The Finnish Solution to Final Disposal of Spent Nuclear Fuel

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11.1 Introduction

Finland is the first country in the world to be in the implementation phase of geological final disposal of spent nuclear fuel (SNF). The implementing company, Posiva Oy, owned by two nuclear power companies Teollisuuden Voima Oy (TVO) and Fortum, has marketed its concept ONKALO and the facilities as a "final solution" to the problem of high-level nuclear waste (HLW). A third Finnish nuclear power company, Fennovoima, is not included in the ONKALO project.

Finland's political culture is based on structural corporatism and high trust of citizens in the state and its institutions, which partly explains the progress of Posiva's project and the relatively minor opposition to it. Public debates have focused more on new nuclear power plants (NPPs), which have been on the political agenda at the same time as the final disposal facility and its expansions. The

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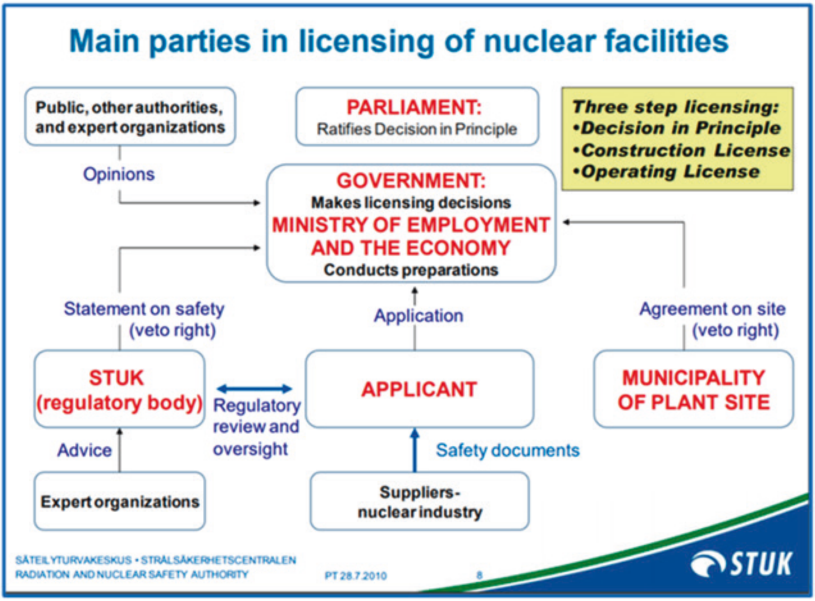

Fig. 11.1 Major actors in the licensing procedure of nuclear facilities in Finland (STUK, 2019)

licensing procedure is the same for all nuclear facilities,[1] including both NPPs and final disposal repositories (Fig. 11.1).

During the process of Posiva becoming the first holder of an operating license for a final disposal facility for SNF, public participation has not been very active and has been considered ineffective by various social scientists. This was one reason to strengthen the role and potential for public participation in the revised Act on Environmental Impact Assessment Procedure (252/2017), which has not yet

[1] According to the Nuclear Energy Act (990/1987), a nuclear facility refers to facilities to produce nuclear energy, facilities for large-scale final disposal of nuclear waste, and facilities for producing, manufacturing, using and storing of nuclear materials and nuclear wastes. A decision-in-principle (DiP) is required for (1) a nuclear power plant with a heat efficiency of 50 MW or more, (2) a facility for final disposal of nuclear waste, and (3) other facilities with a significant amount of nuclear material, nuclear waste, or nuclear radiation, comparable to (1).

Table 11.1 The amount of radioactive waste in Finland (MEE, 2022)

Type of radioactive waste	Stored by the end of 2019	Final disposal by 2019	Final disposal by 2030	Final disposal by 2050
Very low level	204 m^3	n. a.[a]	2,300 m^3	6,900 m^3
Low level	1,691 m^3	6,541 m^3	8,761 m^3	10,661 m^3
Intermediate level	1,970 m^3	2,117 m^3	8,278 m^3	9,078 m^3
High level	2,261 t[b]	0	3,200 t	4,200 t

[a] Included in the figure of low level waste
[b] Amount in temporary storage at the nuclear power plant sites

been applied to nuclear facilities. Furthermore, according to the Ministry of Economic Affairs and Employment (MEE),[2] processing Posiva's application for an operating license for ONKALO will include possibilities for public participation (MEE, 2021), which is new in granting an operating license for a nuclear facility in Finland.

Table 11.1 shows the amount of nuclear waste by 2019 and estimates for 2030 and 2050, Table 11.2 provides information on the Finnish NPPs, and Table 11.3 shows the amounts of SNF in these plants by 2019 and the maximum licensed amounts.

This chapter provides a view of Finnish nuclear waste management (NWM) from the governance ecosystem perspective (see chap. 1 of this volume) and describes how the first final disposal facility for SNF in the world, ONKALO by Posiva Oy, has been smoothly implemented. Section 11.2 describes the development of Finnish NWM. Section 11.3 discusses technological challenges related to the geological disposal of SNF, i.e. stability of the Finnish bedrock, the Swedish KBS-3 V concept, and a less discussed issue—temporary storage of SNF lasting up to 50 years. Section 11.4 looks at the financial side of NWM based on the State Nuclear Waste Management Fund, which also provides resources for scientific research on NWM.

Section 11.5 provides background to Finnish consensus-seeking decision-making by focusing on essential characteristics which enable Finnish govern-

[2] To simplify the English translation of the name(s) of the Finnish Ministry of Economic Affairs and Employment over the historical period described in this chapter, the acronym MEE is used throughout.

Table 11.2 Basic information on the nuclear power plants in Finland

Nuclear power plant	Reactor type and current capacity	Operating license in force
Loviisa 1 (Fortum)	Atomenergoexport VVER-440, 507 MW_e	31.12.2027
Loviisa 2 (Fortum)	Atomenergoexport VVER-440, 507 MW_e	31.12.2030
Olkiluoto 1 (TVO)	AB Asea Atom BWR, 890 MW_e	31.12.2038
Olkiluoto 2 (TVO)	AB Asea Atom BWR, 890 MW_e	31.12.2038
Olkiluoto 3 (TVO)	Areva NP EPR, 1,600 MW_e[a]	31.12.2038
Hanhikivi 1 (Fennovoima)	Rosatom AES-2006 PWR, 1,200 MW_e [b]	

[a] Started on 21 December 2021, grid connection expected in 2022
[b] Reactor in the 2015 construction license application. Fennovoima withdrew the application on 24 May 2022

Table 11.3 Total quantity of spent nuclear fuel produced until decommissioning of the nuclear power plants in Finland (MEE, 2022; Posiva 2021; Fennovoima, 2015)

Nuclear power plant	Quantity of spent nuclear fuel by the end of 2019 (t)	A total maximum quantity of SNF until decommissioning (t)
Loviisa 1–2	690	1,096
Olkiluoto 1–2	1,565	2,904
Olkiluoto 3	–	2,500
Hanhikivi 1	–	(1,800)
Total	2,261§	6,500 (8,300)

ance—structural corporatism, high trust in technology and experts, and the subservient role of the public. These are reflected in NWM via typical Finnish characteristics, including strong energy elites, cross-ownership of nuclear power companies, and the so-called Mankala principle applied in many Finnish energy companies, among them TVO, Fennovoima, and Posiva. Section 11.6 describes an important part of the governance ecosystem, namely weak social inclusion in the Finnish NWM. Public participation in decision-making, the role of anti-nuclear movements, and the media's role are addressed. Section 11.7 concludes and looks at the future of NWM in Finland.

11.2 History of Nuclear Waste Management (NWM) in Finland

Figure 11.2 presents the most recent schedule from the Ministry of Economic Affairs and Employment (MEE, 2022) regarding (1) use and decommissioning of the licensed NPPs, (2) operation and closure of storage facilities for low- and intermediate-level nuclear waste (LILW) at the NPP sites, (3) interim storage of SNF at the NPP sites, and (4) final disposal of SNF.

11.2.1 NWM Before Finland Entered the EU in 1995

Finland began preparing for NWM during the procurement and construction phase of the first NPPs. In 1969, a bilateral agreement was concluded with the Soviet Union, including a principle that the Soviet Union takes back the SNF used in the Soviet-based nuclear reactors. This export of SNF from the two Loviisa reactors started in 1981 and ended when the ban on nuclear waste exports and imports (included in a 1994 amendment to the Nuclear Energy Act) entered into force in 1996. Since then, SNF from Loviisa 1–2 has been first placed in a cooling pool beside the reactor, and then in temporary storage located at the NPP site.[3]

TVO had a different situation with its Swedish nuclear reactors in Eurajoki (Olkiluoto 1–2). According to Raumolin (2011), TVO considered final disposal of SNF in Finland as its preferred option.[4] However, the TVO Board had rejected international negotiations on reprocessing tenders in 1979 for economic reasons (Kojo, 2009). TVO made a schedule for NWM, which allowed temporary storage of SNF for 40 years before its final disposal (Table 11.4).

In 1983, the government made a decision on NWM. It included two basic options. According to MEE (2015a, p. 7), the first involved "centralised international final disposal solutions and contract arrangements that would allow reprocessing SNF to be irrevocably located abroad". In the second option, nuclear

[3] A final repository for LILW in Loviisa came into use in 1998. Expansion for the waste generated during decommissioning of the VVER reactors is expected.

[4] TVO has built cooling pools and an interim storage for SNF in the Olkiluoto site. A final repository for LILW was also built in Olkiluoto and came into use in 1992. Enlargement of this repository has been included in the construction license granted for Olkiluoto 3.

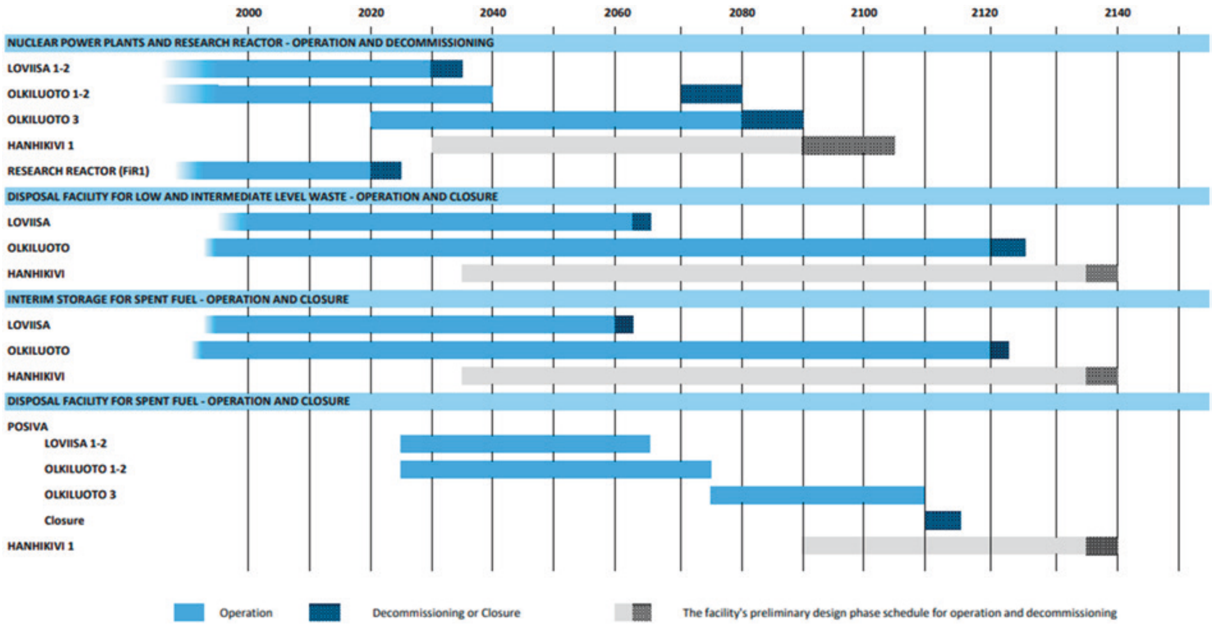

Fig. 11.2 Timetable regarding the use of Finnish nuclear power plants and nuclear waste management. (MEE, 2022)

Table 11.4 Schedule for the final disposal of spent nuclear fuel by TVO (Raumolin, 1982, as cited in Kojo, 2009, p. 167; Kojo et al., 2010, p. 170)

Period	Activity
1980–1982	Suitability study with safety analyses
1983–1985	Preparation for the preliminary site characterisation
1986–1992	Preliminary site characterisation in chosen site areas (5–10 sites)
1993–2000	Additional siting studies (2–3 sites)
2001–2010	Detailed studies on the chosen disposal site and pre-planning of the siting and the encapsulation plant
2011–2020	Planning and construction of the final disposal site and the encapsulation plant
2021–2050	Final disposal facility in operation
2051–2060	Closing of the final disposal site

power companies prepared for final disposal of SNF in Finland. The 1983 decision preferred international solutions, but demanded that the nuclear power companies are prepared for final disposal of SNF in Finland, if necessary (Kojo, 2009).

TVO's original schedule of NWM has been followed without major exceptions. Screening of possible sites started in a large number of areas but dropped to 85 by using extra-geological criteria, e.g., land ownership and municipal acceptability. TVO selected five areas for preliminary site characterisation studies in 1987: Olkiluoto, Veitsivaara, Kivetty, Romuvaara, and Syyry (Fig. 11.3). Olkiluoto as a NPP site had a special position, because the proximity of the facilities would reduce the transportation of SNF. Detailed site characterisation studies started in Olkiluoto, Romuvaara, and Kivetty in 1992 (Kojo, 2009).

11.2.2 Decision-In-Principle and Licensing of ONKALO

In 1995, Fortum and TVO established a joint company Posiva Oy for the final disposal of SNF from their NPPs in the new context of banned exports and imports of nuclear waste and a mandatory Environmental Impact Assessment (EIA) process. Posiva continued the siting process started by TVO, and added Loviisa to the potential final disposal sites in 1997 (Fig. 11.3).

Fig. 11.3 Locations of the final disposal sites for spent nuclear fuel with site characterisation studies and the existing nuclear sites

In the preparatory phase of the DiP application, local acceptability of the SNF repository became a decisive factor for Posiva, especially acceptability by the municipal council of the host municipality. Posiva and the municipality of Eurajoki started negotiations on mutual economic benefits of choosing Olkiluoto as the site for final disposal of SNF. A well-known result of these negotiations is the "Vuojoki agreement". Among other things, Eurajoki agreed to lease a real estate, the Vuojoki Manor, to Posiva, and Posiva agreed to finance construction of a new senior centre in Eurajoki. The municipal council of Eurajoki approved the Vuojoki agreement on 9 May 1999 (see Kojo, 2009).

On 26 May 1999, Posiva applied a DiP to construct an encapsulation plant and final disposal facility for SNF. The only site included in the application was

Olkiluoto in Eurajoki. Posiva stated that "an essential factor regarding the implementation is also to gain local acceptance for the operation" (Kojo, 2009, p. 173).

Posiva estimated the maximum amount of HLW to be 9,000 tons (t)[5] covering the SNF produced in Loviisa 1–2, Olkiluoto 1–2, and two planned new NPPs. Because TVO had submitted an application for a DiP to construct Olkiluoto 3, Posiva changed its DiP application in November 2000 to cover SNF only from the reactors in operation (4,000 t), and submitted a new application for a DiP to extend the repository by 2,500 t of SNF from Olkiluoto 3. Moreover, Posiva asked the government to decide on Olkiluoto 3 and the extension of the final disposal repository at the same time (MEE, 2013; Kojo et al., 2010).

The government issued a favourable DiP on the final disposal facility for 4,000 t of SNF in December 2000. The government stated that, "of the studied disposal options, deep disposal in the bedrock, i.e. geological disposal, offers the best and most realistic possibilities to isolate high-level nuclear waste from the biosphere and the human habitat" (Government of Finland, 2000). The parliament approved this DiP on 18 May 2001 with votes 159–3.

The government made the DiPs regarding the construction of Olkiluoto 3 and extension of the repository for 2,500 t of SNF from Olkiluoto 3 in January 2002, and the parliament approved both in May 2002 (MEE, 2013; Kojo et al., 2010).

In 2004, Posiva introduced the Finnish name ONKALO for the underground research facility excavated in the Olkiluoto bedrock, meaning a cavity or a hidden cave, which sounds "safer" than a normal cave (Auffermann et al., 2015; cf. El-Showk, 2022). Soon it became widely-used for the whole project on final disposal of SNF in Finland. Since 2018, ONKALO has been a registered trademark of Posiva Oy.

In 2007, a group of Finnish power companies and the German E.ON established a new nuclear power company, Fennovoima. Two years later, Fennovoima submitted an application to the government for a DiP to construct a new NPP, Hanhikivi 1, in Pyhäjoki, on the north-western coast of Finland (Fig. 11.2). In the same year, TVO and Fortum submitted applications for DiPs on two new NPPs, Olkiluoto 4 (TVO) and Loviisa 3 (Fortum). At the same time, Posiva submitted two applications for a DiP to extend ONKALO for SNF, one from Olkiluoto 4 and another from Loviisa 3.

[5] 9,000 tons of SNF is around 900 m^3 in volume. The amount of HLW such as SNF is documented in metric tons only.

The MEE processed all five DiP applications during 2009–2010, and the government made the DiPs in May 2010. Construction of TVO's Olkiluoto 4 and Fennovoima's Hanhikivi 1, as well as the extension of ONKALO for SNF from Olkiluoto 4, were deemed to be "in line with the overall good of the society", but Fortum's Loviisa 3, and Posiva's related extension of ONKALO were not.[6] The parliament left the three favourable DiPs in force in July 2010.

In December 2012, Posiva submitted an application for a construction license for ONKALO with a total capacity of 6,500 t of SNF. The final disposal facility will be constructed in such a way that its safety will not be monitored after the repository has been decommissioned and the ownership of and responsibilities for nuclear waste have been transferred to the state (Posiva, 2012). The government granted the construction license in November 2015. On 30 December 2021, Posiva submitted an application for ONKALO's operating license. According to the application, the operation would start in March 2024 (Posiva, 2021). The MEE will organise a public consultation, request statements from authorities, organisations, and municipalities in the affected area, and provide citizens and communities with an opportunity to express their opinions (MEE, 2021).

11.2.3 Cooperation Between Posiva and Fennovoima

In the application for the Hanhikivi 1 DiP, Fennovoima (2009) planned the NWM in cooperation with other licensees responsible for NWM. The MEE appointed a working group in March 2012 to coordinate the three nuclear power companies' joint investigation into alternatives for final disposal of SNF. The working group compared construction alternatives and recommended utilising the competence and field experience accumulated during Posiva's project (MEE, 2013). Moreover, the working group recommended that Posiva and Fennovoima should continue cooperation to solve Fennovoima's NWM—the number of facilities for final disposal of SNF is not an issue (MEE, 2013, p. 15). In 2017, MEE appointed a new working group to investigate future alternatives for long-term NWM, but the working group excluded the final disposal of SNF and stated that the previous working group report is up-to-date (MEE, 2019a).

[6] In 2015, TVO decided not to apply for a construction license, so the DiPs related to Olkiluoto 4, granted in 2010 for TVO and Posiva, lapsed.

In 2016, Fennovoima and Posiva signed a mutual agreement on using Posiva's expertise in planning and developing Fennovoima's NWM activities (Fennovoima, 2016).[7] Fennovoima also submitted its EIA plan as required by the MEE in the Hanhikivi 1 DiP, and announced that the location of the final disposal site will be selected in the 2040s (Fennovoima, 2016).

In 2017, the MEE requested additional information on Fennovoima's NWM before giving its statement on the EIA plan. Fennovoima informed MEE that the location will be decided "after receiving the construction license for Hanhikivi 1 at the earliest, and when applying for the operating license at the latest" (Fennovoima, 2018, p. 4). Fennovoima prefers only one final disposal facility of SNF in Finland (Fennovoima, 2018; MEE, 2019a), but keeps open two siting options Olkiluoto and Pyhäjoki. Posiva, on the other hand, is willing to offer expertise but does not support a joint project in Olkiluoto, which might require a shareholder position for Fennovoima in Posiva Oy.

11.3 Scientific and Technological Challenges

11.3.1 Stability of the Bedrock

Posiva has chosen deep geological storage as the method for the final disposal of SNF. The bedrock of the Olkiluoto site consists of Svecofennian metasediments and plutonic rocks, 1,800–1,900 million years old (Anttila et al., 1999). In Posiva's solution, the bedrock acts as a natural barrier. Its safety functions are intended to (1) isolate the SNF from the surface environment and normal habitats for humans, plants and animals, limit the possibilities of human intrusion, and isolate the repository from changing conditions at the ground surface, (2) provide favourable and predictable mechanical, geochemical and hydro-geological conditions for the engineered barriers, and (3) limit the transport and retard the migration of harmful substances that could be released from the repository (STUK, 2015).

Posiva has accumulated practical experience related to the stability of the bedrock in Olkiluoto from the test drillings started in 1989 by TVO, and during the excavation of the underground rock characterisation facilities from 2004. Posiva considers the bedrock to be sufficiently stable around the deposition tunnels and

[7] In 2016, Posiva established a subsidiary, Posiva Solutions, offering expertise and consulting services on the management of nuclear waste and radioactive materials.

deposition holes. Posiva has studied the geological structures of the bedrock at the disposal site and estimated that at a depth of 400–450 m, the requirements for post-closure safety and the constructability of the disposal facility are fulfilled. According to STUK (the Finnish Radiation and Nuclear Safety Authority), the understanding and measurements of the baseline stress of the bedrock are sufficient at the construction license stage; however, Posiva will have to reduce specific uncertainties and deficiencies before construction of the disposal facilities. Moreover, further investigations are required related to the impact of the heterogeneity of the bedrock on the stability of the bedrock and concerning the rock mechanical properties of the fracture zones on various scales. However, STUK (2015) concludes that the characteristics of the bedrock in Olkiluoto are favourable for ensuring the post-closure safety of SNF final disposal.

The changes of conditions due to an ice age as well as permafrost are seen by Posiva as the most important above-ground natural phenomena regarding final disposal. Based on its own modelling, Posiva has estimated that the permafrost would reach a depth of 60–240 m during a dry, cold period lasting 10,000 years. Using the same analysis, Posiva has estimated that permafrost extending to a depth of 400 m would require a dry, cold period of 100,000 years, which it considers unlikely.

There are uncertainties related to climate evolution analyses that extend far into the future. For this reason, Posiva has also estimated the effects of permafrost that reaches a disposal depth on the performance of the fuel canister and other engineered safety barriers (STUK, 2015; see Sect. 11.3.2 on the KBS-3 V final disposal concept). However, there has been criticism towards the disposal concept, on geological grounds: "All the forecasts of the safety of the disposal site after the next glacier period (55,000–65,000 or 90,000–100,000 years from present) are speculations and are not based on scientific factors" (Saarnisto, 2008, as cited in a popular magazine by Ukkola, 2010).

STUK (2015, p. 41) states that the amount of collected seismic data needs to be extended during the construction and operation of the facility since the safety of the disposal will be evaluated "over timespans that exceed the data coverage presented". STUK does not define the timespans, but the seismic data presented in Posiva's application for the ONKALO construction license covers 1965–2012. Moreover, seismic risks need to be further investigated by taking into account the bedrock structures and their properties in Olkiluoto more diversely, as well as by assessing further magnitudes and frequencies of earthquakes under various geological circumstances (STUK, 2015).

11.3.2 The KBS-3 V Concept

Posiva plans to pack the SNF inside copper-steel canisters at an above-ground encapsulation plant from where they will be transferred into the deep underground tunnels of the repository and placed in the holes excavated in the final disposal tunnels (Fig. 11.4).

The KBS-3V concept was originally developed by the Swedish Nuclear Fuel and Waste Management Company (SKB). Posiva adopted the concept and has elaborated it further together with SKB. KBS-3V has three safety barriers (copper capsule, bentonite clay, and bedrock granite) designed to keep the HLW isolated from the biosphere for at least 100,000 years (Fig. 11.5). According to Posiva (2018), a shortcoming of one barrier does not endanger the safety of the insulation.

Finland proceeds as the first implementer of KBS-3V, as ONKALO is expected to start operating in 2024. About one hundred final disposal tunnels will be excavated during the 100-year operational period of ONKALO. The repository will total a length of 35 km with each tunnel being about 4.5 m high, 3.5 m wide, and 350 m long, each holding about 30 canisters of SNF.

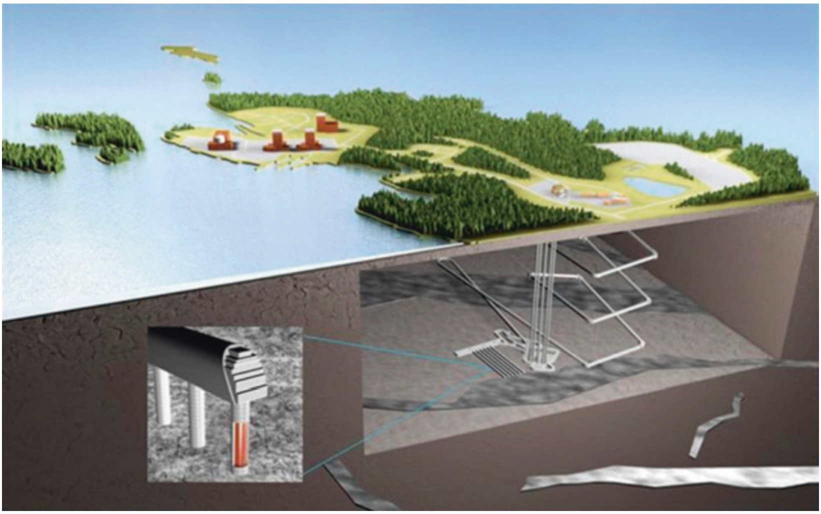

Fig. 11.4 Concept image of the KBS-3V final disposal solution. (Source: Posiva Oy)

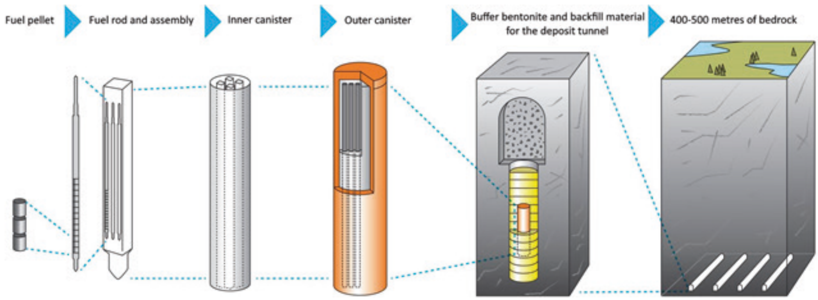

Fig. 11.5 The multi-barrier principle in Posiva's final disposal concept

The copper canister is the most important barrier against the release of SNF (MEE, 2019b). The final disposal concept relies on the assumption that copper does not corrode in anaerobic conditions. Therefore, the canisters used for disposal should corrode extremely slowly when buried deep in the bedrock with bentonite clay surrounding them.

Researchers at the Swedish Royal Institute of Technology (KTH) have repeatedly questioned the KBS-3V method by highlighting greater copper corrosion risks than SKB acknowledges. Experimental studies at KTH concluded that copper in the disposal canisters could corrode even under anaerobic conditions if it takes oxygen from water molecules (Hultquist, 1986; Szakálos et al., 2007; Hultquist et al., 2009; Szakálos et al., 2018). Therefore, contact with groundwater could risk a higher corrosion rate for the copper canisters than is considered safe for SNF disposal.

Posiva and SKB rejected such claims by referring to a similar repeated experiment where no corrosion was detected (SKB, 2016; Ottosson et al., 2017). The appropriateness of experimental test conditions for sensitive copper corrosion research have been disputed. Posiva (2018) has nevertheless been confident that their ongoing research and modelling together with SKB is enough to guarantee the safety of the repository project.

The scientific dispute over copper corrosion has not received much media attention in Finland, while in Sweden it is a potential "showstopper" in the country's own final SNF disposal plans (Litmanen et al., 2017b; Lehtonen, 2021). In 2018, the Swedish Land and Environmental Court of Appeal stated to the government of Sweden that SKB's application for a SNF repository should only be approved if the company can provide further evidence of long-term safety regarding the durability of the copper capsules.

11.3.3 Temporary Storage of Spent Nuclear Fuel

The SNF of a NPP is stored in cooling pools of the reactor for at least two years. Then it will be transferred to an interim storage facility (Becker, 2017). The cooling pool is a vulnerable part of a NPP with a considerable radioactive inventory. If a terror attack causes a breach of the concrete walls of a SNF pool, the cooling water will pour out. This causes the SNF to heat up due to the decay heat. Once the SNF reaches a temperature of 900 °C, the zirconium cladding of the fuel starts to burn in the air (Becker, 2017). This can cause high radioactive releases (National Academy of Sciences, 2016).

According to US National Research Council (NRC) estimates (NRC 2006), a fire in a dense-packed SNF pool could release 100 times as much cesium-137 into the atmosphere as the three reactor meltdowns released in Fukushima. Such an accident would cause a relocation of 3.5 million people (von Hippel & Schoeppner, 2016). NRC (2006) has examined the risks of a terrorist attack on temporary storage of SNF for using these materials for a radiological dispersal device. A successful terrorist attack on SNF pools, though difficult, is possible. A propagating fire in a pool could release large amounts of radioactive material, but rearranging SNF in the pool during storage and providing emergency water spray systems would reduce the likelihood of a propagating fire even under severe damage conditions.

In Finland, the need for modification of the SNF temporary storage has been assessed by the Finnish Radiation and Nuclear Safety Authority (cf. STUK 2021). In Olkiluoto, all SNF from Olkiluoto 1–2 is in the interim storage after being cooled enough in the pools of reactor units. TVO decided to double the number of cooling pools due to the additional operating time of the reactors and the new Olkiluoto 3.[8] The capacity of the enlarged SNF storage is considered to be sufficient for the three Olkiluoto units. The enlargement of the interim storage was included in the most recent operating license of Olkiluoto 1–2. The licensing of the enlargement was conducted as a major plant modification with approval from STUK. When conducting changes in an old nuclear facility, the new safety requirements have to be followed. The major challenge in designing the enlargement of the SNF storage was to modify it to withstand a large airplane crash. The operator chose to cover the pools with protective slabs dimensioned to be light

[8] The government granted TVO an operating license for Olkiluoto 3 in March 2019. All nuclear reactors Olkiluoto 1–3 have an operating license in force up to the end of 2038 (Table 1.2).

enough to ease their handling but strong enough to withstand the impacts followed by an airplane crash to the storage building, and to build a landfill embankment and concrete structures outside the storage, dimensioned to be high enough to protect the pool structures from a direct airplane impact (Maaranen, 2013).

After the 2011 Fukushima accident, STUK required the nuclear power operators to investigate how the NPPs are prepared to withstand exceptional natural phenomena and other unpredictable disturbances in the external power supply, such as a war. Some modifications to the interim storages of SNF were planned after the stress tests.

11.4 Financing of Nuclear Waste Management

In Finland, the nuclear operators TVO, Fortum, and Fennovoima are financially responsible for the management of radioactive waste and decommissioning of their NPPs (Nuclear Energy Agency, 2021). The legal instrument for this is the State Nuclear Waste Management Fund (SNWMF), independent from the state budget but controlled by the MEE (Nuclear Energy Act, 990/1987, Chap. 7). The nuclear operators pay an annual fee to the SNWMF to cover their liabilities. In practice, the SNWMF acts as a kind of guarantee fund from which potential remaining decommissioning and nuclear waste management measures are paid if a nuclear operator does not fulfil its obligations (Nuclear Energy Agency, 2021).

The nuclear operators and their shareholders are entitled to borrow back a part of the accumulated assets from the SNWMF in exchange for the provision of securities. This was a maximum 75%, but was decreased to 60% in 2021, based on recommendation by a working group set up by MEE to improve the investment activity of the SNWMF (see MEE, 2019c). Fortum and TVO have actively used their right for back-borrowing. Regarding the remaining assets, at least 20% must be available for the State, and the SNWMF must actively invest at least 20% to increase the assets against collateral security yielding the best possible return (Nuclear Energy Act, 990/1987, Sect. 52).

The costs of the final disposal of SNF depend on the time horizon of permanent disposal. At the end of 2019, €2.6 billion had been accumulated in the SNWMF from charges on generated electricity, which account for 10% of the production costs of nuclear electricity (Jalonen, 2021, private communication). The SNWMF is expected to cover all the costs of the final disposal of SNF and decommissioning of the NPPs in operation. The total estimated cost is €3.3 billion, which includes

€2.4 billion for the operation of the SNF repository until 2120 and €200 million for decommissioning of the NPPs (Conca, 2021).

Co-ordinated, publicly administrated research programmes on nuclear waste have been in operation since 1989 (VTT, 2006). Financing came mostly from the Ministry of Trade and Industry (currently MEE), Radiation and Nuclear Safety Authority (STUK), Technical Research Centre of Finland (VTT), and the nuclear power companies. Since the funding for research on NWM was institutionalised in 2003, national research programmes have been organised by the MEE and financed by the Nuclear Safety Research Fund and the Nuclear Waste Research Fund, which were established in 2003 to guarantee the sufficient availability of new scientific information about nuclear waste and its management (Nuclear Energy Act 990/1987, Sect. 53).

According to Litmanen (2008), the funding for social scientific research on nuclear waste was first introduced in the JYT2 programme (1994–1996). During that time, the ban on imports and exports of nuclear waste, the introduction of legislation on EIA, and controversy about TVO's siting plans for final disposal facility held by the residents of different municipalities created a political need for social scientific research. The importance of social sciences was emphasised, "as the public debate on nuclear waste had started and opposition to the plans seemed to be increasing" (Litmanen, 2008, p. 435).

After the favourable DiP on Posiva's repository for SNF in 2000 and the extension in 2002, the political need for social scientific research decreased. It dropped out from the first KYT research programme but returned in 2008 under the title "sociological research" (MEE, 2011; Table 11.5). The political need for social scientific research increased because Posiva had started preparing an application for the construction license for ONKALO.

Table 11.5 Total research funding and the share of social sciences according to the final reports of the completed KYT research programmes (VTT, 2006; MEE, 2011, 2015b, 2019b)

Research programme	KYT2005 (2002–2005)	KYT2010 (2006–2010)	KYT2014 (2011–2014)	KYT2018 (2015–2018)
Total research funding	4,157,000 €	7,044,000 €	6,612,000 €	7,391,000 €
Research funding for social sciences	n. a.	150,000 €	100,000 €	285,000 €
Share of funding for social sciences	n. a.	2.1%	1.5%	3.9%

11.5 Structural Corporatism in Finnish Decision-Making

Finland can be characterised more as a consensus democracy than a majoritarian democracy (cf. Lijphart, 1999), or as a coordinated market economy instead of a liberal market economy, following the typology of varieties of capitalism in the theory of Hall and Soskice (2001). The political system of Finland is influenced strongly by corporatist pluralism (Nousiainen, 1985), whereby many interest groups play an important role in national, regional, and municipal decision-making. This includes both employer/entrepreneur organisations and employee/trades unions, as well as a broad spectrum of NGOs, institutions, and interest groups.

Legislation at the top level of the state requires the formally established body of committee hearings with external experts and their consultation on several stages of the law-making process. The preparation of legislation within the ministries requires the consultation of outside experts and stakeholders (Auffermann, 2009). Consequently, at a very early stage of preparation, interest/pressure groups have both formal and informal possibilities to direct the planning of new legislation. In a small country like Finland, with 5.5 million inhabitants, the political, legal, and industrial elite is very small, and “everybody knows each other” (cf. Ruostetsaari, 2010; 2017). Below the state level, this phenomenon continues, and the striving for a consensual solution is distinctive in any political decision-making.

Mainly for historical reasons, the Finnish political system and the political culture of Finnish democracy can be described as a de-politicised system, with of citizens’ high trust in the state and expert authority based on knowledge and integrity. The background is the very deep split in Finnish society after the revolution and the civil war in 1918. The division between “reds” (left-wing working class) and “whites” (right-wing bourgeoisie) could still be felt in the whole society in the 1970s and 1980s, going as far as people buying their food either in the workers’ cooperative food stores or in the privately-owned stores of the bourgeoisie. This has been overcome, however.

Part of the development in the 1970s and 1980s was the consolidation and rapid expansion of a comprehensive social security system and the welfare state following the Nordic model. This process can be characterised as successful, but from the perspective of critical voices it leads to a de-politicisation of Finnish democracy and consequently to a relatively low level of (radical) political opposition movements, including the environmental and anti-nuclear movements. These societal movements, in turn, led to the formation of a new political party. In 1983, two representatives of the societal movement were elected to parliament.

The Green League (since 2006, the Greens) was first registered as an association in 1987, and as a political party in 1988. The Greens quickly became part of the broad societal consensus and has, in 1995–2002, 2007–2014, and since 2019, taken governmental responsibility as a conformist force regarding e.g., environment, human rights, equality, and feminism. The Greens has left the government twice, both times because parliament left a DiP on constructing new NPPs in force (TVO's Olkiluoto 3 in 2002, and Fennovoima's Hanhikivi 1 in 2014).

The traditionally relatively strong post-communist left-wing party overcame its split into radical and reformist wings and over the years joined the government several times, mainly as a representative of the poorer part of the population, but in recent years increasingly as a party favouring reconciliation between environmental and social interests in policymaking.

A Finnish "Untertanengeist", a spirit of subservience, resulting from 700 years of first Swedish and later Russian rule can still be perceived today (Auffermann, 2009). As Lehtonen (2021) puts it, the Finnish post-War policy culture has been characterised by a certain civil passiveness and weak legitimacy of radical citizen activism.

When looking at energy policy in Finland, some typical characteristics reflect structural corporatism. Finland industrialised relatively late compared to many other European countries (Myllyntaus, 1991), and was based largely on state-owned companies. These were established especially in the energy sector. First for producing hydropower (Imatran Voima Oy, currently Fortum) and domestic fuels such as peat and wood (Vapo Oy), then for oil refining (Neste Oy, currently Fortum) and importing natural gas (Neste Oy, currently Gasum Oy), and finally nuclear power production was started by Imatran Voima Oy.

However, private industries established several energy companies, such as Pohjolan Voima Oy for hydropower production and Teollisuuden Voima Oy (TVO) for nuclear power production. Many were originally co-owned by several companies from energy-intensive fields such as the forest industry, base metal industry, and chemical industry. The idea of cooperation was simple: to improve the predictability of the price of an important production factor by investing jointly in electricity production. The purpose of these companies was to produce electricity for the shareholders, not making profit or distributing dividends.

A major boost for industrial power companies was a 1963 Supreme Administrative Court decision that a hydropower company Mankala Oy (established in the 1930s) was not guilty of hidden dividends when its shareholders received the produced electricity at cost price in relation to their shares in the company (Ialenti, 2020). Correspondingly, the shareholders covered all fixed and variable costs in the same way, as indicated in the articles of association of Mankala Oy.

After the 1963 decision, many similar companies were established in the Finnish electricity supply system, and cross-ownership increased. Nuclear power companies TVO and Fennovoima operate under this "Mankala principle", as well as the NWM company Posiva Oy. The future of the Finnish Mankala principle, which is a unique feature in the global energy markets, has been questioned from the perspective of EU competition law (Puikkonen, 2010; Ialenti, 2020), since the shareholders of Mankala-type companies receive electricity at cost price, which usually is below the market price and has been considered to distort competition. However, Mankala principle has been applied successfully to NWM in the ONKALO project by the Posiva shareholders TVO and Fortum, which has been an important part in the Finnish governance of NWM.

11.6 Weak Social Inclusion in Decision-Making on Nuclear Waste

11.6.1 Limited Public Participation

Positive public governance prioritises stakeholders, advances democratic values, and produces widely-valued societal outcomes (Douglas et al., 2019). Open information exchange between stakeholders and public debate is needed to address the challenges of NWM (WNWR, 2019). Public participation is important because citizens and NGOs can bring new perspectives and help to legitimise the process. However, one challenge is how to overcome the largely artificial technical-social divide that characterises NWM, "the definition of waste and safety are political statements and choices" (Nurmi et al., 2012). Recent research has argued for the importance of nuanced public engagement in ensuring socially stable and sustainable nuclear waste policies (Litmanen et al., 2017a; Lehtonen et al., 2021b).

Raittila et al. (2002) have characterised Finland's experience as a "nuclear waste wonder" due to the smooth progress in decision-making and licensing of Posiva's ONKALO. The degree of citizen engagement in nuclear waste issues has been low. According to Lammi (2009) and Lehtonen (2010b), low public participation is partly because too few actors are able to produce reliable information on the subject. This reflects the high trust in the state authorities and experts among the Finns (see Sect. 11.5). The parliament exercises political power when it ratifies or rejects DiPs, while MEE influences the framing and agenda-setting of energy issues, and exercises, together with STUK, considerable administrative power continuously in their regulative and supervisory roles.

In addition to little public debate, there is a high level of trust in technology and technological development among Finnish citizens (Ruostetsaari, 2017). This has served to further de-politicise NWM and weaken civic vigilance by favouring a dominant narrative of an "engineering nation" (Lehtonen et al., 2021b), where the nuclear regime, i.e. the nuclear companies, energy department of the MEE, STUK, and part of the academia studying energy issues, is depicted as by far the most competent and reliable in assessing nuclear waste safety issues. After ratification of the DiP on constructing Posiva's ONKALO by parliament in 2001, requests for increasing public dialogue between different stakeholders almost disappeared.

Although public engagement in Finnish nuclear waste policy has been limited, it has been discussed and developed over time. Posiva's site selection strategy changed from geological criteria to acceptance by the council of the host municipality (Kojo, 2009). The site selection started by TVO was first highly technical and generated opposition in all the selected municipalities. TVO had to reconsider its approach, not only due to local opposition but also due to legislative changes during the process. The Nuclear Energy Act (990/1987) gave a veto right to the selected host municipality and introduced a wide range of statements and a mandatory public hearing. In addition, the Act on Environmental Assessment Procedure (468/1994) made an EIA mandatory before assessing (in the DiP phase) if the proposed nuclear facility is "in line with the overall good of the society".

The EIA procedure is the main venue for public participation in large construction projects in general, and NWM in particular. During the site selection processes, Posiva invested heavily in public participation, most notably within the two-year EIA, allowing citizens to be informed and making their voices heard. However, many questioned if the EIA had any real impacts. In those days, the role of EIA was only advisory, the number of participants was low, and the framing of the discussion included only the already-decided concept of deep geological disposal (Lehtonen, 2010a). Posiva's project was considered too big for an EIA to influence the outcome (Hokkanen, 2002). It has also been argued that in EIA, purposes of public participation are vague and open to industrial bias, manifesting itself in specific institutional arrangements which receive little scrutiny (Strauss, 2012).

Partly for these reasons, the EIA legislation was revised in 2017. The purpose of the Act on Environmental Impact Assessment Procedure (252/2017) is to improve the availability of information and possibilities for public participation, as well as to ensure that the EIA procedure will be taken into account in decision-making. A contact authority (for nuclear facilities the MEE), makes a "reasoned conclusion" on the EIA process, informs the public on the availability of various reports (the EIA plan, the EIA report, and the reasoned conclusion), and organises public hearings on them (Act on Environmental Impact Assessment Procedure, 252/2017). The applicant must include the EIA report and the reasoned conclusion in the DiP application, and the Government has to explain how the EIA documents and results from the related public hearings have been taken into account in the DiP.

11.6.2 Weak Anti-Nuclear Movement

The national portrayal of Finland's nuclear history is characterised by a firm belief in technology, engineers, and authorities; people tend to be more sceptical about the expertise of anti-nuclear movements. However, this has not always been the case. In 1993, the anti-nuclear movement successfully influenced some members of parliament, and finally the parliament rejected a favourable government DiP on constructing a new (fifth) NPP. Since then, the Finnish anti-nuclear movement has weakened due to e.g. organisational discontinuity and a stronger emphasis on the potential of nuclear power in climate strategies and welfare production in the political discourse (cf. Lammi, 2009). Today, a majority of the parties in parliament are in favour of nuclear power, not least because of the "solved waste problem".

The smooth implementation of Posiva's ONKALO project in Olkiluoto has raised the question of why nuclear waste has mobilised so little citizen action in Finland (Kojo, 2014). According to Lammi (2009), the selection of Olkiluoto in the municipality of Eurajoki to host of the SNF repository ended anti-waste-nuclear movements in other potential host municipalities. Similarly, the unused veto right by the municipal council of Eurajoki marginalised the local anti-nuclear-waste movement. Opinions on the final disposal of SNF have been polarised among the Eurajoki inhabitants; 42% favoured and 36% opposed it (Kojo et al., 2012). However, active public participation and expression of criticism still went against the prevailing norm, which could be explained by fatigue, adaptation, and tolerance—Eurajoki has hosted NPPs including the temporary storage of SNF from the 1970s (cf. Kojo, 2014).

These circumstances have led to an asymmetry between pro-nuclear and anti-nuclear views, meaning that comprehensive critical evaluation in terms of contrasting expert views on the project and counter-expertise is more or less excluded from nuclear policy formulation (Lammi, 2009; Litmanen et al., 2017a). This raises a question of whether a final solution to the nuclear waste problem has been found, or if the discursive pro-nuclear dominance has only mitigated the impact of disputes in the public debate on NWM.

11.6.3 The Role of Media

Key actors in Finnish NWM are frequently framed as trusted and neutral sources of information by the print media, which gives them considerable agenda-setting power in a closed communication culture (Kojo et al., 2020). Journalists tend to turn to the regulator and the nuclear waste company for official information (Litmanen et al., 2017a). A longitudinal analysis of two large print media, Helsingin Sanomat and Aamulehti, shows that nuclear waste reporting has become more positive (Kojo et al., 2020). For example, Helsingin Sanomat's news coverage on SNF management mainly stresses performance-relevant information that underpins confidence in the repository project, as "most news articles take it practically for granted that the project can proceed as envisioned" (Lehtonen et al., 2021b, p. 141).

According to Litmanen (2009), two major changes in mass media have led to the situation where the nuclear industry feeds journalists with information regarding nuclear waste issues. Firstly, the structural changes of modern media have decreased pluralism through multi-channel communication strategies that aim to reach as many target audiences as possible through significant news items (Litmanen, 2009). Secondly, the changes in the journalistic profession towards highly educated "workers of the information society" who process results from scientific research and integrate them into their writing. Journalists also lean towards neutrality in their reporting, while news topics are mainstreamed and factualised, which can pose a problem for anti-nuclear views in a small country like Finland, with few independent experts. This lack of alternatives has become something of a journalistic norm. Finnish media tends to de-politicise SNF issues (Lehtonen et al., 2021a), which indicates that the nuclear industry has been particularly successful in its efforts at managing publicity concerning nuclear waste (Kojo et al., 2020).

11.7 Conclusions: The Future of Final Disposal of Spent Nuclear Fuel in Finland

ONKALO, the disposal facility for SNF by Posiva Oy, a joint company of nuclear power companies TVO and Fortum—currently waiting for the operating license—is known as a final solution for the problem of NWM in Finland. However, some challenges remain, such as the safety of cooling pools for SNF assemblies inside the NPP building and tens of years of temporary SNF storage at the nuclear sites. It is also possible that ONKALO will not cover all SNF produced in Finland in the future. A third nuclear power company, Fennovoima, is not involved. Increasing the capacity of ONKALO has not been a problem for Posiva, but it is not yet known to what extent the planned capacity of ONKALO can be realised in practice because final disposal tunnels and holes will be excavated when needed.

From the governance ecosystem perspective, some general conclusions on Finnish NWM can be drawn. First, Finland is a society where citizens' trust in the state and its institutions is very high. The overall governance system of energy policy is dominated by the scientific and technological domain, where energy industries are an important host. Strong connections between energy companies and technical universities are well-established. The same holds for the connections between energy companies and energy administration in the MEE. Representatives of the energy industries, energy administration, and the scientific community are central parts of the energy elite that emerged during the state-driven industrialisation of the country after World War II.

Because of the high trust among the citizens, political decision-making on nuclear facilities can be managed effectively in the existing decision-making institutions. Next to the democratic representative institutions, no additional quest for public participation is voiced. Therefore in Finland, the preparation and decision-making processes, as well as their outcomes, are highly acceptable among citizens.

Finland's political culture, based on structural corporatism, has been central in all national, regional, and municipal/local decision-making. The complex licensing procedure for new nuclear facilities and the high trust of citizens in the state and its institutions are combined with civil subservience and the dominating tendency to prefer decisions in broad consensus. Public and political opposition to nuclear energy projects has been minor, and public debates have focused more on new NPPs than the final disposal of SNF, which have usually been simultaneously on the agenda. This has been a successful tactical choice by Posiva and its shareholders.

However, regular polls on energy attitudes (e.g. Finnish Energy Industries, 2020) have shown that negative opinions on the safety of geological disposal of SNF have been more common than positive ones. This has been poorly reflected in the decision-making processes, partly because surveys in Eurajoki have shown more positive opinions. Arranging a possibility for public participation has been mandatory in the preparation phase of the decision-in-principle, but participation has not been very active, with no impact, as described in Sect. 11.5. The revised EIA legislation (Act on Environmental Impact Assessment Procedure Act 252/2017) will hopefully improve public participation. Posiva's application for ONKALO's operating license, submitted in December 2021, is now in the pipeline, and MEE has made announcements about providing opportunities such as a public hearing and statements to express public opinions (MEE, 2021). This is not mandatory, but the Nuclear Energy Decree (161/1988) allows taking into account other information considered as necessary by the authority (e.g. MEE) before decision-making.

Recently, the NWM of Fennovoima and the construction of Hanhikivi 1 NPP have dropped off the agenda due to the war started by Russia in Ukraine. On 2 May 2022, Fennovoima decided to terminate the contract for the delivery of Hanhikivi 1 NPP with Rosatom. The official reason was "RAOS Project's significant delays and inability to deliver the project" (Fennovoima, 2022a). Three weeks later, Fennovoima withdrew its application for a construction license of Hanhikivi 1 (Fennovoima, 2022b).

The most current issue for Finnish NWM is the operating license of the ONKALO project, for which Posiva applied in December 2021. The political decision-making will take its time, but as learned from history, significant changes to Posiva's plan cannot be expected. Based on a recent survey (Finnish Energy Industries, 2021), public opinion on favouring increased use of nuclear power is at the highest level in Finland since surveys began. The next Finnish nuclear project is likely to be a benchmark of applying the revised EIA legislation in its full form.

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