene sedimentary rocks’.

Following the categorisation of potential host rock environments, a rock type (or a combination of rock types) that represents its corresponding group is identified by key characteristics/properties preferable to geological disposal and subsurface abundance. A relative subsurface abundance (or an area ratio) of each rock type is estimated nation-wide, excluding areas within a 15 km radius circle from the centre of Quaternary volcanoes[1], at depths of both 500 m and 1,000 m below sea level. A group of ‘igneous rocks”, for example, is potentially represented by the most abundant ‘granites’ as the type of potential host rock environments.

VI.C. Geological and Hydrogeological Modelling of Realistic Host Rock Environments

Realistic geological and hydrogeological models are developed stepwise for each of the representative types of potential host rock environments at scales of both several kilometres, for defining the location and layout of a repository and assessing groundwater flow through the potential host rock, and also several hundred metres, for more precisely describing hydraulic properties. Critical information to be represented or stipulated quantitatively in these models with the extent of its confidence, which is required from RD and SA, is derived from a realistic and comprehensive dataset of deep geological environments at a particular site in Japan. Of great importance here is to define the geological and hydrogeological significance of such a site-specific dataset by comparing with the nation-wide geoscientific information on the same rock type.

For geological modelling, key geological structures that control groundwater flow and also have a major influence on solute transport such as faults, fractures and sedimentary structures are represented by a combination of deterministic and stochastic modelling approaches. For subsequent hydrogeological modelling, optimal representations of the distribution of key hydraulic parameters to be stipulated such as transmissivities of water-conducting features and hydraulic conductivities of rock matrices are determined on the basis of the site-specific dataset. In parallel with the geological and hydrogeological modelling, the current groundwater flow regime is determined nation-wide by larger-scale realistic models that include groundwater recharge and discharge areas. Assuming that the current uniform mode and rate of uplift/erosion persists and sea-level fluctuations occur on a 100,000 year cycle, the 4D evolution of groundwater flow regime is simulated on a time scale of about 300,000 years into the future. Groundwater pathways, travel time and hydraulic gradients and their 4D changes are eventually determined, which will be used as the boundary conditions for the hydrogeological model at a scale of several kilometres.

VII. CONCLUSIONS

Whilst at the present generic stage, NUMO has been developing the NUMO 2015 Safety Case to demonstrate the technical feasibility and long-term safety of geological disposal in Japan. On the basis of key evidence from the state-of-the-art geoscientific knowledge, basic concepts and advanced methodologies are demonstrated in a logical fashion to ensure the feasibility of staged identification of a suitable repository site in Japan. These involve both precluding the potentially significant impacts of natural disruptive events/processes during the earlier stages and also characterising the 4D evolution of host geological environments to ensure their long-term stability during the later stages of the site investigations.

The stepwise process and key concepts to be adopted are also demonstrated for the realistic representation of the types of potential host rock environments on the basis of the current best understanding of Japanese geological environments. Of importance to note here is that realistic geological and hydrogeological models to be developed and the 4D evolution of their boundary conditions to be defined are essential for performing RD and SA to demonstrate the technical feasibility and the long-term safety of geological disposal system in Japan.

Demonstration of geological characterisation and synthesis therefore provides a significant contribution to the NUMO 2015 Safety Case, providing multiple lines of arguments and geoscientific evidence for the reliance that can be placed on key safety functions related to the long-term stability of the geological environment in Japan.

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