International Peer Review

of Taiwan Power Company's

Spent Nuclear Fuel Final Disposal Program, Preliminary Development of pre-siting Safety Case

Prepared for Nuclear Information Center by

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Content

1 Introduction

1.1 Background

Taiwan has been using nuclear power for electricity generation since 1978. It is expected that this usage will generate about 5 000 MTU spent nuclear fuel (SNF) in total, including 17 890 BWR SNF assemblies and 4 320 PWR SNF assemblies respectively

Managing radioactive waste such as spent nuclear fuel requires containing and isolating it from humans and the environment for very long periods of time. A geological disposal system provides a unique level and duration of protection for radioactive waste. The deep geological repository concept takes advantage of the capabilities of both the geology and the engineered materials and solutions to fulfil safety functions; the functions work together to isolate, contain, and if necessary, retard the radionuclide transport of the radioactive waste. Recognising that geological repository concepts are generally adopted worldwide for high-level radioactive waste management, Taiwan has adopted disposal in stable geological formations as the strategy for the long-term management of its spent nuclear fuel. Under the current regulatory regime, the owner and operator of the nuclear power plants, Taiwan Power Company (TPC), is responsible for the final disposal of all spent nuclear fuel its plants have produced.

The Atomic Energy Council (AEC) of Taiwan fulfils the regulatory function in the Taiwanese waste management system.

Taiwan has undertaken R&D studies related to disposal of spent nuclear fuel since 1986. On-going activities to develop a geological disposal system are governed by the Spent Nuclear Fuel Final Disposal Plan that was prepared by Taiwan Power Company and approved by AEC in 2006. The Plan, which is reviewed every four years, was last revised in 2018.

The Spent Nuclear Fuel Final Disposal Plan of Taiwan adopts the concept of step-by-step development and decision making, which is an approach that is internationally recognised and implemented by waste management programmes pursuing geological disposal of high-level radioactive waste.

The Taiwanese Final Disposal Plan defines five distinctive stages 1. Potential host rock characterisation and evaluation; 2. Candidate site selection and approval; 3. Detailed site investigation and testing; 4. Repository design and safety analysis assessment; and 5. Repository construction. The current time plan with milestones and the five stages are illustrated in Figure *1*.

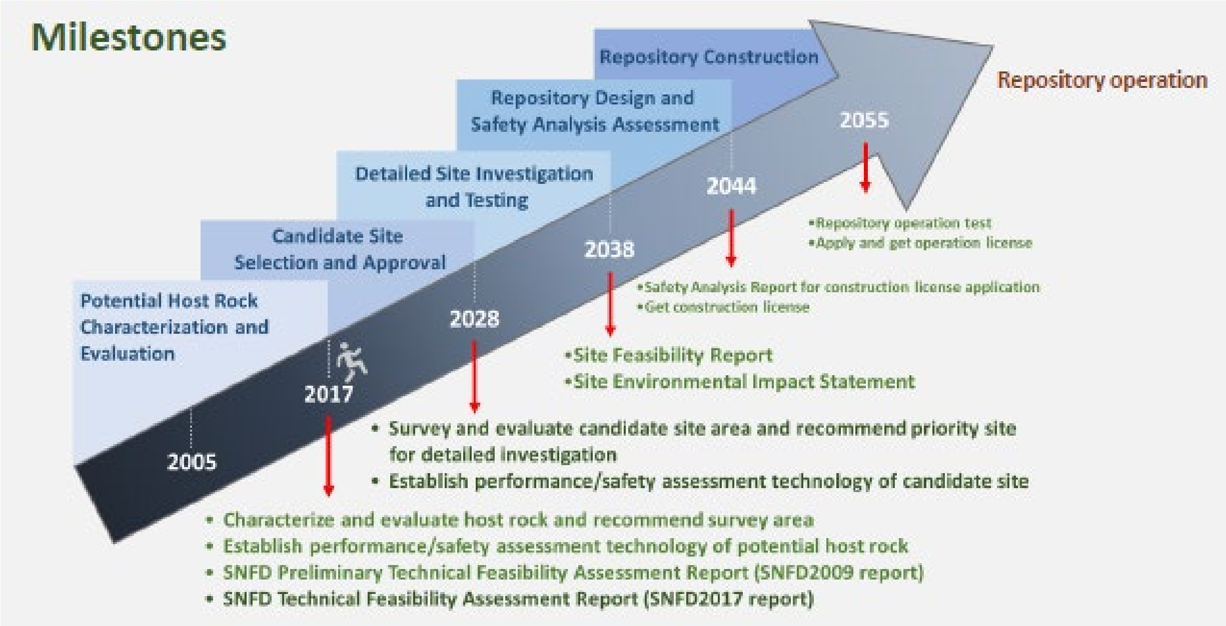

Figure 1 The current time plan with milestones and the five stages of the Taiwan spent nuclear fuel repository programme.

The first stage, Potential host rock characterisation and evaluation, was finalised with the submission of the SNFD2017 Reports; these reports were examined by an international peer review team and by AEC. The aim of the first stage was to assess and develop the technical research and the development of site investigation along with developing the repository engineering and performance and safety assessment capabilities within Taiwan Power Company; the first stage did not involve any siting process for a disposal facility although site investigations were performed at various sites in Taiwan to test and develop future siting capabilities.

The second and current stage, Candidate site selection and approval, were formally initiated in 2018.

The examination of SNFD2017 by the Atomic Energy Council of Taiwan requested that Taiwan Power Company should submit a SNFD2025 Safety Case report and an interim SNFD2021 report, with focus on the post-closure safety assessment.

1.2 The role of the SNFD2021 report

In their review of the SNFD2017 report, the regulatory authority, AEC, requested that Taiwan Power Company submit an interim safety case report before the SNFD2025. The SNFD2021 report fulfils this request.

However, the main purpose of the SNFD2021 report is to continue to strengthen the national capacity to develop and follow a methodology for post-closure safety assessment fully along the directives of international guides of IAEA and OECD/NEA. An additional outcome is an improved understanding of how a systematic and national compilation of a complete safety case for a future spent nuclear fuel repository should be structured and the associated work efficiently conducted.

Finally, identifying the gaps in knowledge, techniques, and methodologies during the examination of the SNFD2021 report directly as reported or during the review process will provide valuable input to the future R&D programme, along with inputs to national programmes for engineered barrier development, the setting-up and development of national organisations for engineering design, site investigations, site modelling, repository engineering, programme management and the potential evolution of respective organisational structures.

1.3 International peer review

Following the request from AEC, Taiwan Power Company commissioned an independent International Peer Review of the interim SNFD2021 report.

To perform the peer review, an international review team was assembled by the review co-ordinator, Nuclear Information Center (NIC), independently from Taiwan Power Company or other entities involved in the production of the SNFD2021 report.

All members of the international review team have experience in the state of the art of geological disposal system and are, or have been, engaged in advanced national programmes for geologic disposal of high-level radioactive waste.

All members of the international review team are free of conflict of interest and have not been involved in any activities associated with the preparation of the SNFD2021 report. All written exchanges between staff of Taiwan Power Company or the Institute of Nuclear Energy Research (INER) and the international review team have been organised and managed through the review co-ordinator.

The international review team members are:

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Simon Norris (UK)
Pekka Kupiainen (Finland)

Annex I of this report lists the international review team members' CVs.

The international review team members listed above is responsible for all statements made in this review. The members express their own views and not those of the institutions with whom they are or have been affiliated.

1.4 This report

The statements in this report are based on the English documentation that was provided including access to the SNFD2017 reports (TPC, 2017), on additional information given in presentations and answers from TPC, INER and ITRI staff to direct enquiries during the peer review examination.

Additionally, the statements are influenced on the understanding that this report is an interim report, and that Taiwan is at an early stage in the step-by-step development of a disposal system in Taiwan.

The statements, recommendations, and suggestions are typically following the suggested terminology by IAEA, e.g. SSG-23.

The international review team recognizes that many more documents and technical reports have been prepared to underpin the SNFD2021 report. However, due to the limited resource of time and the fact that most of those additional documents and reports have not been translated, the examination as such has focused on issues which are highly relevant for the questions (summarized in four bullets below) raised by Taiwan Power Company during introductory presentations for the review team held as a web-based meeting on June 23rd 2022 and at the first day of the international peer review meeting hosted at the Taiwan Power Company headquarters in Taipei, between August 2nd and August 5th 2022.

- The international review team is asked to evaluate whether the capability for establishing a preliminary safety case has been achieved in SNFD2021.

- The international review team is asked to evaluate if with the capabilities and efforts shown in the SNFD2021 report, whether it can be the basis for the SNFD2025 report.
- The international review team is asked to identify the weak points of the SNFD2021 report.
- The overarching goal of the international review is to strengthen, and to help to enhance the preparations of the SNFD2025 report.

Addressing the above questions resulted in differing levels of interrogation and detail across the various topics evaluated. Specifically, the international review team did not conduct any detailed examination of data, calculations, and models used in the safety assessment.

The international review team used the specialist knowledge of its members and its collective understanding of international good practice to evaluate the information provided.

2 Concluding statement

The international review team, collectively, takes responsibility for the selection of topics it deemed pertinent to the objectives of the review and wishes to confirm that sufficient information was made available such that it was able to respond to the requests made for the review. This peer review is based on the written information provided and the detailed, polite, explanations and enthusiastic answers given by Taiwan Power Company colleagues to questions raised by the international peer review team during the sessions of the web meetings and at the peer review meeting held. It is noted that all the expertise evidenced by the international peer view team during its work is based in Taiwanese national Programmes, Universities, and Institutes.

Given the broad international experience of the team and the many observations made, findings presented in the review report are of programmatic nature or are directed to a future safety case report accompanying the ongoing iterative development of a safety case for the Taiwanese national programme.

This peer review report presents the consensus view of the international review team. In keeping with OECD/NEA procedures for independent reviews, each reviewee was given an opportunity to check this report for factual correctness. The report has otherwise not been revised in response to comments from the Nuclear Information Center and the Taiwan Power Company.

The SNFD2021 report is a preliminary compilation of the post-closure safety assessment report now developed during the pre-siting stage for Spent Nuclear Fuel Final Disposal. The report is based on the SNFD2017 Report, which was compiled as a technical feasibility assessment report, along with a synthesis of the subsequent accumulation of data, technology, and domestic and international related information that has been compiled after the SNFD2017 report.

In the SNFD2021 report, the safety concept of the repository system was clearly constructed with reference to the disposal concept of Swedish KBS-3V. The primary safety functions are classified into two categories, the containment safety function and the retardation safety function, and the functions of various components of the disposal system are set as safety function indicators to achieve those safety functions. Furthermore, based on these considerations, some criteria of safety function indicators specific for Taiwan are developed. Then, considering if the safety function indicators meet Taiwan's regulatory requirements, the post-closure safety assessment has been conducted. This perfectly agrees with international standards and shows the capability of Taiwan Power Company to conduct a post-closure safety assessment.

The applied workflow and processes described in this report rely on the internationally recognized OECD/NEA methodology. This too is in good agreement with international standards, but it is crucial that the methodology continues to develop along with the step-by-step approach so that a national dialect develops that agrees with the regulatory framework, the local conditions, and not least the local spent fuel of Taiwan.

The international peer review panel considers that the SNFD2021 report is hence appropriately structured, considers appropriate technical issues, and is rationally and logically presented in a well-thought through manner. Taiwan Power Company is clearly able to construct a reliable post-closure safety assessment with a strategy based on an internationally recognized methodology. This is appropriate considering the current situation.

Although post-closure safety assessment is but one part of the IAEA-defined safety case and the future application for a spent nuclear fuel repository, the SNFD2021 report has managed to indicate that

Taiwan Power Company should have the capability to produce an evolved safety case in the future, as it is needed in Taiwan as the SNFD programme progresses.

As the Taiwan Power Company programme evolves the development of the workflow, processes, and quality assurance from SNFD2021 towards a first outlook of the SNFD2025 report, the technical capabilities and extremely enthusiastic efforts shown in the discussions and responses during the peer review of the current SNFD2021 report are worthy of respect, and in this peer review report, reviewer recommendations are suggested that will allow further enhancement of the Spent Nuclear Fuel Disposal Plan by the Taiwan Power Company.

3 High-level findings

Post-closure safety assessment methodology is applied systematically in SNFD2021 report, but the framing of the report is missing explanations compared to definition of the safety case by IAEA (e.g., IAEA SSG-23) as well as the usage of terminology. It is therefore recommended that the report aims are clarified and that focus is on the post-closure safety only, with the relevant connections to the most important background reports being elaborated on in more detail.

The description of the disposal system and its development process in the SNFD2021 report are not balanced. It is therefore recommended that the assessment basis for the geosphere and biosphere from the relevant site studies (e.g., geological investigations) is better integrated to the safety assessment and its modelling. The integration steps can include verification and validation steps for the data and modelling concepts. Because of the pre-siting stage, also design alternatives of the engineered barrier system (EBS) can be discussed more, unless the compatibility of the Swedish KBS-3V concept can be adequately ensured at all potential sites.

The panel recommends that SNFD2021 be scientifically and academically completely correct in its use of referencing. Make sure that permits, necessary copyrights etc. exist to use pictures, tables, figures, and sketches etc. Consider all references and data sources in the report. Make sure all references are available and accessible for all potential readers.

The post-closure safety assessment should consider the regulated risk. The design should consider optimization, accordingly, covering both economic and technical aspects in BAT (which are also accounted for reasonably in ALARA). Further, it is very important that post-closure safety assessment is reporting only the safety assessment and that the SNFD2021 report is not potentially viewed as a design basis report. The safety assessment should in the early stage of a national programme provide feedback for the design and provide basis for how to create, optimize, and change a given reference design. In the SNDF2021 report and at this stage in the national programme, the peer review panel believes the reference repository design is too detailed.

The peer review panel suggests that design specifications and programmes be part of a different report. If not, Taiwan Power Company may place itself in an awkward position in the future, where it has made it impossible to undertake necessary industrial optimization of a technical design, because the wrong aspects are built into the safety assessments. If the safety assessment were to aim to test a design, the safety assessment will answer questions rather than govern the methods. Similarly, the safety assessment should answer questions and guide the site investigation and the site modelling work, and should not describe the Site Descriptive Model (SDM)-associated work that is described in this report.

It is necessary for the Taiwan national repository programme to proceed with the site selection process from now on, and to that end, the highest priority should be given to ensuring safety, as well as providing information, dialogues, and explanations to stakeholders (e.g., general public, regulator, industrial partners etc.). It is crucial to get good understanding for the exchange of such technical information with the stakeholders. The post-closure safety assessment is what evaluates the selected sites' safety, and it is one of the most important tasks of a post-closure safety programme to be able to explain and actively engage in a dialogue with the general public.

The R&D programme should also be reported in another report. As above, the SNFD2021 report should answer questions and guide research focus and activities. The safety assessment report does not specify tools or concepts. Instead, focus should be on describing 'missing knowledge' from the perspective of features, events, and processes. For example:

(i), the concept of porosity is crucial and assigned values will affect all performance measures - a reduction in uncertainty regarding porosity would significantly affect the outcome of assessment calculations; and

(ii) the occurrence, frequency, and amplitude of earthquakes in Taiwan is the main risk driver for failure of the canister – a reduction in related uncertainties in these parameters would significantly improve the outcome of assessment calculations.

High-level radioactive waste disposal is an important issue nationally and internationally, and international technical information exchange is very important. We recommend that Taiwan Power Company actively promotes and attends international technical exchanges with countries of both advanced programmes such as Sweden, Finland, and France and less advanced programmes such as Japan, Korea, Czech Republic, and US, facilitating learning from advanced countries and the sharing of research and progress with the less advanced. A particular interest may be to exchange knowledge and practises with countries sharing a similar geological environment, for example, to obtain in an effective manner necessary data, technology, information etc.. Participating in international collaboration programme of RD&D using underground research laboratories is also of particular importance, e.g. DECOVALEX (www.decovalex.org). The conclusion of the international peer review panel is that Taiwan Power Company should consider a broader range of national programmes in their safety case work, at the current formative stage and as the programme evolves. This could bring some robustness, resilience, and independence to the Taiwan programme, and could demonstrate that the programme can adapt to national circumstances that may indeed differ to those underpinning other nations' national radioactive waste disposal programmes.

On a general level, the role of the national regulator (AEC) is unclear in relation to the work presented in SNFD2021 and in the staged programmatic approach overall. It is unclear to the reviewers as to what extent the regulator has commented to date on previous work and developments, for instance on aspects of the spent fuel characteristics, on the thermal design aspects, etc. - dialogue, the oversight process, and the interactions between the mandated organisation and the regulation organisation are all of key importance, along with how this information exchange is documented, made scrutable and legally confirmed.

4 Detailed Findings

4.1 Methodology

The methodology applied in the SNFD2021 report strictly follows the methodology assessed by Swedish SKB in their post-closure safety assessment work reported in e.g. SKB, 2011 (SKB TR-11-01) which is based on the OECD/NEA recommendations and which is agreement with the IAEA guide SSG-23. It should be noted that OECD/NEA as well as Finnish Posiva uses the term safety case primary to describe the part related to post-closure safety assessment. IAEA in their guide SSG-23 denotes this part of their broader usage of the term safety case as post-closure safety assessment. IAEA assess the term safety case for the entire compiled information needed for an application related to, siting, design, construction and operation of a final repository of radioactive waste.

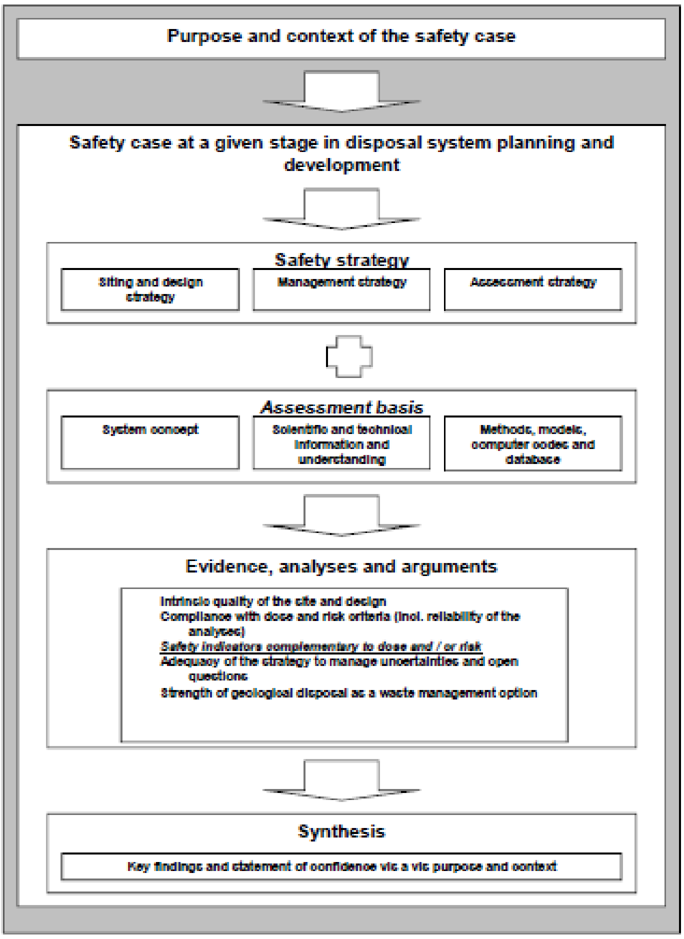

Figure 2 Re-capture of Figure 2: An overview of the elements of a safety case. (from NEA, 2004).

It should be noted that the programme of Swedish SKB is in and advanced situation and that SKB has developed their assessment and associated methodology during the stage process in Sweden. Some aspects of the methodology hence are very suitable for highly detailed design or advanced site descriptive models. It is recommended that Taiwan develop their own methodology along with the national programme development of engineered barrier programmes as well as increased detailed site descriptions.

Detailed comments on parts of the methodology will be considered in adjacent sections below.

Hierarchy of reports

The structure and intended content of the SNFD2021 report is in practical aspects identical with SKB, 2011 (SKB TR-11-01) which is denoted as the main report and as illustrated in Figure 3 below the main report rely on a hierarchy of report where in practice the three levels are all needed together to create a plausible post-closure safety argument.

It is noted that the international peer review conducted have only have access to the main report of SNFD2021 and in some relevant parts have not been able to identify the existence of significant references. This fact weakens the argument of the post-closure safety and sometimes creates uncertainties of the correctness of selections of scenarios and cases.

It is hence strongly recommended that the SNFD2025 report is developed with an associated hierarchy of reports with increasing level of details and that these reports follow international and scientific routines of peer reviews and are available for international scrutiny.

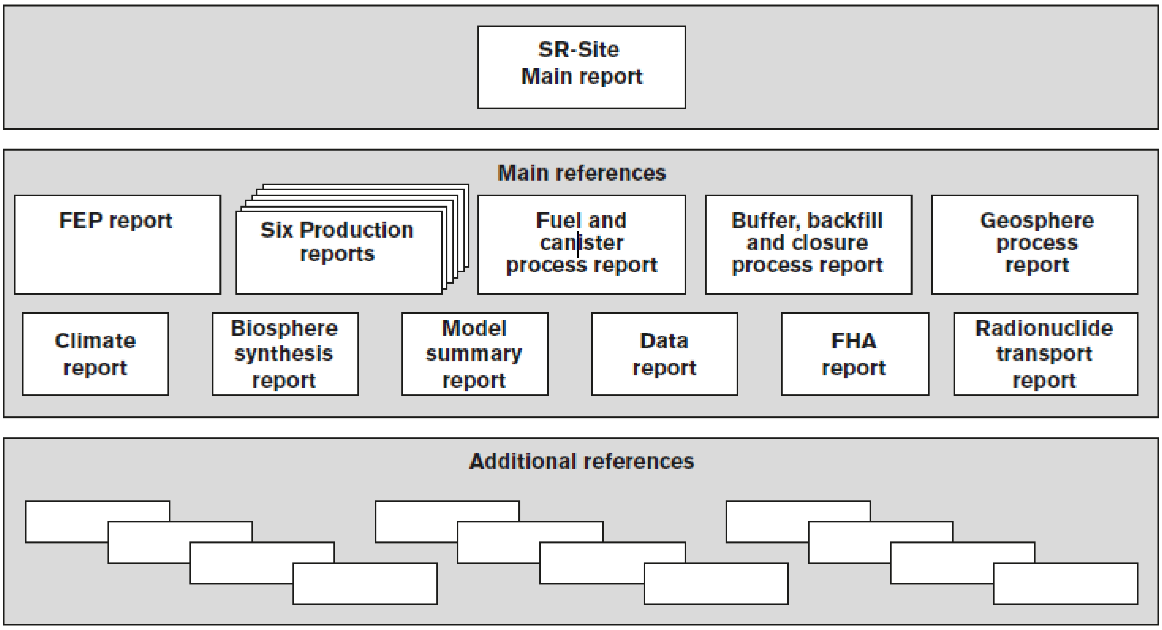

Figure 3 Re-capture of Figure 2-3. The hierarchy of the main and additional references to the SR-Site project (SKB, 2011)

Quality assurance

The quality assurance used in the SNFD2021 report is based on international quality assurance criteria such as US 10CFR50,60 and in accordance with requirements and safety guidelines (e.g., IAEA SSR-5, SSG-23) This approach to establish the quality assurance programme has been developed appropriately and following internationally recognised procedures.

On the other hand, it is important to, at each and relevant stage in the process, rationally show the relationship between the geological environment and the design and safety evaluation, and from such a viewpoint, show the relevant basis for each design value and model parameter, and therewith secure transparency and traceability.

It is recommended to establish a quality assurance system that systematically show throughout the performance evaluation that the quality of all the comprehensive performance evaluation reports related to the development of a geological disposal repository and associated technology fulfils their purpose at each stage in the process.

4.2 Features/Events/Processes

The presentation of features, events, and processes and how the SNFD2021 has assessed and worked with these are considered to follow international practise and methodologies.

However, this is a section where the lack of main references is missing. Hence it is not clearly demonstrated that the process includes all essential steps and considerations. It is therefore recommended that the SNFD2025 workflow and processes around features, events, and processes in the future assessments are re-established and well documented.

It is essential that the assessment of features, events, and processes follows the international standards, and that the national database is in agreement and contains the international databases of relevance. At this stage in the national process the treatment of features, events, and processes in SNFD2021 is good.

However, the features, events, and processes and the workflow around them should also be a guide and help in the processes of the post-closure safety assessment and especially scenario formulation process. Hence, it is highly recommended that the workflow and methodology are developed along with the national programme.

One consideration of interest is the features, events, and processes that could be of relevance concerning the excavation of rock and the associated definition of the rock barrier and the underground disposal facility that is not to be considered a barrier. Similar as the features, events, and processes considers flaws in the design process of the engineered barriers one could consider flaws in the design and construction of the underground disposal facility.

4.3 Initial State of the Repository

The SNFD2021 report presents the initial state as for a fixed reference case setting that relies partly on programme related investigations in laboratories and tests of in-situ conditions but mainly on literature data from local and other site-specific assessments. The setting covers description of the engineered barriers, the geology, thermal and mechanical properties, hydrogeology, hydrogeochemical situation, transport properties, and biosphere and the initial state description, and structurally, covers the areas observed in the descriptions internationally.

In the SNFD2021 report, the reference case setting for the pre-siting stage should be described as hypothetical that is caused by the selections made to perform the safety assessment.

Initial state for the engineered barrier systems in the SNFD2021 report is described according to documentation by Swedish SKB. Important area for safety assessment is related to the uncertainties in the manufacturing and installation of the engineered barrier systems, which have not been assessed or discussed in the SNFD2021 report as seen appropriate for the pre-siting stage. With the current design or alternatives, the manufacturing or installation errors as quality non-conformances at initial state can cause potentially declined barrier performance in the long-term. These uncertainties must be addressed in the future to improve the robustness of the safety assessment.

The SNFD2021 study includes numerical models that assesses the thermal evolution of the repository, based on many assumptions and following the outline approach adopted by e.g. SKB.

The assumptions are reasonable, given the lack of site-specific data to the contrary, and the thermal assessment can be viewed as a demonstration of the ability to conceptualise, construct, and assess numerical models, to run them, and to derive output.

As the Taiwan disposal programme evolves in the future, the modelling undertaken to date should updated. Some questions that could arise as the programme evolves are noted below.

A thermal limit may be applied to the post-closure safety assessment, as is done within other international assessments. It would, however, be good to understand the national position of Taiwan on a maximum permissible temperature, why and how it has been derived and how the repository design, waste packaging, and decision-making regarding spent nuclear fuel storage pre-packaging can be considered cumulatively to address such a maximum temperature requirement.

The SNFD2021 report notes some uncertainties, which is a positive manoeuvre. It would be helpful to understand how calculated maximum temperature varies when related parameters in models are changed, to determine key sensitivities affecting uncertainty. This will allow prioritisation of future research, design, site investigation, modelling etc. to be undertaken, ensuring the programme is needs-driven and does not focus unduly on what are lower priority issues.

It is noted that for the modelling undertaken to date, comment should be provided in relation to the conservatism in the output. For example, if different decisions were made say about the performance of bentonite and the saturation state of the bentonite – canister interface, would the modelled thermal evolution differ significantly from the work presented to date? For the future it is recommended that the national programme should link to other research programme and other national programmes, as there is the opportunity to evolve the design and footprint dependent on national programmatic decisions. The European Commission programme HITEC, for example, is considering the performance of bentonite at temperatures more than 100 Celsius.

The referred geological investigations have been conducted largely before the previous SNFD2017 report and the SNFD2021 report refers to the previous work adequately. By using previous assessments and regulatory framework, approximate boundary conditions for the present-day reference case setting have been established. The important properties include low uplift rate and the situation of the repository at the hypothetical site to be located far from volcanism.

However, due to regional setting of Taiwan and the pre-siting stage, propagation of uncertainties of long-term evolution and impacts of uplift rate and volcanism to repository safety should be further investigated.

Evidence showing the difference in the uplift rate between mainland Taiwan and the reference area is described. However, to increase the clarity, the text is recommended to be restructured in a way such that first explaining the uplift rate in Taiwan has large variability, and then explain how they are variable in each area quantitatively, as well as method being used to estimate long-term estimation of uplift ratio with justification of methods. The uplift rate and denudation (erosion) rate are assumed to be the same. We agree that this is an acceptable and conservative assumption. However, in tectonically active regions, erosion rate needs to be more realistically estimated to avoid overconservative evaluation.

Active volcanism is described as occurring in Taiwan within three regions, 1) the western region, 2) the eastern region, and 3) the northern region. However, no description about the reference site is made and it is recommended to provide some description about the target area. We agree that there is no volcanic activity in the reference area, however, in the long term, the possibility of volcanic activity may need to be evaluated, since the subducting Philippine Sea Plate reach beneath the reference area.

As for the active faults, in the SNFD2017 report, it is shown that the active faults and earthquakes are important in Taiwan.

In the SNFD2021 report, it is stated that the active faults shall be avoided based on the national regulatory requirement, however any ideas how to avoid the active fault are not described. It is recommended to add some descriptions or refer to domestic or international exiting knowledge. For example, the experience in Japan, which has similar geological conditions, may be helpful. Also, if there exist any documents for the background explanations of the regulatory requirement, it is highly recommended to reference such.

Identified geologic units at the hypothetical site include three different units that have been covered by applying two fracture domains for fracture (DFN) description and one unit containing two fracture zones. The top part (wrongly denoted as regolith) above -70m and the rest below -70m comprise the two fracture (DFN) domains both described as granitic rock and containing main water-conducting fractures.

Data for setting the fracture properties have been obtained from other crystalline bedrock sites as proxies (e.g., Forsmark in Sweden) and relevant references are provided.

Fractures in the two fracture domains were modelled using DFN models. The DFN model parameters were derived based on DFN recipe. Models and parameters being selected seem to be reasonable. However, calibration step before simulation seems to be lacking. For example, calibration against performed packer test and tunnel wall mapping should have been presented. Clearly presenting calibration steps increase the reliability of the assessed fracture models and successive simulations.

The reference case setting relies on the properties of the geological investigation area and introduces uncertainty to the modelling and thus, conditions for conclusions in the safety assessment. It is recommended that verification and validation of modelled setting in the safety assessment should be performed against available geological investigations or other data sources. For instance, the flow-related transport resistance (F) is selected as one of the safety function indicators and this selection is reasonable. However, the F-value may be exaggerated by an overestimated fracture intensity (must consider what fractures contribute to flow), lack of relevant assessment of channelling effects. Increasing confidence of the models is quite important and participating international project for validating DFN model is highly recommended.

The hydraulic conductivity for the granitic host rock (the lower fracture domain) was evaluated to be between 4.1 x 10^{-12}m/s and 1 x 10^{-9}m/s based on laboratory investigations and in-situ packer tests, and the hydraulic conductivity for the fracture zones were evaluated to be between 3.0 x 10^{-8}m/s and 1 x 10^{-4}m/s. However, at least some portions of hydraulic conductivities obtained from six investigation boreholes (KMBH01-06) reported in the SNFD2017 reports may be relevant to assess also in the fracture domain descriptions thereby the described effective hydraulic conductivity needs to be re-evaluated.

The hydrogeochemistry has been included as a part of the geological investigations and ranges of composition have been identified. Some of the hydrogeochemical concentrations reported in the SNDF2021 report seems to be lower compared to values presented in the SNFD2017 report and how these lower values are derived are not explained. Justification for the data usage needs to be described. For the safety assessment modelling in long-term evolution, the setting includes consideration of average river and sea water compositions also as possible surface water types.

Hydrogeochemical data presented in the SNFD2017 report illustrate a large variability. This variability needs to be examined and explained. The difference may indicate the flow system is compartmentalized and this should be reflected in the flow model.

The uncertainty of hydrogeochemistry should be propagated in the setting safety assessment, especially in the transport properties of the bedrock. In SNFD2021 report, the transport properties are adopted from Olkiluoto (Finland) and Forsmark sites (Sweden) during the assessment time frame as proxies of possible data but with little discussion of the uncertainties involved. It is recommended that more extensive background reasoning based on assessment of geology, hydrogeology, and hydrogeochemistry for the transport properties of the safety assessment is performed. In future, deeper investigation boreholes are recommended. Such boreholes can be used to define and parametrize the lower boundary conditions.

The reference case setting of the biosphere includes descriptions of landscape and ecosystems with land use. Natural conditions, on-going processes and human habits are described at an adequate level for pre-siting stage with the focus on identifying important exposure situations for humans and characterising potentially exposed groups (PEGs). In future assessments, improvements of reference case setting for the biosphere should focus on process understanding (geological, hydrological and biological cycles) and non-human biota (e.g. representative species) to comply with international recommendations (ICRP 2013, IRCP 2008). The improved process understanding should be focused on improved treatment of geosphere-biosphere interface and related interactions, e.g. when setting the boundary conditions for the groundwater flow modelling in site description or safety assessment modelling.

4.4 External Factors

It is noted that typically external factors are considered within four groups, namely Climate related, large-scale geological processes (e.g. denudation, uplift, tectonics, volcanism), future human actions (FHA), and additional (e.g. meteoric impact).

The SNFD2021 reports considers climate related, large-scale geological processes, and future human actions. This agrees with international practice and is considered relevant.

It can however be noted that the treatment of volcanism, denudation and uplift is relatively brief, which seem to be adequate for the hypothetical site chosen but not for Taiwan as a whole. As Taiwan, has a significant rate of uplift at locations as well as active volcanism it is recommended that the post-closure safety assessment at this stage in the national programme is expanded and developed in the future.

4.5 Internal Processes

It is noted that internal processes are treated in agreement with international practise and standards. The content of the SNFD2021 report is considered relevant in these aspects.

It can, however, be noted that the similar shortage as described concerning the features, events, and processes are apparent. Namely the lack of main references. Hence it is not clearly demonstrated that the process includes all essential steps and considerations. It is therefore recommended that the SNFD2025 workflow and processes around internal processes in the future work are re-established and well documented.

4.6 Safety Function and Safety Function Indicators

It is noted that the SNFD2021 report include the relevant safety functions; these agrees with international practise and standards. The content of the SNFD2021 report is hence considered relevant in these aspects.

However, the development of safety function indicators and safety function indicator criteria are strongly linked to the local site conditions and how the reference design functions in its local site condition and the temporal development of the site conditions.

At this stage, in the national programme it is an acceptable approach to assess international designs and indicators. However, as the programme evolve this workflow, the assignment of safety function indicators and associated criteria need to be in full agreement between the initial state, the reference design, and the reference evolution.

4.7 Input Data and Data Uncertainty

At this stage the available site data as well as national reference design data is limited, to say the least. Hence, it is an acceptable and typically assessed approach to compile international data. The workflow and assessment along with the quality assessment follows international standards and appears scientifically correct.

However, it is noted that the SNFD2021 report contains a variety of assessment of significant numbers in the presentation of results. It is important to be scientifically, academically, and completely correct in applying scientific methods.

Also, it is noted that the compilation of data for the hypothetical site is not well balanced. It is important that the site characteristics is understandable and logical as well as physically realistic. Any model needs to be based on well founded data and repeatable investigations.

Uncertainties

Definitions and classifications of uncertainty as assessed in the SNFD2021 report, are based on OECD/NEA and Finnish Posiva. It is grouped into system/scenario uncertainty, concept/model uncertainty, and data uncertainty.

Regarding the handling of uncertainty as described in the SNFD2021 report, it is deemed as scientifically correct, appropriate and in agreement with other international assessments.

However, for the pre-siting stage it could be worth considering other national programmes treatment of uncertainties, for instance the comprehensive technical report "The NUMO Pre-siting SDM-based Safety Case", as it deals with uncertainties related to the step-by-step site selection and the geological environment survey & evaluation (NUMO,2021).

4.8 Reference Evolution

It is noted that, in a typical post-closure safety assessment report, the reference evolution is by itself the most demanding section. The reference evolution is the basis for the selection of relevant features, events, and processes along with the establishment of the safety function indicators. It is noted the SNFD2021 report is not well balanced. The refence evolution of the reference site, e.g. the hypothetical site, is not very developed and the site story over the evaluated time scale is not fully understandable and logically described. This is in part, understandable, at the pre-siting stage, Taiwan presently resides in the complete story is to be developed further. But on the contrary, picking a stricter and highly developed reference design of the engineered barriers makes the report a bit confusing and the safety assessment additionally contains strangely developed uncertainties.

In the future assessments the reference evolution especially for the site should be well developed and contain a logical and detailed development for the entire evolution time scale. Additionally, this section needs to be scientifically sound and clear references available. The argument for the evolution as a prediction of 100 000 of years into the future is by truism uncertain and hence strong and broad scientific basis is needed.

The reference evolution of the engineered barriers is more complete already in the SNFD2021 report but in the future could consider that the canister failure due to corrosion is an important mechanism for the failure of containment safety function in the KBS-3V disposal system. The SNFD2021 report assesses copper corrosion during the long-term evolution by considering aerobic and anaerobic environments, which are expected during the excavation and operation period and post-closure evolution of the repository. The assessment covers limited and long-term sources of corrosion and presents the results with and without advective conditions of the buffer. The important corrosion rates related to sulphide in the groundwater have been assessed for all the deposition holes and the five deposition holes with the highest corrosion depths have been selected for further analyses in the safety assessment.

The treatment of corrosion loads on the copper canister are at adequate level in the SNFD2021 report but coupled to the hydrogeological model of the hypothetical site. Therefore, there may be a danger of overlooking the hydrogeochemical disturbances that may occur during the repeated glacial cycles. To improve robustness of the safety assessment in the future it is recommended that further assessment of corrosion loads is performed. This can include e.g., the corrosion loads originated from the hydrogeochemical disturbance due to volcanic activity (although limited at initial state), copper corrosion at elevated chloride concentrations and effects of nitrogen compounds from explosive residues on copper stress corrosion. Also, the development needs for corrosion loads and related uncertainties on the performance of safety functions can be more systematically assessed as safety assessment feedback.

Bentonite as a buffer and backfill should have safety functions like, protecting the disposal containers from corrosion due to aggressive chemical species. But also inhibit microbial activity, protect the containers from rock movements, limit groundwater-facilitated migration of radioactive and non-radioactive contaminants away from any failed containers (including colloid transport), and to provide mechanical support to the host rock. Bentonite can fulfil these safety functions because its mineralogical make up means it possesses favourable properties (e.g. a swelling capacity, a low hydraulic conductivity and ion exchange/adsorption capacity).

However, bentonite also has several constraints/uncertainties. Such as high temperatures may cause a phase change from swelling smectites to non-swelling illites. Steam generation in partially saturated bentonites may reduce the swelling ability of bentonite. This is of particular concern in diffusive groundwater regimes with hot wastes, due to the long saturation times, or potentially prefabricated EBS packed under atmospheric conditions. Additional, high ionic strength groundwaters may reduce the swelling ability of bentonite, and impact bentonite pore water buffering capacity. Potential impurities in the bentonite source which can corrode the containers and the behaviour of bentonite in relation to gas generated by the waste and container needs careful consideration

Further piping and erosion, both mechanical and chemical particularly for groundwater entering deposition hole at high flow rates, or for low ionic strength groundwaters has a significant impact on the safety assessment.

Work was presented to the SNFD2021 International Peer Review Team on modelling studies assessing saturation of the buffer and backfill (both assumed to be bentonite). Noting the above requirements relating to bentonite, and constraints/uncertainties, the work reported to date by Taiwan Power Company partially considers the related relevant issues.

Taiwan Power Company work ably demonstrates a capability to model bentonite re-saturation in the context of a hypothetical geology and the KBS-3V disposal concept yet does not consider the broader safety case context of evolving bentonite as a key function of the repository engineered barrier system. Modelling work to date can be built on in the future and should form a reasonable foundation that indicates that Taiwan Power Company has both the access to appropriate software to undertake this rather complicated modelling work, and experienced personnel – this is a creditable achievement, and will ensure that Taiwan Power Company is able to develop its Intelligent Client status relating to EBS evolution.

The SNFD2021 report could usefully have referenced the European Commission project BEACON, which has just completed and considered bentonite mechanical evolution. BEACON output is publicly available (Deliverables – Beacon – Bentonite Mechanical Evolution (beacon-h2020.eu)). Future work needs to include the findings of BEACON and considers how the national work compares with work undertake internationally. This includes comparison in approaches to model verification, model validation, quality assurance, peer review etc..

4.9 Scenario selection

The presentation given on at the peer review meeting impressed the international peer review team, who noted the approach being presented was thorough, showed excellent awareness of the international position on scenario analysis in the context of a geological repository, and had made a meaningful and sensible attempt to contextualise the approach in the Taiwan 'setting' regarding waste to be disposed of, geology and geological processes, etc.

Going forward, it will be important for the output from siting work on e.g. uplift/subsidence and volcanism to be reflected in scenario analyses – it might be the case that other scenarios come to the fore as being more reasonable/higher priority, and that some scenario become less of a concern – this is a normal state of affairs in an evolving programme. It will, of course, be important that all national programmes e.g., siting programmes and design programmes are fully in touch with colleagues working on scenario analyses – working in silos is therefore to be avoided, and the Taiwan Power Company´s internal working procedures need to ensure adequate time for in-house/in-programme knowledge transfer and colleague-upskilling.

One word of caution – it would be helpful to consider more fully how the human intrusion scenario is considered in the Taiwan national programme; the work of the IAEA project HIDRA (Human Intrusion in the Context of Disposal of Radioactive Waste (HIDRA) | IAEA) or Example of Human intrusion scenario (Boring worker activity case), NUMO may be helpful (e.g. NUMO-SC20-SR6-32, 2021). Human intrusion scenarios need some careful consideration; there can be the issue that the scenario assumes a society is skilled enough to drill to repository depths, but not skilled enough to recognise radioactive waste, the container, the EBS etc. – is this reasonable? The assumption that the nature of radioactive waste is not understood then leads to compounding unreasonable scenarios with unreasonable scenarios, and soon the assessment is considering e.g., a resident who is in effect growing food in radioactive waste and consuming it – it should come as no surprise that a high dose is received!

As a somewhat tangential comment, it could be useful for Taiwan Power Company to undertake a thought exercise in the programme now, in advance of new site data becoming available, that considers how scenarios would evolve/become re-prioritised were the siting programme to indicate e.g. the in the future selected site is more faulted than currently believed, or the groundwater chemistry is markedly different. This thought exercise may indicate that e.g. the canister lifetime becomes a key issue to be very confident of, or that perhaps re-design of the same is needed (different choice of outer container material?) Also, it would be useful to ascertain if there are certain site features that could not be tolerated by redesigning the GDF, Engineered Barrier System, container etc. – what could be indicated by siting work that could result in Taiwan Power Company walking away from the site? Such a broader-based scenario analysis could indicate the potential power of the approach to the evolving Taiwan Power Company programme and could also allow Taiwan Power Company to provide some caveats on whether or not there are e.g., site properties, site phenomena etc. that question the compatibility with the current repository disposal concept.

4.10 Analyses

Safety assessment

The safety assessment forms the key contents in the SNFD2021 report. The assessment basis considers a hypothetical site based on partly geological investigations of the K-area with crystalline bedrock, and Swedish KBS-3 disposal concept from the SR-Site safety assessment for Forsmark site in Sweden. The safety assessment follows reasonable methodology adequately: analysis of safety functions, formulation of scenarios, analysis of releases, and demonstration of compliance against the regulatory risk limit. The literature data used for the analysis of releases also includes data from safety assessment for Olkiluoto site in Finland.

For the pre-siting stage, important uncertainties from the assessment basis have been considered in the safety assessment in a limited scope, thus introducing uncertainty to the conclusions of the SNFD2021 report. The robustness can be improved by considering additional scenarios or by including generic variations to the data that is applied. Most importantly, at the pre-siting stage, the reliability of the hydrogeological model is low and propagation of this uncertainty to the safety assessment should be improved. Based on the safety assessment needs, the modelling steps to produce the performance measures could consider identification and calculation of sensitivity cases to improve the understanding of the data uncertainties and reasoning in the safety assessment. As examples for the hydrogeological model with the hybrid Continuous Porous Medium - Discrete Fracture Network approach, this can include e.g., failure of plugs, alternative Excavation Damaged Zone assumptions or enhanced channelling of groundwater flow.

The analysis of releases in the SNFD2021 report with radionuclide release, transport and dose calculations are performed with adequate description but presentation of key data and simplifications is not in balanced for all parts of the disposal system. The calculations apply both data from Forsmark and Olkiluoto safety assessments over the assessment time frame, which can provide reasonable proxies, but credibility for the conditions in Taiwan may have a limited basis. Therefore, added integration with site description and assessment of site evolution is recommended to improve the reasoning for the data selection in the safety assessment.

The uncertainty and sensitivity analyses in the radionuclide transport and dose calculations of SNFD2021 report focus on the parameter uncertainties derived by SKB and the hydrogeological model for the hypothetical site. The calculations are performed for important radionuclide release scenarios of corrosion failure and rock shear failure by using independent sampling (Monte Carlo) with multiple realisations to calculate the results. The calculation end point selected is the annual dose to the reference group individual, which provides a basis for conclusions based on the radiological impacts. Because biosphere assessment data uncertainties are not included (i.e., the biosphere model is fixed), the analyses and conclusions should be viewed as radionuclide release and transport modelling results up to biosphere although in terms of annual doses. It is recommended that important data uncertainties in the biosphere modelling (e.g., in radionuclide migration) are further examined in the future to improve the overall safety assessment and treatment of data uncertainties.

The independent sampling for the data uncertainties is seen suitable for assessing the sensitivities of the model in consideration. However, correlations in the data uncertainties exist (e.g., due to hydrogeological model properties and chemical similarities), for which further improvement is recommended to avoid unphysical parameter combinations (such as very high transport resistance and very low advective travel time for geosphere release paths) to be propagated to the calculation end point uncertainty, especially when comparing the results to the regulatory limit. By performing the calculations with and without correlations, both modelling endpoint uncertainty and sensitivity to input uncertainties can be examined.

The sensitivity analyses in the SNFD2021 report safety assessment have been performed by using a local analysis and a screening method to present the most important data uncertainties included in the safety assessment. The approach is adequate for the pre-siting stage but improvements can be achieved with a more systematic examination of the model sampled model input parameters and corresponding model calculation end points. With the 10,000 realisations applied for the Monte Carlo calculations, also interactions and non-linear effects of the parameters can be identified to help to understand the model behaviour in the probabilistic calculations of the safety assessment. However, the appropriate methods and level of sufficient sensitivity analyses are somewhat dependent on the case study in question and different methodologies exist to capture different aspects of the relations between the model input and output distributions (see e.g., Swiler et al. 2021).

The effect of global warming for the reference site is assessed in the SNFD2021 report to not cause additional alternative lines of evolution or affect the landscape evolution due to sea level decrease over the glacial cycles. However, extending examination of alternatives for the climate evolution and consideration of impacts on the disposal system are seen useful for the future assessments to improve robustness (e.g., extended infiltration of sea water with a high sulphide content).

Biosphere assessment

The biosphere assessment in the SNFD2021 report is covered by multiple sections in the relevant steps of the safety assessment methodology. The assessment methodology has improved from the SNFD2017 report and considers landscape evolution changes and effects to the radiation exposure pathways. The reference case setting for the biosphere is based on a virtual tropical island that experiences transformation to an inland area due to sea level decrease in the long-term evolution. The human habits are covered by applying reasoning from the local activities and identification of potentially exposed groups (PEGs) is adequate for the pre-siting stage.

The dose assessment in the biosphere assessment is based on applying biosphere dose conversion factors (BDCFs) that are based on (constant) unit release rates (1 Bq/year) for each of the source term radionuclides. The BDCFs are applied to convert the calculated release rates to biosphere into annual doses of an exposed individual in each of the PEGs (cautious maximum values over different stages are applied). The methodology follows similar aspects as seen e.g., in the safety assessment for the Forsmark site (Sweden) (SKB 2010), and data selection is cautious to ensure a certain level of conservatism of the radiological impacts.

To improve the biosphere assessment as part of the safety assessment, international recommendations and guidance (e.g. ICRP 2013) can be further applied to formulate fundamental questions to be addressed. The questions in the biosphere assessment should be based on potential evolution of the surface environment after repository closure, understanding of features, events, and processes (migration and accumulation characteristics under the relevant geological, hydrological and biological cycles), understanding of utilisation of surface environment by humans and radionuclide release exposure conditions, and exposure conditions for non-human biota (plants and animals).

Many of the important aspects are included in the SNFD2021 report but there are limitations. As an example, the exposure of non-human biota is not addressed, which is agreeable at the pre-siting stage. The process understanding in the biosphere models for exposure relies on the international approach of similar assessments, but the background data of the important processes are not presented in a balanced way, although the results are at a conservative level compared to other similar assessments (e.g., SKB 2010, Broed 2007). Therefore, it is recommended that key background reports are referenced, and applied data is appropriately presented as included in the SNFD2021 report for the radionuclide release and transport modelling in the near-field and far-field.

The human habits covered by PEGs in the SNFD2021 focus on aquaculture (e.g., fish farming) and agriculture (e.g., cultivation of crops) and usage of forest products is not included in the local activities (although forests ecosystems are described to exist in Taiwan). In future, there is potential to combine some of PEGs and also perform further examination on forests to identify potential exposure pathways (e.g., potential usage of natural edible products).

The biosphere assessment in the SNFD2021 report includes all the radionuclides in the source term applied (about 34 in total) for the SNF canister but only a fraction of them contributes to the annual doses calculated as the safety assessment results. Because the biosphere assessment is focused on the radiological impacts, very pessimistic reasoning can be applied to prioritise the data needs for further stage in the disposal programme (e.g., by screening the most contributing source term radionuclide inventories or releases to the biosphere). Also, according to the SNFD2021 report, the release location of the radionuclide releases in the landscape affects mostly the resulting annual doses. As an improvement of the uncertainty and sensitivity analyses in the safety assessment, effects of important data uncertainties could be included to obtain a more comprehensive understanding of the data uncertainties in the whole modelled disposal system.

The SNFD2021 report applies a simplified treatment of the geosphere-biosphere interface as appropriate for the pre-siting stage, and only release rates to the biosphere are applied in the biosphere assessment to provide results of annual doses to the safety assessment. To improve the reference case setting of the hydrogeological model, a link to the surface hydrology in the biosphere is recommended to be conceptualised. With subsequent modelling of surface hydrology, the treatment of geosphere-biosphere interface can be improved by setting of more valid boundary conditions for the hydrogeological model. On the other hand, understanding of surface hydrology provides important information on radionuclide migration and accumulation to enhance the basis for radiological impact assessments.

4.11 Feedback to Design, Site, and RD&D programmes

Described feedbacks are reasonable and the reviewers agree to most of the feedbacks. However, adding the following points may further improve future program, as example:

We agree to characterize EDZ in the detailed characterization however, the mechanism of EDZ is still poorly understood, especially the understanding of the mechanism of negative skin (reduction in K in radial direction) needs to be further developed.

We agree to reducing uncertainties of the DFN is important. We also agree the described measures are useful to reduce uncertainty. However, due to spatial heterogeneity of fractures by nature and the practical limit of site characterization, we cannot avoid uncertainty. On the other hand, there is a possibility that some DFN geometric parameters are not so sensitive to the consequence. Therefore, understanding sensitivity of DFN model parameters and optimize site characterization is recommended.

We agree that “Identification of the Connected Water-Conducting Fractures” is extremely important. Also, we agree to use in-situ pumping test to identify connected water-conducting fractures. It seems to be the main water-conducting fractures are the primary target. We agree that this will help understanding the hydraulic connectivity of main fractures (or faults). However, it is recommended that targeting less transmissive fractures is also important, since the connectivity of less transmissive fractures which are allowed to intersect deposition hole is important for assessing retardation capability of the host rock.

We agree to develop hydrogeochemical model which considers of hydrogeological model. Also, we agree on the described survey items. It is recommended that the sampling procedure also needs to be established to obtain least disturbed groundwater, such that stop drilling when different pressure encountered and conduct sampling and adding tracer into the drilling fluid and monitor the tracer concentration while sampling and judge whether in-situ water replaced contaminated water by drilling fluid.

In the SNFD2021 report, in the sections of "Feedback to Reference Design and Design Premises" and "Feedback to Detailed Site Investigation and SDM", it stated that it is possible to reduce the uncertainty in the safety design and safety evaluation of the repository by repeating the progress of design and site selection survey and feeding back, so that such a strategic approach shall be a rational methodology to improve the reliability of ensuring safety of the repository. It is recommended to summarize the strategic methodology more in detail including the necessity of integration at each stage.

It is envisioned that the programme will proceed repeatedly through each stage of step-by-step site selection survey. As for the development of the safety case, it is more important to integrate the results of each step and reflect it to the next step. Uncertainties will be reduced by updating and adding to more accurate ones. So, it is recommended that the results on these situations of progress are evaluated and confirmed by the regulator and reported to local governments at each stage and constantly disclosed to the stakeholders with transparency and traceability.

The various benefits of such a stepwise approach to disposal operations in ensuring safety should be clearly stated in this report. (NUMO, 2021; The NUMO Pre-siting SDM-based Safety Case (NUMO-TR-21-01), Stepwise characterization approach, (NUMO-SC20-SR3—07,08))

In the SNFD2021 report, it is stated that various types of monitoring need to be carried out from the viewpoint of ensuring safety and environmental conservation during the period from the site survey stage to the confirmation of closure in the geological disposal project. Monitoring is an important means of confirming that the project is being carried out properly and disclosing the information to the public and residents is indispensable for increasing the credibility of the project. It is recommended to consider and to establish a more detailed concept of monitoring in Taiwan.

Toward developing the safety case step by step, it will be more important to establish an integrated database on the acquired data, information, documents, etc. for the geohydrological survey method/technology, design, construction, barrier performance, safety scenario, safety function and indicator, safety assessment and so on, and then it shall be used to ensure the necessary transparency and traceability for the future development of safety case in Taiwan.

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ANNEX I

Curriculum Vitae

Name: Vidstrand, Patrik Christopher

Born: July 10 1968, Limhamn (Malmö)

Contact: Address: Solvägen 6, SE-183 52 Täby, Sweden

Phone: +46 73 7741687
E-mail: patrik@vidstrand.se

Education:
1999: Engineering geology (Technical licentiate), Chalmers Tekniska Högskola
1995: Civil Engineering (M.Sc.), Chalmers Tekniska Högskola
1988: Chemical Engineering, Pauli tekniska gymnasium

Language:
Swedish (native)
English
German (five years of school German)

Profile

Manager with experience of both small and medium-sized organizations with high technical and scientific competence. Good at enforcing organizational change and implementing new ways of working. Prefers to work at a high pace with many on-going activities, but also thrives in a managerial role where the focus is on nurturing and developing staff within a well-defined business.

Technical focus

Engineering geology with focus on hydrogeology: Conceptual and numerical modeling and site description in all stages of projects, eg. feasibility studies, system design, engineering geological forecasts and outcome evaluations.
Extensive scientific- and consultant-based experience in descriptive geological and hydrogeological modeling, including coupled processes such as thermal, mechanical and chemical.
Many years of consultancy in traditional engineering geological work such as planning and design work related to constructability and grouting issues in hard rock.

Memberships

IAH – International Association of Hydrogeologists
SGF – Svenska Geotekniska Föreningen (Swedish association of geotechnical engineers)

Curriculum Vitae

Professional expirience

2021-	**Managing Director, Foundation of Rock Engineering Research (BeFo)** The Foundation has for 50 years, been the centre of Swedish rock engineering research, development and innovation along with founding research projects. As Director I start-up, follow, and manage research and development project. I also distribute scientific reports, present results and broadly represents the rock engineering companies of Sweden.
2019-2021	**Head of unit, SKB** The unit, Research and post-closure safety, consists of four groups and approximately 50 employees. The main working tasks consisted of establish, operate and further develop the unit's strategic and organizational work as well as its main responsibilities related to analyzing post-closure safety. Also, I participated at an overall level within SKB's work to implement major construction projects, perform forecasting and follow-up work of the geoscientific conditions in planned and operational facilities, and to ensure that safety-related requirements are met throughout SKB's operations. In addition to leading the unit's management team, I was responsible for SKB's research council, participating in several of SKB's safety committees and am part of both international, national and internal steering- and reference groups for various projects and research and development programs.
2018-2021	**Member of the board Foundation of Rock Engineering Research (BeFo)** The main tasks consisted of strategic work as well as financial and organizational follow-up of the foundation's research portfolio. Hold the position as vice chairman in 2019. BeFo's work is partly integrated with work within the Swedish Rock Technology Association and there is some collaboration.
2018-2018	**Assistant head of Research and safety assessment unit, SKB** The main tasks consisted of, together with the unit head, managing and developing the unit via a shared leadership as well as personnel responsibility for about half of the unit's approximately 35 employees. Furthermore, activities related to operations were included within steering and reference groups for various assignments and projects within SKB.
2013-2018	**Expert Hydrogeology, SKB** The main tasks consisted of the responsibility for groundwater modeling, user support and all development of the SKB-owned multi-purpose tool (software) DarcyTools. Participated in analyzes of post-closure safety as a technical manager/assignment manager and contractor. Furthermore, I worked as a technical expert in geological and hydrogeological issues, including support for internal contractors Rock and BBC (Buffer material, backfill material and sealing techniques), Environmental Impact Assessment work, design issues but also directly against technology development projects and as a consultant for SKB International which is a wholly owned subsidiary of SKB that offers consulting services, primarily internationally, in final repository technology including siting processes.

Curriculum Vitae

2012-2013 **Chairman of the board for Aspen Montessori** (Private school)

2008-2013 **Consultant, TerraSolve AB**
The main work consisted of modeling work for SKB's various analysis work, but various infrastructure assignments were also performed for different customers in Sweden. For example, work as a technical expert in construction law disputes, handling of hydrogeological investigations and review of major projects such as the Stockholm By-pass. The work was performed as a task leader, specialist and administrator.

2008-2016 **Member of the board and owner of TerraSolve AB**

2007-2012 **Member of the board for Aspen Montessori**
During the period I was, among other things, property manager and planned and procured on-going maintenance and new construction.

2006-2008 **Head of group Hydrogeology, Bergab**
As head of the Hydrogeology group at Bergab in Gothenburg.

2005-2006 **Member of the board, Bergab**

2001-2008 **Consultant, Engineering geology, Bergab**
Work was performed as a task leader and specialist.

2001 **Associate professor, Geologiska institutionen, Chalmers Tekniska Högskola**
As associate professor, I was responsible for the undergraduate education in technical geology. Planned courses, excursions, responsible for examinations.

2000-2001 **Consultant, Engineering geology, Scandiaconsult Sverige AB**
Work was performed as a task leader and specialist.

2000 **Associate professor, Edinburgh University**

1999 **Guest researcher, Edinburgh University**

1995-2000 **PhD position, Geologiska institutionen, Chalmers Tekniska Högskola**

1994-1998 **Member of the board for Chalmers Studentkårs Restaurang AB**

1994-1996 **Chairman of the board for Chalmers Studentkårs Restaurang AB**
In addition to leading the board and running the restaurant company's long-term work and development, I had personnel responsibility for the company's CEO.

1989-1990 **Assistant Construction manager, Skanska**

Curriculum Vitae

Examples of publications

Peer reviewed	Boulton, G. S., Lunn, R, **Vidstrand, P**., Zatsepin, S., 2007: Subglacial drainage by groundwater-channel coupling, and the origin of esker systems: Part 1-glaciological observations *Quaternary Science Review, Volume 26, Issue 7-8,* April 2007, pp 1067-1090.
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Peer reviewed	**Vidstrand, P.**, Follin, S., Selroos, J-O., Näslund, J-O., Rhén, I., 2013: Modeling of groundwater flow at depth in crystalline rock beneath a moving ice-sheet margin, exemplified by the Fennoscandian Shield, Sweden. Hydrogeology Journal, 21:239–255. DOI 10.1007/s10040-012-0921-
Peer reviewed	**Vidstrand, P.**, Follin, S., Selroos, J-O., Näslund, J-O., 2014: Groundwater flow modeling of periods with periglacial and glacial climate conditions for the safety assessment of the proposed high-level nuclear waste repository site at Forsmark, Sweden. Hydrogeology Journal. DOI 10.1007/s10040-014-1164-7
Peer reviewed	**Vidstrand, P.,** Wallroth, T., Ericsson L.O., 2007: Coupled HM effects in a crystalline rock mass due to glaciation: indicative results from groundwater flow regimes and stresses from an FEM study, *Bulletin of Engineering Geology and the Environment*. Published on-line 21 March 2008.

Revised, June 1, 2022

CURRICULUM VITAE

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Hachiouji-shi, Tokyo
193-0833 JAPAN
Telephone +81-80-3022-9737
E-mail Address mhuchida0721@yahoo.co.jp

EDUCATIONAL DETAILS

2009: Ph.D in Engineering. Graduate School of Natural Science and Technology, Okayama University
1977-1979: M.Sc. in Science. Graduate School of Science, University of Tokyo
1972-1977: B.Sc. in Science. Faculty of Science, University of Tokyo

PROFESSIONAL DETAILS

2020-present: President, Fracture Flow Solutions
2017-2020: Technical Counsellor, Division of Research for Nuclear Fuel Cycle and Radioactive Waste, Secretariat of NRA (Nuclear Regulation Authority, Japan)
2014-2017: Director, Division of Research for Nuclear Fuel Cycle and Radioactive Waste, Secretariat of NRA (Nuclear Regulation Authority, Japan)
2013-2014: Deputy Director, Nuclear Fuel Cycle and Radioactive Waste Management Safety Department, JNES (Japan Nuclear Energy Safety Organization)
2010-2013: Group Leader, Radioactive Waste Disposal Safety Evaluation Group, Nuclear Fuel Cycle and Radioactive Waste Management Safety Department, JNES (Japan Nuclear Energy Safety Organization)
2008-2010: Deputy Director General, Tono Geoscience Center, JAEA
Group Leader, Crystalline Environment Research Group and Neotectonics Research Group, JAEA
2005-2008: Group Leader, Crystalline Environment Research Group,
Geological Isolation Research and Development Directorate, JAEA
2000-2005: Group Leader, System Analysis Group, Geological Isolation Research Division, Tokai-Works, JNC
1998-2005: Waste Isolation Research Section, Environment Technology Development Research Division, Tokai-Works, PNC
1985-1998: Geological Isolation Research Section, Head Office, PNC
1983-1985: Nuclear Safety Section, Science and Technology Agency
1979-1983: Uranium Exploration Division, PNC

PUBLICATIONS

Journal Articles

Uchida, M., Dershowitz, W. and Lee, G. (2009). An empirical probabilistic approach for constraining the uncertainty of long-term solute transport predictions in fractured rock using in situ tracer experiments. Hydrogeology Journal,
DOI 10.1007/s10040-008-0417-8.

Hodgkinson, D., Benabderrahmane, A., Elert, M., Hautojärvi, A., Selroos, J., Tanaka, Y. and Uchida, M. (2009): An overview of Task 6 of the Äspö Task Force: modelling groundwater and solute transport: improved understanding of radionuclide transport in fractured rock, Hydrogeology Journal, DOI 10.1007/s10040-008-0416-9

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Altman, S.J., Uchida, M., Tidwell, V.C., Boney, C.M. and Chambers, B. P. (2004). Use of X-ray absorption imaging to examine heterogeneous diffusion in fractured crystalline rocks. Journal of Contaminant Hydrology, Volume 69, Issues 1-2, pp.1-26

Sawada, A., Uchida, M., Shimo, M., Yamamoto, H., Takahara, H. and Doe, T. (2000): Non-sorbing tracer migration experiments in fractured rock at the Kamaishi Mine, Northeast Japan. Engineering Geology, Volume 56, No.1, pp. 75-96.

Papers in Conference Proceedings

Uchida, M. and Yoshida, H. (2022). Remaining issues of DFN – (1), Discrepancy between Geologic Fractures and Conductive Fractures. To be presented at the 3rd International Discrete Fracture Network Engineering Conference, June 2022.

Lanyon, G. W., Davy, P., Dershowitz, W. S., Finsterle, S., Gylling, B., Hyman, J. D., Neretnieks, I., and Uchida, M. (2021). Pragmatic Validation Approach for Geomechanics, Flow, and Transport Models in Fractured Rock Masses. Paper (21-D-2369-DFNE) presented at the 3rd International Discrete Fracture Network Engineering Conference, Virtual, June 2021, 18p.

Uchida, M. (2018). An idea on “Validation” of DFN modeling and characterization methods for block scale conductive fractures. DFNE2018 Int’l Discrete Fracture Network Engineering Conference

Uchida, M., Hayashi, H., Hosoya, S., Takano, H., Suzuki, K., Sugi, S., Yoshimura, M. (2014). Effect of heterogeneity of ensemble fracture parameters on mass transport properties. DFNE2014 Int’l Discrete Fracture Network Engineering Conference

Hara, A. and Uchida, M. (2004). Evaluating heterogeneity in mudstones based on geologic processes at Horonobe, Japan. 66th EAGE Conference and Exhibition, H007, 4p.

Uchida, M., Makino, H., Wakasugi, K.. Shibata, K. (2004). Development of JNC Geologic Disposal Technical Information Integration System -An Approach to Integrate and Share Technical Information among Safety Assessment, Repository Design and Site Investigation. OECD/NEA Geological Disposal: Building Confidence Using Multiple Lines of Evidence, First AMIGO Workshop Proceedings, Yverdon-les-Bains, Switzerland, 3-5 June 2003 pp.183-190

Kato, T., Suzuki, Y., Makino, H. and Uchida, M. (2003). Biosphere Assessment for High-level Radioactive Waste Disposal: Modelling Experiences and Discussion on Key Parameters by Sensitivity Analysis in JNC. International Symposium on Radioecology and Environmental Dosimetry, Abstracts.

Sawada, A., Uchida, M., Shimo, M., Yamamoto, H., Takahara, H. and Doe, T.W. (2001). Anisotropy, reversibility and scale dependence of transport properties in single fracture and fractured zone – Non-sorbing tracer experiment at the Kamaishi mine. First TRUE Stage – Transport of solutes in an interpreted single fracture Proceedings from the 4th International Seminar pp.151-164.

Dershowitz, B., Doe, T., Fox, A., Uchida, M. and Cladouhous, T. (2001). Learning from recovery: Thoughts on Feature A transport experiments. First TRUE Stage – Transport of solutes in an interpreted single fracture Proceedings from the 4th International Seminar pp.51-70.

Altman, S.J., Tidwell, V.C. and Uchida, M. (2001). Visualization and quantification of heterogeneous diffusion rates in granodiorite samples by X-ray absorption imaging - Diffusion within gouge materials, altered rim and intact rock matrix. First TRUE Stage – Transport of solutes in an interpreted single fracture Proceedings from the 4th International Seminar pp.31-48.

Sawada, A., Uchida, M. and Shiotsuki, M. (2000). Study of Flow Model Comparison in Fractured Rock. 2000 Western Pacific Geophysics Meeting, Presentation No. H31A-04

Altman, S. J., Uchida, M. and Tidwell, V. C. (2000). Visualization and Quantification of Heterogeneous Diffusion Rates in Granodiorite Samples by X-Ray Absorption Imaging. 2000 Western Pacific Geophysics Meeting, Presentation No. H31A-08

Ijiri, Y., Sawada, A., Sakamoto, K., Yoshida, H., Uchida, M., Ishiguro, K., Umeki, H. and Webb, E.K. (1999). Future Prospects for site characterization and underground experiments related to transport based on the H12 performance assessment. Confidence in Models of Radionuclide Transport for Site-specific Performance Assessment, OECD/NEA, pp.227-238.

Ijiri, Y., Sawada, A., Uchida, M., Ishiguro, K. and Umeki, H. (1999). Radionuclide Transport in a Fracture Network System. International Workshop of Approaches for Upscaling Processes Affecting Transport.

Ijiri, Y., Sawada, A., Webb, E.K., Watari, S., Hatanaka, K., Uchida, M.., Ishiguro, K., Umeki, H. and Dershowitz, W.S. (1999). Radionuclide migration analysis using a discrete fracture network model. Scientific Basis for Nuclear Waste Management, Vol.556, pp.729-736.

Shimo, M., Yamamoto, H., Uchida, M., Sawada, A.,Doe,T. W. and Takahara,Y. (1998). In-situ test on fluid flow and mass transport properties of fractured rocks. Proc. 9th ISRM Congress Vol.2, pp.1401-1404.

Uchida, M. (1997). ENTRY-2 Project-Contribution of Engineering Scale Laboratory Experiments to Performance Assessment. Proceedings of the International Conference on Future Nuclear System (Global'97), October 5-10, Yokohama, Japan, pp.934-939.

Uchida, M., Umeki, H. and Yoshida, H. (1997). Tracer Experiment at the Kamaishi Mine- As Part of an Integrated Approach to Geosphere Transport Modeling. OECD/NEA Field Tracer Experiments, Role in the prediction of radionuclide migration pp.191-202.

Hatanaka, K., Watari, S., Uchida, M., Takase, H. and Impey, M.D. (1996). Experimental Study on Groundwater Flow and Mass Transport in a Heterogeneous Porous Medium. Scientific Basis for Nuclear Waste Management, Vol.412, pp.739-746

Uchida, M. and Sawada, A. (1995). Discrete fracture network modelling of tracer migration experiments at the Kamaishi mine. Scientific Basis for Nuclear Waste Management, Vol.353, pp.387-394.

Umeki, H. and Uchida, M. (1995). PNC's Approach for the Resolution of Issues Relevant to Radionuclide migration in Heterogeneous Media. OECD/NEA, PAAG/SEDE Workshop on the Prediction of Radionuclide Migration.

Uchida, M., Doe, T. W., Dershowitz, W.S. and Wallmann, P. (1993). Simulation of Fracture Flow to The Kamaishi Validation Drift. Proceedings Fourth Annual International Conference on High Level Radioactive Waste Management, ASCE, Las Vegas, pp.437-442.

Doe, T., Uchida, M., Kindred, J. S. and Dershowitz, W. (1990). Simulation of dual porosity flow in discrete fracture networks. International Technical Meeting of CIM/SPE, Calgary, Can, Preprints, Vol.3,
Paper No. CIM/SPE-90-120.

International Reports

Dershowitz, W.,Fox, A., Lee, G.,Van Fossen, Uchida, M. (2006). Discrete fracture network flow and transport modelling at the rock block scale: Task 6D, 6E, 6F and 6F2. Swedish Nuclear Fuel and Waste Management Company (SKB), International Progress Report 06-22, 122p.

Fox, A., Dershowitz, B., Ziegler, M., Uchida, M., Takeuchi, S. (2005). BS2B experiment: Discrete fracture and channel network modeling of solute transport modeling in fault and non-fault structures. Swedish Nuclear Fuel and Waste Management Company (SKB), International Progress Report 05-38, 159p.

Doughty, C. and Uchida, M. (2004). PA calculations for feature A with third-dimension structure based on tracer tests calibration. Swedish Nuclear Fuel and Waste Management Company (SKB), International Progress Report, SKB IPR 04-33, 45p.

Dershowitz, W., Shuttle, D. and Uchida, M. (2004). Task 6A and 6B/6B2. GoldSim and FracMan/LTG modelling. Performance assessment modeling using site charaterisation data (PASC). Swedish Nuclear Fuel and Waste Management Company (SKB), International Progress Report, IPR 04-32, 97p.

Dershowitz, B., Shuttle, D., Klise, K., Uchida, M., Metcalfe, R., and Cave, M. (2002). Fracman modelling of geochemical end-member transport pathways. Swedish Nuclear Fuel and Waste Management Company (SKB), International Progress Report, IPR 02-37 96p.

Dershowitz, B., Uchida, M., Shuttle, D. and Fox, A. (2002). Preliminary 2 km scale modelling of geochemical pathways Äspö HRL, Äspö Sweden Task 5. Swedish Nuclear Fuel and Waste Management Company (SKB), International Progress Report, IPR 02-36 40p.

Dershowitz, W., Cladouhos, T., and Uchida, M. (2001). Tracer tests with sorbing tracers. Task 4E-1:SST-1 Blind prediction. Task 4E-II: Analysis of STT-1 blind prediction. Task 4E-III: Predictions for STT-1b. Task 4F: Prediction for STT-2. Äspö Task Force, Task 4E and 4F. Swedish Nuclear Fuel and Waste Management Company (SKB), International Cooperation Report, ICR 01-02.

Uchida, M., Dershowitz, B., Sawada, A., Wallman, P. and Thomas, A. (1997). FracMan Discrete Fracture Modeling for the Äspö Tunnel Drawdown Experiment. Swedish Nuclear Fuel and Waste Management Company (SKB), International Cooperation Report, ICR 97-03.

Uchida, M., Doe, T., Dershowitz, W., Thomas, A., Wallmann, P. and Sawada, A. (1994). Discrete-fracture modelling of the Äspö LPT-2, large-scale pumping and tracer test. Swedish Nuclear Fuel and Waste Management Company (SKB),

International Cooperation Report, ICR 94-09

CV

Motoi KAWANISHI, Dr. （河西 基）

1) Central Research Institute of Electric Power Industry (CRIEPI)
   Honorary Research Advisor
2) Asano Taiseikiso Engineering Co., Ltd. (ATK)
   Director, Chief Engineer

<Personal history>

1979 Completed Graduate of Tokyo University (Doctoral course)

1979 Engaged in CRIEPI
  Environmental Hydraulics Department

1995 Doctoral degree of Tokyo University

2004 Associate Vice President
  Director of Nuclear Fuel Cycle Backend Research Center, CRIEPI

2011 Senior Associate Vice President
  Director of Nuclear Fuel Cycle Backend Research Center, CRIEPI

Jun. 2013～

- Research Advisor (～2015 Mar.), Honorary Research Advisor (2015 Apr.～), CRIEPI
- Director, Chief Engineer, Asano Taiseikiso Engineering Co., Ltd.

Nov. 2013～Mar.2016 (additionally)

- Advisor
- Tokyo Electric Power Company Ltd. (TEPCO)
  Fukushima Dajichi Decommissioning and Decontamination Engineering Company

<Main Research Work>

・Hydraulics of dam and river
・Investigation and modeling of groundwater flow
・Safety assessment on radioactive waste disposal
・R&D for radioactive waste management

<Main related contribution for radioactive waste management projects in Taiwan>

・Oct. 2015 A member of the Japanese team for the “2015 Technical Workshop for The High

Level Radioactive Waste Final Disposal Program” held by Taiwan Power Company.

- May 2016　A member of the international peer review team for the “Evaluation of Technical Feasibility for Low Level Radioactive Waste Disposal International Peer Review Report” prepared for Taiwan Power Company.
- Jan. 2020　A member of the international peer review team for the “Technical Advancement Assessment Report for Low Level Radioactive Waste Final Disposal, Republic of China” prepared for SINOTECH.

<Related Title>

- Former Director of EAFORM sub-committee in AESJ(Atomic Energy Society of Japan)
- Fellow Member of JSCE(Japan Society of Civil Engineering) and AESJ(Atomic Energy Society of Japan)

CURRICULUM VITAE

Dr SIMON NORRIS

Work Contact Details

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Personal Statement

Dr Simon Norris is a well-qualified and authoritative scientist, with over 28 years' national and international expertise in the radioactive waste management industry. He is a highly experienced project manager and line manager, familiar with the technical, financial and human resources aspects of complex projects, including the co-ordination of inputs from a significant contractor and stakeholder base. He has well-developed interpersonal skills, presents frequently, has published extensively, and is a recognised national and international expert in his field. He was recently appointed as an honorary professor.

Career Summary

Principal Research Manager

Radioactive Waste Management Limited, UK
1994 – Present Day

- Responsible for interpreting the needs of the Safety Case, site-specific assessments and RWM Ltd's engineering design for scientific knowledge and translating these into a well-defined research strategy and programme.
- Responsible for contributing to development of RWM Ltd's technical strategy and plan.
- Responsible for obtaining solutions (e.g. scientific knowledge and modelling) by acting as intelligent client for the engineered barrier, host rock and gas research areas of RWM Ltd's programme.
- Responsible for acting as technical authority and providing authoritative advice and input to RWM Ltd in the relation to engineered barrier, host rock and gas research.
- Responsible for acting as RWM, NDA and UK representative at national and international scientific fora and events, as relevant to research expertise.
- Responsible for scientific liaison with University Departments, industry wide scientific fora and scientific institutes.
- Responsible for understanding the content and relevance of overseas research programmes to RWM's safety case and engineering interests.

Achievements (see also Appendix A for publication list)

- Leads company research on engineered barrier, host rock and gas issues, including contributing to status reports, Science and Technology Plan and generic-to-site specific research strategy development.
- Produced the Environmental Safety Case for a Geological Disposal Facility for UK higher-activity radioactive wastes and led the post-closure performance assessment programme to assess the long-term suitability of a site for radioactive waste disposal, resulting in the '*Nirex 97*' assessment.
- Set-up multi-contractor Framework Agreements pursuant to EC purchasing regulations, specifying a strategic multi-year programme of work, setting selection criteria, assessing proposals, and choosing preferred organisations.
- Led company input to the European Commission FORGE, GASNET, CARBOWASTE, CAST, BEACON, Modern2020, MODATS, GAS, HITEC and RED-IMPACT projects – these interactions have allowed the development of an extensive network and personal knowledge base of the national and international status of radioactive waste management.
- Represents UK at International Atomic Energy Agency fora; co-author of TECDOCs.
- Represented RWM at USA Nuclear Waste Technical Review Board workshop on URLs.
- Published in IAEA, Nuclear Energy Agency and European Commission reports, and in industry and international journals.
- Invited by ANDRA and ONDRAF / NIRAS to serve on Scientific Committees for major international radioactive waste conferences.
- Qualified as a scrutineer of Chartered Geologist applications for the Geological Society, assisting with the Continued Professional Development of young professionals. Additionally qualified as a coach within NDA as part of a Capability Framework initiative, assisting colleagues to progress their value to the company.

Research Associate

Department of Earth Sciences, University of Liverpool, UK
1989 - 1994
Employed on BP and Shell UK-funded projects that investigated the structural and thermal evolution of offshore UK sedimentary basins.

Achievements

- Developed state-of-the-art software to investigate offshore UK sedimentary basin evolution in 3D, which had commercial application in a niche market. The application of this software led to highly innovative work, giving the clients a technical advantage for use in commercial activities.
- Presented and reported project deliverables to technical and managerial stakeholders and at international conferences. This benefited the clients by promoting their association with leading edge scientific work, and ensured the related achievements were well-publicised. As a result, the clients subsequently built on their association with the university.
- Submitted a report based on work undertaken for BP as a Ph.D. thesis. Following the examination process, this was judged of a suitable standard for award of a Doctorate.

Education and Training

Qualifications

Honorary Professor, University of Manchester, 2022
Chartered Scientist (The Science Council, 2005)
European Geologist (European Federation of Geologists, 1997)
Chartered Geologist (Geological Society, 1996)
Chartered Physicist (Institute of Physics, 1996)
Ph.D. in *Geophysical Sedimentary Basin Modelling* (University of Liverpool, 1993)
B.Sc. (Honours), First Class, in *Geophysics with Geology* (University of Liverpool, 1989)

Membership of Learned Organisations

Member of the Institute of Physics (1996)
Fellow of the Geological Society (1993)
Member of Petroleum Exploration Society of Great Britain (1992)

Training

Executive coaching (Lance Edynbry Partnership, 2009)
Line management development programme (Blue Beetle, 2009)
PRINCE2 Practitioner (QA IQ, 2008)
Capability Framework coach (Scala Group, 2007)
Influencing Strategies and Skills (Ashridge Business School, 2006)
In-house Mentoring (2006-2008)
Meeting Facilitation and Chairing Courses (Essentia Ltd, 2005)
Employment Law (Prospect Trade Union, 2006)
Handling Personal Cases (Prospect Trade Union, 2005)
Health and Safety (1990s onwards)

Personal

Married with four adult children, he enjoys long walks with the dogs, keeping fit, and a bit of cycling whenever possible. He is keen on football (watching rather than playing now, unfortunately), and international travel (including the associated culinary delights often to be sampled).

Appendix A: External Publications (named attribution)

[1] J.D.A. Piper, D. Atkinson, S. Norris & S. Thomas, 1992. *Palaeomagnetic Study of the Derbyshire Lavas and Intrusions, Central England: Definition of Carboniferous Apparent Polar Wander.* Physics of the Earth and Planetary Interiors *69, 37–55.*

[2] *Nirex 97: An Assessment of the Post-closure Performance Assessment of a Deep Waste Repository at Sellafield, Overview*, S. Norris, L.E.F. Bailey, M.M. Askarieh & G.E. Hickford, Nirex Science Report S/97/012, December 1997.

[3] *Overview Description of the Base Scenario Derived from FEP Analysis*, J. Locke, L.E.F. Bailey, D.E. Billington, A.V. Chambers, G.E. Hickford, M. Kelly, S. Norris, J.D. Porter, J.H. Rees, M.C. Thorne & C.J. Tweed, Nirex Science Report S/98/011, November 1998.

[4] *Modelling Requirements for Future Assessments Based on FEP Analysis*, J. Locke and L.E.F. Bailey, M.M. Askarieh, A.J. Baker, D.E. Billington, A.V. Chambers, K.A. Cliffe, P.J. Degnan, G.E. Hickford, J.L. Knight, D.A. Lever, A.K. Littleboy, U.M. Michie, S. Norris, N.J. Pilkington, J.D. Porter, J.H. Rees, M.C. Thorne & C.J. Tweed, Nirex Science Report S/98/012, November 1998.

[5] *Nirex 97: An Assessment of the Post-closure Performance Assessment of a Deep Waste Repository at Sellafield - Report on Peer Review by QuantiSci Ltd,* S. Norris, N.A. Chapman & P.R. Maul, Nirex Science Report S/98/014, December 1998*.*

[6] *Nirex 97: An Assessment of the Post-closure Performance Assessment of a Deep Waste Repository at Sellafield – Summary Report*, S. Norris (Editor), Nirex Science Report S/98/015, December 1998.

[7] *The Nirex Disposal Concept: Evaluating Performance*, L.E.F. Bailey, A.K. Littleboy, M.M. Askarieh, A.J. Baker, G.E. Hickford, C.P. Jackson, D.A. Lever, S. Norris, M.J. Poole, W.R. Rodwell & P.J. Sumner, Nirex Report N/011, 2000.

[8] *Post-closure Performance Assessment: Generic Performance Assessment*. L.E.F. Bailey, S. Norris, M.M. Askarieh & E.C. Atherton, Nirex Report N/031, 2001.

[9] *The Use of the Generic Post-Closure Performance Assessment in the Nirex Packaging Advice Process*, M.M. Askarieh & S. Norris, Nirex Report N/065, 2004.

[10] *Accounting for Natural Hazards in Safety Assessments*, A.W. Herbert and S. Norris. IBC Technical Services Conference: Radioactive Waste Disposal (London, United Kingdom, November 1996). Also at the "British Association Annual Festival of Science", The University of Birmingham, 8-13 September 1996.

[11] *Use of Uncertainty Analysis for Chloride in the Calibration of Groundwater Flow Models of the Sellafield Site*, A.H. Bath, W.G. Harding, K. Forde, P.J. Degnan, S. Norris, C.P. Jackson and S.P. Watson. In proceedings of NEA-SEDE Workshop on '*Use of Hydrogeochemical Information in Testing Groundwater Flow Models*' (Borgholm, Sweden, September 1997).

[12] *Site Characterisation Strategy and its Role in Post Closure Performance Assessment*, A.K. Littleboy, P.J. Degnan, R.S. McLeod and S. Norris. In proceedings of '*MRS'97: 21st International Symposium on the Scientific Basis for Nuclear Waste Management',* Volume 506, pp 719-730 (Davos, Switzerland, September 1997).

[13] *The Treatment of Water-conducting Features in Groundwater Flow and Transport Modelling of the Borrowdale Volcanic Group in Nirex 97*, C.P. Jackson, S. Norris, S.J. Todman and S.P. Watson. In proceedings of NEA-GEOTRAP Workshop on '*Water-conducting Features in Radionuclide Migration*' (held in Barcelona, Spain, 10-12 June 1998), OECD-NEA, ISBN 92-64-17124-X, 1999.

[14] *Site Investigation and its Role in Post-closure Performance Assessment*, S. Norris, SET99 - Science, Engineering and Technology for Britain (House of Commons, London, United Kingdom, March 1999).

[15] *The Role of Matrix Diffusion in Transport Modelling in a Site-specific Performance Assessment: Nirex 97*, S. Norris & J.L. Knight. In proceedings of NEA-GEOTRAP Workshop on '*Confidence in Models of Radionuclide Transport for Site-specific Assessment*' (held in Carlsbad, New Mexico, USA, 14-17 June 1999). OECD-NEA, ISBN 92-64-18620-4, 2001.

[16] *Use of a Matrix Diagram in Modelling Coupled Transport Processes in Performance Assessment*, L.E.F. Bailey & S. Norris. In proceedings of NEA-GEOTRAP Workshop on '*Confidence in Models of Radionuclide Transport for Site-specific Assessment*' (held in Carlsbad, New Mexico, USA, 14-17 June 1999). OECD-NEA, ISBN 92-64-18620-4, 2001.

[17] *Managing Radioactive Waste*, S. Norris & A.J. Hooper. Chemistry & Industry, No. 22, pp 876-880, November 1999.

[18] *Natural Safety Indicators and their Application in the UK*, W. Miller & S. Norris. Progress report to IAEA Co-ordinated Research Project on "*The Use of Selected Safety Indicators (concentrations; fluxes) in the Assessment of Radioactive Waste Disposal*", International Atomic Energy Authority, Vienna, October 2000.

[19] *The Nirex Phased Disposal Concept for Radioactive Wastes*, L.E.F. Bailey & S. Norris, Waste Management Seminar, The Physics Congress, Heriot-Watt University, 2003.

[20] *Generic Performance Assessment for a Deep Repository for Low and Intermediate-level Waste in the UK – a Case Study in Assessing Radiological Impacts on the Natural Environment*, S.R. Jones, D. Patton, D. Copplestone, S. Norris & P. O'Sullivan, Journal of Environmental Radioactivity, v66, pp89-119, 2003.

[21] *A Thematic Network on Gas Issues in Safety Assessment of Deep Repositories for Radioactive Waste (GASNET)*, W.R. Rodwell and S. Norris, EUR 20620, ISBN 92-894-6401-1, 2003.

[22] *Multiple Lines of Evidence Involved in Safety Case Arguments, Conclusions of Working Group*, S. Norris & E. Mouche. In proceedings of NEA-AMIGO Workshop on '*Geological Disposal: Building Confidence Using Multiple Lines of Evidence*' (held in Yverdon-les-Bains, Switzerland, 3-5 June 2003). OECD-NEA, ISBN 92-64-01592-2, 2004.

[23] *GASNET: A Thematic Network on Gas Issues in Safety Assessment of Deep Repositories for Radioactive Waste*, S. Norris, UK Power Journal, Issue 4, 2004.

[24] *Assessment Methodology for the Treatment of the Chemical Toxicological Impact in the Groundwater Pathway for the Nirex Phased Geological Repository Concept*, M.M. Askarieh, A.V. Chambers and S. Norris, The 10th International Conference on Environmental Remediation and Radioactive Waste Management September 4-8, 2005, Scottish Exhibition & Conference Centre, Glasgow, Scotland.

[25] *Near Field Sensitivity Studies of a Reference Repository Concept for UK High-level Waste/Spent Fuel,* S. Norris & M.J. Poole, Deliverable 5.1.11, European Commission NF-PRO Project, 2006.

[26] *Use of Geoscientific Arguments in the Nirex Phased Geological Repository Concept: Illustrative Desk Study*, S. Norris, B. Breen and J.L. Knight. In Proceedings of Second NEA AMIGO Workshop on *Linkage of Geoscientific Arguments and Evidence in Supporting the Safety Case*, Toronto, Canada, September 2005.

[27] *Impact of P&T on Geological Repositories: An Overview Of The Euratom Red Impact Project***,** D. Westlén, S. Norris, E.M. Gonzalez-Romero, D. Greneche, L. Boucher, J. Marivoet, C. Zimmerman and W. von Lensa, Global 2007 Advanced Fuel Cycles and Systems Conference, Boise, Idaho, USA, September 2007.

[28] *Comparison of Results from the MAGGAS and SMOGG Gas Generation Models*, Serco Assurance report SERCO/ERRA-0802 Issue 1, A.R. Hoch, S. Norris, B.T. Swift and M.M. Askarieh, 2007.

[29] *Understanding and Physical and Numerical Modelling of the Key Processes in the Near-field and their Coupling for Different Host Rocks and Repository Strategies, Deliverable 5.2.3 to EC NF PRO Project,* L. Johnson, J. Alonso, F. Plas, D. Pellegrini, O. Bildstein, M. Van Geet, D. Becker, P. Sellin, J.L. Cormenzana, H. Nordman, J. Lehikoinen, X. Sillen, E. Weetjens, H. Schnier, A. Vokal, D. Hodgkinson, C. Serres, S. Norris, M. Amme, C. Bauer, G.Mathieu and A. Hautojärvi, 2008

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Modelling Expert

Incisive and technically knowledgeable professional with demonstrated expertise in developing, implementing and extending sophisticated models to predict long-term safety and risks associated with disposal of spent nuclear fuel. Adept at leading teams in building and analysing models as part of larger research projects, ensuring timely delivery of high-quality results. Extensive experience in collaborating with multidiscipline internal and international colleagues, researchers and other experts.

Areas of Expertise

- Long-term Safety Assessments
- Radionuclide Transport Modelling
- Modelling Task Project Management
- Statistical Analysis Methods
- Data Science Techniques
- Programming/Coding
- Machine Learning/Deep Learning
- Spent Nuclear Fuel Disposal
- International & Team Collaboration

Career Experience

Posiva Oy – Helsinki, Finland

Modelling Expert, 1/2017 to Present

Oversee planning and co-ordination of modelling tasks for long-term safety assessment project related to Posiva's operating license application for spent nuclear fuel disposal facility. Collaborate with biosphere assessment and primary safety assessment project teams. Attend international meetings and seminars focused on sensitivity analyses, long-term safety assessment modelling and other specific topics.

- Leverage expertise to develop and execute complex models, building on previous research to determine long-term safety and risks of disposal of spent nuclear fuel.
- Performed data processing to modelling parameters, including assessment of uncertainties.
- Produced technical reports on topics relevant to long-term safety, such as conceptual models, modelling methodology and quality assurance.

Fortum Power and Heat Oy – Espoo, Finland

Design Engineer, 11/2014 to 1/2017

Implemented model created for thesis in Ecolego software, developed modifications to extend usage (report published by Posiva) and performed additional studies. Managed inventory assessment for Loviisa LILW repository and assisted with international activities in support of Posiva, including IGD-TP and IAEA MODARIA meetings