Spent Nuclear Fuel Management and Disposal in Finland - Status and Lessons Learned at the End of 2015 - 16507

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ABSTRACT

In November 2015 the Finnish Government approved and the Parliament ratified Posiva's 2012 License Application for Construction of a mined, deep geological repository for the spent nuclear fuel (SNF) at the Olkiluoto site in the Eurajoki municipality based upon recommendations provided by the Finnish Radiation Safety Authority (STUK), international expert groups and long-standing local support. The preceding siting process began in 1983 and it included disposal-concept selection (KBS-3V), "consent-based" site selection and large-scale in-situ tests conducted in an underground research laboratory, the ONKALO, situated ~440 m below the mean Sea level immediately adjacent to the planned repository at the Olkiluoto site. At the end of 2015, the Finnish SNF repository is projected to open in 2024 as the first of its kind.

Four related lessons learned in Finland during the past 30 years are [1]:

1. The selection of potentially-suitable sites for geological disposal of SNF proved to be more difficult and more time consuming than initially envisioned.
2. The siting of nuclear facilities has evolved from being mainly a radionuclide containment and isolation challenge to becoming a critical moving-target, socio-political challenge governing progress with majority local acceptance being a fundamental imperative.
3. Public and political acceptance and support are strongly linked to the competency, credibility and transparency of the involved organisations and the maturity/pedigree of the proposed disposal concept.
4. Timely sharing lessons learned and conducting selective collaborations with other countries proved to be successful keys to timely and cost-effectively obtain and maintain public and political acceptance and support.

INTRODUCTION

The nation-wide search for a suitable site for safe disposal of SNF in Finland began in 1983. In 2001, the ratification of the Finnish Governments Decision in Principle (DiP) allowed Posiva to commence detailed, on-site investigations and analyses on one candidate site, the Olkiluoto site in the municipality of Eurajoki. In November 2015, with the consent of the related host community, Posiva's license application for the construction (CLA) of a deep geological disposal system (repository) and an encapsulation facility for the SNF generated by the Finnish nuclear power generating companies, Teollisuuden Voima Oy (TVO) and Fortum Power and Heat Oy (Fortum) at the Olkiluoto site in the municipality of Eurajoki was accepted by Finnish Government and ratified by Finnish Parliament accordingly. The next planned steps in the phased Finnish licensing process are to: 1) Submit a license application in 2020 to open and operate the two aforementioned facilities at the Olkiluoto site; and 2) Open both of them in 2024.

As summarised above, Finland has a long-standing SNF-repository siting program and is currently at the forefront of many SNF-repository siting and development (S&D) areas. However, the related path to get there included facing and overcoming a broad range of challenges. Some, but not all, of the lessons learned in Finland since 1983 deemed to be of potential interest and benefit to other nations and their respective SNF generators and SNF-facility hosts are concisely described and discussed herein, as are the legal and organizational frameworks for the Finnish SNF-disposal programmes. Additional information is available in the references listed herein and on or via the links provided on Posiva's home page (http://www.posiva.fi).

BACKGROUND

Legal and Regulatory Frameworks for SNF Repositories in Finland

Studies on the management of SNF were initiated during the construction stage of the power plants in the 1970s. In addition to work relating to the reprocessing of SNF, the studies also included planning and the readiness to build additional storage space. At that time use of nuclear power was governed by the Nuclear Energy Act of 1957 (NEA) [2]. The NEA was amended in 1978 to take into account nuclear waste management. The objectives and schedules relating to implementation of nuclear waste management, including SNF disposal, and associated research and planning were then defined in the Government´s related DiP in 1983. The overall schedule for the safe disposal of SNF in the 1983 DiP required that research and planning of the disposal of SNF in Finland was to progress so that "*by the end of the year 2000, a suitable disposal site has been chosen and studied so that the repository can be built if required*". The 1983 DiP also included several milestones for research and evaluation to be carried out to choose the final disposal site, technical design of the repository, and for safety assessment. The programme started with the screening for potential candidate SNF-disposal sites in the whole country.

The Nuclear Energy Act and Decree (NEAD), which came into force in 1988, provided clear guidelines on the implementation of nuclear waste management in Finland. Under a 1994 amendment the NEAD, the responsibility to safely manage and dispose of nuclear waste rested with the respective license holder (operating body) and importing and exporting nuclear waste became prohibited.

Pursuant to the 1988 NEAD, a favorable, ratified, DiP by the Finnish Government is required for commencing each of the following three life-cycle stages of an SNF repository:

1. Siting.
2. Construction.
3. Operation/opening.

Each of these milestones also requires a favorable ruling by the Finnish Radiation Authority (STUK). STUK is an integral legal participant throughout the aforementioned life cycle stages; responsible for promulgating and overseeing compliance with applicable regulations, setting reporting requirements for companies generating nuclear waste, and inspecting the surveys and technical plans

aiming at safe disposal of SNF. It also takes care of international obligations, which is handled through Nuclear Guidelines issued by STUK. It can request additional information on any of the aforementioned three license applications. It can also reject/veto any given SNF disposal solution.

Past and Current SNF Generators

TVO and Fortum (previously known as Imatran Voima/IVO) [1] currently operate two nuclear reactors each at two different locations/sites in Finland, i.e. the Olkiluoto and the Loviisa sites, respectively (Figure 1). In addition TVO has a third reactor under construction and supposed to be in operation by the end of 2018. These five reactors will generate a total of about 6,500 tons of uranium (tU) as SNF during their expected life time. Pursuant to the NEAD, the SNF generators are individually responsible for the safe management and disposal of the nuclear waste they generate as well as for the financing of these endeavors. From a very early stage, both TVO and Fortum accepted their respective related responsibilities. Two historical components of this responsibility with regards to the safe management and disposal of SNF are:

1. The accumulation of funds in advance for the safe storage and disposal of the generated waste in the State Nuclear Waste Management Fund.
2. The establishment in 1995 of a jointly-owned, independent, company, Posiva Oy (Posiva); chartered to develop and construct the facilities required for safe disposal of the SNF generated by TVO and Fortum. However, TVO´s planning and preparations for the siting of a safe SNF repository began in 1983.

Fig. 1. Nuclear Power Plant sites in Finland [4].

[1] A third nuclear power generating company, Fennovoima, has been established in Finland, but it will not operate a nuclear reactor until late 2020. Notwithstanding it may be an entity generating SNF in the future, it is not mentioned further in this paper due to its current lack of data relevant to this paper.

The Decision In Principle Process

In general, to be able to design and construct any nuclear facility in Finland, a national political DiP is required according the NEAD. The related process to apply and receive all needed permits and licenses shall proceed stepwise. The first step is to gain the Government´s DiP. The main purpose for this political decision is to ascertain whether the proposed nuclear facility is beneficial for the whole society, i.e., *is in line with the overall good of the society*.

When judging the whether or not to grant a DiP, the Government has to conclude that the following conditions are met:

1. There is a need for the facility.
2. The use of nuclear energy has to be safe.

The Government has also to consider the suitability, including public health and environmental impacts, of the intended site. Put simply, the requirement on safety means that no factors or conditions are indicated or found suggesting that safety could not be achieved.

Since the criteria and conditions for this decision making process are general, i.e., qualitative, and not defined implicitly, i.e., quantitatively, decisions are susceptible to prevailing political sentiments. When it is argued that disposal of SNF could be done safely, from a political perspective it may raise the following questions:

- Does it provide a positive change to claim that nuclear energy becomes safer considering the whole life cycle of nuclear power production; and
- Does it make it easier to grant more licenses to power companies based on their interest?

However, deep underground disposal in a carefully selected and designed repository is inherently safer than storages above ground. These aspects have made it a difficult topic to handle even among politicians. On a side note, an overwhelming majority of parliament members who voted in favor of granting the DiP to construct the final repository on the Olkiluoto site are on record to be against nuclear power; mainly new build.

During the political decision making process, the host municipality for the nuclear facility considered has the right of veto. To aid the host municipality and other affected and interested parties, each DiP is closely monitored by STUK. Besides controlling license holder activities, STUK also ensures that planned and executed actions do not threaten the overall safety and complies with applicable laws and regulations. In the event they do, STUK can stop any given activity, which, de facto, means that its staff must possess or have prompt access to a broad range of relevant subject matter experts to serve as a credible and trustworthy overseer.

In cases the Government’s decisions are positive, it has to notify and send the DiP to the Finnish Parliament (the Parliament) for ratification, which further illustrates the political nature of the DiP process.

DESCRIPTIONS AND DISCUSSIONS

Site Selection Process and Related Demographics and Key Events

Studies to evaluate the suitability of Finnish bedrock for safe disposal of SNF began in late 1970. Site characterization and geological research aiming towards site selection and identifying a suitable SNF-disposal site then started in 1983.

In May 1999, Posiva submitted a site-selection application to Government for a DiP on making the Olkiluoto site in the Eurajoki municipality the only candidate SNF-repository site. The Olkiluoto site is located in the immediate vicinity of TVO's nuclear power plant (NPP) site (Figure 1). TVO is currently operating nuclear reactors OL1 and OL2, and OL3 is under construction at the site. The TVO site also hosts a liquefied natural gas (LNG) power plant and a wind mill. The local host authority, the municipality of Eurajoki, has a population of 6,000 inhabitants and a neighboring municipality, the city of Rauma, has approximately 40,000 inhabitants.

Based on the information gained during the initial countrywide study, several potential sites were identified and communication with local representatives and authorities of potential candidate site locations were initiated. The selection of candidate sites was mainly based on the scientific material accumulated during a 15–year-long period of site characterisation and evaluation. In addition, an Environmental Impact Assessment (EIA) was conducted for all potential sites between 1997-1999 [5]. A long-term (post-closure) safety assessment, called TILA-99 [4] supported the EIA. The results of TILA-99 showed that regulatory requirements on long-term safety could be met with considerable safety margins for all potential site locations. The related assessments of operational safety of the facility and transportation safety resulted in similar conclusions.

In the EIA process, SNF-disposition alternatives were studied at various levels. They included assessments of options for SNF management, different concepts for geological disposal, comparison of proposed disposal concepts versus the long-term storage option, and finally, assessment of siting alternatives. In order to compare the results of the assessment for alternative sites a set of criteria was developed and used for this purpose. Since there was no requirement to find and select "the best location in Finland", the aim for the comparative assessment was to point out site candidates that were deemed most suitable for the planned actions. As mentioned in the preceding text, the results presented in the safety assessment TILA-99 showed that all site candidates were suitable. The TILA-99 assessment also showed that there was no possibility for an objective ranking of the site candidates in terms of long-term performance of the repository; the other criteria were used.

Posiva's related communications and negotiations with the potential host communities aimed at starting detailed site characterization and research activities at each location. Each of the resulting candidate sites were then envisioned to be subjected to an extensive programme, including surface-based investigations and modelling studies comprising at least 10 boreholes to depths of up to 1,000 m.

Social impact and infrastructure of the sites were emphasised in the final selection. All communities were found to be able to gain positively from socio-economic

impacts. On the basis of the EIA studies, the social acceptance and expected social impact varied most among the siting alternatives. Social impacts were evaluated based upon economical effect on local businesses, and fears and effects on peoples mind, feelings, etc. The social acceptance was highest in communities which were already familiar with nuclear power. The most defending attitudes towards final disposal were seen in communities which had no previous exposure to or experience with operating nuclear facilities. For these reasons, the most promising municipality to be selected for hosting the candidate site was Eurajoki. The infrastructure of Olkiluoto in the municipality of Eurajoki also provided excellent support to the disposal facility and most of the SNF will be generated by the Olkiluoto NPPs.

Accordingly, Posiva submitted an application to the Government on the 26th of May 1999 for a DiP to conduct site-specific investigations for an SNF repository at the Olkiluoto site rather than at any of the other three potential sites (Figure 2). The Finnish Government first held hearings on the EIA, which was appended to Posiva's application. The purpose of this process was to establish whether the EIA was complete enough and covered all aspects brought forward in the assessment process, including public participation. Thereafter, a general hearing for Posiva's application was arranged. The Government also requested separate statements from ministries, neighbouring communities, and governmental bodies. The statements given by these entities were mainly supportive to favorable decision making. Furthermore, STUK conducted a review of the scientific and technical material for its statement on safety. The EIA played an important role in the judgement of the local municipality, as well as for neighbouring municipalities, in preparing their respective statement. During the site selection process, STUK oversaw Posiva's siting efforts, including related off-site activities and actions giving it an opportunity to control that everything was done according to applicable laws, regulations, designs, and agreements.

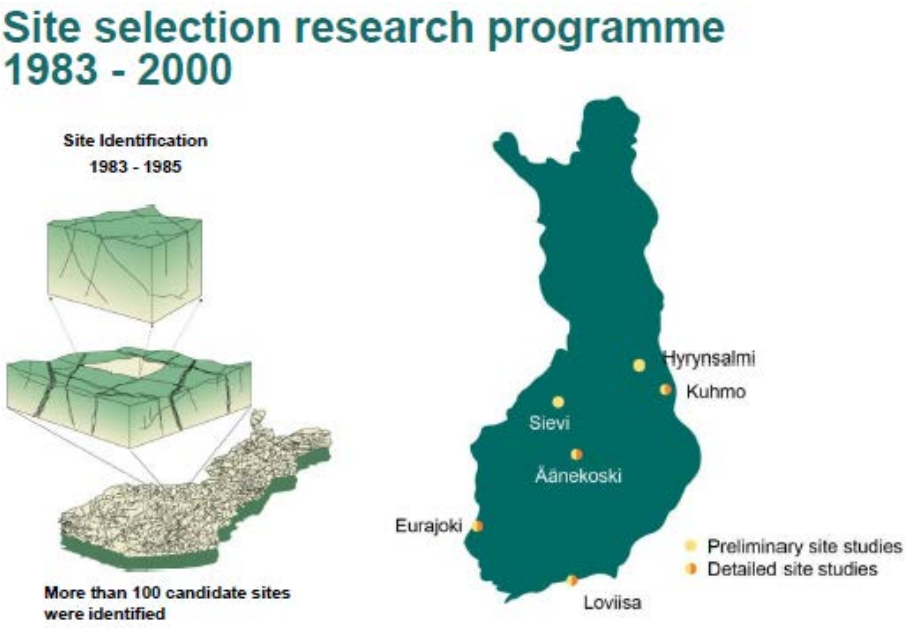

Fig. 2. Sites investigated during late siting process.

STUK submitted its statement to the Government in January 2000. It stated that a favourable decision can be made based on safety. The council of the proposed host municipality, Eurajoki, decided to accept the facility by voting 20 in favour and 7 against in January 2000. Appeals were filed to the administrative court by opponents to the favourable decision reached by majority vote of the municipal council. The handling of the appeals postponed the Government's DiP until December 2000.

The Parliament then started the discussion on ratification of the DiP in February 2001. After the required hearings and debates, the Parliament voted on May 18th 2001to ratify the Government's DiP based upon 159 votes in favour and 3 votes against. The discussion in the Parliament focused largely on:

- Available alternatives;
- Knowledge and understanding of long-term safety;
- Decision making steps to follow in the future; and
- Possibilities for retrieval.

The need to continue the preparation of the current alternative for deep geological disposal was recognised, as was the need to take the step to go underground. The aforementioned site selection process is described in greater level of detail in a summary report [1].

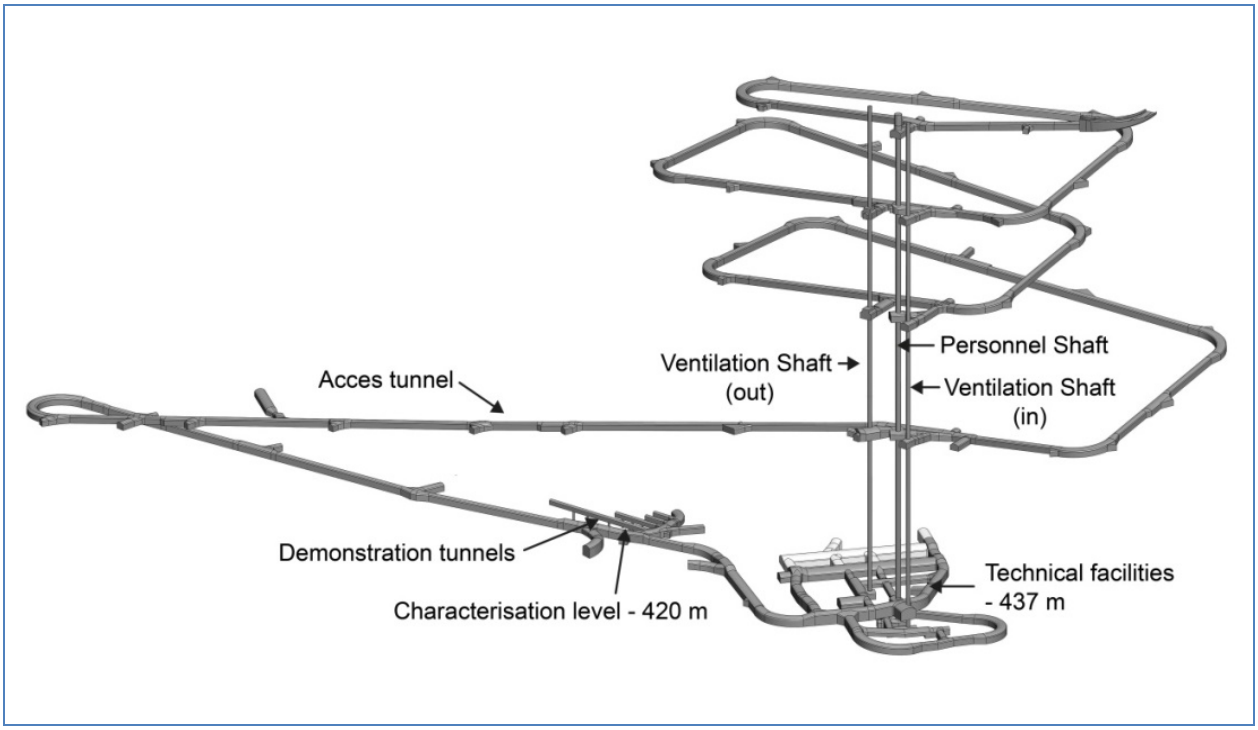

Fig.3. Layout of the ONKALO URL.

Notwithstanding the site evaluations and analyses for the Finnish SNF repository had been in progress for 15 years, the means to obtain new essential data by the methods used until the 2000 DiP was ratified in 2001 had been limited. Following its 2001 ratification, Posiva promptly devised a new site characterization programme that included an on-site underground rock characterisation facility (URL); named ONKALO, designed to be used as a passage to the repository during its construction and operation. As illustrated on Figures 2 and 3, ONKALO is located in the same rock and at the same depth as the planned repository, thereby facilitating the integrated conduct and design of both surface-based and underground-based in-situ investigations of host rock conditions aimed at establishing the prevailing rock mass conditions in greater level of detail and then be able to more confidently use them to project the long term performance of the SNF repository and optimize its design. The related site-specific data and information, and the construction experiences gained were used in support of the 2012 CLA [6].

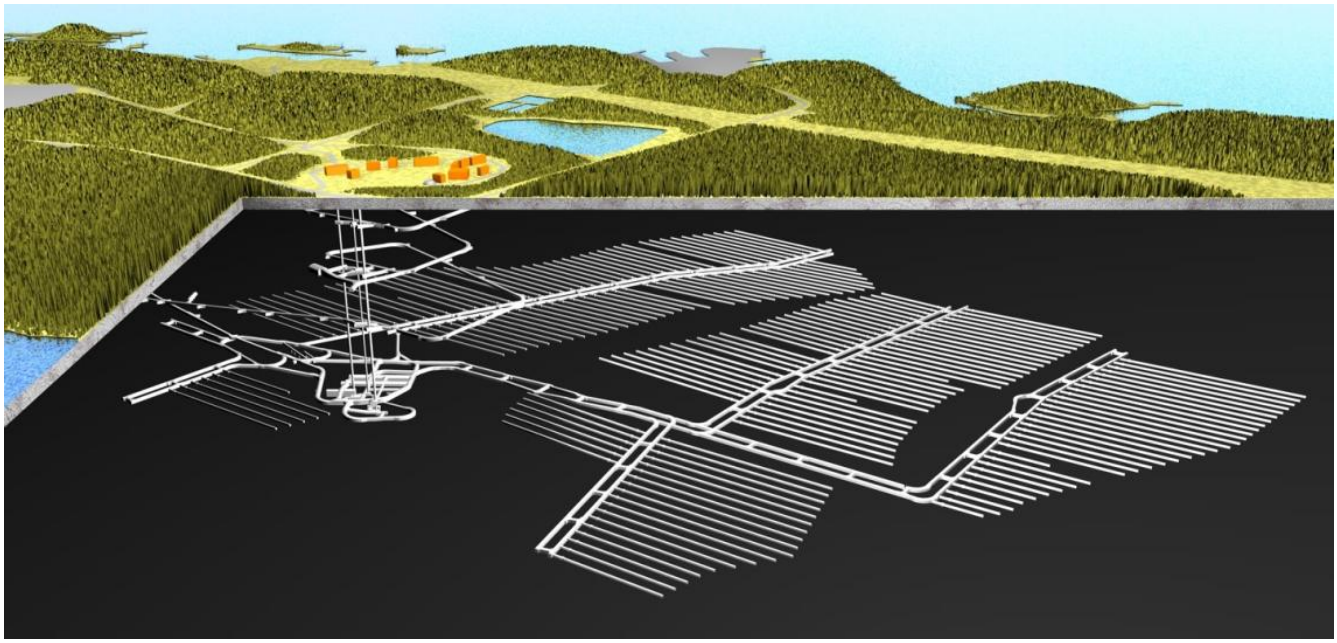

Fig. 4. Layout of the Finnish SNF repository at the Olkiluoto site (the layout of the Onkalo URL can be seen at the bottom of the shafts and on Figure 3).

Unfortunately, in early 2001, there was no operating SNF-disposal facility anywhere in the world and the KBS-3V concept (Figure 5) had not been tested thoroughly with regards to its long-term performance. These conditions gave birth to the idea, to be agreed upon with STUK, to submit a preliminary CLA in 2009 and postpone the final CLA to 2012. The underlying benefit of this approach would be the early identification of:

a. Data packages and studies related to rock characteristics and safety evaluations that were deemed insufficient by STUK; and
b. Expeditious conduct of data acquisitions, studies, analyses, and results needed to successfully apply to the Government for a construction license,

because both STUK and the Government, as well as the host community, were expected to base their decisions on the validity of data and results presented in Posiva's total system performance analysis, referred to herein as the "Safety Case".

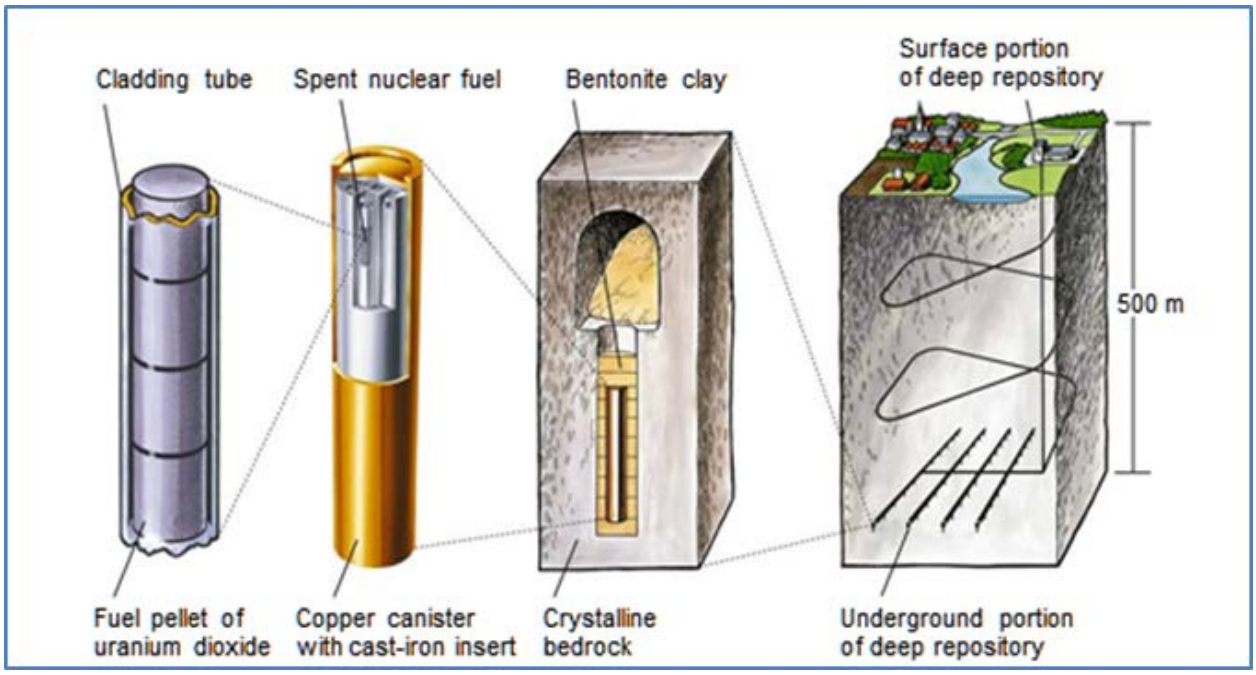

Fig. 6. Schematic illustration of the KBS-3V SNF-disposal concept.

Also, following the 2001 ratification of the DiP on the selection of the Olkiluoto site, Posiva, being a relatively small company, faced logistics, skills, and resource challenges to promptly change gear and aim for the next site characterization phases, because the 2001 DiP also meant that Posiva promptly had to plan and prepare construction license applications for both the Olkiluoto SNF repository and an adjacent encapsulation plant at the Olkiluoto site. Up until 2001, the preceding siting process was very much focused on host rock characterization and related safety assessments. With the 2001 ratification of the site-selection DiP, in addition to the Olkiluoto SNF repository, Posiva now also had to focus on several new topics, some of which lacked adequate in-house subject matter expertise, including the planning and design of the process for final disposal that in turn required SNF encapsulation. One of the related inherent challenges was that safety issues differ during different repository life-cycle phases. Whereas the safety requirements for the above-ground management and handling of SNF were well known, those for the underground management and handling of SNF were not. Neither were the post-closure safety requirements, including the period to be regulated, nor the related features, events and processes (FEPs) that could detrimentally impact the safe, long-term, performance of the SNF repository during the regulated post-closure period. In addition, the aforementioned post-closure safety also depends upon conditions created inside the bedrock during the more than 100-hundred-year-long repository-construction, -operation and -closure period, that may include different types of man-made barriers, also commonly referred to as engineered barriers, to radionuclide migration.

Based upon the site-specific information gathered and carefully analysed since 2001 and the related adaptation of the Swedish KBS-3V concept (Figure 6) to the conditions at the Olkiluoto site, at the end of 2012, in compliance with NEAD §32, Posiva submitted a CLA to the Government for a DiP on both an SNF-encapsulation facility and a mined, deep geological repository (Figures 3 and 4) for safe disposal of up to 6500tU of SNF situated ~ 440 m below MSL in the crystalline bedrock, also commonly referred to as “granite”, at the Olkiluoto site. Actually, the CLA was submitted to the Ministry of Employment and Economy (the Ministry) and the related Safety Case was submitted to STUK. In addition, an extensive amount of material, including the Safety Case,was submitted to STUK by Posiva that includined the following conclusion [7]:

"The disposal can be done safely provided it is done in accordance with the assumptions used in the Safety Case."

In addition to using international specialists to make some of these evaluations, STUK was also required to make exhausting evaluations of all material Posiva provided in the CLA according to the NEAD § 35. STUK then gave its statement and safety assessment report on the CLA to the Ministry on the 11th of February 2015. STUK’s main conclusion therein was:

"Encapsulation plant and repository for SNF can be built to be safe".

STUK also emphasized in its statement to the Government that the level of safety and facility design presented by Posiva was acceptable for the construction license stage based on the Ministry’s 2001 DiP on the siting of an SNF repository at the Olkiluoto site. However, STUK also concluded that, additional work was needed on some open minor topics and unanswered questions, including a detailed facility design, RSC process, demonstration of engineered barrier component installation and performance, and post-closure safety case for operating license application (OLA).

As mentioned in the preceding text, in November 2015, the Finnish Government ratified Posiva’s CLA, allowing Posiva to commence the construction of the Olkiluoto repository and the encapsulation facility. This was a global-first-of-its-kind milestone crowning a site selection process that begun in 1983 and included large-scale, in-situ, tests in the candidate repository horizon. As illustrated on Figures 2 and 3, the Olkiluoto SNF repository and the ONKALO URL will be located close to each other.

As mentioned in the preceding text and as schematically illustrated on Figure 2, the 2012 CLA was preceded by full-scale, in-situ, tests conducted in the ONKALO URL repository. Some of the in-situ tests conducted prior to and during the CLA process will continue during the construction of the repository, because the ONKALO URL will be part of the final repository. As such, it is the first and only of its kind worldwide. And additional in-situ tests are likely to be conducted in the repository area during the construction phase.

The 2015 Construction License was a global, first-of-its-kind, milestone preceded by more than 30 years of nation-wide and site-specific SNF-repository suitability and safety evaluations. The next step in the in the statutory-mandated licensing process

is to apply for a license to open and operate both an SNF-repository and an SNF-encapsulation facility at the Olkiluoto site. At the end of 2015, this license application is scheduled to be submitted at the end of 2020 and operations are scheduled to commence in 2024.

Posiva has benefitted from significant time and cost savings through its long-standing co-operation with Svensk Kärnbränslehantering AB (SKB) of Sweden. Following Posiva's adaptation of SKB's KBS-3V -concept (Figure 6), Posiva has continued to collaborate with SKB on the adaptation of the KBS-3V concept to the prevailing rock mass conditions at the Olkiluoto site and in other SNF-disposal-related areas, including more detailed technical designs for the disposal facility and its systems.

CONCLUSIONS

Political decision making related to the siting and development (S&D) of nuclear facilities has been difficult in Finland, as well as, elsewhere during the past 40+ years, because views and opinions among citizens and their elected representatives vary widely and for a multitude of different reasons. Furthermore, it has been particularly difficult to S&D disposal solutions for SNF and other high-level radioactive waste (HLW). Indeed, virtually every country attempting to S&D SNF and/or HLW disposal solutions have experienced opposition and delays. Indeed, some countries, including Sweden, have also been forced by local or political opinion to abandon a given potential site for socio-political rather than safety reasons. Two of the main related reasons among laypeople are the "incomprehensible" state-of-the-art sciences and engineering concepts and the related, unprecedented, time scales involved. As follows, even if a site may have been found "suitable" based upon applicable performance and safety requirements, it may still be opposed and even rejected based upon local and/or political resistance. In addition, as demonstrated e.g., in the USA, local acceptance of a given site, whether it exists or not, is ultimately governed by decision making at the national level.

As demonstrated in e.g., Finland and Sweden, the scientific and temporal challenges can be mitigated, at least partially, by extensive public and political outreach. One of the related lessons learned in Finland is that it is imperative to local and political acceptance and progress of a given SNF-disposal solution that this outreach is not limited to science and engineering. According to experiences gained from the long siting process in Finland there are some basic elements which have made it possible to develop the "trust" needed for timely decision making. Put simply, after more than 40 years of efforts around the world to S&D a broad range of SNF-disposal solutions, the sciences and engineering challenges are typically, but not always, overshadowed by the socio-economic and political challenges.

In Finland nuclear power producers are responsible for all actions and costs needed to deal with the disposition of the nuclear waste they produce. To follow and control that these responsibilities are carried out in a safe and timely manner, the Finnish Government requires that all nuclear license holders prepare and submit planning and progress reports every third year. This procedure has offered and will continue to offer Posiva the possibility to proceed stepwise and to get periodic feedback from

STUK and the Ministry during the implementation of the CLA and the planning and preparation of the OLA.

One long-standing related Finnish conclusion is that adopting a mature SNF-disposal solutions and promptly adapting it to domestic conditions embody significant benefits in terms of public and political acceptance. Case in point, Finland adopted and promptly adapted the Swedish SKB-3V disposal concept for its SNF-repository in 1980´s, and it is now projected to open the world's first SNF-repository in 2024. Clearly this is not the only reason Finland is the current global front runner to open an SNF repository, but it is certainly one of the key contributing reasons to its current pre-eminent global status that, in turn, has translated into significant time and cost savings. A related component contributing to the aforementioned time- and cost-savings is that Finland has continued to collaborate with the Swedish SNF disposal programme and intends to continue these collaborations into the foreseeable future. One reason for this collaboration is that notwithstanding the Olkiluoto site has been evaluated since 1983, unexpected rock mass conditions and related safety issues are anticipated and their timely and cost-effective resolution could benefit from lessons learned in Sweden, due to the close similarity of the two SNF-repository programmes.

The Finnish licensing process is a stepwise approach that gives TVO and Fortum and, on their behalf Posiva, the opportunity to proceed in a controlled way with one licensing phase after another. But it still does not guarantee that the SNF repository can open and commence disposal operations after the next licensing step, the OLA, unless Posiva has credibly demonstrated that everything has been done according to applicable laws and regulations, and all other requirements set have been met. Because, the stepwise licencing process also provides the opportunity for both STUK and the local authority, i.e., the municipality of Eurajoki, to use their respective right of veto through the CLA and CLO processes if Posiva's post construction license phase Safety Case update doesn't cover or meet all safety issues or requirements, respectively. The aforementioned step wise licensing process and its embedded continuous regulator oversight made it easier for other parties besides STUK to give positive statements on safety issues related to the proposed host rock and its characteristics before the license for the construction of the Olkiluoto SNF repository was granted in November 2015.

Finally, in addition to convincingly demonstrating that the proposed nuclear facility meets all applicable legal and regulatory requirements, it is also important that the local municipality benefits economically from hosting it. Whether these socio-economic benefits are significant or not, they should be discussed and agreed upon at an early stage in the S&D process with the host community, e.g., in conjunction with the siting EIA process, to ensure they don't become an issue later in the S&D process that may result in a veto. In the case of Posiva's pending facilities at Olkiluoto site, the local municipality will benefit from both increased tax revenues and many more long-term-employment opportunities.

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