THE ROLE OF KEY CONSULTANTS IN THE FINNISH RADIATION AND NUCLEAR SAFETY AUTHORITY'S 'CONSTRUCTION LICENSE APPLICATION' REVIEW AND ASSESSMENT

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In 2012 Posiva Oy submitted a construction license application (CLA) for a KBS-3 type repository for the deep geological disposal of spent nuclear fuel in crystalline rock at Olkiluoto, Finland. To aid its own CLA review, the Finnish Radiation and Nuclear Safety Authority (STUK) established a framework for technical review by independent external experts. In addition, STUK selected us as three Key Consultants (KCs) in the areas of site characterization (Site), performance of engineered barriers system (EBS), and performance assessment (PA) to assist in coordinating this external review process. As the KCs, our role was to aid STUK in organizing, collecting, interpreting, and integrating the diverse set of external reviews. KC activities included planning and conducting topic-specific workshops with STUK and its external reviewers, participating in direct STUK-Posiva meetings regarding the CLA, identification of cross-cutting topics across all three areas, and regular consultation with STUK on key, safety-significant topics. The KCs compiled all of the separate external review reports into 3 Consolidated Review Reports (CRRs) that STUK plans to publish as part of its documented CLA review process. STUK will use the CRRs as the principal sources of supporting material for its internal considerations as it develops its independent assessment of the CLA. STUK's assessment of the adequacy and acceptability of Posiva's CLA is expected to be presented to the Finnish government in early 2015.

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I. INTRODUCTION

In December 2012, Posiva Oy submitted a construction licence application (CLA) to the Finnish Government proposing construction of encapsulation and disposal facilities for spent nuclear fuel at Olkiluoto, Finland. In addition to the description of the site, the KBS-3 vertical emplacement concept for spent fuel encapsulated in copper canisters and surrounded by a compacted bentonite clay buffer (Fig. 1), the CLA also contained a safety case that included analysis of the operational safety for the initial construction and emplacement period and long-term safety for up to 1,000,000 years after repository closure.

The Radiation and Nuclear Safety Authority of Finland (STUK) are evaluating the CLA. To assist in review and evaluation of the diverse parts of Posiva's CLA, STUK engaged several consultants with expertise in various disciplines and formed three core Review Teams (RTs): (1) site, (2) engineered barriers system (EBS), and (3) safety assessment. STUK selected a "key consultant" for each core team. The key consultant (KC) had the responsibility for coordination within each RT, as well as coordination among the three teams, eventually leading to compilation of a consolidated review report (CRR). Each CRR represents an integration of the review comments and findings of STUK's consultants in the three specific areas.

II. APPROACH

The Finnish Government Decree on Waste Disposal (Ref. 1) sets the policy for geologic repositories in Finland. STUK's Guide YVL D.5 (Ref. 2) lays out the regulatory requirements for implementing the government decree. These regulatory documents cover the whole life cycle of a disposal facility (site investigations, design, construction, operation, and closure). To conduct its role in the review of the CLA, STUK developed a review plan based on these two documents. The aim of STUK's review plan is to conduct the review of the CLA in a manner that will lead to appropriate conclusions regarding the adequacy and quality of Posiva's CLA in general and the safety case in particular. It tends to focus the regulatory review on topics that are highly relevant to long-term safety.

Posiva's CLA consists of 14 Turva-2012 Portfolio Main reports and 7 Supporting reports (Refs. 3, 4) and a much larger set of other references. STUK contractually assigned selected reports (or parts of reports) for review to appropriate experts of each RT. Workshops were held periodically at STUK offices, where consultants presented and discussed each other's review comments. Some workshops involved meeting with Posiva staff aimed at getting clarifications on certain selected topics.

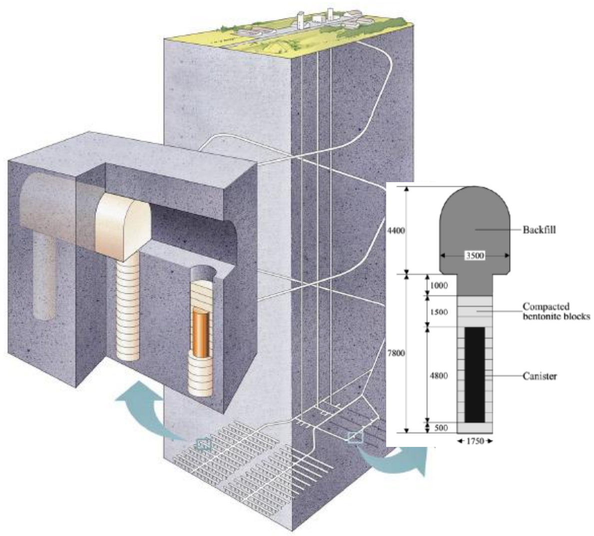

Fig. 1. Schematic of KBS-3 vertical emplacement concept (compiled from Refs. 3-8).

Based on consultant comments, STUK also sent written "requests for additional information (RAIs)" to Posiva. To organize and guide the review by individual external experts, STUK provided to each reviewer a template based on its review plan. Following STUK's instructions, the structure of this review report follows that template.

It should be noted that STUK's CLA review process was adversely impacted by delays by Posiva in completing key reports. While such delays did not prevent eventual conclusions from being reached, it was the general feeling by external reviewers that STUK ought to take a firmer position with respect to only beginning any future review of an Operational License Application until and unless all relevant documents have been submitted.

In each of the three areas of site, EBS and safety assessment, the CRRs consolidate and summarize the separate template reports. In the process, material has been significantly condensed and edited to provide a more readable summary. Workshop discussions within and among RTs allowed identification of the key issues, enabled common positions to be reached, and facilitated the subsequent consolidation of comments and conclusions. Thus the CRRs represent a consensus view in each area.

The following sub-sections summarize the main observations and conclusions from the site, EBS and safety assessment CRRs, respectively. Overall, the CRRs consider that none of the concerns identified have such significance for the current safety case or for Posiva's construction plans that it would prevent STUK from granting a construction license. Nevertheless, these topics will need to be addressed by Posiva over the coming years. The background to these topics and the detailed considerations on how to address them can be found in the CRRs. In general there are two classifications of concerns:

- Topics where further information will be required from Posiva to match a specified schedule and/or before specific milestones can be passed: for example, the Operating License Application (OLA) and its Safety Case. Some topics might also form the basis of a longer lasting programme of work that will run through the construction period and beyond the OLA.

- Topics where Posiva would be expected to carry out further work and make a commitment to doing so, but it is not a condition of licensing that the work is linked to a specific schedule or to a specific milestone. However, the OLA Safety Case would be enhanced if elements of this work were developed sufficiently to make major contributions at the time of delivery of the OLA.

It is vital to caution that these CRR commentaries are the opinions of STUK's external technical experts, and do not necessarily represent the views of STUK's own technical staff. STUK will be preparing their own summarized review of Posiva's CLA to be presented to the Finnish government early in 2015.

IIA. Summary of Site CRR

STUK's Review Team for Site, with Chapman as the Key Consultant, was composed of diverse hydro-geological experts who had been working as a core SONEX team advising for STUK for many years. This extended involvement allowed the Site CRR to probe deeply into the many, long-term site investigation and characterization activities that Posiva had been conducting at the Olkiluoto site (Ref. 5).

The overall judgment by the Site CRR is that Posiva has carried out a thorough and comprehensive program of work to characterize the Olkiluoto site, both from the surface, using boreholes and drill cores, and in the ONKALO underground facility. The quality of the investigation work and the modelling and interpretation of its results is generally of a very high standard and, in many areas, represents the state-of-the-art in methodology and technology. The expert reviewers have been impressed by the totality of the work carried out by Posiva's expert staff and contractors, and by their commitment to continue and improve both understanding and application during the construction phase. If continued and completed as intended, the planned program of work should deliver a high-quality facility to host the EBS, and all the geoscientific data necessary to support a successful safety case at the time of submission of an operating license application (OLA).

For any repository program that has conducted decades of site investigations, the size, complexity and importance of site characterization make it inevitable that some areas require further work during the construction period. Several areas will require acquisition of more construction experience and some areas still involve uncertainties that will need reduction and resolution. As noted in the Safety Assessment CRR, however, there has not yet been an opportunity to examine all of the site concerns within a safety-significance context.

Some of the specific concerns and recommendations by the Site CRR include:

• A strategy and plan should be presented for the continued and progressive reduction of critical uncertainties in groundwater flow and chemistry characteristics during the construction period.

• Posiva should present plans for improving its current rock stress model and stress measurement database to a point that it is adequate to support the design decisions to be made during construction and for the boundary conditions of the rock mechanics models. These plans, including campaigns of stress measurements, should be implemented when work begins at ONKALO.

• The rock suitability criteria (RSC) development and demonstration work is well conceived but at an immature stage and is a priority. Hydrogeological characterization for further demonstration excavations and for the main construction phase needs more work. An improved and state-of-the-art hydrogeological testing program for proposed deposition areas that includes routine head measurements and interpretation, and the extended testing and use of pilot holes is required. This program needs to be conducted before the OLA and should be integrated with the RSC development and design planning and decision-making strategy.

• Global climate models indicate a possibility that there could be continuation of current temperate conditions for a considerable period of time – at least several tens and possibly some hundreds of thousands of years. The deep groundwater system may be progressively flushed with dilute meteoric waters, replacing brackish waters in fractures at disposal depth during this period. Sustained and wide-spread penetration of extremely dilute (< 4 mmole) groundwater around deposition holes could enable 'chemical erosion' of the buffer, with progressive loss of density and swelling pressure. The impact on long-term safety, however, becomes progressively less over long time scales.

• Presentation of a strategy, plan and allocation of responsibilities for the design adaptation and construction decision-making procedures.

• The overall monitoring program should be developed, improved and made more precise. It should be integrated with the RSC measurements that will be made and to monitoring work already in place (e.g. geodetic, GPS). Gaps in the factors being monitored should be filled (e.g. micro-seismicity; groundwater heads; trace elements in groundwater as indicators of anomalous conditions; microbiology).

• The large-scale thermal response of the rock mass from repository to ground surface is not well understood and there is no analogous experience in heating such a large body of rock at relatively shallow depth. It is speculated that stress changes could shift some fractures out of their stability fields, causing shear movements. This could happen at any scale, from 'critical fractures' to large brittle fracture zones (BFZ). In the latter case, small to medium magnitude earthquakes could affect the repository and any surface nuclear facilities that are present on the whole Olkiluoto site in the first decades to 1000 years after disposal. It is not expected that the characteristics of this scenario would lie outside the bounds of the earthquake scenario already studied by Posiva, but it could occur much earlier.

IIB. Summary of EBS CRR

Apted was the Key Consultant who headed the EBS Review Team for STUK. This team included experts in the main components of the EBS, including compacted bentonite buffer, bentonite-based backfill in tunnels, and mechanical deformation and failure of copper canisters and interior cast-iron insert. Chemical modes of copper corrosion were not included. Although Posiva excludes spent fuel as a "barrier" with assigned safety functions, STUK did include analysis of the potentially extremely low dissolution rate of the UO_2 matrix under reducing conditions. Potential issues associated with fabrication of EBS components, however, were not part of the EBS review. Furthermore, there were limited opportunities to develop a system-level, integrated review of the EBS. On the other hand, the EBS review had the benefit of being able to base judgments not only on data, models and assumptions cited in Posiva reports, but also on parallel studies of the KBS-3 concept in Sweden and additional studies on EBS and spent-fuel disposal concepts worldwide. Unfortunately, as with the Site CRR, many of the various issues raised in the EBS CRR were not evaluated with respect to long-term safety significance.

Some of the specific observations, concerns and recommendations by the EBS CRR include:

• The basic post-closure safety assessment structure and methodology that Posiva reports in its CLA documents on the EBS are of high quality, and many of the assessment codes are among state-of-the-art options. Decisions on the selection of assumptions, models and data for EBS components are generally adequately reported, although reviewers identified specific omissions and suggested credible alternatives. These alternatives ought to be incorporated into STUK's oversight and review of future safety assessments by Posiva.

• Posiva's own safety analyses (for example as documented in Refs. 6, 7) compelling indicate that the EBS is the primary sub-system of the KBS-3 repository concept that assures post-closure safety. Of course the successful containment and isolation performance of the EBS relies on the favorable environmental, or 'service', conditions imposed by the Olkiluoto site. However, the basic sense is that Posiva's program mis-judges the safety-importance of the EBS relative to the site system. Posiva is urged to apply in its own CLA safety assessments to guide it in identifying and prioritizing its R&D in the period before the OLA.

• Based on Posiva's identification of the primacy of the EBS with respect to long-term safety, the most important, near-term priority must be early demonstration to reproducibly fabricate, transport and emplace its engineered barrier system at their intended 'initial state' in underground conditions. The necessity for such demonstration by Posiva prior to a future operational license application (OLA) is based on two concerns; (1) if Posiva finds impediments to building the EBS as designed and with designated performance targets, then Posiva would need to explore possible modifications and adaptations to overcome such impediments, and (2) if Posiva still finds it cannot build the EBS as designed, it seems sensible that further extensive underground exploration, excavation and development of rock suitability criteria would need to be postponed until Posiva devised a different, viable EBS disposal concept, established that this new concept would also provide adequate post-closure safety, and demonstrated that is new concept could be built and emplaced as intended.

• As a key part of future safety assessments, Posiva ought to apply the same sensitivity analysis methods (as illustrated in Refs 6, 7) to a wider range of scenarios and parameters within scenario variants. This will enable Posiva to evaluate and achieve a fuller understanding of the safety importance of Safety Functions, and establish a more rational basis for focusing future RD&D, and post-CLA adaptation/ optimization of their KBS-3 design.

• Posiva's chemical modeling of expected evolution of the near field, and its effects on safety functions, has certain limitations and omissions that will need to be addressed in future assessments. One major concern is that the geochemical models being employed by Posiva do not include clay-mineral hydrolysis, dissolution and precipitation reactions, which are likely to control chemical conditions over the time scales of repository assessments. Also the potential impact of cementitious, high pH waters coming from cements used as structural and grouting materials will need continuing "real time" analysis during the construction and operational period. Furthermore, Posiva's CLA modeling of possible chemical transformation of smectite in buffer and backfill ought to consider the potential for zeolitization of smectite under elevated pH and thermal conditions during the early evolution of the near field.

• At this CLA stage, Posiva's Safety Functions are predominately qualitative, possibly to provide Posiva with flexibility and latitude to explore in the future exactly how different design factors and processes might combine or be adapted to contribute to safety. It is expected that underground demonstrations, combined with more detailed sensitivity analyses, will enable Posiva to evolve more quantitative expressions of specific Safety Functions prior to an OLA.

• Posiva CLA documents argue for ready substitution of different montmorillonite-bearing "bentonites" if future circumstances dictate. While recognizing that it is sensible to make such contingency plans, any new buffer or backfill material will require substantial testing and modeling to qualify its use as a substitute for the reference MX-80 bentonite.

• The pinhole "base" case in Posiva's CLA derives significant post-closure safety arising from unknown and uncertain properties of a hypothetical 'defect' (e.g., an unintentional flaw from a electron-beam welding error in the as-emplaced KBS-3 concept) and an extremely pessimistic assumptions regarding rapid corrosion rate of the zircaloy cladding releasing C-14. This seems an anomalous and potentially misleading case on which to establish post-closure safety. The reported change by Posiva from electron beam welding (EBW) to friction stir welding (FSW) further undercuts justification for perpetuating this as a "base" scenario.

• With respect to analysis of alternative, credible scenarios, analysis beyond the 'pinhole scenario' would provide Posiva and STUK increased understanding and confidence in the specific roles and impacts of different Safety Functions of EBS barriers. Such an expanded set of scenarios would provide meaningful sensitivity analyses of Safety Functions, and might include consideration of (a) improper emplacement of waste packages, (b) delayed buffer saturation for many 1000's of years, (c) potential creep ductility failure of copper canister, and (d) anaerobic corrosion of the cast iron insert impacting post-containment radionuclide releases.

• Sensitivity analyses by Posiva show that a basic property of spent fuel, the measured low dissolution rate of UO_2 matrix, provides one of the most significant contributions to safety in the KBS-3 system (Refs. 6-8). This is consistent with other international safety cases for disposal of spent fuel where the long-term, slow dissolution rate is considered a key safety factor. "Slow release from the spent fuel matrix" has long been recognized by Posiva as one of its key pillars of safety (Refs 3, 4) Posiva's CLA argues that no specific Safety Function can be assigned to spent nuclear fuel because it cannot be 'engineered'. Incongruously, however, the 'site/ host rock/ hydrology' also cannot be 'engineered', yet Safety Functions are assigned for these parts of the system of repository barriers.

IIC. Summary of Safety Assessment CRR

The Safety Assessment (SA) Review Team was headed by Sagar. In addition to assessing Posiva's overall approach to safety assessment and compliance results, the SA Review Team specifically reviewed the aspects related to radionuclide transport and sorption, biosphere pathway analysis, and conducted limited confirmatory calculations. Key findings are summarized here.

• In the various reports supporting its safety case, Posiva demonstrates that the proposed repository for spent fuel will comply with the safety standards set in GD 736/2008 and in YVL D.5 (Refs. 1, 2) with comfortable safety margins. "*Safety margin*" is viewed as the difference between the regulatory constraint and Posiva estimates of either the radiation dose or normalized release rate. The substantial safety margins in Posiva's safety analyses are interpreted as indicators of system robustness. No serious flaws were identified in Posiva's compliance demonstration, but some points for clarification and future work are noted in the SA CRR.

• As noted in Posiva's CLA, significant residual uncertainties remain in describing the early and long-term evolution of the system. It is expected that these uncertainties will be reduced as more information is gathered during underground construction, fabrication of engineered barriers, and confirmatory testing during any post-CLA period, and the quality of the safety case, and confidence in it, will improve.

• The SA CRR recommends that Posiva should fully integrate the safety case for its deep, spent-fuel repository with its plans for co-location of a shallower-depth intermediate- and low-level waste disposal facility.

• Regarding future safety assessments, Posiva should more clearly explain the formulation of the calculation cases and the lessons learned from each. In future licensing steps, Posiva should consider expanding its use of probabilistic sensitivity analyses (Refs. 6, 7) to demonstrate the robustness of the system and clearly identify processes, models and parameters that most influence the safety. Furthermore, Posiva should establish and document clear links between the design specifications and overall safety; this relation is obscure in the current safety case. The descriptive safety functions and performance targets are good as a guidance tool but these do not provide a clear picture of the capabilities of the individual barriers.

• Posiva (Ref. 5) proposes a large number of topics for future RD&D, but not they are prioritized. The SA CRR recommends that such topics for RD&D be prioritized based on the significance of these topics to design, operational, and long-term safety.

• Posiva should consider constructing a more credible "base" scenario then the current pinhole scenario. The inferred mass-transport properties of a hypothetical, 'pinhole' defect actually masks latent safety contributions from all other barriers and processes. This ill-serves Posiva in developing a better understanding of the actual robustness of its multiple barrier system.

• If Posiva is allowed to proceed to the next licensing phase, its safety assessment should include, in much greater detail, analyses of 'what-if' scenarios that include common cause failures of the barriers. The purpose of these analyses should be to demonstrate the extreme (and therefore unlikely) failures that will be required for exceeding the regulatory safety measures.

III. CONCLUSIONS

To assist in review and evaluation of Posiva Construction License Application (CLA), STUK engaged external technical consultants with expertise in various disciplines and formed three core review teams: (1) site, (2) engineered barriers, and (3) safety assessment. STUK designated a Key Consultant for each core team who had the responsibility for coordination within the team and compilation of Consolidated Review Reports (CRRs). The timeliness of STUK's own reviews and reviews by external technical experts, started in 2012, was somewhat adversely impacted from delays by Posiva in completing and submitting key reports (e.g., Ref. 5 on models and data being submitted in 2013).

The CRRs prepared from reviews by STUK's external technical experts did not find any safety concern/issue that, in the collective judgment of these external reviewers, would prevent STUK to submit an affirmative statement of safety to the government. If a CLA is approved by the Finnish government in 2015, there are, however, several technical topics and questions raised by external reviewers that are identified in the CRRs. Such CRR issues, summarized here, are organized, prioritized, and documented into three categories with respect to a post-CLA/ pre-operating license application (OLA):

- Issues to be addressed before EBS component fabrication or underground construction in the disposal rock volume should begin;
- Requirements on safety issues to be achieved before a future OLA;
- Topics requiring commitments to longer-term (through and post-OLA) RD&D efforts, assuming a future operating license was to be granted.

In each area, the expectation is that Posiva will report and coordinate regularly with STUK so as to assess that adequate progress is being made, thus maintaining regulatory confidence and effectiveness in the step-wise licensing process.

The CRRs recognize that it has been necessary for Posiva to focus on site characterization and siting issues in the lead-up to its CLA. If a construction license is granted, a top priority in the period between approval of the CLA and Posiva submitting an operational license application (OLA) ought to be an immediate and more focused demonstration of the feasibility of constructing the EBS as set forth in the CLA. Such are studies and demonstrations are required to further confirm achieving the intended initial state and performance of the EBS, which has a primary role in assuring long-term isolation and safety. Another top priority ought to be for Posiva to use the results of its own safety assessments to prioritize future RD&D according to the safety-significance (and associated uncertainties) of barriers and processes.

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