INTERNATIONAL PEER REVIEW

of Taiwan Power Company's

TECHNICAL FEASIBILITY ASSESSMENT REPORT ON SPENT NUCLEAR FUEL FINAL DISPOSAL (SNFD2017)

05 November 2017

At the request of the Taiwan Atomic Energy Council (AEC), the Taiwan Power Company (TPC) has commissioned an independent international peer review of the report entitled "Technical Feasibility Assessment Report on Spent Fuel Final Disposal (SNFD 2017)". The SNFD 2017 report has been prepared by TPC with support from the Institute of Nuclear Energy Research (INER) and the Industrial Technology Research Institute (ITRI) and has been finalised in early 2017. The international peer review assesses the sufficiency and credibility of the SNDF2017 report to demonstrate the technical capability of spent fuel final disposal in Taiwan.

Acknowledgements

The members of the International Review Team (IRT) would like to thank the TPC staff for their hospitality during the brief visits to Taipei, and for their excellent organisational support, which facilitated the work of the IRT. The IRT would also like to thank the staff of TPC, INER and ITRI for the helpful and open way they responded to the review. The IRT was impressed by the willingness of the scientific staff to contribute positively to discussions, ask questions, and confidently respond to queries posed. Finally, the review coordinator would like to thank Alan Hooper (United Kingdom) for his help in the launching phase of this review.

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1. Introduction

1.1. Background of the Taiwanese spent fuel disposal programme

Taiwan has been using nuclear power for electricity generation since 1978. Assuming a service time of about 40 years, the operating nuclear power plants in Taiwan will generate approximately 5,000 tons of spent nuclear fuel (SNF).

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 high-activity, long-lived radioactive waste. The concept takes advantage of the capabilities of both the local geology and the engineered materials to fulfil specific safety functions that work together to isolate and contain the radioactive waste.

Recognising that geological disposal is generally adopted worldwide for high-level radioactive waste (HLRW) management, Taiwan has adopted disposal in stable geological formations as the strategy for the long-term management of its spent nuclear fuel (SNF).

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 (SNF) produced from its nuclear power plants. TPC is currently operating as the nationally mandated waste management organisation, a function that is expected to transition in the future to a newly established legal entity which will be the formal future operator of the final disposal facility. The Atomic Energy Council (AEC) of Taiwan fulfils the regulatory function in the Taiwanese waste management system.

1.2. The role of the SNFD2017 report in the step-wise decision making of the Taiwanese programme

Taiwan has undertaken R&D studies related to the safe disposal of spent nuclear fuel (SNF) since 1986. Current activities to develop a geological disposal facility for SNF are governed by the Spent Nuclear Fuel Final Disposal Plan that was prepared by TPC and approved by AEC in 2006. The Plan, which is reviewed every four years, was last revised in 2014.

The Spent Nuclear Fuel Final Disposal Plan of Taiwan adopts the concept of step-wise decision making which is internationally recognised and implemented internationally as good practice for waste management programmes pursuing geological disposal of higher-activity 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 stage of the programme is the '*Potential host rock characterisation and evaluation* stage'. The main point of this stage is the technical research and the development of site investigation and repository engineering capabilities; this stage does not involve the siting process for the disposal facility.

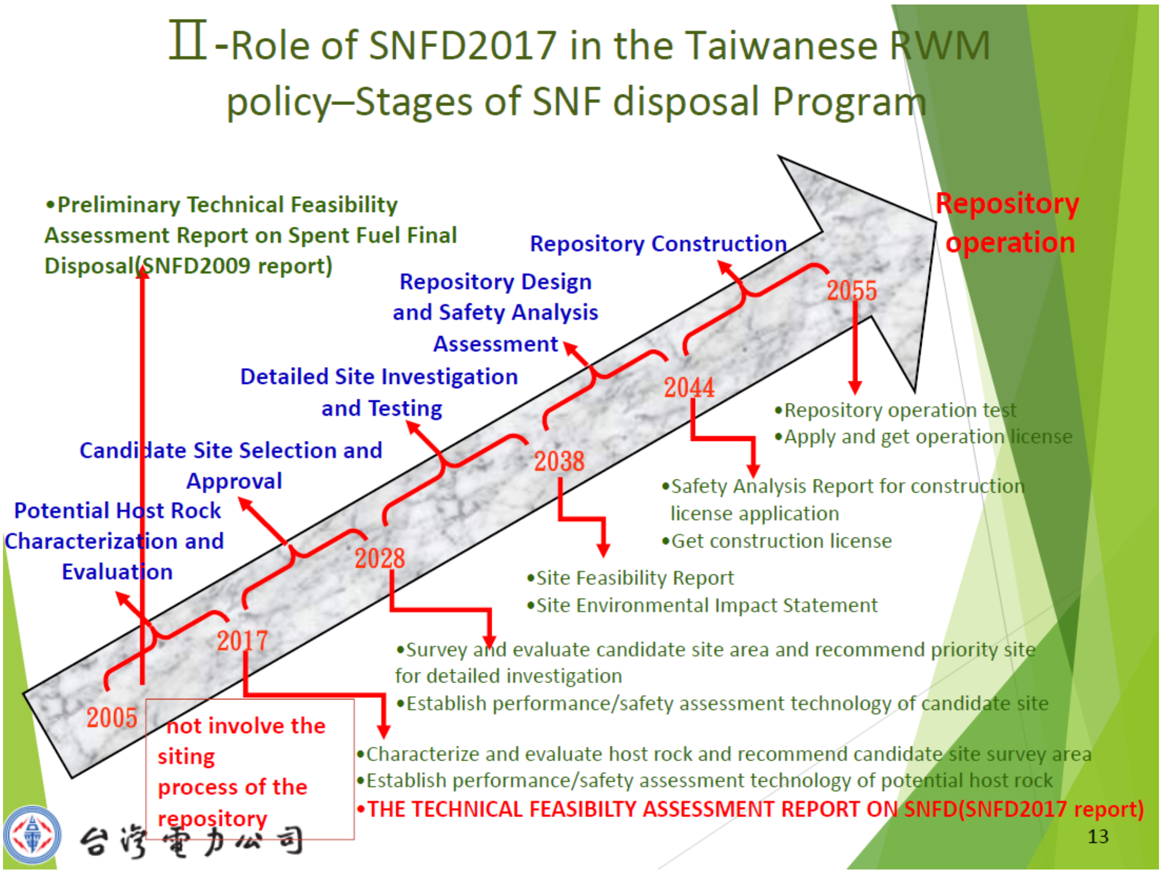

Figure 1: Stages of the Taiwan Spent Nuclear Fuel Disposal Programme (*Origin: Presentation at the IRT Orientation Meeting, 28th March 2017*)

To demonstrate the technical feasibility of final disposal of spent nuclear fuel and the related site investigation, repository engineering and safety assessment capabilities, the Atomic Energy Council (AEC) requested TPC to prepare a study with the goal to:

- confirm whether a scientifically suitable granitic rock body for geological final disposal could be identified in Taiwan or not;
- confirm whether adequate engineering capabilities for constructing a geological repository have been established in Taiwan or not; and
- confirm whether adequate capabilities for assessing the long-term safety for a repository site have been established in Taiwan or not.

In response to this request TPC prepared a Feasibility Assessment Report for the Spent Nuclear Fuel Final Disposal Technology in Taiwan (SNFD2017) with support from the Institute of Nuclear Energy Research (INER), the Industrial Technology Research Institute (ITRI) and other scientific groups. The SNFD2017 report uses reference geological data from a specific area in Taiwan (which has been excluded as a candidate site according to regulations) and adopts the Swedish KBS-3 concept for the disposal facility design, safety strategy and supporting models and assumptions to complete a generic safety assessment.

Given the generic character of the SNFD2017 study to demonstrate feasibility of geological disposal of spent nuclear fuel in the pre-siting stage of the programme, the report can be seen as a preliminary Safety Case, comparable to similar reports in other national programmes used to demonstrate and communicate safety of geological disposal to regulators and other stakeholders. As such, SNFD2017 is considered a key milestone to consider if the first stage of the Taiwan disposal programme has been successfully completed, and influences how the programme will develop in the future towards the next stage of '*Candidate site selection and approval*'.

The AEC has requested TPC to carry out an international peer review of the SNFD2017 report before submitting the report to AEC as part of this staged and formal decision-making process.

1.3. International peer review

Following the request from AEC, TPC commissioned an independent International Peer Review of its "Technical Feasibility Assessment Report on Spent Nuclear Fuel Final Disposal" (SNFD2017).

1.3.1. Objectives and scope

The objectives and scope of the review are laid down in the Terms of Reference (ToR) as agreed between the International Review Team (IRT) and TPC.

The ToR (IRT, 2017a) requests the reviewers to "*assess the sufficiency and credibility of the SNDF2017 report to demonstrate the technical capability of spent fuel final disposal in Taiwan*" as specified by the three main objectives of the report (see above), thereby to "take into account the current stage of the implementation of the Spent Nuclear Fuel Final Disposal Plan of Taiwan".

The key documents of SNFD2017 reviewed include:

- the Technical Feasibility Assessment Report on Spent Fuel Final Disposal (SNFD2017), Main Report (TPC, 2017a); and
- three supporting technical reports covering the Geological Environment of Taiwan (TPC, 2017b), the Repository Design and Engineering Technology (TPC, 2017c); and the Safety Assessment (TPC, 2017d).

Further, the ToR state that the international peer review is organised according to NEA's guidelines for international peer reviews for radioactive waste (OECD/NEA, 2005).

The full ToR (IRT, 2017a) are presented in Annex I.

1.3.2. The International Review Team (IRT)

To perform the peer review, an International Review Team (IRT) of experts has been assembled by the review co-ordinator, independently from TPC or other entities involved in the Taiwanese programme. All members of the IRT have experience in the international state of the art for final disposal and are, or have been, engaged in advanced national programmes for geologic disposal of high-level radioactive waste. Furthermore, they were selected to provide a broad range of international experience and a balance of expertise from implementing, regulatory and policy-making perspectives. All IRT members were chosen to be free of conflict of interest and have not been involved in any activities associated with the preparation of the SNFD2017 report. All written exchange between the reviewee and IRT has been organised and managed through the review co-ordinator.

The IRT members are:

- Michael Sailer (Germany), Chairman
- Kenji Amano (Japan)
- Tara Beattie (United Kingdom), Technical Writer
- Lise Griffault-Sellinger (France)
- Hiromichi Higashihara (Japan)
- Jaakko Leino (Finland)
- Hans Riotte (Germany), review co-ordinator

Annex II of this report lists the IRT members' CVs.

The IRT members listed above are responsible for all statements made in this review. The experts express their own views and not those of the institutions with whom they are affiliated.

1.3.3. Conduct of the review

The organisation of the international Peer Review was guided by the OECD/NEA guidelines for international peer reviews for radioactive waste management' (NEA, 2005) which describes a peer review as the "*systematic examination and assessment of a national waste management programme or a specific aspect of it, with the ultimate goal to help the requesting country to adopt best practices, [and to] comply with established principles*". As such, the review is not intended as a formal approval of the Taiwan disposal programme, rather it is to be used as an input for decision makers assessing the current stage of the Taiwan disposal programme, and reviewees continuing to develop the national programme.

The IRT performed its work between March and October 2017.

In order to fulfil its mandate, the IRT assessed the SNFD2017 reference documentation taking into account complementary information gained from presentations and related discussions with TPC. This included direct discussions with experts and others involved in the production of SNFD2017 at two seminar meetings held in Taipei, written answers to questions raised by the IRT in writing, and additional technical information provided by TPC.

The IRT held two meetings in Taiwan:

- an orientation meeting at TPC premises in Taipei, on 28-30 March 2017; and
- a review meeting at TPC premises in Taipei, on 28 August - 1 September 2017.

The orientation meeting was held over three days, organised around detailed presentations provided from TPC, ITRI, and INER experts covering background information on the Taiwanese radioactive waste management framework, the SNFD2017 main report and its three supporting technical reports. Specific sessions were dedicated for questions and answers on the items presented and to discuss specific issues. The IRT also held internal sessions to organise its work and to divide among themselves the detailed evaluation of the reference documents, such that each member could focus their review on sections of the documentation appropriate to their professional experience and technical expertise.

Following the orientation meeting, the IRT completed their initial review and prepared two rounds of written comments and questions to TPC (May 9th and July 15th) requesting clarification of issues and further detailed and additional information. All questions were satisfactorily answered by TPC and its supporting institutions within a reasonable time frame. The two sets of written comments and questions submitted, together with the corresponding written responses provided by TPC, have been documented as a questionnaire of the international peer review team (IRT, 2017b) that is provided together with this review report.

A second one-week IRT workshop (review meeting) took place in Taipei at the end of August/beginning of September 2017. The workshop comprised internal sessions for IRT members to discuss major findings and to develop a common view on its evaluation. The review workshop also included a series of in-depth discussions between the IRT and TPC, INER and ITRI experts on key development issues, including the interaction between safety assessment and design adaption, further development of the Taiwanese waste management programme, and planning of research and development (R&D). At the end of this workshop the IRT chairperson gave an oral report on the basic findings of the review.

The IRT noted that the success of the two workshops was facilitated and conducted in an open and transparent manner, leading to excellent discussions with the reviewee following each presentation. In particular, the IRT appreciated the high level of engagement of the young professionals involved in preparation of SNFD2017. Their contributions to both technical and strategic discussions, alongside their more senior counterparts, provided a clear insight into the impressive leadership and management in operation within the TPC, INER and ITRI organisations.

1.4. Report of the International Review Team

1.4.1. General

The findings of the international peer review are based on the (English) documentation that was provided, on additional enquiries with TPC, INER and ITRI staff during the review process, and on the understanding that this is the first step in the stepwise development of a spent fuel repository in Taiwan. The IRT used the specialist knowledge of its members and its collective understanding of international good practice to evaluate the information provided and to make findings and recommendations.

The IRT recognise that many more documents and technical reports have been prepared to underpin the SNFD2017 report. However, due to the limited resource of time and capacity of the IRT and the fact that those additional reports have not been translated, the IRT have concentrated on issues which are highly relevant for the questions raised by ToR. This results in differing levels of interrogation and detail across the various topics evaluated by the IRT.

Specifically, the IRT did not conduct detailed evaluation of calculations and data used in the phenomenological modelling and safety analysis. Equally, to review the engineering competence, only some representative samples of technical computations have been examined (e.g., canister-buffer-rock interactions, seismic action estimation and long-term groundwater simulation).

The IRT 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 fulfil the ToR.

Given the broad international experience of the team, many observations made and 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 programme.

The peer review report presents the consensus view of the IRT. In keeping with OECD/NEA procedures for independent reviews, the reviewee was given an opportunity to check the report for factual correctness. The report has otherwise not been revised in response to comments from TPC.

1.4.2. Structure of the report

The peer review report is presented in this document and is structured into six chapters and three Annexes.

Chapter 1 presents background information on the Taiwanese repository programme, the SNFD2017 documentation and its role in the stepwise process towards a deep geological repository in Taiwan. The objectives and scope of the international peer review and the conduct of the review are also specified.

The findings of the IRT are presented and separated into high-level findings in Chapter 2 (major findings regarding the remit of the review), generic findings regarding the waste disposal programme in Chapter 3 (findings that relate to broad aspects of implementing geological disposal in Taiwan) and detailed findings in Chapters 4, 5 and 6 for each of the key SNFD2017 objectives (i.e. geosynthesis of the K-area, design and engineering competence to construct a repository in Taiwan, and the preliminary safety assessment).

Finally, the Annexes reproduce the Terms of Reference and present the CV’s of the IRT members and the list of documents reviewed and other documents quoted in the review.

2. High-level findings according to the remit of the review

The purpose of the review is to assess the sufficiency and credibility of the SNFD2017 report to demonstrate the technical capability of spent fuel final disposal in Taiwan. In assessing the SNFD2017 report the review has taken into account the current stage of implementation of the Spent Nuclear Fuel Final Disposal Plan of Taiwan. This is defined as the '*potential host rock characterisation and evaluation' stage (2005 - 2017)*'. In carrying out its review, the IRT took account of the fact that the SNFD2017 report is only one stage in a stepwise decision-making process, and that the decisions to select and investigate a preferred regional geological site and then to develop a disposal facility will be made in future stages.

As part of the Taiwanese Radioactive Waste Management (RWM) policy framework, the AEC specified that the SNFD2017 report be subjected to an international peer review, prior to formal submission as part of the process to progress to the '*candidate site selection and approval*' stage of the disposal programme (2017 – 2028).

SNFD2017 and earlier SNFD2009 describe that there are three potential host rocks available in Taiwan for geological disposal of radioactive waste: granite, mudstone, and Mesozoic basement rock. SNFD2017 focuses on granite as a reference host rock and illustrates feasibility using available data for the K-area which is representative of the geological characteristics for the offshore granitic islands in western Taiwan. The IRT understands that the K-area is chosen as the reference case study because there are relatively more geological data and research results available than other areas, but that this area would not be a candidate disposal site according to the current Taiwan regulations (TPC, 2017e).

The findings of the review are based on the English version of the SNFD2017 documentation supplied and other formal correspondence and communications between TPC and the IRT (as described in Chapter 1 and the full list provided in Annex III). The review findings aim to support ongoing development of the Taiwan disposal programme and are anticipated to be important to the formal decision-making process to consider if the '*potential host rock characterisation and evaluation*' stage is successfully completed and influence how the preceding '*candidate site selection and approval*' stage should commence. Review findings therefore indicate conclusions and recommendations that are directly applicable to the current stage of the programme and others that relate to future stages of the programme.

2.1. High-level findings

2.1.1. Maturity of the SNFD2017

According to the Terms of Reference, the objective of the international peer review is to evaluate the SNFD2017 "*taking into account the current stage of the implementation of the Spent Nuclear Fuel Final Disposal Plan of Taiwan*". The plan is currently nearing the completion of the first stage, described as '*Potential Host Rock Characterization and Evaluation*' which does not involve the siting process for a repository.

The SNFD2017 report, together with its supporting technical reports, has been prepared to demonstrate the feasibility of geological disposal of spent nuclear fuel in a generic way, at an early stage of the disposal programme when no siting-related decision has yet been taken.

With regards to the three objectives set by AEC, the IRT considers that SNFD2017 broadly confirms that both adequate engineering capabilities for constructing a geological repository and for assessing the long-term safety for a repository site have been established in Taiwan. Using the focus on granitic rock and K-area data, the SNFD2017 study also demonstrates adequate capability and state of the art methods appropriate to confirm whether a scientifically suitable granitic rock body for geological final disposal could be identified in Taiwan or not. It is anticipated that such methods will be used as a basis for assessing potentially viable granitic sites once the programme formally enters the siting stage.

The SNFD2017 report presents the technical basis for the current stage of the programme and provides a platform for its future development. From an international viewpoint, the SNFD2017 study represents what is also called a preliminary safety case, comparable to similar reports produced at an early stage in other national programmes for the purpose to demonstrate and communicate safety of geological disposal to decision makers, regulatory authorities and other stakeholders, in a generic way.

Having this role of the SNFD2017 report in mind, the IRT found the SNFD2017 report to be consistent with international good practice for preliminary safety cases. By building a reference case based on the experience and disposal concept adopted by two prominent and advanced disposal programmes (Sweden and Finland), the SNFD2017 exceeds, in several areas, the scope and detail of analyses that have been presented in some other national preliminary safety cases at such an early stage.

The IRT considers, by international standards and experience, that the SNFD2017 study is adequate for the decision at hand and that the competences and technical capabilities in site investigation, repository engineering and safety assessment demonstrated are sufficient to allow the Taiwanese programme to move forward. As such, the SNFD2017 is fit-for-purpose and can play an important role in decision making whether the first stage of the programme has been successfully completed and the programme can move on to the second stage '*Candidate site selection and approval*'.

The detailed findings of the IRT presented in this report point to some specific areas, where the IRT feels that the SNFD2017 assessment, or its presentation, could be improved beyond the needs of a preliminary safety case to meet even higher standards. The IRT does not recommend amending the current SNFD2017 report to address these findings, but rather to take account of these findings in a future, advanced safety case related to the progress of the Taiwanese disposal programme.

The technical knowledge base represented by the SNFD2017 is expected to develop significantly as the programme moves into the '*candidate site selection and approval*' stage. It is therefore proposed that the results of the international peer review should be included as input information to the Taiwanese decision process regarding the next steps of the final disposal programme.

2.1.2. Resource and capacity

The SNFD2017 report does an excellent job of assimilating international knowledge of granitic disposal of Taiwan radioactive wastes utilising the KBS-3 concept and presents a good integration of technical expertise on geological disposal in Taiwan from three organisations (TPC, INER & ITRI). The skills and competence of staff from all organizations has clearly been enhanced through strong co-operation between the main national organisations and through interaction with international experts, most notably SKB. In particular, the IRT noted the inclusiveness and openness of TPC, INER and ITRI staff during direct interactions throughout the peer review process. Sessions were attended by a wide number of staff from each organization, with question and answer sessions engaging. A broad capacity of people was evident, including young talent to provide continuity for the future. The IRT was impressed by the willingness of staff to contribute positively to discussions, ask questions, and confidently respond to queries posed. The eagerness to learn and develop further from the IRT members' shared experience was particularly encouraging and demonstrates the capacity of the TPC, INER and ITRI staff to continue to develop and communicate well at a strategic level, in addition to detailed technical discussions.

2.1.3. Structure of SNFD2017

SNFD2017 collates and integrates a considerable body of information from within the Taiwanese disposal programme and, where appropriate, uses information from other national waste management programmes to supplement its own knowledge base. The presentation of the aims and objectives of SNFD2017 are communicated well, particularly with respect to the programme boundary conditions set by AEC and the reasoning for the choice of options (e.g. adoption of the K-area for the site reference case and the KBS-3 disposal concept).

In order to meet the objectives of SNFD2017 the report adopts the framework of the Japanese H-12 report (JNC, 2000) which is sufficient for the current early phase of the programme. Future iterations should align with international good practice and consider revision towards a structure which sets the safety case and safety assessment at the core of the documentation suite.

SNFD2017 documents show the large effort undertaken and the IRT is impressed by the overall strength and quantity of the information presented. The IRT finds that there are areas for improvement with respect to utilisation of contextual data, particularly to how information is acquired. Discussions with TPC indicate that plans are in place and work is ongoing to improve and adequately manage quality control of data and information (for example the Data Management System planned to manage acquired site and geological data). As such, the technical and scientific basis of geological disposal in Taiwan is adequately communicated in SNFD2017 (*for the KBS-3 concept in the granitic K-site area*), but going forward the data, information and management tools necessary to progress a successful disposal programme could be emphasised and demonstrated more prominently in future iterations of the safety case.

In assessing engineering competence, the IRT acknowledge SNFD2017 as a sound basis for progressing to the next stage of the programme and highlights areas for future focus on qualification of the programme's technical readiness. A concept of

Technology or Technical Readiness Levels (TRLs) or Scientific Readiness Levels (SRLs®) has been used, e.g. in the UK, as a mechanism for calibrating the maturity of underpinning science and engineering across different topic areas, and for plotting a route to attain the required level of understanding through future RD&D activities (NDA, 2016). Such qualification would improve communication of current engineering capacity in Taiwan and aid the future work programme to adequately capture the knowledge gaps, uncertainties and issues that need to be addressed in the area of engineering competence for the future stage.

Lastly, with respect to the overall presentation and structure of the SNFD2017, a key area for future improvement considered important by the IRT is the communication of key safety arguments to a wide range of stakeholders, including the general public. As TPC proceeds to the next stage of the programme, it will be important that a future iteration of the study is accessible and presented in a way that promotes the key safety arguments in a clear manner.

2.1.4. Safety assessment methodology

SNFD2017 has demonstrated the capability to successfully apply the SKB approach for post-closure safety evaluation. The IRT finds, in general, the safety case presented based on a foundation of sound science and important international literature and international guidelines are adhered to. In a number of areas, potential for methodological improvement is shown and some recent publications are noted to ensure future development keeps up to date with internationally recognised good practice.

Regarding the safety approach, the main safety arguments are presented and the reference evolution and series of scenarios have been developed and quantified considering the KBS-3 concept and K-area data. The structure adopted in SNFD2017 is adequate for this stage. Going forward, a more robust and fully-integrated approach in building a safety case needs to be developed when considering site-specific assessment and the IRT strongly recommends revision of the scenario development methodology towards a more top-down approach with a focus on development of intermediate level safety functions. Likewise, with regards to safety assessment and the national regulations for radiological criteria, some improvements to performance assessment methodology are noted to align further with international good practice.

Overall, the safety assessment considers the relevant issues appropriate for the current stage of the programme. The IRT recommends in the future to increase reliability of the safety case by exploring sensitivity analysis in a more extensive way and to improve the transparency and traceability of information.

2.1.5. KBS-3 disposal concept

SNFD2017 has adopted the KBS-3 disposal concept, taken over directly from its development and use by the Swedish waste management company (SKB), for disposal of spent nuclear fuel in a granite hard rock. The KBS-3 system is an in-tunnel vertical deposition hole concept that has been extensively studied in Finland and Sweden for many decades. Both Posiva (in Finland) and SKB (in Sweden) have submitted licence applications based on the KBS-3 concept, with Finland gaining approval in 2015 and the government granting the licence after the Finnish radiation safety authority (STUK) statement to construct a final repository for this type of concept.

The IRT considers the adoption of a well-researched and internationally accepted concept, such as the KBS-3 concept, of direct benefit to the Taiwanese disposal programme. Given the current preference of a granite host rock environment as the target geological setting to host the disposal facility in Taiwan, there are clear advantages to adopting the KBS-3 system, although it does present challenges to understanding the boundary conditions when transferring knowledge and models. The IRT considers the KBS-3 system (or a modified form of this multi-barrier concept) appropriate, provided a granite host rock remains as the preference target geological setting. It will be necessary in the future stage of the programme to continue to assess the compatibility of the KBS-3 system with granitic host rock settings in Taiwan, other than the K-area.

Should the Taiwanese disposal programme in a later stage broaden or change to consider other host rock settings and / or significantly altered disposal facility designs, revision of the assessment methodologies demonstrated by SNFD2017 may be required. The SNFD2017 report does not present evidence or experience of disposal systems developed specifically for lower-strength host rocks. As such, the IRT recommends that future stages of the disposal programme broaden its knowledge base to be able to consider a wider range of suitable disposal concepts for the full range of possible geological settings. Direct discussions during the review indicated that technology options from other disposal programme were already under review by TPC and as such would be addressed by the forward work programme.

2.1.6. Uncertainty and sensitivity analysis

All data and arguments supporting the long-term safety of a geological disposal facility have to be checked for their uncertainties. Understanding, evaluation and reduction of the remaining uncertainties require the best scientific knowledge available. Therefore, the pursuit of improved uncertainty treatment is an area of ongoing development and of common high interest to spent fuel disposal programmes internationally (IGD-TP SRA, 2010). The SNFD2017 report recognises the importance of uncertainty treatment and the need for its continued development in future iterations of the safety case (as exemplified by the application of DarcyTools to the K-area data). Direct discussions between the IRT and TPC during the meetings in Taiwan included consideration of this important topic and concluded with a clear recommendation for enhanced sensitivity analysis as part of the future safety assessment methodology. This is considered important in preparing for the next stage of the programme when a good methodology for treatment of uncertainty will aid the management and acquisition of site data. Also, enhanced sensitivity analysis can aid competence development of the assessment tools and support progressive reduction of uncertainties in parameters and models used in the safety assessment.

2.2. High-level findings in specific areas identified in the ToR

2.2.1. To confirm whether a scientifically suitable granitic rock body for geological final disposal could be identified in Taiwan or not;

SNFD2017 demonstrates the safety of geological disposal of Taiwanese Spent Fuel for the KBS-3 concept in the granitic host rock environment of the K-area. The IRT recognise that granitic sites (with either similar or differing rock properties and characteristics to the K-area) that are scientifically suitable for geological disposal may potentially exist in Taiwan, and that their identification and confirmation will be the primary focus for the next stage of the Taiwanese disposal programme. Identification and selection of a suitable rock body for geological disposal will require detailed geological investigations as part of the next siting stage of the programme, building on the integration of facility design concepts and preliminary safety evaluation methodology demonstrated by SNFD2017.

Geosynthesis of potential host rocks in Taiwan

TPC gave in-depth understanding of the regional geology including the three potential host rocks (granites, mudstones and Mesozoic basement) in Taiwan. Most of the claims are reasonably described and draw from reliable scientific publications, thus providing a certain degree of confidence that the geo-scientific evidence necessary to implement geological disposal in Taiwan can be appropriately developed.

In that sense, the geological evolution of the two granitic body groups, Pingtan-Dongshan Metamorphic Belt (PDMB) China, and Tananao Complex and Metamorphic Belt (TCMB) Taiwan, is also well studied by using a variety of geological methods. It shows that PDMB and TCMB are located in relatively stable areas where there are no active volcano or faults or any significant neotectonic activities such as diapirism and rapid uplift/subsidence from the formation ages to the present day. Future improvements are anticipated with regards to describing an understanding of their geological stability for the next one million years, incorporating renewed data and interpretations for the long-term movement trends and generation patterns of active volcanos/faults due to plate motion. Particularly, it would be important in the H-area to consider the thermal/mechanical impact on rocks and reactivation of faults by the approaching Okinawa Trough.

Regarding the safety functions in the geosphere, safety functions R1 '*Provide chemically favourable conditions'* and R2 *'Provide favourable hydrologic and transport conditions*' could be confirmed in the K-area based on the surface-based investigation data and the modelling results. There still remain some uncertainty for parts of the data, for example it is expected in the future that traceability of measurements would be enhanced. The reviewers found it difficult to trace the judgement criteria of groundwater Eh measurements cited in SNFD2017. Moreover, more hydraulic conductivity data of intact rocks would be required for the statistical representativeness of the dataset used for the precise safety assessment.

The results of SNFD2017 demonstrate adequate capability and state of the art methods appropriate to confirm whether a scientifically suitable granitic rock body for geological final disposal could be identified in Taiwan or not. It is anticipated that such methods will be used as a basis for assessing potentially viable granitic sites, once the programme formally enters the siting stage. As demonstrated for the K-area in SNFD2017, it will be possible to assess potential host rocks in other areas of Taiwan to confirm if their characteristics and properties meet the long-term stability requirements of the geosphere and respective safety functions.

Regarding the site characterisation techniques reviewed and discussed in SNFD2017, the set of investigation methods and modelling techniques applied in the K-area demonstrate the acquisition of data suitable for completing preliminary safety assessment. The applied technologies for the measurement and evaluation of geological characteristics using the K-area data are comparable with those used in other countries at a similar stage of investigation. When developed further, in future stages of the programme, improvements are anticipated with respect to treatment of uncertainty when selecting and using site data in quantitative assessments.

Once the Taiwan disposal programme commences site selection activities and detailed characterisation of one or more sites, the methods and techniques demonstrated in SNFD2017 could be applied for site data with broadly similar geological characteristics to the K-area (i.e. crystalline rock and fresh groundwater). The methods and techniques would however require modification and their suitability re-evaluated if significantly different geological settings are considered, e.g. mudstones and/or saline groundwater.

2.2.2. To confirm whether adequate engineering capabilities for constructing a geological repository have been established in Taiwan or not;

The SNFD2017 main report and the Technical Supporting Report 2 (TSR2) set the steps for adaptation of the KBS-3 concept to local conditions and SNFD2017 succeeds in these steps on a conceptual level using K-area data.

Design basis of the KBS-3 concept

During the conceptualisation phase an implementer considers potentially suitable sites and design options, establishes the safety strategy (approach to developing a disposal concept, approach to safety assessment and basis for the management system) and carries out preliminary assessments. Regulatory interaction at this stage should guide the implementer on the likelihood of achieving the necessary demonstration of safety and should help the implementer decide whether to commit resources to move to the next phase of the project.

The SNFD2017 presents the design concept and provides preliminary assessment and demonstration of post-closure safety. SNFD2017 also presents and identifies the key factors that are important to safety. However, since the siting phase has not been completed, it is difficult to present how the design concept integrates properties and characteristics of the host rock, engineered materials and spent nuclear fuel. TPC constructs a reference case, for developing and evaluating the technical feasibility of the K-area properties and characteristics to other possible sites for final disposal using the KBS-3 concept and assessment methodology.

SNFD2017 describes the design methodology and presents the functions assigned to each component of the disposal system. The expected evolution of each component is described and factors influencing them. Features, events and processes, (FEPs) that are most important for the safety of the disposal system are identified based mainly on the concept development in Sweden and Finland and

FEP-analysis made for the reference case site. IRT notes that a principle of the multi barrier system is explained and described adequately.

During the siting phase the implementer confirms the suitability of potential sites according to the safety strategy and characterises these sites. A safety case is developed to the extent that a decision can be made on the preferred site.

During the reference design (and application for construction) phase, the implementer adapts the conceptual design to the site properties, substantiates and finalises the design of the disposal facility, and develops the safety case, to support the implementer's application to construct, operate and close the facility. Based on the review of the safety case, the licensing body would decide whether to grant a licence for the implementer to construct the facility. This is a crucial milestone in the development of a repository.

Demonstrating the safety of geological disposal is a process that needs to be undertaken systematically and through all phases of the development of a disposal facility. The safety case evolves and matures throughout these phases, as new information, experience from practice, and results from research and safety assessments become available. Furthermore, each barrier has uncertainties related to its performance. Effects of these uncertainties should be explored and evaluated in the performance assessment as is discussed in the following Section 2.2.3.

Constructability of a geological disposal facility In Taiwan

A major focus of the engineering considerations covered by SNFD2017 centres on the design basis for the KBS-3 engineered barrier system and its suitability for Taiwan boundary conditions. Little attention is given to the full-scale facility design and its constructability. Accordingly, much of the review results shown below refer to the engineered barrier system. The IRT consider the focus of the design works on assessing compatibility of the engineered barrier system wholly appropriate given the current stage of the programme.

In the stepwise implementation process, final design and construction are planned to start two decades after the present time. Although construction engineers will join, observe and offer relevant advice during the siting process, for the preliminary safety assessment it is not necessary to decide the exact nature of the disposal facility construction. Particularly since general practicalities and available technologies are assumed given the current focus on the KBS-3 concept. As is mentioned in Chapter 3.5, major construction know-how has become a well-shared commodity. Construction business is a competitive market and subject to cost/profit principles. Given the long timescale to construction and the conceptual and early stage of the Taiwan disposal programme, it is not commercially viable for individual firms in Taiwan to keep pace with the disposal project or for a large proportion of current resources to be focused on this aspect.

Generally, construction firms are good at agile adaptation to new, urgent needs. From the replies to our queries (IRT, 2017b; questions 6-1, 6-2) concerning the Suhua projects or Hsuehsan Tunnel, no technical defects were seen.

Overall the IRT considers that general construction issues do not need to be the focus of priority for the current stage of the programme.

2.2.3. To confirm whether adequate capabilities for assessing the long-term safety for a repository site have been established in Taiwan or not.

The Safety Assessment developed in the SNFD2017 reports indicates that TPC has the capability to conduct post-closure safety evaluations of a geological disposal facility for spent fuel. The SKB methods using the KBS-3 concept and K-granite data have successfully being applied and dose and risks associated to a series of scenarios have been evaluated.

The ability to build a specific Taiwanese Features, Events and Processes (FEP) database using the K-area data was clear and represents a good foundation for future development and integration of new data. A powerful tool of FEP processing has been developed, integrating analyses of features and events that may affect safety functions in order to derive the scenarios and calculation cases, which is in line with current international practices.

The structure adopted in the SNFD2017 is adequate at this stage of the programme considering the KBS-3 concept and the K-area granite; going forward, a more robust and fully-integrated approach in building a safety case needs to be developed when considering site-specific assessment. The IRT recommends in a number of specific areas of the post-closure safety assessment (e.g. biosphere modelling and scenario development) the adoption of latest developments which are considered by IRT members as international good practices (suggested references for consideration in future updates are cited in Chapter 6).

The IRT considers, however, that further work would be needed going forward to improve several methodological issues on scenario development methods. In future steps, the IRT recommends making the selection methodology of scenarios more visible in the overall post-closure safety approach flowchart. It might be useful to consider the recent international practices in this area, which rely more on the safety function at an early step in the approach. It is a practical way to expose the safety functions that natural and engineered barriers are expected to provide, at what period and for which duration, and to give insight to design of the engineered barrier system.

Going forward, and to aid future design optimisation with a selected site, a more systematic development of safety functions and safety function criteria for all the main components is required (i.e. for the container, the buffer/backfill and the geological barrier). The IRT recommends to move forward in this direction to enable examination of the robustness of the system in a more systematic way.

Some performance assessments (distinct from safety assessments) have been realised in the framework of the SNFD2017 reports. The IRT recommends developing further such performance evaluations as it may provide insight to the development of design, particularly for the engineered barrier system.

It is important to develop and update the performance assessment along with safety case development to take account of local data during site selection and assessment and later stages of more detailed site characterisation. This includes taking into account the results of future R&D work up to and including the construction stage of the disposal facility. Technical Supporting Report 2 collects the future work plans in the design area. The IRT wants to point out that there are considerations affecting the overall performance of the programme that should be addressed early on, including, for example, long-term evolution of corrosion, earthquake induced shear load scenario, the possible role of an underground research laboratory, and a platform for the use of local field parameters.

It is important that the future development work is continued systematically and that each possible R&D task is linked to safety and safety functions. IRT recommends that all future research topics from all the supporting reports are collected in an established R&D programme where these topics are integrated to strengthen the safety case and its development.

This approach will give a good foundation for future post-closure safety assessment which will require a systematic approach in the development of scenarios and should consider a complete set of scenarios (including consideration for the more recent international trends for inadvertent human intrusion, see Chapter 6 for specific citations).

The conceptual model of the biosphere followed the main lines of the IAEA BIOMASS methodology but not in a systematic way. The IRT notes that the most exposed group will have to be demonstrated in future stages in order to conform to long-term safety international recommendations such as ICRP and good practices. The assumption will have to be demonstrated with a detailed biosphere conceptual model which will include landscape evolution and the identification of the most exposed group with its food consumptions habit.

3. Detailed findings regarding generic aspects of SNFD2017

3.1. Stepwise process

In Taiwan, a stepwise process of siting and constructing a final disposal facility for spent nuclear fuel is foreseen. The first stage '*potential host rock characterization and evaluation*' covers the time period from 2005 – 2017. SNFD2017 communicates clearly the context of this stepwise process, and the report is understood as an important document at the end of the first stage of this process.

The IRT emphasises that this stepwise approach is in accordance with the international regulations and state of the art. The lessons learned in other countries which deal with the disposal of high-level radioactive waste show that a stepwise process towards implementation is a good practice and helps to avoid major flaws in technical and scientific issues. The stepwise process is also a strong component to communicate and interact with the public and other stakeholders. The adoption of a phased approach towards implementation is on par with international experience and successful advanced programs (e.g. Sweden, Finland, France).

Conclusions:

The IRT encourages the relevant Taiwanese authorities and stakeholders to continue in this stepwise manner.

Comparing the SNFD2017 report with reports from other countries at the first stage of a stepwise process shows clearly the SNFD2017's maturity and its overall compliance with the international state of the art.

3.2. Role of the implementer/operator and regulator

In the first step of the stepwise process TPC has been charged to act in the implementer/operator role. This is a reflection of the current organisation of the nuclear competence and skills base within Taiwan.

IRT can confirm that TPCs scientific and technical endeavours which are documented in SNFD2017 and its supporting reports are in accordance with the requirements for an implementer/operator in the first stage of the process.

TPC has informed the IRT in the answer to question 1-1 (IRT, 2017b) that a future organisation is currently in development that will be formally mandated to act in the role of the implementing body "... *The Executive Yuan has submitted a governmental proposal (ID15844) to the Legislative Yuan on 2016/11/18 for forming a new, independent and dedicated agency responsible for the repository siting, design, construction, operation, maintenance, closure, etc. This proposal is still under the reviewing process of Legislative Yuan*..."

IRT sees these upcoming changes for the role of the operator as an important step. This appropriately recognises the background that the role of the implementer and operator for the disposal facility will last for many decades up to the start of the operation of the repository (planned for 2055) and further up to the final closure of the disposal areas (expected at the beginning of 22nd century). The role of the implementer and operator includes other duties above those currently fulfilled by an electricity-producing company. The countries with an advanced disposal programme are organised in a similar way as is discussed now in Taiwan (e.g. implementers in Sweden (SKB), Finland (Posiva), France (Andra), Swiss (Nagra)).

The AEC Taiwan has the clear role of regulator and supervising authority. In general, this is in accordance with the international rules.

The IRT has learned that the development of a legal framework for radioactive waste disposal in Taiwan is under way. With this a more advanced understanding in the future will be possible with respect to roles and responsibilities of both the implementer and regulator, including the question of who decides on which issue.

The IRT recognise that the resources on the side of the actual implementer are very good (as reflected by the quality of the SFND2017 documents). It will be important that with the transfer of the implementer role to another entity the resources and competence remain on a similar high level.

Regarding the resources of the regulator, the IRT did not have direct access to detailed information in this field (this issue was not covered by the terms of reference of the IRT). Nevertheless, the IRT drawing from international experience considers that when developing an overall disposal programme the availability of good scientific resources for the regulator is very important. Especially in the later stages of the siting process, adequate resources help the regulator to act efficiently and on par with the implementer.

The experience in other countries shows that in this field it is important to have a clear separation between the experts who work for the regulator and those experts who work for the implementer. The reason for this is on one hand the need for independence between regulator and implementer. On the other hand, public perception of the regulators independence may also play a crucial role.

Conclusions:

The IRT emphasises that with the potential installation of a new implementer there is a high need for enough resources in terms of experienced staff and manpower.

The IRT share their international experience that the national regulator needs enough expertise and external experts which are independent from the implementer, to be on par with the expertise of the implementer (the so-called ‘four-eye-principle’).

3.3. Technical concept of the disposal facility

The technical concept is a fundamental part of the overall safety strategy during siting and in the subsequent stages. During the siting process, a good knowledge of the scientific basis of the technical concept and origins of developed design requirements is essential. The technical concept spans from waste canisters, buffer and other features in the direct environment of the canisters, operation of the disposal facility in all safety relevant issues, and techniques for closing the mine to questions about how retrievability would be implemented.

The IRT understands that the primary target is for the facility to be located in a crystalline rock formation. Consequently, TPC presented a lot of research on site characterization in a zone called the K-area, which is a granitic site.

Regarding the technical concept, TPC decided to take over the KBS-3 concept which has been developed in Sweden. TPC also started a close cooperation with SKB, the Swedish implementer, with a lot of continuous exchange of technical and scientific information.

Through the technology transfer of the KBS-3 concept from Sweden to Taiwan, a clear disposal option and safety concept (at a conceptual level) has been adopted for the Taiwanese spent nuclear fuel disposal programme. The IRT review confirms a good conceptualisation of the KBS-3 system in SNFD2017. In the view of the IRT, this is considered a big advantage as it provides a very good base for the further realisation of the programme.

Some questions remain regarding the transfer from the reference Swedish concept to a real crystalline rock site in Taiwan. In the view of the IRT these are non-crucial questions, but they must be addressed as part of the ongoing and future programme. Examples for those questions include:

- Do the specifics of the Taiwanese disposal programme boundary conditions give a need for modifications of the technical concept and its components?
- Does the Taiwanese legal situation on retrievability give a need for an adjustment of the technical concept (e.g. canister, backfill, technical procedures for closing a deposition hole or a deposition tunnel)?
- How do uncertainties differ for the KBS-3 concept in the Taiwanese boundary conditions? In particular, what data is directly transferable, what safety margins exist and how are these taken into account and managed in preparation for site assessment when recognising that the performance of the system will require a good handle on uncertainty treatment?

Conclusions:

To start in the SNFD2017 with the well-developed KBS-3 concept is in the view of the IRT a big advantage and a good base for the further realisation of the disposal programme of Taiwan.

IRT recommends that early in the next stage a systematic evaluation shall be performed, which gives a clear view

- in which fields adjustments to the concept are necessary or helpful, and
- in which fields a 1:1 transfer of the Swedish concept is appropriate.

3.4. Technology transfer

SNFD-organisations are about to embark on more applied work as the programme moves towards the siting stage where they will be required to put the learning from SNFD2017 into practice. This is technology transfer: where there will be the need to adapt their learnings to different conditions. This is logically an extension of their learnings and not simple duplication. At the same time, there is a shift of the nature of work from research-based to implementation-oriented.

In SNFD2017 and during the March meeting at TPC, the prospective necessity of flexibility when applying the learnings to domestic sites was frequently emphasised by presenters, suggesting they were well aware of the challenges of the next stage of the programme. Therefore, the IRT highlights the question of how flexibility can be realised?

Here, we will take, as an example, the case of computation of seismic shearing of the canister and buffer. Popular commercial software programs could calculate details of mechanical response, if boundary conditions were given appropriately. TPC followed the SKB methodology, which had given the boundary conditions in the form of the rock's shear displacement value. The requirement prescribed in SNFD is as 5cm or 10cm, derived from SKBs design value, without any justification or supporting information for how this relates to the Taiwan boundary conditions. This is understandable if the researchers' concern was based on the study of computing practices. But now that the application of the developed methodologies for support of site assessment moves closer, there is a need to understand clearly the derivation of requirements that are directly applicable to the Taiwan disposal programme, and can be taken over directly, versus those that need to be evaluated and justified appropriately for different boundary conditions to those in other national programmes.

Study of the theoretical process that arrived at the 5cm and 10cm, will be a good entry point into a know-how transfer process. TPC will need to shift its focus from computation skills to capability of setting the boundary conditions or other input parameters. In the example chosen, a new alternative model that is more relevant to high seismicity areas like Taiwan may be developed.

Conclusions

In the future site selection stage of the programme, a major component will be the completion of site assessment and further safety analyses using detailed site data from site characterisation activities. This will involve the re-evaluation of technology (and data) transferred from other international programmes for suitability for use by the Taiwan disposal programme. Maintaining flexibility within the programme to adapt available technology options is strongly recommended.

Close cooperation between the site characterization team and the computation team is also advised. For example, current advanced computational fluid dynamic (CFD) codes have strict requirements for input data, requiring users to have appropriate training and experience. Therefore, the computational teams need to establish important targets for safety-assessment calculations and inform them to the site survey team. Detailed comparison between measurements and calculations will be valuable for both teams. Simultaneously, the computation teams need to prepare for complex parameter definition and data selection in readiness for site assessment.

3.5. Management aspects within implementation

Civil engineering has paid considerable attention to management issues through its long history since the very beginning of the days of *l'ingénieur civil* who built up the modern civil engineering. Taking a holistic approach, their work integrates the assessment of environmental impacts and social requirements, including cost estimation works which influence design and management practices alongside safety factors.

While current civil engineering has become an enormous entity of know-how, the spirit of *l'ingénieur* remains at its core. For example, in any big construction project, survey of the environment has become a standardised component including environmental impact assessment to consider the near-term impacts, in addition to those covered by the long-term safety assessment of the disposal facility. This important aspect does not alter the engineering and design principles operating at the heart of a major infrastructure project such as constructing a geological disposal facility.

Today, implementing geological disposal requires broad technical expertise combined with strong dialogue and engagement with a large and diverse group of stakeholders, among which the public and government are highly influential. The implementer needs to rightly respond to and appropriately manage these important stakeholder requirements, taking account of the people-government dimension reflected in the country's political climate. A huge number of factors therefore contribute to this process, which requires careful management during implementation.

Despite that, within the different facets of the programmes management system, there are different considerations regarding governance, timescales, openness and transparency of decision making processes that directly affect the ability of the programme to be successfully implemented. Construction of big facilities is a long process, where researchers/engineers are faced with unanticipated events and the need to solve problems regularly. They have to be able to operate quickly, seek and find solutions, define new approaches and organise task forces. Progress of other disposal programmes (e.g. in Sweden and Finland) that are entering the construction stage have benefited from a management approach geared up for implementation, experienced and ready for the task at hand, and with a clear mandate to fulfil the roles and responsibilities through the establishment of procedures and good practices for managing such large multi-disciplinary projects.

Conclusions

The development and construction of a nuclear waste disposal facility requires an agile management approach. The future organisation that is currently in development in Taiwan and that will be formally mandated to act in the role of the implementing body, will be expected to adopt such a management approach and develop its management procedures as the programme progresses.

3.6. Final disposal in host rocks other than granite

In the middle of the current stage of the disposal programme, TPC performed the study '*Preliminary Technical Feasibility Assessment Report on Spent Fuel Final Disposal*' (TPC, 2009) to compile and analyse the research results from Taiwan's spent fuel disposal program over the past 20 years. The study concluded that three potential host rocks exist in Taiwan (granite, mudstone, and Mesozoic basement rock) for siting a disposal facility for spent nuclear fuel. SNFD2017 adheres to this conclusion, but heavily focuses on granitic data and the setting of the current boundary condition to consider the K-area as a reference site. Therefore, within SNFD2017, the description of granite and the KBS-3 system is detailed enough for a preliminary safety case. For the other potential host rocks, SNFD2017 gives no technical concept for disposal and not enough detailed geological information.

IRT agrees that it is good practice to consider the broad range of possible host rock formations nationally. In doing so, one has more possibilities for finding a suitable site.

In addition to geosynthesis of other host rocks, it is equally important to understand the key controls for siting a disposal facility in rocks with different characteristics and properties to granite:

- For other host rocks, another technical concept of disposal becomes necessary;
- The exploration methods for other types of host rock can be (more or less) different from those performed to explore granite sites; and
- Some other possible host rocks in Taiwan are not accessible for deep tunnel disposal because they are too deep for this technique (i.e. part of the Mesozoic basement rock). SNFD2017 and the questionnaire (IRT 2017b; see Q 1-15) discuss consideration of deep borehole disposal at those sites. In that case, the technical conditions for both exploration and disposal operation are extremely different from the experience of “traditional” disposal.

SNFD2017 is limited to conceptualisation of a tunnel concept in granite host rock and is not a basis for future safety assessment in other host rocks (e.g. mudstones) or other technical concepts (deep borehole disposal). Therefore, the transfer of experience gained in the first stage of the stepwise development process (as described in SNFD 2017) to other host rocks is clearly more challenging than the transfer to other granitic sites.

In the case of a decision to explore sites in mudstone and/or Mesozoic basement rock, in the view of the IRT a systematic re-evaluation of the existing experience becomes necessary. Regarding the technical concept, it then becomes necessary to develop a concept for each type of host rock under investigation, either by adaption of an existing concept or by developing a new concept. Regarding the methods of investigation and site characterisation an adaption of existing experience is likely to be necessary.

Conclusions

The IRT recommends that early in the next stage of the disposal programme a re-evaluation of the experience in the light of its transfer to other host rocks should be performed. Depending upon the results a programme to develop both adequate characterization methods and technical concepts should be started.

Independent from these needs it could be helpful, if host rock other than granite is seriously considered, to carefully consider how the parallel exploration and comparison of possible host rocks would be managed during the initial site assessment period. This should include technical criteria for different host rocks, in addition to the preparing for the practicalities of managing and financing the acquisition of data for more than one site to support key decision making. Such a clear statement and strategy is required to be put in place by the relevant Taiwanese authorities to support open and transparent discussions with key stakeholders. Based on the outcome of Taiwanese authority siting advice, the future programme may need to consider a more comprehensive coverage of other potential host rocks in Taiwan.

3.7. Necessary volume of the disposal facility

The volume of waste influences the necessary size of the disposal facilities.

In SNFD2017, the types of high-level radioactive waste to be disposed in the future disposal facility are adequately described. It is clearly stated, that only spent fuel from the operation of the Taiwanese Nuclear Power Plants (NPPs) is assumed. One important consideration in calculating total quantities of spent fuel from Taiwanese NPPs is the assumption regarding the extent of reprocessing, fuel treatment processing and the design packaging assumptions.

The basis for the calculation of approximately 5,000 tons of spent nuclear fuel is an operation time period of 40 years of the existing six nuclear reactors in Taiwan. Regarding the dates of start one can see that 40 years will be fulfilled between 2017 and 2025. The actual legal situation in Taiwan does not allow operation of a nuclear reactor longer than 40 years. At a first glance this means that the calculation of volumes meets the maximum number of spent fuel bundles which will arise.

In the view of the IRT it nevertheless would be helpful if a certain degree of conservativism be added to ensure that the chosen site has enough capacity to take account of uncertainties (i.e. non-predictable circumstances that make more space necessary). Following the KBS-3 concept, rock suitability criteria are used to accept or reject disposal locations after the disposal hole itself is drilled. This may result in potential disposal areas with low utilisation, and requirement for additional volume.

Whether a drilled hole can be used or not, depends on:

- Existing cracks in the wall of the specific hole, which show a local fault cutting through the disposal hole; this means that stronger shear loads for the bentonite/canister system are possible which exclude the use of this hole;
- Possible local findings in the wall of a drilled hole that cannot be evaluated remotely, resulting in drilled holes that have to be excluded.

It is not possible to see these situations earlier in the process before the drilling is done. Both effects reduce the number of holes usable for disposal of the total number of the canisters. In other ways, this leads to the need to provide a higher number of disposal holes than resulting from a calculation on the base of necessary canisters. It is important to decide on the necessary conservativism in terms of a higher number of necessary holes early in the process, because it influences the necessary usable volume of host rock.

Conclusions:

In the view of IRT it will be helpful to define the degree of conservativism in the number of necessary deposition holes to cope with non-predictable circumstances. This influences the necessary volume of the final disposal, and should be considered in the future stage of site selection.

3.8. High active waste other than spent fuel

Beside SNF some other material exists which has a high content of radioactivity, which can exceed the upper margins defined for medium level waste.

One group of other high level radioactive waste comprises materials from nuclear power reactors. Examples are control rods, fuel element boxes from BWRs, highly irradiated core equipment. The other group consists of material with high content of radioactivity from other applications (e.g. irradiation in research, medical and industrial applications). Both groups include very different types of material regarding their mechanical and chemical forms and also their content of specific isotopes.

Some of these materials clearly differ from the standard low and medium activity wastes. Therefore, the question will come up whether it is possible to dispose of them in a disposal facility for low and medium activity waste or whether it is more appropriate to handle those materials together with spent nuclear fuel.

The experience in other countries shows that, depending on the waste classification scheme adopted, a broad range of waste disposal routes are considered for the full national waste inventory for higher activity wastes. Wastes destined for different treatment or disposal facilities at present may change in the future. As TPC pointed out in answer 1-6 (IRT, 2017b), there exists a clear legal definition in Taiwan. But it seems that the definition does not reflect the technical situation regarding the above-mentioned wastes. The IRT suggests that the relevant authorities in Taiwan analyse the detailed types of waste potentially destined for disposal, including both their upper potential packaged volume and total activity during the next update and revision of the national waste inventory. Based on this it would be helpful to decide which types of these waste will be disposed where. It should be decided whether these materials also have to be disposed in the disposal for SNF or, if not, in which other way they have to be handled or disposed.

For the siting process of high level waste disposal it is helpful to know which other waste types could be included. Primarily this is important in terms of technical concept and size. On the other hand, a clear decision also can help in the debate with the public. In some cases public perception is quite negative if the waste inventory is changed after the process has started, especially when a new type of material is added even if it is not a large amount.

Conclusions:

The IRT recommends gaining clear information on the amount of other wastes which will possibly not fit with the planned disposal for low and medium level waste. With that information it would be helpful to decide whether those wastes have to be disposed in the disposal for high level wastes, and as a consequence, it may require a different concept for those waste (i.e. to check if KBS-3 is an appropriate concept for such waste types).

3.9. How will the public be involved in future stages of the program?

The experience in many countries, which are implementing a radioactive waste disposal programme, shows a strong need for involvement of the public. The public always asks for participation in such a process. In these countries the interaction with the public influences strongly the success of specific steps of the implementation process and even of the process as a whole. Poor interactions with the public can create difficulties leading to longer implementation timescales or result in restarting the process under new conditions (e.g. Germany).

One lesson from the successful countries is that the process of interaction with the public runs smoother if the roles and rules of the process are clearly defined. This includes, for example, the formats to be used for the interaction, the rules for transparency, the definition of roles for individuals and groups (e.g. implementer, national government, local government, citizen groups) and fixing of points/periods in time, in which specific interaction is foreseen.

In the view of the IRT it is important to realise that the approach adopted strongly depends on national culture and experience, so exactly transferring experience from one country to another country is often not possible.

The IRT has observed that for the first phase in the Taiwanese program there has been no formal process for interaction with the public. Therefore the IRT has put a question to TPC '*1-17 How will the public be involved in future stages of the program?*' (IRT, 2017b).

In the answer TPC pointed out: "*For now, Taiwan doesn't establish the siting law, but we learned from the international practices that siting by the consent-based process would be high possibility to success. TPC will suggest to the legislators that invite public to participate in the process of making siting law and provide the information to stakeholders transparently shall be included. The related activities include Information-sharing, open discussion, answering questions, and mutual learning with potentially interested stakeholders. These activities will continue throughout the consent-based siting process"* (IRT, 2017b).

The IRT´s understanding of this answer is that TPC sees the need to involve the public in the future. According to the international experience all players, including the government and other stakeholders, are important in developing a specific process of interaction with the public in their country.

According to the experience of the members of IRT, it can be helpful to give specific attention to different parts of the public. 'Public' is often considered to mean the general public. But there are important sectors of the public with specific importance within the process. This includes people with background in natural sciences and/or engineering, because they are very often interested in detailed discussion and diverging proposals related to geological disposal. Another specific sector of the public are those geologists who are not part of the siting process; they of course have a good knowledge of geology of Taiwan. It can be very helpful, if the process of interaction with the public includes specific possibilities for both of these groups.

For future SNFD studies, it will be important to consider the addition of contextual or background information to effectively communicate the research results to interested stakeholders (including the general public).

4. Detailed findings regarding geology and suitable granite formation

The geological environment of Taiwan presented in Chapter 3 and the respective supporting report of SNFD2017 play a key role in supporting and determining the approach to future site selection processes and siting criteria, in addition to demonstrating the technical feasibility of current engineering techniques and safety assessment technology in Taiwan with a high reliability.

The review was carried out to evaluate scientific validity of the text on the original objectives that TPC defined as follows:

- Whether a scientifically suitable granite body can be located in Taiwan for geological disposal?
- Whether Taiwan's techniques are feasible for deep geological characterization?

In response to the objectives, the review work mainly focuses on the critical features and processes that could have a great effect on the safety functions. Also the following questions were defined to proceed and articulate conclusions effectively given the early stage of the disposal programme and the large amount of information presented:

- Is the geosynthesis of the K-area carried out according to the international state of the art and is this communicated well by TPC (as far as one can read in the published documents)?
- How traceable are the application of the methods used and the measurements and calculations?

4.1. The Role of the geosphere in disposal

The description in this section is clear and well structured, covering an appropriate and comprehensive range of topics. However, it was felt that the required functions in the geosphere could be more clearly stated by using the same figure as in the safety assessment (i.e. R1 - R4 in the Figure 5-4). Also, it would be easy to understand for readers if this figure could be described in the earlier section (i.e. Section 2. Geological disposal System and Safety Concept).

4.1.1. Geological setting of Taiwan

The linkage and hierarchal structure between the main reports and the supporting reports is unclear in this section. For example, the volume of the text in the supporting report (10 pages) does not greatly differ from that in the main report (7 pages). In some parts, exactly the same texts are written in both the main and the supporting reports (e.g. (9) Volcanic activities and (10) Faulting and seismicity). Therefore, it would be expected to re-organise the levels of context in the main and the supporting reports (the same comment applies to other chapters).

Technically, the documentation provides readers with an appropriate level of detailed information to understand an overview of the Taiwanese geology with the exception of citation matters. There still remain scientific claims without citations.

4.1.2. Tectonic Setting and Evolution of Taiwan

The document here was described appropriately with enough evidence in terms of the current scientific level.

Conclusions

The IRT understand the geological setting (i.e. the K-area and focus on granite) as a specified boundary condition decided at the outset of SNFD2017. However, the contextual background and high-level information on the role of the geosphere in the disposal concept and key boundary conditions that affect its treatment in the safety case should be defined well upfront so that they can be referred to in later chapters, without the need for repetition. In particular, it is critical to provide an overview of the key characteristic of the geological setting of Taiwan that would impact the setting of timescales, initial boundary conditions and spatial and temporal evolutions in the post-closure phase. Note that these aspects are always kept in plain words as much as possible.

The IRT also recommends to check the documentation thoroughly and include proper citations where claims or assumptions are made in future updates (the same comment applies to all main technical chapters of SNFD2017).

4.2. Feasibility of siting a repository in Taiwan

4.2.1. Volcanism

In general, enough scientific information on each volcanic process was provided based on a considerable amount of references in this section. However, it is difficult to determine the possibility of avoidance of volcanic activities within the granitic area for the next million years. If TPC wishes to show the long-term stability of the granitic area in terms of volcanism, more straightforward facts and interpretations should be described by focusing long-term trends and/or patterns of volcanism in Taiwan. For example, the plate reconstruction results in the Figure 3-7 (b) (3) and the tectonomagmatic evolution in the Figure 3-8 would be useful for this work, because they show the systematic plate movement and the expectable volcano formation/shift from the several million years ago to the present.

Although it might not have a direct implication on volcanism in Taiwan, the high thermal gradient points along the Lishan fault (Figure 3-36 (a) (1)) should be considered from the standpoint of deep crustal fluid. This would be also related to the Kueishan Island volcanism and the surrounding rift-fault system where there is the line that extends of the Lishan fault.

It is understandable that SNFD2017 does not cover the topic of “deep crustal fluid” at the present moment, however, nationwide investigations by using seismic tomography, MT resistivity survey, denser data of geothermal gradient (in boreholes and hot springs) and soil/groundwater gas data to exclude possible highly connecting structures are recommended for future processes. The Lishan fault would be prioritised in terms of its dimension and the location where there is mudstone as another potential host rock.

4.2.2. Faulting and seismicity

The similar kind of question as for volcanism is raised in this section. The phrase of "The active faults are mainly distributed in three neotectonic areas: the deformation front of Western Foothill, the Longitudinal Valley in East Taiwan and the Northern Extensional Region" on page 3-48 must be the most important results, but the claim would be strengthened more if it could be indicated that there is little possibility of active faulting in the granitic area for the next one million years. The capability to avoid significant neotectonic activities is the essential point for the safety case.

4.2.3. Diapirism

The document here describes the situation appropriately with enough evidence in terms of the current scientific level.

4.2.4. Uplift/subsidence

A lot of data are presented here. The applied investigations and the conclusions seem to be reasonable and acceptable, considering both the techniques utilised and the data quantity and data quality. However, it would be nicer to draw the current interpretation that is described in 3.2.4. (3) and (4) as a conceptual model. At least the H-area and the K-area should be described in more detail for the next one million years. It is also not clear which data were used for the safety assessment (or the reason for not to consider the uplift and subsidence process).

4.2.5. Climate and sea level changes

The document here describes the situation appropriately with enough evidence in terms of the current scientific level.

4.2.6. Natural Resources of Taiwan

The document here describes the situation appropriately with enough evidence in terms of the current scientific level.

4.2.7. Potential Host Rocks of Taiwan

To avoid misleading or withholding information from the reader, the documentation should be clearer regarding decisions or reasoning for prioritising granitic rocks as a preference host rock in Taiwan. Scientifically, comparison of the geological characteristics in each potential host rock could be presented, based on available data and research results. Considering the limitation of data at the current phase, there would be more direct data and more comprehensive assessments for deciding the final host rock in Taiwan during future stages of the programme.

Conclusions

SNFD2017 shows that there exist stable areas not affected by active volcanoes, active faults and other significant neotectonic activities, and this evidence is presented more confidently than in SNFD 2009. Viewed in the granitic rock areas, a good indication of the long-term stability in the past to the present day is presented, with future improvements anticipated during siting to expand knowledge for the long-term (i.e. to be clear that this continues in the future).

The future programme should consider a more comprehensive coverage of all potential host rocks in Taiwan, especially avoiding significant neotectonic activities for the next one million years.

4.3. Geosynthesis of granite host rock

A lot of data was collected by the surface-based investigations in the K-area and it was transferred to the engineering analyses and the safety assessment as a well-summarised dataset. In general, it met current requirements in terms of data completeness, data quantity and data quality although there is uncertainty in relation to the area specific problems (ex. available data is limited to K-area, geological/hydrogeological heterogeneity of the granite). IRT recommends the following practical issues for the future siting phases in Taiwan.

4.3.1. Strategic data management

As shown in Fig-3-26 (b), the hydraulic conductivity data taken from the intact rock parts are quite limited compared to the ones of the MWCFs. More balanced data strategies from the barrier function viewpoint would be required for the precise safety assessment.

4.3.2. QC/QA systems

TPC is likely to adapt as much data as possible for answering the questions in this section. It must be a straightforward attitude as a scientist, however, there still remain vague data such as dissolved oxygen (DO) in the groundwater. Two sets of DO values are reported for each corresponding Eh value for some reason in the final dataset. It shows low Eh value in some data, nevertheless a certain value of DO was also reported. According to the answers on the IRT questionnaire, TPC clearly recognised this issue as the electrode problem. If so, this should be dealt with more carefully for the final data set based on clear criteria (i.e. QC/QA system). Same thing could apply to the data of charge balance in the groundwater.

It is also not clear what processes are considered to fix the final data in some cases. Though it must have a long process to finalise Eh value and penetration depth, for example, there is little information even in the supporting report.

4.3.3. Reproducibility

It is still hard to reproduce the same models even if we read the supporting report deeply. For example, there needs to be prepared the composite log that is composed of parallel drawn fracture frequency, location of fracture zones, hydraulic conductivity/transmissivity profiles and pore water pressures in each borehole for making the DFN model at least. It must be described in the references somehow but many documents could not be accessed at ease.

In the same way as SKB or POSIVA, all data and modelling reports need to be published/opened as the TPC's official report, and then those are fully integrated and interconnected into the summary report (corresponding to the level of the supporting report in SNFD2017). Such a hierarchical report system with full accessibility would make a more robust safety case report.

Conclusions

The geological characteristics in the K-area were obtained and characterised by a well-organised approach, and were integrated for developing the site descriptive models adequately.

The items of data are mostly covered for performing preliminary engineering analyses and the safety assessment. In comparison with the front-running projects in other countries, there is room to further improve reliability of the results, especially in data quality and model validation/verification.

The IRT recommends developing the planned 'Data Management System' and to integrate it with the planned 'Database System'. There are no perfect success examples internationally; however, it is expected that the Taiwanese project can contribute greatly to this challenging task in the future work.

5. Detailed findings regarding repository design and engineering technology

In the framework of a stepwise disposal process, typically five phases describing broadly the progressive development of a repository (and its safety case) are considered together with information necessary in each phase (IAEA, 2014). These phases are the site evaluation and site selection phase (which includes facility conceptualisation), the site characterisation phase (which includes engineering and facility design), the facility construction phase (and license application for construction), the facility operation and closure phase, and the post-closure phase.

TPC has adopted an advanced safety concept and design from the Swedish KBS-3 concept but the disposal site has not yet been selected. Therefore, it can be considered that the Taiwanese process is somewhere between phases 1 and 2 (i.e. between conceptualization and reference design) because of the advanced design and conceptualization.

In this chapter the maturity of the Taiwanese disposal program is reviewed with respect to the criteria that are foreseen in these phases.

5.1. The engineered barrier system

5.1.1. Spent nuclear fuel

An overview of spent nuclear fuel (SNF) characterization is provided and averaged fuel parameter values for enrichment of the fresh fuel, burn-up, and decay heat are provided. Information is sufficient to carry out the required source term calculations based on defining a representative reference inventory that takes account of the full range of SNF.

The method for deriving the reference inventory from the activity calculations is presented.

The source term is appropriately set up according to different radionuclide inventories in the SNF components, and different release (i.e., dissolution rate for UO2 matrix and instant release fraction) rates of these radionuclides into groundwater once the containment is breached. Corrosion rates for cladding and structural steels are not mentioned. Even if they are not needed for the current approach to determine the source term, it would be helpful to address them in later stages.

No detailed information or implied impacts on the source term relating to possible leakage or damage in the fuel rod or bundle are provided.

SNFD2017 does not assign any functions or set performance indicators for spent nuclear fuel.

One conceptual model to describe the source term is used and applied to all fuel types in the inventory, irrespective of irradiation history.

Fuel dissolution is assumed to take place at a constant fractional rate, with congruent release of radionuclides. For the UO2 matrix, the release rate of 10-7/year is selected, which is sufficient and includes a clear statement of the cautious nature of this rate.

The amount and behaviour of the instant release fraction (IRF) is presented.

Conclusions

SNFD2017 adequately characterises SNF and the source term for this stage of the disposal licensing process.

The waste acceptance criteria (WAC) should be considered regarding inventory of the most significant nuclides and fuel alteration rate which are consistent with the analysis made in the safety case. WAC should also include other criteria which are significant for operational safety.

5.1.2. Canister

SNFD2017 states that highly pure oxygen-free copper has been chosen for the shell material because of its well-known corrosion-resistance properties. Cast iron has been chosen for the insert to provide mechanical strength, radiation shielding and to maintain the fuel assemblies in the required configuration.

It is noted that '*The basic function of a canister is to confine the spent nuclear fuel and its radioactive materials inside the canister, so as to prevent radionuclides from leaking into biosphere and meet the statutory requirements set forth in the laws and regulations governing the radiation safety during the operation*.'. According to the report, the requirements for the canister are: to withstand isostatic pressure, uneven swelling pressure, rock shear load and corrosion load. The canister is also required to act as a barrier for limiting radiation dose and to limit surface radiation dose rate, and to prevent criticality.

It also noted that the cast iron insert provides good mechanical properties. Therefore, there is a relationship between canister material properties and safety functions.

Copper has been chosen as the shell material for its well-known properties and resistance to corrosion in reducing environment, which can be considered to be appropriate. However, there are emerging issues regarding corrosion resistance of copper when the processes involved are not well understood at present. SNFD2017 mentions all the relevant processes regarding general corrosion and a clear statement that localized corrosion does not occur is made. However, justification for that statement is missing.

There are also issues regarding the mechanical properties of copper e.g. creep resistance of copper.

The materials for the canister has been selected appropriately based on properties of canister materials and the majority of the critical properties are well understood at the present. However, there are some topics (especially copper creep and corrosion) that need further clarification in the future.

Canister manufacturing and inspection methods are described on a general level which is appropriate at this phase.

Sealing method for the canister: Friction Stir Welding (FSW) has been chosen for its quality properties but the Electron Beam Welding (EBW) is mentioned.

Any allowable weld defects for FSW including defect types that are not allowed in high quality weldments are not mentioned. IRT recommends that development of FSW (with SKB) will continue concerning this area.

The preliminary acceptance criteria for the canister components have been set.

The very general description of the manufacturing methods for the canister components fulfils the required level at this phase.

Performance of the canister is assessed partly by referring to the SKB reports and partly by reproducing SKB analysis with limited amount of local data and characteristics, e.g. corrosion assessment and mechanical analysis.

The creep properties of FSW are almost the same as for the base material. The main reasons for these results are that variation in the microstructure between the weld and the base material is small and matches previous studies as in grain size. Creep ductility of copper is a function of creep/strain rate, which is controlled by the evolution of the external pressure on the canister. Possible large variation in strain rate caused by possible large variation in buffer re-saturation time could implicate creep-ductility failure of the copper canister arising from delayed saturation. IRT recommends more studies to confirm current interpretations of this issue after and during site selection and characterization.

From SNFD2017 reports that are based on the mechanical analysis it seems that the safety factor is around 1,5 in the case of isostatic loading. Design analysis regarding the shear displacement gives a safety factor slightly above one in all cases variants being shear angle and shear displacement.

Different corrosion processes and chemical loads have been taken into account and corrosion depth due to different corrosion processes are mentioned. The chemical integrity of the copper overpack is highly dependent on the performance of the buffer and on sulphide concentration in the groundwater, although there are numerous aggressive species or processes that can affect the corrosion rate of the copper overpack, such as oxygen, chloride, nitrogen compounds, acetates, ammonia, radiation, microbes, etc. The bentonite buffer is expected to limit the transport of aggressive species towards the canister, which is the most important assumption regarding chemical integrity of the copper overpack.

Approach for evaluating corrosion is based on thermodynamic and mass-transport-limited approaches. The longest phase or period of time is the anoxic phase, after oxygen has been consumed, and buffer re-saturation, when corrosion is expected to be caused only by sulphide and chloride. According to calculations SNFD2017 indicates that general corrosion is not the determining factor when designing canister wall thickness.

Localized corrosion processes have been ruled out, e.g. pitting, crevice corrosion and stress corrosion cracking (SCC).

The key uncertainties regarding corrosion of copper are thus in processes such as corrosion in oxygen-free water, microbial-induced corrosion and SCC. There has also been discussion about hydrogen embrittlement of copper, radiation induced corrosion of copper and SCC caused by sulphides.

Conclusions

The performance of the canister has been described and justified adequately at this phase. However, there will remain uncertainties regarding performance of the canister that shall need further research, development and demonstration (RD&D) work in the future. Furthermore, once the disposal programme enters into the next stage, it will be important to update the performance assessment with local data after site selection and to complete a thorough site characterisation process. The performance assessment should address the recognised uncertainties which can be handled in the safety case, e.g. by the means of scenario methodology or sensitivity analysis.

5.1.3. Buffer, backfill and plug

The functions of the buffer are to deliver containment and retardation as part of the safety design of the repository.

SNFD2017 states that the functions of the buffer are provided by the THMC-properties and gas permeability. Based on the SNFD2017 the functions of the buffer are to limit advective transport of groundwater, to limit microbial activity, to damp rock shear movements, to resist transformation, to keep the canister in position, to keep limited pressure on canister and rock, to prevent colloid transport through buffer, to sorb radionuclides and to allow gas passage. SNFD2017 describes the evolution of buffer from unsaturated conditions to saturated conditions and also water vapour diffusion.

The SNFD2017 states that the functions of the backfill are to sustain the deposition tunnel, keep the buffer in place and limit the flow of groundwater, and the safety functions of the backfill are to restrict upwards buffer swelling, to limit flow of water (advective transport) in deposition tunnels and to sorb radionuclides.

The description of long-term stability of bentonite and backfill materials under repository conditions requires future consideration of safety-relevant knowledge gaps currently under investigation in several national disposal programmes considering clay-based barriers. Examples of such knowledge gaps that may influence performance of the system include the long-term chemical stability of montmorillonite and microbial activity in the buffer and backfill.

SNFD2017 presents the reference buffer material, MX-80 type, with a montmorillonite content 75-90 wt% and other design parameters and requirements. For the backfill no reference material is mentioned but the design requirements are presented respectively.

The design of the plug is the current dome-shaped reference design for the Swedish KBS-3 concept.

The performance assessment of the buffer, backfill and plug strongly relies on SKB references, which is understandable when adopting an advanced disposal concept. In other countries conditions and events have been identified that may have an effect on the performance of the buffer and backfill and that may affect post-closure safety. Such conditions and events are eg. reduction of sulphate to sulphide, which causes corrosion of the canister overpack, in low-density areas due to insufficient homogenisation of backfill, and chemical erosion of the buffer due to infiltrated fresh water, which may reduce the buffer density in some deposition holes.

In addition to identified conditions and events listed above, the possible factors that may affect the performance of the buffer and backfill may include the following, for example:

- mineralogical transformation of montmorillonite clay in the disposal groundwater conditions;
- microbial activity that may contribute to formation of sulphide, which causes canister corrosion, and dissolution of montmorillonite;
- piping erosion due to groundwater flow from the disposal hole to the disposal tunnel; and
- cementation of the buffer, which may, for example, reduce its plasticity and swelling properties.

Especially microbial activity and the mineralogical transformation of montmorillonite can be considered significant in terms of buffer and backfill performance because their effects may impair the performance of the barrier safety functions in the deposition tunnel and deposition hole. These factors can affect each canister, thereby accelerating their loss of integrity. Piping erosion as a factor, even if it affects just a part of the deposition hole, may be a significant factor that affects the buffer and canister performance because it takes place during the early stage of disposal, which enables it to have a significant effect on the later development of the surroundings of the deposition holes. Cementation of the buffer is a key factor when evaluating the possible effects of rock displacement from seismic activity on the mechanical durability of canisters. In Sweden and Finland, significant uncertainties related to the time needed to reach the intended buffer and backfill performance have been identified, in other words significant uncertainties related to buffer re-saturation, time and mechanism, and their effects on the performance of the buffer remain.

Conclusions

The performance related issues such as those mentioned above require local site data after site selection and data gathered thorough the site characterisation process. The safety significance of the factors that affect the performance of barriers must be further specified by examining the effects of these factors and their related uncertainties on the performance of the buffer and backfill. In future performance assessments, a more detailed analysis regarding buffer re-saturation and performance assessment will be necessary when more comprehensive and confirmed local site data are available.

5.2. Disposal facility design

The disposal facility design includes three parts: the surface facilities, underground facilities and interconnecting facilities (shafts or ramps), as well as the disposal tunnels and disposal holes, which contains a variety of different structures, systems and components. SNFD2017 presents the design criteria of the disposal facility. Criteria refer to IAEA requirements, national regulations requirements, engineering requirements and some general criteria. Concerning disposal facility design SNFD2017 presents many aspects, one of them being optimisation.

In the optimisation of the design many different aspects are taken into account, such as thermal effects, effects of earthquakes and disposal hole space capacity. Discrete fracture network (DFN) model is used when assessing space capacity. IRT notes that

DFN is only a stochastic model based on limited amount of site investigations and actual capacity can only be verified during construction of the facility.

Thermal and earthquake analysis relies on SKB methodology and is reproduced in the SNFD2017.The most important boundary condition for avoiding thermal effects such as overheating of buffer is the buffer temperature which is set at 100 degrees Celsius. This parameter with the local site characteristics such as water content and conductivity of host rock determines the spacing between deposition holes among with fractures in the host rock. According to SNFD2017 the host rock temperature is higher in Taiwan than in Scandinavia; therefore the thermal analysis has been calculated under specific local conditions.

Methodology for earthquake analysis follows the similar methodology as in Sweden. Parameters considered in the analysis are fracture shear displacement, fracture radius, EQ magnitude, fracture orientation and distance between fracture and fault. The EQ analysis is supplemented with PSHA which is also done in Finland and Sweden.

Conclusions

The conceptual disposal facility design, derived from the thermal spatial requirements to meet the specified 100 degree Celsius thermal limit on the canister-buffer interface is appropriate for the current stage of the programme. Future works should consider how the facility design may need to be adapted for specific Taiwan boundary conditions (for example, alteration of the waste package for Taiwan spent fuel), or changes to the layout of the facility to accommodate aspects from other disposal concepts that may need special consideration in Taiwan (for example, multi-horizon layouts or changes to the emplacement technology of engineered barriers that would impact significantly the facility layout, such as prefabricated engineered barriers or so-called super container designs). The major works on adaptation of the facility design can only be made once potentially viable sites have been identified and detailed site characterisation has been completed, therefore until this time, it is appropriate that the disposal programme continue to progress ‘conceptual design’ development in a generic way and remain flexible to adaptation to address the full range of possible disposal concepts and site requirements that may arise.

5.3. Seismic analysis of the engineered technology

Many countries and researchers are interested in how Taiwan can overcome its seismic severity and succeed in building a geological disposal facility for radioactive waste. Taking into consideration the presentation given at the Taipei meeting, we have reviewed the described seismic hazard assessment (SHA) methods: considering probabilistic SHA (PSHA) versus deterministic SHA (DSHA).

Whenever PSHA is employed, it needs to be complemented by means of DSHA. This is particularly true when particular facilities like deep tunnels are treated. This is because DSHA has an immediate root in physics. Its reasoning is easier to accept intuitively (i.e. from an engineering viewpoint, it is intuitively digestible knowledge that is valuable because it often changes into tacit knowledge and further becomes settled beneath engineering senses).

While the 500m depth of the anticipated geological disposal facility is an unexplored region, past PSHAs were basically built on the records of seismic motion at the ground surface. Therefore, existing PSHA methods need to be applied carefully, i.e., a physics-based careful examination of their content is needed. PSHA never violates physics. Therefore, the best way to a deeper understanding of PSHA modelling would be a thorough re-development of the system by decomposing the whole scheme into components, and recompose them one by one based on physics. Usage of PSHA could be misleading if it is apart from such endorsement from physics.

Taiwan has a long history and rich knowledge of physics-based seismology and earthquake engineering. There are no concerns regarding the skills available for utilizing DSHA. However, improvements could be made in the future for how the results of such assessments are presented within the context of the safety case. Since the audience of the SNFD reports is not necessarily only specialists, but also politicians, administrators, and many stakeholders (including the general public), discussion of PSHA results should be carefully communicated to avoid, for example, statistical aggregation which could distort how the results are understood.

Conclusions

Multiplicity of analysis methods is common when solving complex phenomena, and PSHA is in this sense useful. There are many PSHA models: users need to study them, compare them and establish their own version. Specific areas that will require more precise analysis in the future once site-specific data are available include seismic interaction within the canister-buffer-rock system, and the possibility for giant nearby earthquakes during the pre-closure phase of implementation.

6. Detailed findings regarding safety assessment

The comments on this chapter refer to the safety assessment goal of SNFD2017 (TPC, 2017a), also listed as item (3) of the review's terms of reference (IRT, 2017a) '*to confirm whether adequate capabilities for assessing the long-term safety for a repository site have been established in Taiwan, or not*'.

6.1. Safety strategy and procedures

The baseline for post-closure safety evaluations are presented in the SNFD2017 reports.

Requests from national regulations are exposed which is an important input regarding the objectives and development of the SNFD2017 post-closure safety assessment. In that respect, major articles of the AEC 2013 (cf. TCP, 2017a) are listed in the reports.

The report also finds its foundation on an important collection of international literature (IAEA, NEA, and organisations' safety cases produced over the last decades) which is a good basis for building the SNFD2017 report and to outline where it stands relative to international good practice.

A list of safety principles has been formulated upon the IAEA SF-1 (IAEA, 2006), which shows the consistency in the main lines with the guidelines established by IAEA and NEA for deep geological disposal.

Such international review should be continued in future steps and complemented with some recent IAEA safety references such as, for example, the Radioactive Waste Disposal Facilities Safety Reference Levels report produced by the Western European Nuclear Regulators' Association (WENRA, 2014). It is now considered in some programmes as a safety reference document to conform to.

Conclusions

The overall safety strategy and principles which form the baseline for post-closure safety evaluations are presented in the SNFD2017 reports.

6.1.1. Safety approach

The SKB's eleven steps method for scenario development has successfully been applied. Safety arguments are presented. The reference evolution and a series of scenarios have been developed and quantified considering the KBS-3 concept and K-area data. Dose and risks have been evaluated showing capability to realise the calculations. Some sensitivity analyses have been performed and a set of arguments for future research and development are proposed.

Scenarios usually form the central part of post-closure safety assessment. The importance to have a good view on the scenario development method together with the base line guiding their identification and classification methodology is a clear objective of the SNFD2017 report (Chapter 5.1):

(1) *Develop safety assessment scenario development methodologies (and connection with the needed parameters);*

(2) Present the case based on the characteristics of the domestic geological environment;

(3) Complete planning for future objectives of the research and development program.

Current methodology used in the SFND2017 report for scenario development is modelled on SKB safety assessment methodology in the SR-site application. This procedure is structured in eleven steps. Each of these steps is explained in the reports.

A flow chart showing the main elements considered in the SNFD2017 post closure safety evaluation has been proposed. The main blocks of a safety case are there when compared to some international generic high-level flowchart as proposed in (NEA, 2014).

In future step, the approach would gain in clarity if a more detailed flowchart showing all the linkages between the different blocks necessary for the post closure safety evaluation was introduced to expose in a detailed manner the classification and place of the different scenarios in the overall approach, their assessment basis (request from national regulations, safety function, the scientific knowledge of FEPs, the design options…) and their linkage with uncertainty treatment, sensitivity analysis.

Other programs adopt such detailed flowchart to expose their safety assessment approach and procedures. Illustrations of such flowchart are given in the following recent international publications:

- PAMINA, Performance Assessment Methodologies in Application to Guide the Development of a Safe Case, 2011, A European Commission project (PAMINA, 2011).
- MeSA, Methods for Safety Assessment of Geological Disposal Facilities for Radioactive Waste, Outcomes of the NEA MeSA Initiative (NEA, 2012).
- Scenario Development Workshop Synopsis (NEA, 2016).

In the answer to question 5.1 of the first questionnaire (IRT, 2017b), it was clear that safety assessment teams are well aware of those more recent international practices (documented in NEA or IAEA reports) in terms of structure of a safety case and in term of scenario developments.

Conclusions

The structure adopted in the SNFD2017 is adequate at this stage considering the KBS-3 concept and the K-area granite.

Going forward, a more robust and fully-integrated approach in building a safety case needs to be developed when considering site-specific assessment.

The IRT recommends using those more advanced international practices in the future development of post closure safety assessments.

6.1.2. Safety assessment procedure

The procedure chosen for post-closure safety evaluation is clearly exposed. It consisted in applying the eleven steps method for scenario development of SKB.

Application of the procedure relies upon the KBS-3 concept and a defined site, the K-granite. SKB's methodology is an acknowledged method that has been successfully applied and conforms in the main lines to international practices.

The SNFD2017 reports indicate the capability to apply successfully the SKBs eleven steps methods for scenarios development. Such a procedure used at this stage considering the KBS-3 concept and K-granite is adequate.

The first step of the methodology for scenario development consists in a systematic FEP screening and processing. After building a FEP database, the analysis aims at identifying the features, events and processes that are to be included in the safety assessment.

Other programmes structure the scenario definition using a top-down approach, i.e. identifying first the crucial safety functions and then focusing on what combination of conditions can jeopardise one or more safety functions.

The scenario development approach described in SNFD2017 does make a clear link with safety functions, for example, it is indicated that the report aims to study the failure scenarios related to the safety function (chapter 5.7, p.5-105). It is the baseline to define causes or factor that can make the disposal system deviate from the reference evolution which is fully in line with international practices.

For future developments, it might be useful to consider the recent international practices in this area, which rely more on the use of safety functions at an early step in the approach. It is a practical way to expose the functions that natural and engineered barriers are expected to provide, at what periods and for which duration. This approach can be of some use to explore alternative ways to fulfilling safety functions.

Conclusions

The SNFD2017 reports indicate the capability to apply successfully SKBs eleven step method for scenario development.

The current international trends for scenario development should be considered in future steps with a focus on the development of intermediate level safety functions as a first step in order to clearly set the role of each component and derive scenarios and calculation cases on this basis.

Such a so-called top-down approach may reveal useful information for future siting, concept development, safety requirements, research program, and safety assessments.

6.1.3. Scope and objective of the safety assessment

The SNFD2017 reports present the objective of the post-closure safety assessment which is to evaluate the radiotoxicity of the spent nuclear fuel, and show that it conforms to dose and risk limits given by AEC 2013 (cf. TCP, 2017a). An annual effective dose limit of 0.25 mSv/yr (criteria for operational period, chapter 1.3.1 p. 1-8) is to be respected for public outside the facility. The disposal facility shall be designed to ensure that the personal annual risk caused by the radiation to a person in the key groups outside the facilities is not more than 1/1,000,000. Those values are used for all classes of scenario without distinction and consider them to apply for a one million years' timeframe. Therefore, the evaluations presented in chapter 5 of the main report are from disposal closure up to 1 Ma as a mean annual effective dose with a dose limit corresponding to the personal annual risk of 1/1,000,000.

Scope and objectives of the safety assessment relies upon the national regulations (AEC 2013) and an international review of dose and risk assessment limits used by other organisations or defined in international IAEA reference standard which indicates consistency with international practices.

It is to note that one million years for evaluation is sometimes questioned, see international NEA reports on timescales (NEA, 2012). For example, some programs consider the date of maximum release of a radionuclide, as calculated in a performance assessment, which can be after one million years.

It is indicated in the SNFD 2017 reports that the safety assessment strategy consists at this point of a combination of performance and safety assessments. The use of the combined term “safety/performance” is not a problem at this step.

Other programs structure their safety evaluation using those two notions in a distinct way. They usually follow the IAEA 2007 glossary which defines performance assessment and safety assessment as follow: *performance assessment can be applied to part of the system and doesn't require to assessment of radiological impact, when safety assessment include all aspect relevant to protection and safety, it includes siting, design and operation of the facility, this will normally include risk assessment* (IAEA Safety Glossary, Terminology used in nuclear safety and radiation protection 2007 edition, p. 24). Some programs (for example in France) consider the use of indicators other than dose or risk to evaluate the performance of some part of the component. It usually reveals to be useful, for example, to evaluate the attenuation and retardation brought by a component in the overall disposal system. Specific performance assessments are sometimes preferred because they are independent from biosphere uncertainties and they help to define design requirements.

Conclusions

The objective of the safety assessment and the radiological criteria to be respected are clearly exposed.

Some performance assessments (distinct from safety assessments) have been realised in the framework of the SNFD2017 reports which is appropriate.

The IRT recommends developing further such performance evaluations as it may provide insight to the development of design, particularly for the engineered barrier system.

6.2. Application of the scenario development procedures

6.2.1. FEPs and internal processes

A clear and detailed explanation of the FEP processing and elaboration of the Taiwan FEP database is presented in the SNFD 2017 reports and further illustrated in answers to the first questionnaire. An example of FEP processing tool has been provided (in Chinese) for illustration.

The first step of the methodology is the construction of a specific Taiwan FEP database using when possible the K-granite data. Then, a systematic FEP analysis is realised in order to identify the features, events and processes that are to be included in the safety assessment. The analyses identify features and events that may affect safety functions in order to derive the scenarios and calculation cases, which is in line with current international practices.

Completeness of the Taiwan database was assessed by comparison with the international NEA database which is current practice. It is to note that the NEA FEP data base has been updated which may prove useful for future comparisons.

The FEP processing step is also seen as the establishment of the initial and external conditions. In line with SKB approach, the links with processes are clearly exposed in the *process tables* of the main report.

Taiwan FEPs database as built today represent a powerful tool for safety assessment in the following area:

- to structure scientific and technological knowledge, especially for establishment of the initial and external conditions;
- for traceability, for example to keep track of uncertainties; and
- to identify causes and events that may jeopardise the safety functions.

Conclusions

The ability to build a specific Taiwan FEP database using the K-area data was clear and represents a good foundation for future development and integration of new data.

The approach considers the analyses of features and events that may affect safety functions in order to derive the scenarios and calculation cases, which is in line with current international practices.

A powerful tool of FEP processing has been developed. It should be considered in future step to develop further such a tool to gain in clarity with scenario selection and calculations cases having for example clear links with the safety functions the FEP can affect, and its modalities of treatment in scenarios (reference scenario, main scenarios, variant scenarios or disturbance scenario).

6.2.2. Safety functions, safety function indicators and safety function indicator criteria of the disposal system

It is indicated in the report that following the national regulations isolation is the first priority of a radioactive waste disposal. In SND2017 case, the isolation is provided by the depth of the repository in the bedrock. Containment and retardation are also two important topics introduced based on SKB experience, containment being the most important one.

Those safety functions are detailed in the reports in the SKB's structured way which is appropriate at this stage. It is indicated for example how the safety functions are used to identify all factors that cause an impact to be important or unimportant, direct or indirect, natural or manmade on the disposal facility. The potential loss of containment/retardation functions is examined.

This approach is in line with the international practices currently developed (sometimes so-called risk analysis for analogy with operational safety methods), and should be continued in future step.

The approach relies upon component properties as defined in KBS-3 and scientific knowledge obtained in K-area to define quantitative criteria. For example, it has been determined a posteriori that 5 cm of copper gives an adequate corrosion protection in a one million years' time frame.

An alternative way to proceed could be to define a more detailed intermediate level safety functions and perform performance evaluation of some component to set safety requirements and safety criteria. As mentioned in the answers given to the first series of question, the safety assessment teams are aware of more advanced international "top down" methods approach which rely upon a well-developed definition of safety functions as a first step (instead of FEP processing).

Conclusions

The safety functions are exposed with an emphasis on the containment function of the container. Going forward for future design optimisation with a selected site may require a more systematic development of safety functions and safety function criteria for all the main components (the container, the buffer/backfill and the geological barrier).

The IRT recommends to move forward in this direction as it may reveal helpful for design optimisation and examination of the robustness of the system in a more systematic way.

6.2.3. Scenario selection and classification

The classification of scenarios is presented. Two main classes have been considered (1) main scenarios and (2) disturbance scenarios with the following philosophy:

- Three main scenarios examine the canister failure mode based on the canister's safety functions: includes the corrosion scenario, shear load scenario and isostatic load scenario; and
- Disturbance scenarios are defined upon FEPs of external conditions that are unlikely to happen.

Main scenarios provide a qualitative description of the processes affecting the canister and then a description of the radionuclides pathways in the system up to the biosphere. In the context of Taiwan, the shear load scenario becomes the most important one for building the safety case.

Main scenarios consider:

- The base case which is constructed on the basis of the characterization of the K-area and the reference evolution;
- Variant cases which are considered to study the parameter conditions of the hydrogeological and geological models and to explore the effect of global warming, sulphides contents, …

Disturbance scenarios result from the FEP processing exploring potential effect on safety functions of external events from natural (global climate changes, geological evolution, and geological uncertainties) of anthropogenic origin (seal failure, abandonment of the disposal, container failure, inadvertent human intrusion and intended intrusion, wars…). They are important aspects of the safety case.

The categorisation in the two main classes (main and disturbance) scenario relies upon the likeliness of FEPs causing the failure of safety functions which is in line with current international practices.

The chosen classification refers to ICRP 122 (e.g. planned situations, emergency situations and existing situations). Some organisations prefer the scenario classification presented at the NEA scenario workshop (NEA, 2016) held in Paris in 2015 (e.g. normal evolution of the disposal, altered evolution scenario or disturbance scenarios, what-if scenarios) in order to make a clear link with likeliness of FEPs.

There is no problem in using either one. The NEA classification is sometimes adopted because the vocabulary is more in line with the following WENRA 2014 recommendations in terms of scenario development:

- DI-36: The licensee shall design the disposal facility giving due consideration to both normal evolution of the disposal system after closure and scenarios involving events and processes that might disturb the normal evolution of the disposal system.
- DI-101: The licensee shall include in the post-closure safety assessment a scenario analysis that considers the possible features, events and processes that might affect the performance of the disposal system, including events of low probability.

In all cases, inadvertent human intrusion and future human actions are usually addressed in a specific category at the international level (cf. IAEA HIDRA project launched in 2012 (IAEA, 2012)).

In this framework, some programs consider the notion of What-if scenario, or residual scenario to consider FEPs not likely to occur (as Finland, France and Sweden do, for example). Such scenarios may prove useful to address robustness of the disposal system.

Regarding scenario development within the safety case and safety assessment, key statements from IAEA guides can also be found in IAEA SSG-14, para 5.12; IAEA SSG-14, para 5.15; IAEA SSG-23, IAEA para 6.41; and IAEA SSG-29, para 5.18.

The SNFD2017 approach for scenario selection and categorisation follow in the main lines the international practices. The selection methodology could be more visible and gain in clarity with a detailed flowchart including scenario categorisation and linkages with assessments basis (e.g. safety functions and FEPs). As well, the generic rules for selecting scenario parameters, e.g. to justify the conservative character of the evaluation, could be more visible.

Traceability of assessment basis is an important input of safety cases. A large number of input data are presented in the SNFD 2017 reports submitted to the IRT. Some organisations now consider a self-supporting document, which is part of the safety case, for the collection of all input data used in the quantitative evaluation in order to gain in clarity and traceability.

For future development of safety cases, the IRT recommends to develop further traceability, transparency, and quality assurance systems.

The reference situation is presented in detail in the report based on the FEPs (data base of Taiwan), the initial state of the engineered components, the internal processes and analyses of variables, the external conditions and the activities of the current biosphere are taken into account. A detailed description of the evolution of the disposal system, thermal evolution, hydrogeology evolution, rock mechanics evolution, chemical evolution, the buffer and backfill evolution, and the canister evolution have been considered in a quite exhaustive analysis. This description is the basis for the description of the reference evolution. The logic to structure the reference evolution is based on SKBs approach which is in the main lines consistent with international practices for the description of the normal evolution scenarios.

Seal failure, abandonment of the disposal, and undetected structure in the geological rock were not considered to develop disturbance scenarios. The reason for not considering these could be more visible. At this stage, it is not a problem, but in a future step, a systematic approach should be considered with a complete set of scenarios.

Conclusions

The SNFD2017 approach for scenario selection and categorisation follow in the main lines the international practices. In future steps, the IRT recommends making the selection methodology more visible in the overall safety approach flowchart.

Scenarios related to the main containment function were developed in SNFD 2017 which was appropriate at this stage. It is to note that for future post-closure safety assessment a systematic approach should be considered with a complete set of scenarios, including all human intrusion scenarios.

The IRT recommends developing further traceability, transparency, quality assurance system in future safety cases.

6.3. Treatment of uncertainties in calculations

6.3.1. Utility of sensitivity analyses

Some sensitivity analyses are proposed in chapter 5 of the SNFD 2017 main report (TPC, 2017a). They mostly concern parameters necessary for the transport calculations in the corrosion scenario and in the shear load scenario. Such analyses are used to deduce a series of important parameters that may influence the evaluation of dose which is good practice.

At this step, sensitivity analyses are classified in reliability of the safety assessment in the SNFD2017 report (TPC, 2017a). The reasoning for the use of sensitivity analyses and the linkages of the results for future R&D could be more visible, for example, for future site screening and for identifying the need for future research on fuel dissolution rates and their importance to safety.

Sensitivity analyses are therefore important aspects in the iterative approach of a safety case. As seen in recent international literature, most organisations have a more extensive use of sensitivity analyses especially in supporting the performance assessments of the disposal system, and to ensure scenarios and their relevant calculations address key FEPs that are affecting safety functions of the disposal system. Those international approaches are in line with the IAEA WENRA recommendations (for example the DI-92 recommendation: *the licensee shall identify all uncertainties significant to safety and shall demonstrate that these uncertainties are adequately taken into account in the safety case. As part of the safety case, the licensee shall describe a program for uncertainty management*) (WENRA, 2014).

In line with those international practices, the use of sensitivity analyses initiated in the SNFD2017 report should be further developed and the linkages with uncertainty management and future R&D plans clearly exposed.

Conclusions

The IRT recommend exploring sensitivity analysis in a more extensive way to increase reliability of the safety case. This has wide applicability. In line with the development of safety cases, the use of sensitivity analyses in the overall safety case will have to be more visible and present clear linkages with future R&D plans and development of scenarios and their calculation cases in term of handling uncertainties.

Sensitivity analysis is not limited within natural processes; for example, the flowchart-based design method of project management has been developed in advanced countries and was treated in the SNFD documents and was discussed extensively in the query sessions.

6.3.2. Treatment and management of uncertainties

Safety Assessment of a deep geological disposal facility includes the use of long-term underground computational fluid dynamics, requiring progressive reduction of uncertainties in key parameters and models as the disposal programme develops. Calibration and verification of models should therefore continue with appropriate use of sensitivity analysis to guide developments.

Analysis of Geological Disposal Facilities (GDF) needs to combine the computational underground fluid dynamics with the long-term prediction of future evolution for the engineered barrier system, the host rock and geosphere. Describing the deep underground environment where disposal is planned, taking account of the variety of physio-chemical processes is complex. Owing to the long assessment timescales (hundreds to thousands of years), appropriate treatment of uncertainty is essential.

6.3.3. Treatment of uncertainties in computation

Existing scientific approaches to computational modelling require clear articulation of model assumptions and simplifications. As many models covering a broad range of features, events and processes (FEPs) contribute to the overall safety assessment and performance assessment, a clear understanding of what FEPs have been omitted or included and their respective treatment of uncertainty for input data and results is required. In future iterations of the safety case, improvements in site-specific modelling and parameter uncertainty are anticipated, as well as updated facility designs.

6.3.4. Computational underground fluid dynamics (CUFD)

Many codes for CUFD exist, but because of their specialised nature and treatment of intrinsically difficulty phenomena, they require careful management of uncertainties to ensure results are understood correctly. The statement "… *the user of the code is also important. CFD simulations are still far from routine calculations*…" (SKB 2010) is agreed by many experts. The IRT acknowledge the use of comparison of CUFD results with analytical solutions as one accepted approach, which should be complemented by a more thorough investigation of repeated computations, guided by sensitivity analysis.

CUFD modelling is an ongoing research and development activity internationally, and needed for both the future iteration of the long-term safety assessment, together with guiding site assessment and characterisation. CUFD engineers will therefore need to be involved proactively in various geological or hydrological exploration activities on the ground, to propose acquisition of informative data, to carry out computation and to make integration of computational and observational information. As such they will be key contributors to the project.

At a more advanced stage of the project (site investigation), early start of usage of CUFD on the ground is a key for the growth of the codes themselves. For example, DarcyTools was built up by an implementer and underwent many detailed testing and verifications. Its strength seems to originate from a strong feedback between the codes and the experiences on the ground. CUFD model simulations will require calibration and verification. Accordingly, continued work is needed to integrate and improve how simulations are verified alongside data collected as part of the site characterisation phase. This should include appropriate sensitivity analysis to guide model and data developments.

6.4. Development of the biosphere model

The development of the biosphere conceptual model is presented in the SNFD2017 reports. The IAEA BIOMASS methodology was chosen which is appropriate. It is an internationally acknowledged method used by most of the organisations building a safety case for waste disposal.

The purpose of the biosphere modelling is clearly shown; it is used to derive Biosphere Conversion Factors for each radionuclide. Those factors allow converting the release rate of radionuclide per year (1Bq/yr) into an annual effective dose to a future hypothetical person living in the area and consuming food products from his activity (Sv/yr).

The report indicates the capability of estimation of the biosphere conversion factor for a "temperate biosphere" at the K-area granite and the capability to perform quantitative assessments of dose and risk calculations.

The radionuclide model for the biosphere is a compartment model, where biosphere system components are considered internally homogeneous in their properties and represented by distinct compartments. This is standard practice.

Two aspects of the biosphere modelling are discussed in the following sections:

- The development of the biosphere conceptual model and the definition of the "key group"; and

- The consideration of climatic evolution.

6.4.1. Development of the biosphere conceptual model and definition of the key group

A description of the actual biosphere system in the K-area for all the major components of the biosphere system was provided and further detailed in the TRS-3 report. Building of the conceptual model includes FEPs processing, interaction matrix, and identification of the exposure groups (farming, fresh water fishing and marine water fishing). Multiple factors are taken into account (deposition/erosion, soil sorption, plant root uptake, fish and animal production). The three exposition pathways, ingestion, inhalation and external exposure factors are considered in the model.

In practice, only one key group has been considered for evaluation of the Biosphere Dose Conversion Factors (BDCFs). The three different food supplies of the three potentially exposed groups have been summed up, providing an approach that is assumed to be conservative according to the answers to IRT´s first set of questions.

The justification for the definition of a single conservative key group could be more visible in the approach. Such a key group doesn’t seem to correspond to the spirit of the ICRP which recommends examining a representative individual of the most exposed groups, neither to the spirit of BIOMASS which recommends evaluating a priori all potentially exposed groups and uses the result to define the most potentially exposed group. As indicated in BIOMASS, food consumption ratios and characteristics of the well water (e.g. the concentration in well water and release rate by well capacity) have big influence on BDCFs.

At this stage, non-human biota is not considered which is fully understandable without a site. Protection of the environment may be considered in further steps as current international practices trend to. Methodologies developed on international level are now available (e.g. ERICA project).

Conclusions

The conceptual model of the biosphere follows the main lines the IAEA BIOMASS methodology. Improvements could be made in the future to adopt the IAEA BIOMASS methodology in a more systematic way.

It is to note that the most exposed group will need to be identified in future steps in order to conform to international recommendations. The assumption will have to be demonstrated with a detailed biosphere conceptual model which will include landscape evolution of the identification of the most exposed group with its food consumptions habit.

6.4.2. Consideration of climate evolution

Glacial cycle is taken into account together with effects on the coastline and sea level in the main scenarios which is appropriate at this stage. The global warming effect is considered in a disturbance scenario.

Some programs, following BIOMASS approach, now consider the development of several conceptual models in order to cover future climate state and their consequences, focussing for example on temperate condition, glacial conditions and anthropic warming effects.

Conclusions

For further stages of the programme, a more detailed landscape evolution should be considered to support the development of the biosphere conceptual model, for example to capture major changes in the landscape, especially the GBI (location of outlets) not only the coastline and sea level. Glacial conditions should for example be explored further, as a decreasing sea level may uncover more farming area, change water source supply, and food habit.

6.5. Future human actions

Future Human actions are developed in the logic of SKB. The general principles for human intrusion actions are in line with current international practices with the following philosophy:

- They are carried out after the closure of the repository;
- Take place at or near the repository;
- Are unintentional;
- Impair the safety functions of the barriers in the repository.

The proposed approach considers a technical analysis, and analysis of societal factors, and then the choice of the representative cases and the scenario description and quantitative analysis which is an appropriate logic. As an illustration, the definition of the drilling case together with consideration of a hypothetical family that settles at the repository site and uses the borehole for water supply as presented in SNFD2017 is in line with international practices.

Conclusions

The SNFD2017 reports indicate that inadvertent human intrusion scenarios are categorised in a specific class of scenarios which is in line with the current international practices as discussed in NEA reports and IAEA HIDRA projects. The current trend in those international exchange groups is to favour a determinist approach; probabilistic approach being questioned for human intrusion.

The IRT recommends for future stages of the programme to consider the more recent international trends for inadvertent human intrusion.

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Annex I – Terms of Reference (ToR)

International Peer Review of the Technical Feasibility Assessment Report on Spent Fuel Final Disposal (SNFD2017)

Background

Taiwan has been using nuclear power for electricity generation since 1978. Currently, there are three nuclear power plants in operation in Taiwan with a total of six reactor units (4 BWR and 2 PWR). A fourth nuclear power plant (2 advanced BWR) is under construction; however, the project has been suspended. Under the current regulatory regime the owner and operator of these nuclear power plants, Taiwan Power Company (TPC), is responsible for the final disposal of all spent nuclear fuel (SNF) produced from these power plants.

Radioactive waste in Taiwan is classified into two categories: High-level radioactive waste (HLRW), and low-level radioactive waste (LLRW). Spent nuclear fuel represents the bulk of high-level radioactive waste, by volume and radiotoxicity. Assuming a service time of about 40 years, the operating nuclear power plants in Taiwan will generate about 5,000 tons of spent nuclear fuel (SNF).

Recognising that geological disposal is generally adopted worldwide for high-level radioactive waste (HLRW) management *[Ref 1]*, Taiwan has adopted disposal in stable geological formations as the strategy for the long-term management of high-level radioactive waste.

A recent study *[Ref 2]* compiling and analysing the research results from Taiwan's spent fuel disposal programme over the past 20 years concluded that there exist three kinds of potential host rock in Taiwan (granite, mudstone, and Mesozoic basement rock). At present granite is seen as the preferred host rock for a geologic repository in Taiwan and has been chosen as reference medium for the further development of Taiwan's Spent Fuel Final Disposal Programme.

Spent Nuclear Fuel Final Disposal Plan

Taiwan has undertaken R&D studies related to the safe disposal of SNF since 1986.

As stipulated in the Nuclear Materials and Radioactive Waste Management Act (2002) TPC prepared a Spent Nuclear Fuel Final Disposal Plan that was approved by the Atomic Energy Council (AEC) of Taiwan in 2006[1]. The Plan, which is reviewed every four years, defines five successive stages:

(1) Potential Host Rock Characterization and Evaluation;

(2) Candidate Site Selection and Approval;

(3) Detailed Site Investigation and Testing;

(4) Repository Design and Safety Analysis Assessment;

(5) Repository Construction.

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[1] The *Spent Nuclear Fuel Final Disposal Plan* was revised in 2010 and 2014

The tentative schedule proposed in the Spent Nuclear Fuel Final Disposal Plan foresees that candidate sites for the SNF final disposal in Taiwan should be decided by the end of 2028, and the final disposal site should be decided by the end of 2038. The repository is scheduled to start operation in 2055.

Currently the programme is in the Potential Host Rock Characterisation and Evaluation stage. The main point of this stage is the technical research and development of site investigation and repository engineering capabilities; this stage does not involve the siting process of the repository.

SNFD2017 Study

According to the Spent Nuclear Fuel Disposal Plan, TPC is requested to prepare a R&D progress report demonstrating the technical capability of spent fuel final disposal in Taiwan and to submit it to AEC by the end of 2017.

The main objectives of the report as set by the AEC are:

- To confirm whether a scientifically suitable granitic rock body for geological final disposal could be identified in Taiwan or not;
- To confirm whether adequate engineering capabilities for constructing a geological repository have been established in Taiwan or not;
- To confirm whether adequate capabilities for assessing the long-term safety for a repository site have been established in Taiwan or not.

In order to take advantage of international R&D results and experiences as well as in view of the similarity of geological environments in Japan and in Taiwan, the AEC requested that the structure of the report should be based on the Japanese H12 report *[Ref 3].*

In response to this request from AEC, TPC prepared the Technical Feasibility Assessment Report on Spent Fuel Final Disposal (SNFD2017).

To demonstrate the technical feasibility of final disposal of spent nuclear fuel in Taiwan the SNFD2017 report uses a reference case built on:

- crystalline rock as host medium;
- adoption of the Swedish KBS-3 concept for geologic disposal of spent nuclear fuel;
- geological models and data from a specific area in Taiwan (K-area), which had been excluded as a candidate site due to the statute of limitation;
- adoption of models and assumptions for safety assessment that are used in international programmes, in particular the Swedish SR-Site *[Ref 4]* project.

The SNFD2017 report has been prepared by TPC with support from the Institute of Nuclear Energy Research (INER) and the Industrial Technology Research Institute (ITRI) and has been finalised in early 2017. AEC has requested TPC to carry out an international peer review of the SNFD2017 report before TPC submits the report to AEC.

Independent Peer Review (IPR)

The international peer review is organised according to the practice and experience of the OECD Nuclear Energy Agency (NEA) in conducting international peer reviews in the area of radioactive waste management. According to the guidelines for International Peer Reviews for Radioactive Waste Management *[Ref 5]* of the NEA a peer review is described "as the systematic examination and assessment of a national waste management programme or a specific aspect of it, with the ultimate goal to help the requesting country to adopt best practices, [and to] comply with established principles".

The review will be based on national and international legislation and guidelines, international best practice and good strategies of national programmes, as established within the NEA.

Objectives of the review

The objective of this International peer review is to provide an independent review of the SNFD2017 study.

The review will assess the sufficiency and credibility of the SNDF2017 report to demonstrate the technical capability of spent fuel final disposal in Taiwan as specified by the three main objectives of the report (see above).

In assessing the SNFD2017 report the review will take into account the current stage of the implementation of the Spent Nuclear Fuel Final Disposal Plan of Taiwan.

Basis for the review

The review will be based on the following reference material:

- the Technical Feasibility Assessment Report on Spent Fuel Final Disposal (SNFD2017), Main Report; and
- three technical reports supporting the main report: on the Geological Environment of Taiwan, on the Repository Design and Engineering Technology, and on the Safety Assessment, respectively.

For all reports the English versions as provided to the review team are the reference documentation for the peer review.

International Review Team (IRT)

The international review team is nominated independently by the review co-ordinator. To ensure independence and to avoid possible conflicts of interest, the experts chosen have not been involved in any activities affiliated with the preparation of the SNFD2017 report.

The IRT comprises six experts including the chairperson and an expert as of the technical writer. These experts are independent consultants or experts from advanced radioactive waste management programmes. They express their own views and not those of the institutions to which they are affiliated.

The review co-ordinator is a member of the IRT whose role is to act as the guardian of the ToR, to ensure the independence of the review, and to act as the contact point between the IRT and the reviewee.

Conduct of review and estimated schedule

The international peer review will be organized in accordance with the NEA guidelines for international peer reviews of radioactive waste management *[Ref*

5]. The main phases of the review will include an orientation seminar at the beginning of the formal review process, a phase of exchange of written questions and answers, a review workshop and the preparation of the review report.

The orientation seminar is scheduled to take place in Taipei on 28-30 March 2017 and has the objective to help the IRT to become familiar with the project, its documentation and with the national context of the project. The orientation seminar will also serve to organise the review activities within the IRT.

During the question-and-answer phase written questions of the IRT will be transferred to the reviewee in one or two batches and written answers to these questions should be prepared by the reviewee in corresponding documents. This phase will evolve between May and August.

The one-week review workshop will take place in Taipei at the end of August/beginning of September. The workshop will provide for in-depth discussions between the IRT and the reviewee as well as for internal work for the IRT to develop a common view and to start drafting its findings. At the end of this workshop the IRT chairperson will provide an oral report on the basic findings of the review.

Peer review results

The final report of the review presents the consensus view of the IRT.

It is anticipated that the final peer review report will be issued end of September 2017, in English only. Beyond the reviewee, the members of the IRT, their home organisations (if applicable) and the secretariat of the NEA will receive a copy of the report.

The final peer review report will be delivered to AEC together with its reference documentation of the SNFD2017 report.

Financial arrangements

The peer review will be funded by the reviewee, through a third party, based on cost estimates provided by the review co-ordinator.

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Annex II – International Review Team

Amano, Kenji

Bachelor's and master's degrees in Earth Sciences at the Ehime University in the early 1990's and completed his PhD at the same university on fracturing and faulting evolution in granite in 2005.

Dr Kenji Amano has been working JAEA (Japan Atomic Energy Agency) and its predecessor organisations for over 20 years. JAEA has been conducted the fundamental R&D works on geological disposal in Japan including the URL projects. He was involved in the crystalline projects (Kamaishi In-situ Experiments and Mizunami Underground Research Laboratory) and the sedimentary projects (Tono Natural Analogue Projects and Horonobe Underground Research Laboratory) as a research scientist. Currently, his main research area is uncertainty analyses in geological/hydrogeological models with a focus on limited data conditions. He has been the principal investigator of geological studies in the Mizunami Underground Research Laboratory Project (1999-2009), the Horonobe Underground Research Laboratory Project (2009-2013) and Geosynthesis coordinator (2013-present) in JAEA (Japan Atomic Energy Agency). He is also involved in several international collaborations with Nagra (National Co-operative for the Disposal of Radioactive Waste, Switzerland) and KAERI (Korea Atomic Energy Research Institute) on the URL related projects.

Dr Amano has contributed to over 20 publications (technical reports and scientific papers) in waste disposal. A recent achievement, through collaboration with the Kyoto University, was to have his contribution chosen for the "Best paper award" of the Journal of MMIJ (The Mining and Materials Processing Institute of Japan) in 2010 and "Best paper award" of the Japan Society of Geoinformatics in 2012.

Beattie, Tara

Bachelor of Science Degree in Analytical Chemistry (2003) and PhD Radiochemistry (2008) Loughborough University, UK.

Dr Tara Beattie is a Director of MCM Environmental Ltd., a UK-based international consultancy and advisory service which provides strategic, scientific and technical experience in radioactive waste management. Prior to joining MCM, Dr Beattie held the positions of Disposal Systems Issues Manager and Near-field Evolution Research Manager at the Nuclear Decommissioning Authority Radioactive Waste Management (RWM).

Dr Beattie is an experimental chemist and technical integrator with over 10 years' experience working in applied research and technical integration activities in support of the UK and other national geological disposal programmes. Her experience includes undertaking and managing complex projects related to disposal facility authorization, safety assessment, safety case communication and stakeholder engagement and issues management processes. Most recently these have been focussed on disposal concept options assessment for the design of the UK geological disposal facility, the specification, review and underpinning of safety functions and long-term performance of waste conditioning options and engineered barrier systems for the storage and disposal of radioactive wastes. Tara has a proven track record in contributing and coordinating technical input from large project teams and providing leadership and direction to ensure a successful project outcome. Specific technical areas of high competency include safety case development, engineered barrier system performance, particularly spent fuel source term treatment, long-term chemical evolution of cementitious and clay-based barriers, and radionuclide behaviour in complex environmental systems.

Griffault-Sellinger, Lise

Lise Griffault-Sellinger has a PhD degree in Geochemistry (University of Poitiers, France).

Dr Griffault-Sellinger is presently a Post-Closure Safety Expert Engineer at the Safety Environment and Waste Management Strategy Division, Post-Closure Safety Department, in the French National Radioactive Waste Management Agency (Andra).

Dr Griffault-Sellinger has been involved in issues concerning environment and safety of nuclear waste disposal throughout her carrier. From 1989 to 1995, she worked at AECL Pinawa, Manitoba, as part of the Canadian Waste Management Program. In 1995, Dr Griffault-Sellinger joined the scientific division of Andra, working as a research engineer in the field of geochemistry. In 2001, she joined the Safety Division of Andra, where she contributed to the production of Andra's safety cases, in particular for deep disposal in geological formation as part of the 2005 feasibility safety study in granite and in clay. She also participated in the 2009 intermediate safety case and more recently the 2016 Safety Option Study. She was also involved in the 2016 safety case studies for the Aube surface disposal centre. For the two 2016 studies, Dr Griffault-Sellinger was responsible for the post-closure safety evaluations.

Andra is an independent public body in charge of the long-term management of radioactive waste in France, under the supervision of the Ministry of Ecology, Energy, Sustainable Development and the Ministry of Research. It benefits from more than 40's years' experience in the management of radioactive waste. Within her position, Dr Griffault-Sellinger is more particularly involved in the preparation of the post-closure safety evaluation of Cigéo, Industrial Center for geological disposal for its license application.

At the international level, Dr Griffault-Sellinger contributed to several OECD/NEA or European Community working groups dedicated to scenario development methods and their place in the safety case. She also contributed to program committee of OECD/NEA workshop on scenario developments, Paris, 2015.

Higashihara, Hiromichi

Academic degree in civil engineering (Dr. engineering.) from the University of Tokyo, in 1970, and is now Professor Emeritus, Earthquake Research Institute, Univ. of Tokyo.

He has more than 50 years of experience in the field of civil engineering, including aerodynamics of civil engineering (i.e., bluff body) structures, CFD and its applications to air pollution or thermal pollution simulations, and structural analysis and design of long suspension bridges that span more than one km. He joined a national giant project of constructing three routes that cross over the Seto Inland Sea.

After moving to Earthquake Research Institute, Univ. of Tokyo, he worked about the dynamic interaction between big structures and the ground, and applied it to earthquake-resistant design. He also promoted tight collaboration with earth scientists for development of a brand-new active underground exploration method. This human network so far provided and is providing him with abundant knowledge and opinions about the long-term tectonic evolutions of the Japan arc.

He then moved to National Research Institute for Earth Science and Disaster Prevention, and organized collaboration with medical specialists for a post-Kobe national research project for disaster medicine as Director of Earthquake Disaster Mitigation Research Center: protection of medical facilities and engineering support for nation-wide dispatch of emergency medical teams.

In his 20 years' activity at Nuclear Safety Commission of Japan, he examined the seismic design of newly-built nuclear power plants and other nuclear installations, as member of both Committees (2001-2012): Examination of Reactor Safety and Examination of Nuclear Fuel Safety. He elaborated an integrated examination scheme that spanned from seismogenetic process, crustal propagation of seismic waves, interference of waves in near-field, soil-structure interaction and structural dynamics.

Regarding the final disposal of radioactive wastes, he started activity from a preparatory task force discussing backend programs (1997-2000) and then joined the review team for the 2nd Progress Report on the geological disposal of HLW (2001). He was vice-chair of the Special Advisory Board on High-Level Radioactive Waste Disposal Safety (2001-) and then chaired it (2006-2011). Since 2012, he is member of the Board of Councillors of the Nuclear Waste Management Organization of Japan (NUMO), the sole implementer of the national final disposal program of radioactive wastes, and is engaged in the technical research and development.

Leino, Jaakko

Master of Science in Material Chemistry and Metallurgy.

Jaakko Leino is currently the Head of the Nuclear Waste Safety Assessment Section at Finnish Radiation and Nuclear Safety Authority's (STUK) department of Nuclear Waste and Material Regulation. The supervision in the department covers nuclear materials and nuclear waste. STUK is tasked with establishing detailed safety requirements with regard to the use of nuclear energy and ensuring, by way of independent supervision, that power companies producing energy operate in accordance with the requirements. The supervision is based on up-to-date guidelines, extensive inspections and regularly performed safety reassessments. The regulatory control of nuclear waste management includes oversight of handling, storage and disposal of low- and intermediate-level radioactive waste as well as spent nuclear fuel and decommissioning of nuclear facilities.

Jaakko Leino's section is responsible for oversight of post-closure safety and review of post-closure safety assessment of nuclear waste disposal facilities. The section also reviews repository design, performance of the engineered barrier system and material issues. He has participated to regulatory oversight of Posiva and followed closely the development of the post-closure safety case, the repository design and engineered barrier system since 2010 and was responsible for the review of post-closure safety case in Posiva's construction license application and is thus very familiar with the KBS-3 concept. Currently, his main focus is on the oversight of the development and preparation of the post-closure safety case for the operating license application. He is also responsible for the development of the regulatory oversight and review of nuclear waste facilities' safety assessments. His education is Master of Science in material chemistry and metallurgy. He has have been working at STUK since 2010, the last four years as Section Head.

He is involved in NEA's Integration Group for the Safety Case (IGSC) and other international groups and projects e.g. SITEX II. He is also involved in IAEA's development work for safety standards as a member state representative in the area of the safety of radioactive waste (WASSC).

Riotte, Hans

Hans Riotte graduated as a physicist from university of Cologne, Germany, where he also received a PhD in nuclear physics. He has more than 30 years' experience in the nuclear energy field.

He started his professional career at the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) in Germany, a Technical Support Organisation (TSO), working in the areas of reactor safety and in radioactive waste management, with a focus on storage issues and geologic disposal, and research management.

Hans Riotte joined the Federal Ministry of Education and Research (BMBF) and was the responsible desk officer for the German government's R&D programme on deep geologic disposal. He later became deputy head of planning and strategy, in charge of technology foresight and general R&D policy issues.

In 1998 Hans Riotte joined the OECD Nuclear Energy Agency (NEA) as Head of the Division of Radiation Protection and Radioactive Waste Management. In this function, he managed the NEA secretariat's work to organise technical co-operation and information exchange between regulators, implementers, R&D experts, and decision makers to support policy-making amongst the NEA member countries. Under his leadership the NEA published the guidelines for waste management reviews and organized about ten international peer reviews of national waste management studies.

Since his retirement in 2012 Mr Riotte has participated in several important reviews of the nuclear R&D programme of the European Commission.

Sailer, Michael

Academic degree in chemical engineering (Dipl.-Ing.) from the Technische Universität Darmstadt; Germany, 1982.

He has more than 35 years of experience in the field of nuclear energy, most notably regarding the safety of nuclear power plants and other nuclear installations, the storage of nuclear waste and the final disposal of radioactive waste. He is currently CEO of Oeko-Institut (since 2009). Previously he was head of Oeko-Institut's Nuclear Engineering and Facility Safety Division.

Oeko-Institut e.V. (Institute for Applied Ecology) is an independent scientific research institute with some 170 staff; it was founded in 1977 and is a non-profit association. It gives scientific advice to governmental and non-governmental organisations. Major fields of its national and international work are:

- Nuclear safety and waste management
- Energy and climate issues
- Sustainability regarding products and resources
- Governance and public participation

He is chairman of the Nuclear Waste Management Commission (ESK), which advises the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (since 2008). He was member of the German Commission on the disposal of high-level radioactive waste of the German Federal Parliament, which worked from 2014 to 2016.

He was chairman of “The Post-Closure Radiological Safety Case for a Spent Fuel Repository in Sweden - An International Peer Review of the SKB license-application study of March 2011”.

He was from 1999 to 2014 member of the Reactor Safety Commission (RSK) of the German Federal Ministry for Environment, Nature Conservation, Building and Nuclear Safety and is since 2012 member of the Expert Group on Reactor Safety (ERS) of the Swiss Federal Nuclear Safety Inspectorate (ENSI).

Annex III – Documents reviewed

For its evaluation, the International Review Team (IRT) used the following documents provided by TPC:

1. Core documentation of SNFD2017:
    - The Technical Feasibility Assessment Report on Spent Nuclear Fuel Final Disposal - Main Report; Taiwan Power Company, March 2017
    - The Technical Feasibility Assessment Report on Spent Nuclear Fuel Final Disposal - Technical Supporting Report (1) - The Geological Environment of Taiwan; Taiwan Power Company, March 2017
    - The Technical Feasibility Assessment Report on Spent Nuclear Fuel Final Disposal - Technical Supporting Report (2) - Repository Design and Engineering Technology; Taiwan Power Company, March 2017
    - The Technical Feasibility Assessment Report on Spent Nuclear Fuel Final Disposal Technical Supporting Report (3) - Safety Assessment; Taiwan Power Company, March 2017

2. Additional technical reports made available to the IRT:
    - Appendix A: The Taiwan Reference Case of the SNFD2017 Report – Table-2: Geological Conceptual Models and Characteristic Data; Industrial Technology Research Institute (Commissioned by Taiwan Power Company); March 2016 (SNFD-ITRI-TR2015-0001-V2)
    - SNFD2017 reference case–regulation and concept for disposal; Table 1：Regulation_1060324 (Eng. v2)); SNFD-RC2015-1214
    - SNFD2017 Reference Case – Table 2; Table 2：Geological characterization_1060324(Eng. version); SNFD-RC2015-1231
    - SNFD2017 Reference case – model and parameters of SA; Table 3：Model and parameters of SA_1060324(Eng. v3); SNFD-RC2017-0323

3. Responses to two sets of questionnaires from the IRT:
    - Responses to International Peer Review of the Technical Feasibility Assessment Report on Spent Nuclear Fuel Final Disposal (SNFD2017 report) - RESPONSES TO SECOND QUESTIONNAIRE; 14th August 2017
    - Attachment to Q3-70 (Figure_3-49; Table_3-2)

4. Presentations:
    - Presentations from TPC, INER and ITRI staff at the IRT Orientation meeting (the slides have been transmitted to IRT)
    - Presentations from TPC, INER and ITRI staff at the IRT Review meeting (the slides have been transmitted to IRT)

Errata

INTERNATIONAL PEER REVIEW

of Taiwan Power Company's

TECHNICAL FEASIBILITY ASSESSMENT REPORT ON SPENT NUCLEAR FUEL FINAL DISPOSAL (SNFD2017)

05 November 2017

The following **errata** have been found in the report of the International Peer Review of SNFD2017:

Page	*Location*	*Change*
Cover	Box	"… credibility of the SNDF2017 report …" *should read:* "… credibility of the SNFD2017 report …"
35	Sec 5.1.1.	"For the UO2 matrix, the release rate of 10-7/year is selected …" *should read:* "For the UO_2 matrix, the release rate of 10^{-7}/year is selected …"
46	Sec 6.2.2	"In SND2017 case, the isolation is provided …" *should read;* "In SNFD2017 case, the isolation is provided …"

The IRT takes responsibility for these misprints.

Hans Riotte, co-ordinator of the International Peer Review