EUROPEAN COMMISSION

Community research

(Contract Number: 269906)

Working Paper

Adaption of the Swedish KBS disposal concept to Finland:

A technology transfer case study

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Start date of project : **01/03/2011** Duration : 40 Months

Project co-funded by the European Commission under the Seventh Euratom Framework Programme for Nuclear Research &Training Activities (2007-2011)		
Dissemination Level		
PU	Public	X
RE	Restricted to a group specified by the partners of the InSOTEC project	
CO	Confidential, only for partners of the InSOTEC project	

EURATOM

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Date of issue: 4 June 2014

ISBN 978-951-44-9515-1

Contents

Glossary

ACP	Advanced Cold Process canister
BWR	boiling water reactor
CLA	Construction License Application (in accordance with the Nuclear Energy Act)
DiP	Decision-in-Principle (in accordance with the Nuclear Energy Act)
Fennovoima	Power company established in 2007. It plans to build a new NPP unit at Pyhäjoki, Finland.
Fortum Power and Heat	Fortum Power and Heat Ltd (formerly IVO), part of Fortum Consortium, the State of Finland is the biggest shareholder of Fortum with an over 50 per cent holding. Fortum Power and Heat operates the NPP at Loviisa and owns 25,8 per cent of TVO
GTK	Geological Research Centre of Finland
IVO	Imatran Voima Ltd, 100 per cent state-owned power company established in 1932. Known as Fortum Power and Heat since 1998
KBS-3	Kärn bränsle säkerhet, the concept for final disposal of spent nuclear fuel
LO1-3	Nuclear power plant units in Loviisa, LO1-2 are in operation, application for LO3 was rejected by the Finnish government in 2010
MEE	Ministry of Employment and the Economy (formely Ministry of Trade and Industry)
MTI	Ministry of Trade and Industry
NPP	nuclear power plant
OL1-4	Nuclear power plant units at Olkiluoto in Eurajoki, OL1-2 are in operation, OL3 is under construction and OL4 in planning
PASS	Project on Alternative System Studies
Posiva	Nuclear waste management company owned by Teollisuuden Voima (60 per cent) and Fortum Power and Heat (40 per cent), established in 1995
R&D	research and development
SKB	Svensk Kärnbränslehantering AB, Swedish Nuclear Fuel and Waste Management Company
SKBF	Swedish Nuclear Fuel Supply Company
SNF	spent nuclear fuel
STUK	Finnish Radiation and Nuclear Safety Authority
tU	tons of uranium
TVO	Teollisuuden Voima Ltd, operates the NPP at Olkiluoto site in Eurajoki
VTT	Technical Research Centre of Finland
VVER	Voda Voda Energo Reactor
YJT	Nuclear Waste Commission of the Finnish Power Companies

1. Introduction

Sweden has been the role model for Finland in many sectors. In general Sweden has been perceived in Finland as a modern, prosperous and advanced society. The nuclear energy sector, including nuclear waste management, was no exception. The Swedish nuclear industry was aware of its role and thus consciously built up the relationship with the Finns on the basis of collaboration (see e.g. Björklund et al., 1994, 26–27). In their book focused on the development of the final disposal of spent nuclear fuel (SNF) the senior advisors of Posiva[1] and Teollisuuden Voima (TVO) point out that in the early stage of the power company TVO was inspired by the Swedish power companies' building and operation of nuclear power plants (NPP) (Nikula et al., 2012, 20–22). As the Swedish nuclear energy debate spread to Finland the nuclear waste management of the Olkiluoto NPP was influenced by the development in Sweden. The actors of the Finnish nuclear energy sector followed the Swedish debate closely and observed how a Swedish NPP succeeded in getting an operating licence in line with the Swedish Stipulation Act of 1977. The provision of this Act required that prior to fueling an NPP, its owners had to show how and where SNF could be finally stored with absolute safety (Sundqvist, 2002, 76–77; also Elam & Sundqvist, 2009).

The objective of the case study is to analyse the transfer and the major modifications of the Swedish KBS-3 disposal concept for spent nuclear fuel by TVO and later Posiva in Finland, and further to understand how the disposal concept has developed in the long-term and adapted to new societal situations. The research questions are as follows: What have been the main modifications of the final disposal concept? What kinds of societal arguments by TVO and Posiva can be found behind the modifications? In which ways has the relationship between TVO, Posiva and SKB in information sharing and technology transfer changed since the 1970s? Our argument is that TVO adopted a pragmatic and cost-conscious policy regarding nuclear waste management already in the early days. Furthermore, this pragmatic mode of operation was supported by the Finnish nuclear waste management system and thus a very positive attitude to international cooperation and follow-up of foreign R&D dominated the work.

The paper covers the time period from 1978 to 2012. In 1978 the first reference concept for nuclear waste management was introduced in Finland. The concept, KBS[2], was adopted from the Swedish R&D work conducted by the Swedish Nuclear Fuel Supply Company (SKBF) which in 1984 was

[1] Posiva is the nuclear waste management company jointly owned by Teollisuuden Voima and Fortum Power and Heat. The mission of Posiva is to plan and implement the final disposal of spent nuclear fuel produced by its owners.
[2] KBS, Kärnbränslesäkerhet in Swedish.

transformed into Svensk Kärnbränslehantering AB (SKB), the Swedish Nuclear Fuel and Waste Management Company (Elam & Sundqvist, 2011, 250–253). At the time Finnish nuclear waste policy and the plan by TVO was based on shipping nuclear waste abroad for reprocessing and disposal. A repository in line with the KBS concept (later called as KBS-1) was planned for the disposal of reprocessed vitrified high-level nuclear waste if it were shipped back to Finland. An intermediate storage facility was also thought to be needed. The time period ends in 2012, when Posiva submitted the Construction License Application (CLA) for the final disposal repository to the Government. Now Posiva is planning to dispose of SNF into the bedrock in canisters of copper and cast iron at a depth of 400–450 meters.

Even if this paper concentrates on the modifications of the KBS concept, part of the story is about the changing role of TVO and Posiva in the field of nuclear waste management. Currently Posiva describes itself and Finland as a forerunner in certain sectors of nuclear waste management in an attempt to render reputable its know-how in the export business. Furthermore the Posiva final disposal facility at Olkiluoto site is seen as a world-leading solution by the main shareholder TVO (2012a; 2012b.) Thus, due to successful technology transfer the novice aims at becoming the trendsetter. However at the same time the new role seems to create some pressure, as there is no one to follow, which Posiva has recognized (see e.g. Nikula et al., 2012, 50).

The structure of the paper is as follows: In Section Two we introduce the framework of the paper, which is based on the translation model by Latour (1986). In Section Three the case study, the data used and the Finnish nuclear waste policy are introduced. In Sections Four and Five, which comprise the main body of the paper, the development of the technology transfer process between TVO, Posiva and SKB and the modifications of the final disposal concept are analysed. Conclusions are drawn in Section Six.

2. Theoretical framework

In this section we focus on three terms – technology transfer, diffusion and translation – applied in analysing technology transfer and knowledge management. The objective is to identify the differences in the approaches and then apply the chosen approach, namely the translation model (Latour, 1986), in the case study of final disposal concept.

This paper is a part of the InSOTEC Project, the aim of which is to create a better understanding of the complex interplay between the technical and the social in radioactive waste management and, in particular, in the design and implementation of geological disposal. InSOTEC aims to study "*how socio-technical combinations (initial projects) are evolving by integrating concerns and constraints leading to compromises and as such to new socio-technical combinations. The robustness of such compromises are about the ability to integrate external constraints and adapt to these, including the adaptation and change of artifacts, interests as well as identities.*" (InSOTEC, 2011.)

Next we introduce three approaches, namely technology transfer, diffusion and translation to develop a framework for analysing the relationship between the concept level modifications and social choices (i.e. arguments evinced the reports) (See Table 1). We start with technology transfer.

Table 1. Differences between approaches to understanding technology development.

Technology transfer	Diffusion	Translation
- a producer orientation	- a user orientation with a focus on utilization and implementation, reinventions	- active networks as mechanisms
- planned and directed	- emphasizes the person-to-person social networks	- highlights the evolving nature of the technology
- separation of R&D and user organizations	- more spontaneous, mainly under the control of the user	- continuous transformation of the token, not transmission

Sources: Rogers, 2002; Elbanna, 2007; Latour, 1986.

According to Rogers (2002, 326–327; based on Eveland 1987) technology, which may include a hardware and/or a software component, is "*information that is put into use to accomplish some task*" and transfer is "*essentially the communication of information (technology)*". Thus in Rogers' view *technology transfer* is the application of information to use. The main type of technology transfer introduced is the process of moving ideas from an R&D laboratory to the marketplace. This is noted as a producer orientation.

Rogers (2002) notes two perspectives on the technology transfer process. The first one is the unidimensional perspective, where it is assumed to be possible to identify “sources” and “receivers” of technology. In the literature terms such as ‘transfer agent[3]’, ‘transfer object[4]’, ‘transfer medium[5]’ and ‘transfer recipient[6]’ are also used (Bozeman, 2000). The second perspective on the technology transfer process is the two-way, interactive communication process. According to this perspective receptors are not necessarily passive objects in a technology transfer process, but the process is more like a transaction process where questions, answers etc flow in both directions. Thus there are no ‘sources’ and ‘receivers’, but ‘transceivers’ or ‘participants’. With the term absorptive capacity – which refers to the degree to which an organization is able to devote the resources needed to adopt a new technology (Rogers, 2002, 331) – one could then depict the capability of ‘participants’ for technology transfer.

As strategies of technology transfer Rogers et al. (2001, 254–255) notes as follows:

(1) Create a boundary-spanning unit in an organizational structure that is responsible for technology transfer.

(2) Transfer personnel in order to transfer their technology.

(3) Form network relationships linking R&D organizations and receptor organizations.

(4) Encourage the formation of high-tech spin-offs.

(5) Organize consensus development conferences to create practice guidelines concerning a technology.

Barriers inhibiting technology transfer have also been identified. For example, according to Gilsing et al. (2011, 641) these are the risk of information leakage, a conflict of interests and scientific knowledge being too general.

To summarize the technology transfer approach briefly, it seems to be based on a producer orientation (although a feedback loop is identified), a planned and directed process in which R&D and user organizations can be separated.

Another approach is based on diffusion. Rogers defines the diffusion of innovation as follows: “*a process through which an innovation is communicated via certain channels over time among the units in a social system*”. According to Rogers (2002, 329) the key question of technology transfer is “How

[3] The organization or institution seeking to transfer the technology (Bozeman, 2000, 637).
[4] The content and form of what is transferred, the transfer entity (Bozeman, 2000, 637).
[5] The vehicle, formal or informal by which the technology is transferred (Bozeman, 2000, 637).
[6] The organization or institution receiving the transferred object (Bozeman, 2000, 637).

do research results get commercialized?" whereas the key question in the diffusion of innovations is "How does an innovation, once available in the system, spread among the systems members and become widely adopted?" Diffusion emphasizes the person-to-person social networks, is more spontaneous and is thus more user oriented and mainly under the control of a user.

Bruno Latour (1986) has contested the model of diffusion as it only explains the slowing down or acceleration of a process. According to Latour (1986, 266–267) the model of diffusion defines three elements in the spread of a token[7] through time and space. These are as follows: (1) the initial force that triggers the movement and which constitutes its only energy, (2) the inertia that conserves this energy and (3) the medium through which the token circulates. According to Latour (1986, 267) in the diffusion model everything is explained either by referring to initial power or by the resistance of the medium. Thus in the case of faithful execution, 'successful' execution indicates the power of the master whereas the case of undesirable and incomplete execution is an indication of resistance. Elbanna (2007, 254) has noted that the traditional diffusion model in its simplistic linear form assumes a technology push based on previous merits, where the user's role is seen to either adopt or reject the technology. She notes that even when the need-pull is incorporated in the model, the role of the user changes only slightly. As a result one can classify technology adopters into different categories according to the time of adoption (such as eager minority – awkward laggards).

The third approach introduced in the paper is based on the notion of translation. Latour (1986) introduces the model of translation where "*the spread in time and space of anything – claims, orders, artefacts, goods – is in hands of people*". These people may act very differently in relation to the token. The point of the model is that acting people are needed, because otherwise the token simply stops, as, according to Latour (1986, 267) "*there is no inertia to account for the spread of a token*". The token derives its energy from "*the everyone in the chain who does something with it*". As an example Latour refers to rugby players and a rugby ball. The ball will not move on unless there is fresh source of energy all the time. Therefore, according to Latour (1986, 267), one can never rest on what one has done before.

The role of people in the chain is important for the model of translation. Latour (1986, 258) states that people are actors, as "*they are doing something essential for the existence and maintenance of the token*", they are not merely resisting or transmitting the token, as is assumed in the diffusion model, but "*everyone shapes it according to their different projects*".

[7] According to Elbanna (2007, 254) the token refers to a claim, order, project, idea, gadget, life style, product, or other artefact.

Elbanna (2007), who extends and complements the research in the area of technology drift (drift model) based on actor network theory, has emphasized the evolving nature of technology projects. According to Elbanna (2007, 254) the drift model "*gives more weight to organizational actors and allows them the possibility of moving the project from its initial discourse towards of their own*". Elbanna (2007, 255) notes that the translation model "*is not about transmission of the same token but the continuous transformation of the token*".

The translation model is applied in this case study. We are interested in the continuous transformation of the final disposal concept between 1978 and 2012 (See Appendix 1.) and the societal arguments related to major modifications by TVO and Posiva. However, we do not analyse the whole actor network behind the TVO and Posiva reports in detail nor the societal debate concerning nuclear waste disposal in the Finnish media (Raittila, 2001) or Parliament (Raittila & Suominen, 2002). That would be beyond the scope of this case study. Instead, we take the reports as products of the network in which TVO as a licensee has the final responsibility for deciding how the results of all investigations are introduced to the regulator and political decision-makers. The TVO and Posiva reports have been more or less influenced by societal requirements regarding the final disposal of SNF and therefore it can be argued that the reports include, although often between the lines, the responses of the licensee, i.e. TVO, to society.

According to Posiva, the final disposal plans are based on the KBS-3 concept, developed by SKB. Posiva (2013) states that "[*t]he solution is based on the multiple barriers principle. Radioactive substances are contained within several redundant protective barriers so that no deficiency in one barrier and no predictable geological or other change will endanger the isolation.*" Release barriers according to Posiva (2013) are the physical state of the fuel, the disposal canister, the bentonite barrier, the backfilling of the tunnels and the surrounding rock. These barriers and changes therein, which also reflect the modification and translation of the whole final disposal concept, are described by analysing certain features of the barriers. The main focus is on canister development, which is followed by tracking monitoring the changes in four features: design of the canister, alternative canister designs, number of canisters/Capacity (tU) of canister type and (thickness of) canister wall. There would have been others, too, such as the welding technology of canisters. Posiva is planning to apply electron beam welding for sealing the canister lids whereas friction stir welding is the primary welding method in SKB. The bentonite barrier (backfilling of the deposition tunnels and the barrier surrounding the canister) and bedrock (tunnel depth/minimum distance between the holes) are each followed by two features. All features are listed in Appendix 1.

This set reflects the importance of the canister as the main technical barrier and thus emphasizes the changed interpretation of geology. Today the primary aim of the bedrock is to safeguard the function of the technical barriers and the secondary aim is to prevent any releases. Previously the prevention of any releases was the main aim of the host rock (Kojo, 2009a; Nikula et al., 2012, 175). The physical state of the fuel is taken into account only on the level of different NPP units included in the disposal plan by Posiva. The spent fuel produced by the operating OL1 and 2 boiling water reactor (BWR) units is different from the fuel from the Lo1 and 2 VVER units. Moreover, the OL3 unit (European Pressurized Reactor) under construction at Olkiluoto will produce a new type of spent fuel. For example, the heat production of OL3 spent fuel will be higher, which has to be taken into account in canister design and in placing the holes for the canisters in the tunnels.

On the basis of the main reports selected (see Section Three on data) it is possible to monitor and describe the major modifications and also some arguments for these, but it is a challenge to point out the relationship between these modifications and social choices and so to understand the socio-technical combination of the (development of) the final disposal concept.

3. The case study data and Finnish nuclear waste policy

3.1 The data

The main data of the paper consists of the research reports published by TVO and Posiva due to the regulations (See Table 2). The licensees have been required to report regularly on the progress of their work. The schedule was set in 1983 in the decision by the Council of State (1983). The aim was to start final disposal from 2020 onwards and to select a site by 2000. By 2010 the licensees had to prepare themselves to introduce plans for the construction licence. The licensees were also obliged to pursue three subsidiary aims. By the end of 1985 technical reports regarding the final disposal had to be updated, by the end of 1992 the technical plan for the final disposal taking into account the alternative sites, was to be completed and by 2000 the technical plan for final disposal was to be drawn up.

The Ministry of Trade and Industry changed the schedule once, as in 2003 the licence holders were given two more years to submit the application for the construction licence. The new deadline was the end of 2012. This extension was justified by safeguarding the safety of final disposal. (Kojo, 2004, 232.) Thus, following the schedule set in the above-mentioned decisions, we have used as data the summary reports from the years 1978, 1982, 1985, 1992, 1999 and 2012. Furthermore, we have also analysed interim report TILA-96 and the Posiva Decision in Principle (DiP) application of 2008 to obtain more detailed information. The former was reported by Posiva due to the STUK recommendation presented on the basis of the review of the reports of 1992 (Posiva-96-17, 2). The latter, the application for a DiP was due to the nuclear new build plan.

Table 2. Main data of the case study.

Year	Main Report	Due to
1978	Nuclear Waste Study	Planning of nuclear waste management
1982	TVO-82 Summary Report	Requirement set in the NPP operating licence
1985	TVO-85 Summary Report	Following the decision by the Government in 1983
1992	TVO-92 Summary Report	Following the decision by the Government in 1983
1996	Interim Report (TILA-96)	Recommendation by STUK
1999	DiP application	Following the decision by the Government in 1983
2008	DiP application	Nuclear new build plans
2012	Construction Licence Application	Following the decision of the Ministry of Trade and Industry in 2003

The reports describe the main technical outline of final disposal concept of the time. We claim that by comparing the outlines it is possible to trace the major modifications of the disposal concept (KBS concept) by TVO and Posiva. These reports are also seen in the case study as being responses by TVO and Posiva to regulation and direction from the state on nuclear waste management. We argue that the reports help to understand the socio-technical combination of the modification of the KBS concept in Finland. We focus on the specific sections of the reports which include descriptions of the disposal concept planned by TVO and Posiva. For most reports this meant reading the abstract, introduction and those parts of the reports introducing the concept design. In some cases more detailed reports were used to clarify the reasoning and details of modifications. We are aware that there is much more detailed information available regarding the modifications and scientific argumentation related to the R&D activity, but as our objective is to analyse how the KBS disposal concept was modified by TVO and Posiva and the nature of the main modifications in 1978–2012, we need to limit ourselves and focus on those parts of the reports where the outline of the disposal concept modifications can be traced. A tentative breakdown of the major modifications is presented in Appendix 1.

In addition to the reports the former CEO and the Executive Vice President of Posiva[8] were also interviewed. The interviews focused on understanding the development of the context in which the disposal concept transfer took place between the Finnish nuclear waste management and the Swedish and other international agencies. Two books focused on the history of TVO (Björklund et al., 1994) and the development of final disposal in Finland (Nikula et al., 2012) also provided valuable background information concerning different stages of the project and the thinking of TVO and Posiva.

3.2 Legislation and responsibilities

To understand the timing and objectives of TVO and Posiva reporting, the reader should be acquainted with the responsibilities of the utilities. In 1978 the Government outlined the organizing of nuclear waste management in Finland. The waste producers were responsible for implementation and costs under the supervision of the Ministry of Trade and Industry (MTI). The first operating licences of the NPP units in 1976 and 1978 also imposed requirements regarding nuclear waste management. For

[8] Veijo Ryhänen was the first Managing Director of Posiva in 1995–2005. Before that he worked almost for ten years as the Manager of the TVO nuclear waste office (Posiva, 2000). He had worked for TVO since 1977. In 2005 Ryhänen was appointed Corporate Adviser at TVO responsible for international relations and special matters related to nuclear waste management (TVO, 2005). Ryhänen was interviewed in July 2012.
Timo Äikäs was the Executive Vice President of Posiva 2009–2013. Before that he had worked for TVO and Posiva since 1982. In 2013 Äikäs was appointed Corporate Adviser at Posiva. Äikäs was interviewed in June 2013.

example, to meet the requirement regarding organizing research activity, the power companies established the Nuclear Waste Commission of the Finnish Power Companies (YJT[9]) in 1978. (Björklund et al., 1994, 96–97, 145–147; Suominen, 1999, 26–28; Michelsen & Särkikoski, 2005, 242–243; Kaijser & Högselius, 2007; Nikula et al., 2012, 24–28, 59–60.) One of the first outputs of this collaboration was the Nuclear Waste Study (Ydinjäteselvitys[10]) of 1978 (Ydinjäteselvitys, 1978), which is the starting point of our analysis of the final disposal concept development.

The responsibilities of the main actors of the Finnish nuclear waste policy were further specified in the Nuclear Energy Act of 1987[11]. One of the main principles which was already included in the governmental decision of 1978 on organizing nuclear waste management and cost liabilities is that waste producers are responsible for the planning, implementing and costs of nuclear waste management. A power company which has been granted a licence to operate a nuclear power plant (NPP) unit is a *licensee under nuclear waste management obligation*. Due to this obligation, utilities play a major role in Finnish nuclear waste policy management (See Suominen, 1999).

After the amendment of the Nuclear Energy Act in 1994 banning the export and import of nuclear waste, TVO and IVO in 1995 established a joint company, Posiva, to take care of SNF disposal in Finland. There has never been a governmental agency[12] implementing nuclear waste management in Finland as there is in many other countries (See NWTRB 2009). The Ministry of Employment and the Economy (MEE)[13] is responsible for overall management and supervision in the nuclear energy sector. The Ministry also directs the planning and implementation of nuclear waste management. Säteilyturvakeskus (STUK), the Finnish Radiation and Nuclear Safety Authority is responsible for the supervision of nuclear safety and the use of radiation.

3.3 Outlining the nuclear waste policy of TVO

Reprocessing and final disposal of high-level waste abroad was proposed as the primary option in the Nuclear Waste Study of 1978. The negotiations on reprocessing reflect the fact that at that time the

[9] Voimayhtiöiden ydinjätetoimikunta in Finnish. It was discontinued in 1995 when Posiva was established.
[10] The objective was to ensure that nuclear waste management can be taken care of safely in Finland from a technical point of view and to establish frames for the waste management planning of the power companies (Ydinjäteselvitys, 1978, 3).
[11] Preparation of the new Act was already begun in the 1970s (Ruostetsaari, 1986, 155–159; Nikula et al., 2012, 62–70).
[12] The establishment of a governmental agency was proposed in the 1970s (Ruostetsaari, 1986, 157; Nikula et al., 2012, 62–64).
[13] Kauppa- ja teollisuusministeriö (Ministry of Trade and Industry) before 1 January 2008.

focus of nuclear waste policy was on international nuclear fuel cycles[14]. An operator, such as TVO, was planned to be part of the multinational nuclear fuel cycle to reduce costs and to control nuclear materials. The Swedish KBS concept introduced in 1977 was used as a reference concept by IVO and TVO (Ydinjäteselvitys, 1978, 2, 112–124). The KBS concept was chosen because of the similarity of the geological conditions in Finland and Sweden (Ydinjäteselvitys, 1978, 63). According to TVO it was rational to wait for clarification of the situation regarding reprocessing and long-term storage internationally before taking any decision in Finland. At that time there were no technical solutions available for final disposal. (Björklund et al., 1994, 145–146.)

The operating licence[15] of the TVO1 (Olkiluoto1) unit, issued in 1978 for five years only, obliged TVO to negotiate a reprocessing contract for all spent fuel, but later in 1980 the Ministry of Trade and Industry announced informed that TVO had not violated the preconditions of the operating licence although the company did not sign a reprocessing contract. After this announcement TVO discontinued negotiations on reprocessing (Björklund et al., 1994, 145–149; Kaijser & Högselius, 2007; Nikula et al., 2012, 29), although only after the decision of 1991 by the Ministry of Trade and Industry and the amendment of the Nuclear Energy Act in 1994 final disposal became the primary alternative for TVO (Sandberg, 1999).

In the 1970s and 1980s the two power companies IVO[16] and TVO had different company specific nuclear waste policies and objectives in practice, although the main line of the policy was based on reprocessing and shipping the waste away from Finland (Suominen, 1999; Kaijser & Högselius, 2007; Kojo, 2009a). IVO transported spent fuel produced in the Loviisa VVER-440 type NPP units to the Soviet Union and to Russia in 1981–1996. This arrangement was agreed in the contract signed by the Government of Finland and the Government of the Soviet Union in 1969 (Sandberg, 1999). TVO was also guided towards reprocessing by the Finnish nuclear waste policy decisions issued in 1978 and 1983. However, TVO was also considering direct final disposal[17].

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[14] In the 1970s international nuclear fuel cycles were accounted for in the Regional Nuclear Fuel Cycle Centres (RFCC) study by IAEA and in the International Nuclear Fuel Cycle Evaluation (INFCE) initiated by the United States. In the INFCE Finland was one of the chairing countries of the studies focused on nuclear waste management.

[15] In 1975–76 TVO wrote a report on alternatives in nuclear waste management. One of the alternatives was long-term storage of spent fuel and direct final disposal later. Long-term on-site storage at the Olkiluoto site was also the basis of SNF management when TVO applied for the operating licence in 1977.

[16] Nowadays Fortum Power and Heat Oy.

[17] According to Kaijser and Högselius (2007, 23) "*TVO:s strategi för hantering av använt kärnbränsle såg i slutet av 1970-talet med andra ord ut att vara på väg i en ny riktning: bort från såväl upparbetning inom landet som upparbetning utomlands. Vad man hade i åtanke var istället något vid denna tid så radikalt som direktdeponering av det använda bränslet.*"

Following the practices of IVO, in the early 1970s TVO investigated the opportunities for transporting spent fuel produced in Olkiluoto NPP to the Soviet Union. The request was denied as the Soviet Union accepted only spent fuel produced in Soviet-type reactors (Kaijser & Högselius, 2007, 22). For TVO it was important to keep the reprocessing option available, as that was a precondition of the operating licence for the NPP imposed by the Ministry of Trade and Industry. TVO negotiated on reprocessing with United Reprocessing GmbH (URG), and later with Compagnie Générale des Matières Nucléaires (COGEMA) and British Nuclear Fuels Limited (BNFL), but no contract was ever signed as the economic and other conditions, e.g. the return of residual high-level waste, were deemed too strict by TVO. (Björklund et al., 1994, 145–149; Nikula et al., 2012, 79.) Later, in the early 1980s, TVO had the option to sign a contract for the interim storage of spent fuel in Sweden, but due to schedules and costs TVO preferred to build an interim storage of its own[18] at Olkiluoto site (Haapala, 1988, 10). Reprocessing was an alternative which TVO needed to keep alive mostly for regulatory reasons.

According to Ryhänen (1979), who reported on the alternatives of spent fuel management and the foreign services from the viewpoint of TVO, in the early 1970s it was expected that reprocessing services would be available by the end of the decade. However, the situation changed and the large-scale reprocessing of light water reactor fuel was expected to start only in the second half of the 1980s in Western Europe. Thus storage capacity was required for long periods. Research focused on the direct final disposal of spent fuel without reprocessing was on-going. International Nuclear Fuel Cycle Evaluation (INFCE), in which Finland was involved, was hoped to clarify procedures at the end of the fuel cycle.

In 1979 Ryhänen (1979, 11) reported that according to the Swedish government the KBS solution met the requirements of the Swedish Stipulation Act. Furthermore, a detailed plan for the direct final disposal of spent fuel had been presented by the Swedes in the later part of the KBS account (Ryhänen was referring to Kärnbränselcykelns slutsteg – Slutförvaring av använt kärnbränsle, del I … II Projekt Kärnbränslesäkerhet, Stockholm 1977). Ryhänen noted that if the final disposal alternative was considered, fuel would first be stored for several decades. Before final disposal the fuel rods would be sealed into copper canisters. Thus the Finns were aware of the research and development regarding the KBS concept. However, in 1979 it was concluded that both from the point of view of safety and economy it would obviously be most profitable if temporary storage and final disposal of the waste

[18] The plan to build a central storage for spent fuel in Finland was abandoned as IVO had no need for a separate storage in the late 1970s. IVO had enough storage capacity for cooling spent fuel for three years. After this fuel was transported to the Soviet Union. TVO prepared to build a separate storage of its own at Olkiluoto against the contingency that there would be no reprocessing capacity available when the storage pools of the NPP were filled. (Ydinjäteselvitys, 1978, 20–21.)

were carried out in a concentrated way, i.e. in the countries which were the major producers of nuclear energy. (Ryhänen 1979, 11, 14.)

By 1981 the outline of spent fuel management alternatives in TVO had changed. Ryhänen et al. (1981, Summary) stated that "*at the moment it seems apparent that interim storage capacity is needed for TVO's spent fuel management at the end of 1980's*." TVO was moving further away from reprocessing although in the 1980s it was still the primary option of Finnish nuclear waste policy. Ryhänen et al. (1981, Summary) concluded that direct disposal was the only alternative available for TVO at that time. The most important measure was to arrange for additional storage capacity by the beginning of the 1990's. TVO needed more time "*to follow universal development and evaluation of alternatives to arrange TVO's spent fuel management at the right time in a safe and economic way. The question, if the fuel will be reprocessed or disposed without reprocessing has to be solved with a long range aim.*" (Ryhänen et al., 1981, Summary.) According to Ryhänen et al. (1981, Summary, 43) TVO should aim to get to use foreign research and development work and experiences, particularly in interim storage, encapsulation and disposal technique.

4. Development of the technology transfer process between TVO, Posiva and SKB

In the case of transferring the KBS-3 concept for the geological disposal of spent nuclear fuel from SKBF/SKB to TVO, TVO was clearly the initiator. TVO was looking for a solution for managing the spent nuclear fuel from its power plants under the pressure of the requirements imposed by the Government on the operating licence of the TVO-1 unit in 1978 and on the Government decisions of 1978 and 1983. According to Nikula et al. (2012, 80–81) it was natural to first look at what others had done so far regarding the issue. The State of Finland moreover supported technology transfer.

In 1978 the Ministry of Trade and Industry established a working group to prepare a proposal concerning the outlines of the Finnish nuclear waste research and time schedule. The focus was on studies on the final disposal of spent fuel and its residuals after reprocessing. The report was published in 1980. The working group had a very positive attitude to international cooperation and the follow-up of foreign research. It was stated that "*Therefore in studies and research concerning handling, transportation and storage techniques the business idea is to create readiness so that as far as possible a suitable technique could be chosen and applied in Finland in light of foreign research*" (Nuclear Waste Working Group, 1980, 5.) The group argued that the Finnish nuclear waste decisions were heavily dependent on the international development and solutions in other nuclear energy countries. According to the group, appropriate use of the Finnish resources required utilization of foreign research, especially on topics which were not site-specific. The group noted that international exchange required that we [the Finnish actors] also have something to offer. Furthermore, adaptability was needed as a small country could not influence the timetables of international projects. Thus the Finns should be ready to get involved even if the timetable was not optimal from the Finnish perspective. As one example of international cooperation mentioned was made of the Swedish KBS project on which "technical reports including detailed results" were received directly from the KBS project. Information and experience exchange with the Programrådet för radioaktivt avfall (PRAV) was also brought up. (Nuclear Waste Working Group, 1980, 16, 18.)

The closest relationship regarding technology transfer was developed with Sweden, although there were also connections to other countries, such as Switzerland and Canada (Nikula et al., 2012, 81–59). According to Ryhänen (2012) the Finns first asked for approval to refer to the results of the KBS project in the late 1970s as the power companies were preparing the Nuclear Waste Study of 1978. The first reaction by SKBF was positive and they were keen to know if the conclusions drawn on the Finnish investigations differed from those drawn in the Swedish case. Thus SKBF was interested in having feedback on the disposal concept. The request for feedback could be seen as a first step towards a two-way communication process between the parties. In 1980 TVO established an internal management group and a small nuclear waste office to coordinate the questions and projects regarding finding a solution to the nuclear waste issue. Before that TVO staff in the various departments took care of the fuel issues but now for the first time expertise and some resources were organized into one office. TVO also started networking with consultants and research institutes[19] and signed research agreements. Publicly funded research was part of the network. (Ryhänen, 2012; Nikula et al., 2012, 29–30) According to Nikula et al. (2012, 24–25, 29) the primary objective was to publish reports in fulfilment of the requirements of the operating licence and thus to ensure further operation on the TVO NPP. The main objective was to establish a basis for long-term nuclear waste management at TVO.

The Swedish nuclear power and waste policies and the referendum of 1980 were closely followed in Finland as they influenced the Finnish debate and decision-making regarding nuclear power issues. In the debate TVO was criticized for lack of expertise, plans and funds for nuclear waste management. TVO needed to have a long-term plan for final disposal in Finland and connections with more experienced foreign organizations. (Ryhänen, 2012; Nikula et al, 2012, 20–22, 29–30, 81). At this stage TVO searched for knowledge and information from existing projects abroad. By the end of the 1980s TVO, together with IVO, had signed information exchange contracts with SKB, NAGRA, AECL and Ontario Hydro. In practice the arrangement included annual meetings for updating the progress of the programmes and exchange of research reports. (Ryhänen, 2012; Nikula et al., 2012, 86.)

The thematic meetings between SKB, Nagra and TVO were a basis for the development of the so-called Crystalline Group, where organizations studying final disposal into crystalline bedrock collaborated unofficially. The most active period of the Group was in the mid-1990s[20]. Later, at the end of the 1990s, due to the deceleration of the Group, SKB and Posiva started negotiations on extensive bilateral collaboration in crystalline bedrock research. (Nikula et al., 2012, 93.)

Access to the KBS project and the other international contacts with the Canadians and the Swiss provided the Finns, according to Ryhänen, with a basis for a ‘flying start’. The ‘flying start’ was partly based on the earlier connections of the Finnish nuclear industry sector to Sweden due to activities related to nuclear power plants (see e.g. Jåfs, 2009, 174–176). In the field of nuclear waste

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[19] In Finland GTK, VTT, the Department of Radiochemistry of the University of Helsinki and Helsinki University of Technology were the main partners (Nikula et al., 2012, 30).

[20] According to Nikula et al. (2012, 90–91, 94) relationships between the implementors became closer in the 1990s. Strategies and experiences were exchanged at the Directors’ Meetings, to which the most advanced countries were invited. Since 1999 EDRAM has continued this meeting tradition.

management the Technical Research Centre of Finland (VTT) and later also the Geological Research Centre of Finland (GTK) took part in Nordic co-operation in the 1970s.

Technology transfer between TVO and the foreign agencies was first non-commercial in nature. This mode is characterized by *information exchange*, in practice this refers, for example, to reports, workshops and personal contacts. Information exchange was followed by *commercial consulting* already in the early days of the disposal project. Ryhänen (2012) called this stage moving towards more project-type work. As TVO tested rock drilling methods in the municipality of Lavia in the mid-1980s, some measurement work was commissioned from Sweden. According to Ryhänen (2012; cf. Nikula et al., 2012, 84) the Swedes expected to derive some economic benefit as they were ahead in the investigations compared to the Finns[21]. Thus the contracting parties negotiated on keeping the balance. (Nikula et al., 2012, 94). International co-operation is still an important factor for the work of today. The modes of work are quite the same as they have been; agreements on consultation work, knowledge exchange and international projects. The Äspö project has been an important project, also participating in the work of the International Association for Environmentally Safe Disposal of Radioactive Materials (EDRAM) has continued. Posiva has also been part of the Club of Agencies group. The collaboration between SKB and Posiva has strengthened in line with new agreements on co-operation in 2001, 2006 and 2011. (Nikula et al., 2012, 94.)

According to Äikäs (2013) the Swedes were sometimes unhappy because they felt that the Finns were only picking up their results. Attitudes started to change, however, when the Finns introduced the idea of a cold process canister design to replace the use of molten lead (on ACP canister design, see Nikula et al., 2012, 109). Later in the 1990s the PASS[22] project further strengthened the collaboration. According to Äikäs (2013) the PASS project was the first big joint project between the parties, where actual technical development work was done together. During the same period the site selection process had advanced in Finland, when again in Sweden the process came to a halt, giving TVO the opportunity to provide information on the site selection process to SKB. Äikäs describes this change as TVO becoming a resource for SKB.

Äikäs (2013) refers to the collaboration and underlines the importance of the collaboration in the beginning of the nuclear waste management process. As one of the most successful collaboration projects, he mentions the STRIPA project (1977–1992), which was organized and funded by different countries. It was initiated by SKB and the Department of Energy (US), but since 1980 it was

[21] Posiva sold services to SKB for the first time in 2005 (Nikula et al., 2012, 95).
[22] In Swedish Project Alternativ Studier för Slutförvar.

coordinated by the OECD Nuclear Energy Agency (Nikula et al., 2012, 85). In 1980 TVO, IVO and the Ministry of Trade and Industry joined the project (Ryhänen, 2012). According to Nikula et al. (2012, 85) the best result of the project was technology transfer to the participants, which was based on well-established publishing and meeting arrangements without too complex bureaucracy. Furthermore, the project was deemed cost-efficient, "which offered for a small country such as Finland a unique option to learn about sectors needed in the implementation of a final disposal programme and access to research results". Äikäs describes the project as a learning project and advanced training.

When the Stripa project was still ongoing SKB started their project in Äspö which the organizations which had been participating in STRIPA were asked to join. The Finns decided not to collaborate in the construction phase of the Äspö rock laboratory, since at the same time a site selection process was being conducted in Finland. According to Äikäs the methods that were used in the construction of the test laboratory were also different from those intended to be used in Finland. TVO joined the Äspö project later, in 1992, and was a part of the Äspö project until 2012, when Posiva's own research rock characterization facility ONKALO was completed and their own test laboratory was therefore built.

In the Äspö project which Finland joined in 1992 (Nikula et al., 2012, 82–85, 178) participants paid a participation fee to compensate the costs of operations, test etc.[23] Later the Finns paid a separate fee for technology transfer to get access to Swedish know-how related to welding technology for the lids of capsules. Currently, SKB-Posiva co-operation is based on identifying issues of joint interest, for example the development of final disposal technique and encapsulation (Ryhänen, 2012.) According to Äikäs (2013), the collaboration and agreements have been cost effective for both parties.

In general the connections to the Swedes seem to have been quite unproblematic, although TVO was a newcomer to nuclear waste management. Ryhänen refers to a mutual understanding, which could be interpreted as similarity in organizational culture, which made cooperation easier. Äikäs, like Ryhänen, stressed the importance of informal discussions and face-to-face meetings in information exchange. Äikäs also mentioned the building of trust in face-to-face relations. In addition to this finding, a common language, i.e. Swedish is one of the two national languages of Finland, was important. According to Äikäs, reports written by the Swedes were very welcome in Finland, but the language barrier made the Swedes selective about the reports written in Finnish. The language issue also came up in relation to the informal communication in the sense that it is easier to build a good relationship when sharing a language, even if the research language were English.

[23] According to Äikäs Posiva paid around a hundred thousand euros annually to SKB in the latest stage of the Äspö project.

According to Äikäs, the collaboration between SKB and Posiva Sweden and Finland is a product of at least three important factors. Firstly, there is a common desire (all the way from top level) to collaborate and acknowledgement of the advantages of collaboration both in costs, problem solving and risk management Secondly, the strong tradition in the collaboration affects the work even today, making collaboration a natural way of working. Thirdly, Äikäs stressed the importance of a strong and shared vision, which leads the way for both companies and helps them in finding solutions. In addition to this, the already mentioned co-operation regarding NPP also had a major role in establishing co-operation in new areas.

5. Modifications to the final disposal concept

5.1 KBS as a reference concept

The case study starts in 1978, when a report on nuclear waste repository building was released. In the report TVO and IVO presented the results of a joint nuclear waste research project launched in 1977. The main focus in this report was on the final disposal of reprocessed waste while the disposal of spent nuclear fuel was again paid less attention. Consistent with Finnish nuclear waste policy, TVO NPP units were planned to be part of international nuclear fuel cycle, as were IVO NPP units. The IVO and TVO Study of 1978 (Ydinjäteselvitys, 1978, 1) stated that from a technical point of view there was no compelling need for the final disposal of waste. The final decision on the method could be taken when the measures were really needed. This would guarantee the benefits of technical development. The report also noted that only in recent years had research activities focused more on the nuclear waste issue. One factor was public opinion, which had demanded that the waste management issue to be solved before waste was produced.

The study relied mainly on research conducted abroad, and especially on the Swedish KBS project. The Swedish model KBS was chosen as a reference model because of the similarity of the geological conditions. Other possible solutions for the disposal of waste are also mentioned; such as disposal into the ground, the seabed, salt constructions or other geological constructions. These alternative methods were predicted to be feasible while transmutation, sending the waste into space or disposing of it into the polar ice were deemed mere ideas and very costly. Much was demanded of the geological formations where the waste could be disposed of. The report mentioned that areas with bedrock are suitable options for such a disposal method. Disposal into the earth was claimed to be uncertain because of the thickness of the earth cover and geological conditions. Disposal into the seabed was deemed unsuitable because of geology and international agreements. (Ydinjäteselvitys, 1978, 2, 62–63.)

At this time the most preferable option was shipping the waste abroad for reprocessing and disposal. A repository would be built for the use of the reprocessed waste if it were to be shipped back to Finland. The reprocessed waste was planned to be disposed of into the bedrock at a depth of 500 metres in canisters positioned vertically and in canister holes made in the distance of four meters of each other. The materials proposed for the canisters were titanium, steel or copper and lead, with copper aluminum oxide likewise proposed as a suitable option. Quarz-bentonite was suggested as a filling material of the tunnels and holes. (Ydinjäteselvitys, 1978, 2, 63-65, 113, 201.)

5.2 Introducing alternative disposal concepts

In 1982 the reference disposal concept was changed to KBS-2, introduced by SKBF in Sweden in 1978. Compared to KBS-1 concept KBS-2 was designed for the disposal of spent fuel, not reprocessed vitrified high-level waste. Two alternative ways of managing spent fuel were presented in the feasibility study by TVO: disposal without reprocessing, or reprocessing fuel and disposal of vitrified residual high-level waste. The starting point for the report was the disposal of spent fuel without reprocessing. A concept for final disposal into the Finnish bedrock was presented in the report, but the solutions and final design were left open by suggesting that the final selection of the method would be made relatively far in the future. The bedrock of Olkiluoto was used as a reference site for the final disposal. (YJT-82-46, 1.)

According to TVO (YJT-82-46, 58) the Swedish KBS-2 concept was chosen as a reference concept because:

- the fuel types were similar in Finland and Sweden,
- the bedrock conditions were similar,
- the KBS study was very extensive,
- the Swedish spent fuel was similar,
- further studies were usable, it was easy to get information and collaboration was good,
- the similarity in construction technology and the possibility to cooperate in solutions and work (STRIPA project).

Even if the Swedish model was chosen as a basic concept, also alternatives were introduced. The Canadian and Swiss models were discussed as alternatives to the Swedish one. (YJT-82-46, 62-65.) It was emphasized that it was essential to collect information from other countries as well as do Finnish research on the subject. In Canada, Sweden, Switzerland, and the USA similar research was conducted. It was stated that it was important to actively follow what other countries were doing and also to do adaptive work and to facilitate the Finnish disposal. TVO also stated that Finland could, with a slower timetable, await results from other countries. (YJT-82-43, 1-3.)

In the Canadian model the canisters were planned to be placed in holes drilled into the floors of tunnels. The canisters were planned to be located rather closer together than in the reference concept, which, according to the report, might lead to higher temperatures. In the Swiss model the canisters were planned to be placed at the centre of a tunnel and in horizontal position. (YJT-82-43, 20–32; YJT-82-46, 62-64.) According to TVO, both the Canadian and the Swiss model were more economical than the KBS-2 solution. (YJT-82-43, 31-32.) In the Swedish model the fuel rods were to be encapsulated in canisters which could be manufactured from copper, titanium or titanium alloys, nickel-base alloys or austenic-stainless steels. The canisters were planned to be disposed of in the bedrock 500 metres down in drilled tunnels. The wall thickness of a copper canister was planned to be 200 mm. Fuel assemblies were to be dismantled before encapsulation. (YJT-82-46, 41–43, 45, 56.) The distance between the canisters was planned to be six metres. (YJT-82-43, 21.) Even if the Swedish model was retained as a reference model, the report also stated that new solutions might emerge during the years before the final technical method was selected. (YJT-82-46, 128-129.)

By 1985 reprocessing had become a more uncertain option for TVO. Therefore the option for the final disposal of SNF had to be taken into account in the plans (see Kaijser & Högselius 2007). The report of 1985 mentions two options; exporting the waste abroad for disposal or disposing of it in Finland. The report states that if an international agreement on exporting cannot be reached, then final disposal in Finland is the option. From this, one could say that at this time exporting was still considered the method of choice. (YJT-85-30, 5, 147.) This was also in line with the nuclear waste policy outlined by the Government (Suominen, 1999). For the encapsulation and siting solutions the KBS model was chosen as a reference concept. It was, however, mentioned in the report that the timeframe was so long, that it allowed developing technical solutions introduced. (YJT-85-30, 8.)

The report of 1985 (YJT-85-30, 14–15) notes that many materials might be suitable for the canisters. Copper, however, was the most studied material. The research results of titanium, titanium alloys and nickel-based alloys were also studied, and ceramic materials were also mentioned as one possible material in the future. According to TVO, the high price of nickel might inhibit the use of nickel based materials. (YJT-85-30, 14–15.) Due to new results in copper corrosion studies, the copper wall thickness was reduced from 200 mm to 100 mm. (Nikula et al. 2012, 104, 106.) Lead was planned as filling material for the canisters. (YJT-85-30, 16.) The canisters were planned to be emplaced into holes drilled in the floors of tunnels. The holes were planned to be situated six metres apart. Compacted bentonite blocks were planned as filling material between the canister and the bedrock and the tunnels were planned to be filled with sand and bentonite. Eight fuel assemblies were planned to fit the canister. (YJT-85-30, 16, 25–27.) While in the report of 1982 both the Canadian and Swiss concepts were referred to as alternatives to the KBS concept, in 1985 only one alternative was presented and it was said to resemble the Swiss concept. The report did not disclose, why this concept was chosen as an alternative except that it was regarded as suitable for the geological conditions. (YJT-85-30, 30.)

5.3 Changes in canister design

In the report of 1992 (YJT-92-31E) an alternative encapsulation method was presented that had been under development from 1986 to 1990 in order to find an encapsulation process that would be "simpler, safer in operation and less costly than the previous system". (YJT-92-31E, 22.) The new canister model also meant moving away from cast lead, which made the construction of the canister more economical. Handling molten lead was also seen to entail a risk of fire and the formation of unhealthy gases. The design process of the canister evolved towards a design where the inner part of the canister was not filled with any material and an inner part of steel was instead developed to maintain the mechanical strength of the canister needed due to pressure. (Nikula et al. 2012, 110.)

> *"The ACP [Advanced Cold Process] canister developed by TVO consists of two containers, one inside the other. The outer container will be made from oxygen-free copper that provides the necessary shield against corrosion. Inside it, there is a steel cylinder whose primary function is to ensure the mechanical strength of the canister.* (YJT-92-31E, 22).

The buffer material between the two layers of metal was planned to consist of solid granules. The new ACP canister had a copper wall 60 mm thick. The buffer material was planned to consist of lead shot, quartz sand or glass beads. The repository was planned to be of a depth of 300 to 800 metres and the canisters were to be placed six metres away from each other. (YJT-92-31E, 23–31.) The total disposal capacity for spent fuel increased first from 1200 tU to 1270 tU and later to 1840 tU due to modernization and the extension of reactor lifetimes. Reactor capacity at Olkiluoto NPP had been increased several times due to modernizations. The original capacity was 660 MWe per NPP unit, but today in 2013 it is 880 MWe per unit. Due to higher capacity more SNF will be produced.

In the report of 1992 alternative final disposal systems were studied such as WP cave, Very Deep Holes and Very Long Holes and Medium Long Holes concepts. Alternatives were studied together with the Swedes in a co-project entitled PASS (Project on Alternative System Studies) (YJT-92-31E, 37.) All these concepts according to Nikula et al. (2012) were possible alternatives in theory, but uncertainties were found in demonstrating long-term safety, which again would have needed investments in further research and thus would have caused more costs for TVO. The Very Deep Holes concept was not deemed a good option because in this concept the only buffer material was the bedrock. (Nikula et al., 2012, 110.)

The amended Nuclear Energy Act passed by Parliament in 1994 forbade any import or export of nuclear waste after 1996. In this situation TVO and IVO established the joint company Posiva to develop spent nuclear fuel disposal. This also meant that the other fuel type from the Loviisa NPP units had to be taken into account in R&D activities. Consequently the total amount of fuel increased to approximately 2600 tU[24]. (Posiva, TILA-96-17, 5).

In the report of 1996 the repository was planned to a depth of about 500 metres in the bedrock. The copper canisters were planned to be emplaced in vertical holes in the horizontally built tunnels. To fill up the space between the canister and the bedrock, compacted bentonite was to be used. The tunnels were to be filled with crushed rock and bentonite. (TILA-96-17, 10.)

A new canister design was introduced in this report, where the internals of the ACP canister were replaced with a cast inner component with holes for the fuel assemblies. A total of 11 bundles fitted into one canister. The advantages of the new design were stated to be:

> "*simpler encapsulation process, increased compressive strength, reduced risk of internal corrosion inside of an intact canister, thanks to the inert gas atmosphere, reduced risk of inward collapse due to the corrosion of the inner container in case there is a defect in the copper overpack, and it is easier to show subcriticality in all plausible situations.*" (TILA-96-17, 10–11.)

The spent fuel from the two NPPs had an impact on the size of the canister which was chosen according to the two different fuel types. The total number of canisters was thought to be about 1500 (960 for BWR fuel and 560 for VVER fuel.) The copper overpack was reduced from 60 mm to 50 mm. (Posiva 1996-13, 43; YJT-92-31E, 23.) Alternative concepts investigated were KBS-3-2C with two canisters in a deposition hole, short holes and medium Long Holes. It was concluded in a report that the other concepts offered no advantages over the KBS concept:

> *"The KBS-3 design is robust and flexible and provides excellent post-closure safety. The transfer, emplacement and sealing operations are technically uncomplicated. The alternative options assessed do not offer any significant benefits in safety or cost over the basic design, but they are technically more complex and also in some respects more vulnerable to malfunction during the emplacement of canisters and buffer, as well as common mode failures."* (Posiva 96-12, abstract.)

[24] 1870 tU of BWR and 740 tU of PWR fuel.

5.4 Decision-in-Principle for the KBS-3 final disposal concept

On 26 May 1999 Posiva applied for a Decision-in-Principle for a repository for spent nuclear fuel. (Posiva DiP, 1999.) The safety assessment report TILA-99 included extensive research material and formed the basis for the application.

According to Posiva the repository was planned to be built at a depth of 400–700 metres in the crystalline bedrock (Posiva DiP, 1999, Appendix 5, 2). The canister model to be used was a copper-iron canister. The space between the canister and the rock was planned to be filled with compacted bentonite clay. The filling of the tunnels was intended to be done with crushed rock and bentonite clay (Posiva DiP, 1999, Appendix 5, 2–7). The canister was planned to be of copper with a cast iron insert. The canister was designed to hold 9–12 fuel assemblies (Posiva DiP, 1999, 6, 44). The void inside the canister would have been filled with a gas, for example helium. (TILA-99, 22.) The thickness of the copper overpack wall was planned to be 5 cm, although some studies suggested that it could be only 3 cm. (TILA-99, 24.) Even though the thinner copper wall would have been less expensive for Posiva, it was due to results of the manufactory technic tests that 5 cm was predicted as a better option. (Nikula et al., 2012, 114.)

According to the reference case in the TILA-99 report (TILA-99, 24) a total amount of about 1400 canisters containing 2600 tU of spent fuel was to be disposed of. An extension in service life-times of all four reactors to 60 years would, according to the report, increase the total amount of spent fuel to approximately 4000 tU and 2180 canisters. If two new reactors were operated for 60 years, the total amount of fuel would be 9000 tU and 4500 canisters would be needed. (TILA-99, 24.) Posiva applied for a DiP for a disposal capacity of 2600 to 9000 tU in May 1999, but, due to political pressure, the disposal capacity introduced in the DiP application was modified by Posiva to cover 4000 tU, i.e. spent fuel produced by the four operational NPP units during a 60-year lifetime. (Kojo, 2009b, 225–226; Nikula et al., 2012, 158.) Some of the politicians were reluctant to give a positive signal to nuclear new build by granting advance approval for the disposal of the spent fuel of the planned new NPP units.

The canisters were intended to be emplaced at distances of 6–8 metres from each other (Posiva DiP, 1999, Appendix 5, 15). The final disposal repository was planned to be sealed off and abandoned. The DiP of 1999, however, also mentioned that the disposed canisters could be retrieved (technically possible) in all phases of the project. (Posiva DiP, 1999, Appendix 5, 9–10.)

Alternative repository concepts were introduced in TILA-99. These were as follows: the KBS-3-2C design with two canisters in a vertical deposition hole, Short Horizontal Holes (SHH) in the side walls of the tunnels, and the Medium Long Holes (MLH) concept, where about 25 canisters are emplaced in a horizontal deposition hole. (TILA-99, 26.) However, the alternative concepts were not deemed to offer any improvement on the KBS-3 concept:

> "*On the basis of the assessment, it was recommended that further development and studies should focus on the basic KBS-3 repository design with a single copper-iron canister in a vertical deposition hole. The design is robust and flexible and provides good post-closure safety. The transfer, emplacement and sealing operations are technically uncomplicated. Only the basic KBS-3 repository design will be analysed in the present study.*" (TILA-99, 26.)

The concept with horizontal emplacement was considered a viable alternative as regards post-closure safety, but the advantages (in safety or cost) compared to the reference model were few. The horizontal model was also considered to be technically more complex, which might increase technical vulnerability. (TILA-99, 26.) In the DiP application alternatives of the basic concept such as deep holes, WP Cave and transmutation were also mentioned. Posiva concluded that there were no such alternatives for final disposal which, according to current knowledge, could fulfill both the safety requirements and objectives of the legislation. Posiva stated that the safety of the concept proposed was superior and further that the development stage of the concept was more advanced than the others. Furthermore, the concept offered options for development and did not exclude withdrawal from final disposal in the future. (Posiva DiP, 1999, Appendix 3, 4–5).

A change of thought regarding the multibarrier system was apparent during the first decade of 21th century. The role of the bedrock was changing from being one important release barrier towards securing the technical barriers at first hand and at second hand to function as a release barrier. This change of vision also changed the view on the long term predictability of the bedrock regarding the endurance of the technical release barriers. (Nikula et. al. 175, 195.)

5.5 More detailed development work

After the decisions-in-principle of 2001 and 2002 implementation of the final disposal started at Olkiluoto (Nikula et al., 2012, 124). One could perhaps therefore say that from the beginning of the twenty-first century onwards more detailed development work was needed, such as getting the canister design into industrial production and conducting tests on the iron casting and different welding techniques on the copper canister. Development work on the bentonite buffers was also done, taking into consideration the salty groundwater and the compactness of the bentonite. According to Nikula et al. (2012), a very important step in the development of the canister was the co-operation contract signed in 2001. Due to this contract Posiva gained access to the same level of knowledge and research as SKB, through access to the research results from SKB. (Nikula et al., 2012, 115.)

In 2008 Posiva submitted the application for a decision-in-principle for an extension to the repository for SNF produced by the Olkiluoto 4 NPP unit. The decision on the Olkiluoto 4 unit increased the disposal capacity of the repository to 9000 tU and later the application for the Loviisa 3 unit increased the amount of fuel to 12000[25] tU. The reference concept in the DiP application (Posiva 2008) was KBS-3V, with vertical siting and a canister with two canisters inside each other (copper and nodular graphite cast iron) and compacted bentonite clay blocks was planned to be used as filling between the canister and the bedrock. The repository was planned to be built at a depth of 400–700 metres. As an alternative concept horizontal disposal (KBS-3H[26]) was also studied. In the horizontal version no holes in tunnel floors were needed. (Posiva, 2008, Appendix 12A, 4–3, 30.) In the repository design a change was made from one shaft to several shafts, thereby making the construction less complex by avoiding demanding construction inside the shaft. (Nikula et al., 2012, 132.)

Posiva submitted the application for a construction licence for the repository in December 2012. The repository will be built at a depth of 400-450 metres. (Posiva CLA, 2012, Appendix 5, 3.) Detailed safety and security research was ongoing and the technical details were further developed. The KBS-3V model has been the reference design for Posiva for the final disposal, but the alternative horizontal design is being developed. In KBS-3H the canisters are placed horizontally in tunnels filled with bentonite. It is also possible that several canisters can be emplaced in the same tunnel. In the KBS-3V design the canister is made of copper-iron and compacted bentonite is planned to be used as buffer material. The canisters will be emplaced in a hole in the floor of the repository tunnel. The tunnels will be filled with buffers made of Friedland clay. The number of fuel assemblies to be placed in a canister will vary depending on the reactor from which the fuel originates. For example, only four fuel assemblies of the Olkiluoto 3 unit will be placed into one canister due to their greater heat production compared to the Olkiluoto 1 and 2 units. (Posiva CLA, 2012, Appendix 7, 5–8.)

[25] In 2008 the power company Fennovoima proposed that total capacity at Olkiluoto should be 18000 tU as the company wanted to join the project. The proposal was rejected. (Kari, Kojo & Litmanen, 2010, 8).

[26] Äikäs (2013) believed that Posiva could perhaps apply the KBS-3H concept in the future, but that operations would begin with the KBS-3V concept.

In the application Posiva requested a change in the approval procedure. The company suggested that possible changes to be made to the plans presented in the CLA would need only approval by STUK and not by the Government. (Posiva CLA, 2012). The Finnish Association for Nature Conservation opposed this change. The Association argued that if there were essential changes in the current concept, a new environmental impact assessment process would be needed for an alternative concept. (The Finnish Association for Nature Conservation, 2013.)

6. Conclusions

This paper reports a case study analysing the transfer and major modifications of the Swedish KBS-3 disposal concept for spent nuclear fuel by the power company Teollisuuden Voima and later by the waste management company Posiva in Finland. The case involves international nuclear waste politics, national policies, the role of private companies in the energy market and the overall development in the field of nuclear waste management. The research questions of this paper were as follows: (1) What were the main modifications to the final disposal concept? (2) What societal arguments stated by TVO and Posiva can be found behind the modifications? (3) How has the relationship between TVO, Posiva and SKB in information sharing and technology transfer changed since the 1970s? The case study covers the time period from 1978 to 2012, i.e. from the first Nuclear Waste Study to the Construction Licence Application of the repository.

Differing views on technology transfer were presented: the technology transfer model, the diffusion model and the technology translation model. The technology translation model was applied because it emphasizes the continuous transformation of the token, i.e. the final disposal concept. Latour (1986) introduces the model of translation where "*the spread in time and space of anything – claims, orders, artefacts, goods – is in hands of people*". People may act very differently in relation to the token. The point of the model is that actors are needed, because otherwise the token simply stops, as according to Latour (1986, 267) the token derives its energy from "*the everyone in the chain who does something with it*". Therefore the actors of the network are assigned an important role in the translation model. There is also an active network behind the translation of the KBS concept. The objective of this case study was not to analyse these actors and their initiatives in shaping the concept in detail, but to form a holistic picture of the major modifications to the concept and the societal arguments for either changing the concept or keeping it untouched.

Societal argumentation as such by the main actors TVO and Posiva was scarce in the research data. This was not a great surprise as the data consisted of technical oriented reports, but we felt that it was important to trace societal argumentation regarding the development of the 'technical' concept as these reports have been submitted and applied as references in the Finnish decision-making process. However, the argumentation can be summarized in the leading guiding principle of the actor, i.e. TVO and Posiva adopted a pragmatic and cost-conscious policy regarding nuclear waste management.

As TVO was a novice in nuclear waste management in the 1970s and still in the 1980s, the company deliberately started to compile information and experiences from abroad, especially from Sweden, where the reactor technology for the Olkiluoto 1 NPP unit was acquired. The pragmatic operating mode was supported by the Finnish nuclear waste management system and thus a very positive attitude to international cooperation and follow-up of foreign R&D dominated the work. Furthermore, the geology, crystalline rock type of the Fennoscandian Shield is partly similar in Finland and Sweden, which made the KBS concept attractive to TVO.

In 1978 the first reference concept for nuclear waste management was introduced in Finland. At that time nuclear waste management and the concept development was very closely linked to the licence procedures for NPPs, which put pressure on TVO as a licensee. The concept, KBS, was adapted from the Swedish R&D work conducted by SKBF. At the time Finnish nuclear waste policy and the plan by TVO was based on shipping nuclear waste abroad for reprocessing and disposal. A repository in line with the KBS-1 concept was planned for the disposal of the resultant vitrified high-level nuclear waste if shipped back to Finland. However, due to the changes in international nuclear waste politics and the cost-conscious policy of TVO, the reprocessing option was displaced by the KBS-3 concept and later rejected. Problematization of the concept changed as nuclear waste management became a national issue instead of being part of the international nuclear fuel cycle.

Moreover, the relationship between TVO, later Posiva, and SKB has changed as the novice has become a collaborator. Currently, SKB-Posiva co-operation is based on identifying issues of common interest. From the viewpoint of Posiva the collaboration and agreements have been perceived to be cost effective for both parties. However, the new position in technology transfer has also created a challenge for Posiva as it can no longer solve problems by relying on technology transfer. The situation is described as exceptional in the Finnish nuclear power business (Nikula et al., 2012, 125). The development and planning needed for implementation has to be gained on the basis of research conducted mainly in Finland.

The KBS-3 final disposal concept has been very resistant against direct societal concerns. Therefore the main principle of the concept has remained almost the same for nearly 30 years. The major change has been the re-interpretation of geology. First the role assigned to the host bedrock was to function as one important release barrier, whereas later its primary role was to safeguard the technical barriers and to serve only secondarily as a release barrier. This change of vision also changed the view on the long-term predictability of the bedrock from the viewpoint of the endurance of the technical release barriers. (Nikula et. al. 2012, 195.) This change of thought due to new knowledge could become quite significant in the future. As Äikäs commented in his interview, this could also mean changes in how to look at site selection in the future. According to Äikäs (2013), this could leave more flexibility in the selection of a site and the final disposal could be designed to fit a certain place.

However, it would be unfair to claim that the KBS-3 concept has remained unchanged and not been developed (see Appendix 1). It has only been very resistant to any sudden fundamental changes due to uncontrolled societal pressure. The most obvious modifications can be seen in the technical design of the inner part of the canister. Canister materials and the filling of the canisters have also been subject to change. The size of the canisters has also been modified, because the different types of reactors operating in Finland are producing different kinds of spent fuel. Later on the modernization of the NPP units and nuclear power new build in Finland have increased the amount of SNF, and therefore the final disposal capacity of the repository has been increased from 1200 tU to 9000 tU. Decisions on nuclear new build are examples of the direct impact of political choices on the disposal concept. These impacts, for instance in the form of increased disposal capacity, have been in line with the interests of pro-nuclear policy arrangements (Litmanen & Kojo, 2011).

The modifications of the concept have taken place more or less under the control of R&D activity in which the waste management company has been the driving force. As the reference concept has remained unchanged for decades we surmise that the planning of R&D programmes has managed to address and filter most of the societal concerns relating to the concept. Another explanation would be that Finnish society has not voiced powerful concerns or exerted political pressure on the concept (see e.g. Raittila, 2001; Raittila & Suominen, 2002). As in many other countries the focus of local civil society in Finland was more on the site selection process and related procedures. For instance, those recent societal concerns (such as retrievability, copper corrosion and permafrost) that have generated some more debate around the concept have been incorporated into the R&D planning system (see e.g. Litmanen et al., 2013). Concerns have turned into research issues but not directly to technical modifications. For example, according to Lehtonen (2010; see also Darst & Dawson, 2010) Posiva integrated the demand for retrievability into the concept as a result of a public debate. However, the demand did not change the technical core of the final disposal concept as such, but the idea of the retrievability of spent nuclear fuel changed the interpretation of the concept. This kind of persistence (or fluidity) of the KBS Program has also been reported in Sweden (Elam & Sundqvist, 2011, 260).

The flexibility of the KBS concept is perhaps one reason why the concept has been so resistant towards major changes. According to Nikula et al. (2012, 125), a certain reflexivity had to be retained, which they also described as a challenge for the project. This led to a process in which the design developed in two ways; some parts at a very conceptual level, while other parts were planned in a very detailed manner. This notion also appears in the research data. Flexibility could at least partly be understood as a result of company driven policy. The responsibility for the planning and implementation of final disposal is in the hands of industry (the licensees) in whose interests it is to safeguard their long-term business interests. The recent request of Posiva to change approval procedure of some concept modifications suggests an attempt to ensure flexibility in decision-making, also in the future. The possible impact of the unpredictable and less controllable 'social dimension' on the concept is limited and decision-making power is vested in the technical experts.

In the pragmatic style of Finnish nuclear waste policy the final decisions are kept open until the decision has to be taken. In maintaining flexibility towards the future, one can wait for new technical innovations and also better technical solutions, but at the same time in accordance with pragmatism, the current disposal concept is urged forward.

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Appendix 1.

		1978	1982	1985	1992	1996	1999	2008	2012
	Main Report[27]	Nuclear Waste Study	YJT-82-46	YJT-85-30	YJT-92-31E	Posiva-96-17	DiP Application	DiP Application	Construction Licence Application
	Ref. concept	KBS-1	KBS-2	KBS-3	KBS-3	KBS-3	KBS-3	KBS-3V	KBS-3V
	Main alternative concepts	Reprocessing and disposal of vitrified high-level waste	Swedish model, Canadian model, Swiss model	Reprocessing and shipping SNF abroad, Swiss model.	WP cave, Very Deep Holes, Very Long Holes, Medium Long Holes	KBS-3-2C, Short Horizontal Holes, Medium Long Holes.	Deep hole or WP Cave. Siting straight into tunnels or in horizontal position	KBS-3H	KBS-3H
	Planned capacity	-	1200 tU	1270 tU	1840 tU	2600 tU	2600–9000 tU	12000 tU	9000 tU
	NPP units	TVO1, TVO2	TVO1, TVO2	TVO1, TVO2	TVO1, TVO2	OL1, OL2, Lo1, Lo2	OL1-3, Lo1-3	OL1-4, Lo1-3	OL1-4, Lo1-2
Canister	**Design of the canister**	Copper, steal, lead, and titanium or copper and aluminium-oxide	Copper. Filling aluminium, zinc, or lead. ⌀ 77 cm, length 4,7m	Copper Filled with lead. ⌀ 80 cm, length 4,5 m	Copper canister filled with cast lead. ACP canister with copper 6 cm and steel 5,5 cm. Filling quartz, glass beads or lead shot. ACP canister: ⌀ 80 cm, length 4,5 m	Copper canister, with nodular graphite cast iron insert. The air in the canister replaced with helium. Two different types of canisters: for BWR fuel 4,5 m and for VVER fuel 3,55. ⌀ 0,880 m. Filling helium.	Copper-iron canister. Filling helium. Buffer, compacted bentonite and bentonite clay Outer ⌀ ~1m. Length: LO 3,60 m, OL 4,80 m	Copper-steel canister. ⌀ 1,05m. Lengths: BWR canister 4,8 m EPR 5,2 m VVER 3,6 m	Copper-steel canister. ⌀ 1,05 m. Lengths: BWR 4,8 m PWR 5,2 m VVER 3,6 m BWR 2100kgU, VVER 1464 kgU, PWR 2128 kgU
	Alternative canister designs	Aluminium-oxide and ceramic glass materials.	Copper, titanium titanium or nickel-base alloys, austenic stainless steels, lead	Copper, titanium and titanium alloys, nickel-base alloys, ceramic					
	Number of canisters, **Capacity (tU) of canister type**		~ 850 canisters, holding 498 fuel rods (1,4 tU)	900 canisters with 8 assemblies (1,4 tU)	1200 canisters with 9 fuel assemblies (1,6 tU)	BWR 960 canisters/ 11 bundles (1,96tU) EVVR 560 canisters / 11 assemblies (1,32 tU)	For 2600[28] tU LO 530 canisters containing 12 assemblies (1,44 tU), OL 870 canisters 12 assemblies (2,14 tU)	4-12 assemblies depending on type of fuel 1,4–2,2tU depending on fuel.	LO1-2 750 canisters, OL1-2 1400 canisters, OL3-4 2350 canisters, 4–12 assemblies depending on fuel type
	Canister wall	20 cm	20 cm	10 cm	6 cm	5 cm	5 cm	5 cm	5 cm
Bentonite barrier	**Backfilling of disposal tunnels**	Quarz-bentonite	Sand and bentonite	Sand and bentonite	Sand and bentonite	Bentonite and crushed rock	Crushed rock and bentonite	Compressed filling blocks	Compressed filling blocks of Friedland clay
	Barrier surrounding the canister	Quarz-bentonite	Compacted bentonite (pure)blocks	Compacted bentonite (pure)blocks	Bentonite blocks	Compacted bentonite	Compacted bentonite clay	Compressed bentonite clay	Compressed bentonite clay blocks
Bedrock	**Tunnel depth / Minimum distance between the holes**	500 m / 4 m	500 m / 6 m	500 m / -	300–800 m / 6 m	500 m / Olkiluoto 7,3 m, Kivetty and Romuvaara 8 m.	400–700m / 6–8 m	400–700 m / 6–11 m	400–450 m / 9,5 m

[27] The information in this table has been collected from the main reports as well as other reference reports (see research data on pages 11–13).
[28] 60 years life-time of four reactors would generate approx. 4 000 tU (about 2180 canisters) and with two additional 1500 MW units in total 9 000 tU (about 4 500 canisters) (Posiva, 1999, 24).