ALTERNATIVE OPTIONS FOR THE TRANSPORT AND INTERMEDIATE STORAGE OF SPENT NUCLEAR FUEL FROM THE FINNISH TRIGA REACTOR FIR 1 TO THE DOMESTIC FINAL REPOSITORY OF POSIVA

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ABSTRACT

End of 1980's a technical plan was made how to transfer the spent fuel from the FiR 1 reactor in Otaniemi, Espoo to the Posiva final repository 250 km to the north west from Otaniemi. The solution was to load the TRIGA fuel elements in the reactor pool into assemblies consisting of nine long tubes in a formation mimicking a TVO 1 / 2 fuel assembly. These assemblies would then be loaded in the reactor hall into a CASTOR-TVO transport and storage cask. The cask would be transported to Olkiluoto NPP site for intermediate storage and then finally to the nearby Posiva encapsulation plant. Loading of the bundles already at the reactor into a Posiva copper canister is also considered.

This plan can be modified so that the bundles would mimic VVER-440 fuel assemblies and would be loaded into a CASTOR-VVER-cask. That cask could be stored at Loviisa NPP to be incorporated later into the Loviisa SNF transport chain to Posiva.

As another concept loading of the fuel into a research reactor specific transport and storage cask with dedicated TRIGA fuel holders is considered. That cask would be transported either to Olkiluoto or Loviisa NPP sites for intermediate storage. Transfer of the TRIGA SNF into the bundles to be put into the Posiva canisters could take place in the SNF pools of the Olkiluoto or Loviisa NPP's. From there on the bundles would be handled as regular fuel assemblies when transporting to the Posiva encapsulation plant. Alternatively the FEs from the transport cask could be transferred directly into bundles inside a Posiva canister at the Posiva encapsulation plant.

Available technical solutions will be discussed.

1. Introduction

FiR 1 –reactor located in Otaniemi, Espoo, Finland is a TRIGA Mark II type research reactor manufactured by General Atomics (San Diego, CA, USA). The FiR 1 started operation in 1962 and reactor power was increased in 1967 from 100 kW to 250 kW. Boron Neutron Capture Therapy (BNCT) patient treatments dominated the utilization of the reactor since late 1990's. The weekly schedule allowed still three days for other purposes such as isotope production, neutron activation analysis as well as education and training [1]. The operating licence of the reactor was extended for the period 2011 to 2023 by the government of Finland in December 2011.

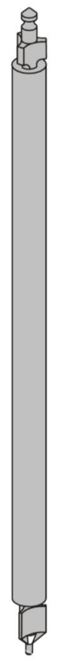
In June 2012 VTT Technical Research Centre of Finland as the licensee of the government owned research reactor decided to close down the reactor as soon as it is technically and legislatively possible [2]. An environmental impact assessment of the decommissioning was conducted as a prerequisite for the application to the government for renewing the license of the reactor for decommissioning [5,6,7].

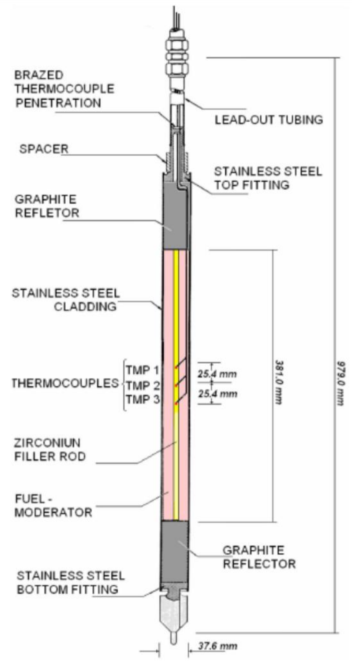
As the primary solution for the spent fuel back-end preparations are made for the US-DOE Foreign Research Reactor Spent Nuclear Fuel Acceptance Program. The contractual framework for this has been complicated by the uncertainties in US Department of Energy capabilities to receive spent TRIGA fuel to the storage facility in Idaho [3].

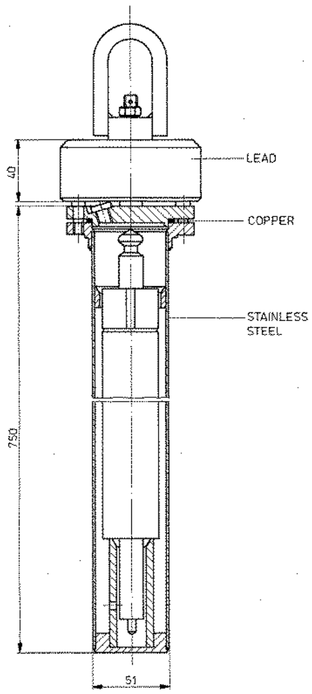
As the spent fuel should be removed from the reactor facility before dismantling works can start alternative pathways for this have now been updated and studied more in detail. The goal is to facilitate a timely removal of the fuel soon after the government has granted a decommissioning licence for the reactor. The primary destination considered is still the US-DOE facility in Idaho but the Finnish Posiva final repository 250 km to the North West from Otaniemi is considered as the second option.

Already in the 1980´s a plan was made how to transfer the spent fuel from the reactor to the Posiva repository. Details of this plan are now reconsidered and various different technical options for this are discussed. All options should preferably include a later possibility to divert the spent fuel to either of the destinations, the US-DOE facility in Idaho or Posiva repository.

2. Description of the spent fuel at FiR 1







A	B	type B instrumented FE	
Total length: 720 mm Diameter: 37.5 mm Weight: 2370 g	Total length: 733 mm Diameter: 37.5 mm Weight: 2370 g	Total length: 740 mm (with cut lead out tube) Diameter: 37.5 mm Weight: 2370 g	Total length: 865 mm (with handle) Diameter of lead shield: 93 mm

Figure 1. Types and dimensions of the fuel elements (FE) at FiR 1 [4]. The instrumented fuel element here is of type B. The Type A instrumented fuel element is similar. The instrumented fuel elements will have the first part of the lead out tubing remaining, sealed with a blind nut. Leaked fuel element in VTT-bottle.

The spent fuel at FiR 1 consist of

- 66 Aluminum clad 8.0 m% Uranium, <20% enrichment standard TRIGA fuel elements (type A)
- 2 Aluminum clad 8.0 /20 instrumented TRIGA fuel elements
- 7 Stainless steel clad 8.5 /20 standard TRIGA fuel elements (type A)
- 1 Stainless steel clad 8.5 /20 instrumented TRIGA fuel element
- 25 Stainless steel clad 12/20 standard TRIGA fuel elements (type B)
- 1 Stainless steel clad 12/20 instrumented TRIGA fuel element
- 1 Canned aluminum clad standard TRIGA fuel element (type A in a VTT-can)

3. The different destinations considered

Both return of the spent fuel to country of origin, USA, and domestic disposal are considered here. If the spent nuclear fuel will be exported to the USA, the two options are direct export or export after intermediate storage at another site in Finland. If the spent nuclear fuel will be disposed in Finland, it is preceded by an intermediate storage, alternatively at Loviisa or Olkiluoto NPP, because the Posiva repository will not be able to receive the fuel but later in the 2020's.

In this study the two alternative endpoints for the spent fuel from FiR 1 are (see Figure 2):

1) Fuel elements in NAC-LWT TRIGA baskets in the US-DOE INTEC dry storage facility in Idaho. Leaked and suspicious fuel elements are in special INTEC stainless steel bottles [9].
2) Fuel elements in bottle cask assemblies of similar dimensions than a power reactor fuel assembly, in one cask the VTT-bottle will be incorporated. Three of these bottle cask will be in a sealed Posiva KBS-3 copper canister surrounded by bentonite and bedrock in the Posiva repository 500 meters underground [10].

3.1 Destination US-DOE INTEC facility in Idaho

INTEC can receive only TRIGA fuel loaded in NAC-LWT TRIGA baskets and transported in a NAC-LWT cask. So if the fuel is removed from FiR 1 using some other packing and cask system it has at a later stage to be transferred into these baskets. This will be done underwater.

The intermediate storage on the way to Idaho means parking the cask in a suitable location in the US. As an example similar procedure has been done and licensed for tritium targets in a NAC-LWT at the US-DOE Savannah River Site [11].

3.2 Destination Posiva repository in Olkiluoto, Finland

End of 1980's a technical plan was made how to transfer the spent fuel from the FiR 1 reactor in Otaniemi, Espoo to the Posiva final repository 250 km to the north west from Otaniemi. The Posiva repository for spent nuclear fuel from Olkiluoto and Loviisa nuclear power plants uses copper canisters of the KBS-3 type [13] (see Figure 4). The solution was to load the TRIGA fuel elements in the reactor pool into assemblies consisting of nine long tubes in a formation mimicking a TVO 1/2 fuel assembly. Each assembly would accommodate 45 standard fuel elements. Three assemblies would be enough to accommodate all the spent fuel including the fuel element in bottle (see Figure 5).

As another option bundles of VVER-440 fuel assembly size were considered to be incorporated into the Loviisa SNF transport chain to Posiva.

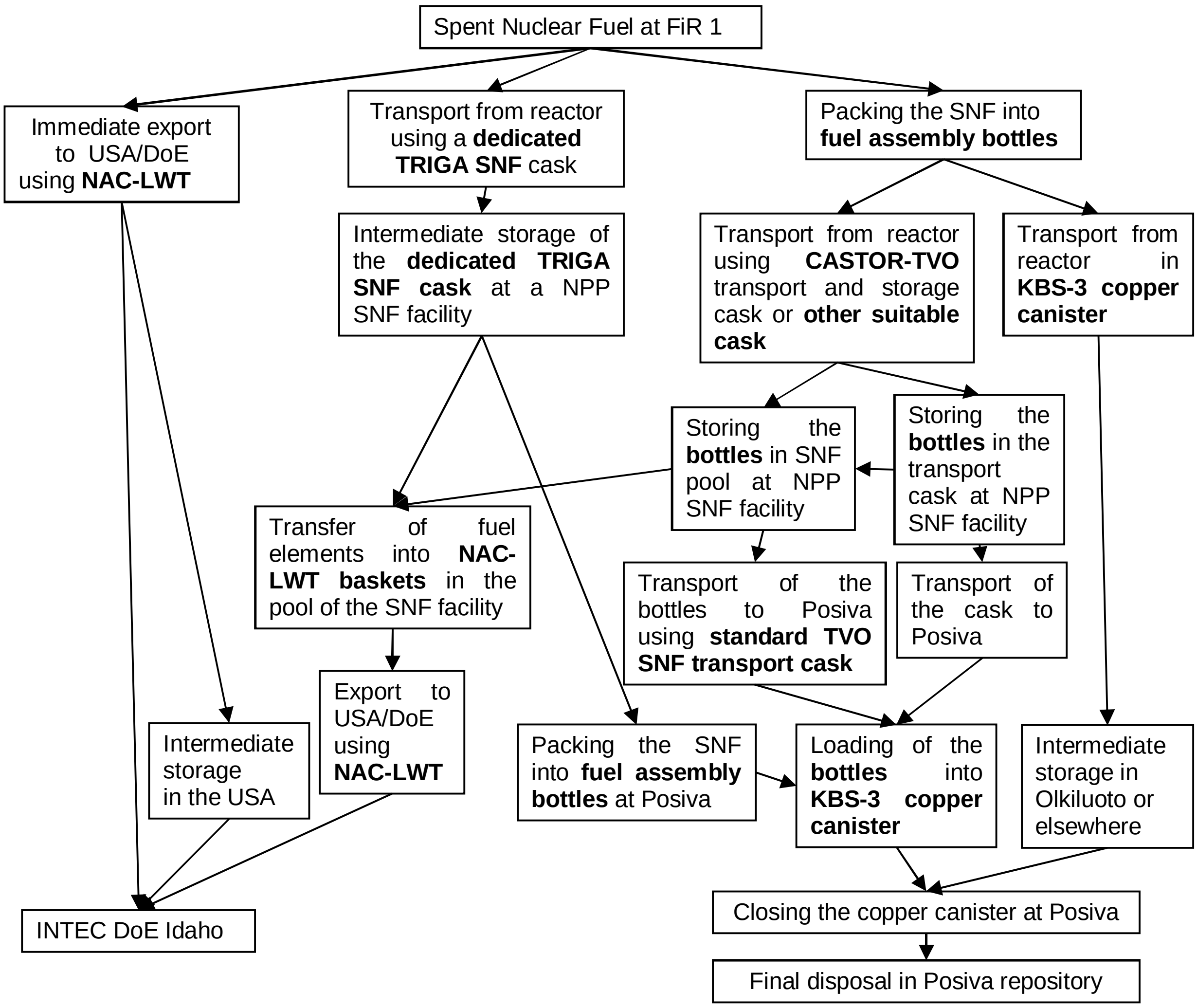


Figure 2. The different pathways considered in this study.

3.2.1 The FiR 1 TRIGA SNF bundle bottle

The FiR 1 TRIGA SNF bundle bottle is made of nine stainless steel tubes. Supporting grid plates collect the tubes into a 3×3 system. At the upper end there will be a lid with a handle compatible with the NPP fuel assembly systems. A schematic drawing of the bundle bottle is shown in Figure 6 and the parameters are given in Table 1. Each approximately 400 cm long tube will accommodate five fuel elements. There will be spacers between the fuel elements fitting to the different type of end plugs and thermocouple wire tubing.

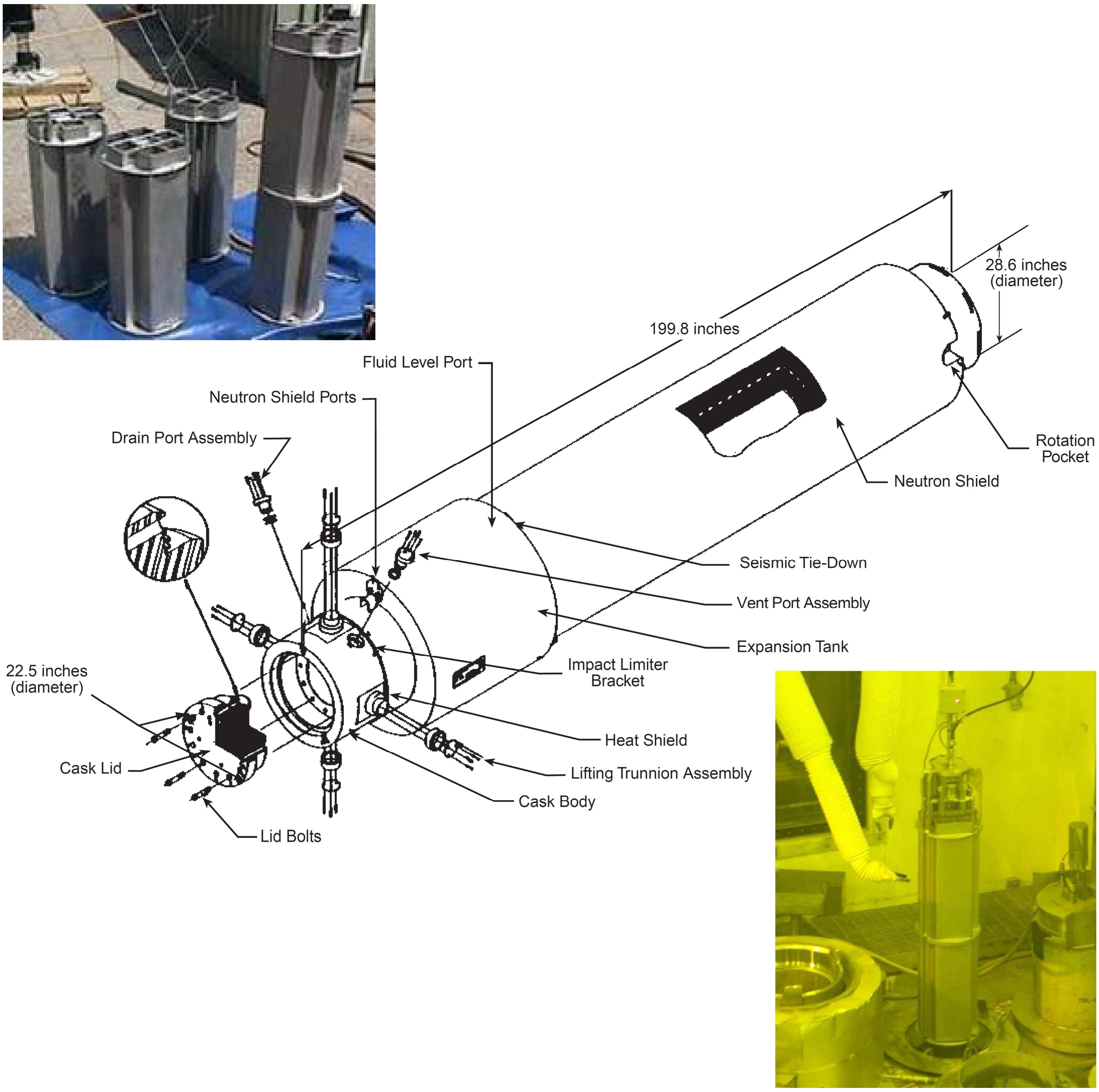


Figure 3. From upper left corner: NAC-LWT TRIGA baskets, drawing of NAC-LWT cask [12] and a long TRIGA basket being loaded from the transport cask into a fuel storage canister at INTEC [14]**.**

Inner radius of steel tube	r_{t1}	[cm]	1.995
Thickness of steel tube	d_t	[cm]	0.125
Pitch of tube grid	Δx	[cm]	4.48
Spacing between tubes	Δp	[cm]	0.24
Width of bundle	L_b	[cm]	13.2
Height of steel tubes appr.	h_b	[cm]	400

Table 1. Parameters of the bundle collecting the TRIGA fuel elements into a structure resembling a BWR-type assembly [10].

At the reactor the bundles can be loaded either under water in the reactor tank or outside the reactor tank in air. If the bundle is loaded in the reactor tank, a transfer shield is required for transferring the bundle from the tank into a transport cask. Alternatively, the bundle system can be loaded when it is already inside a vertically oriented transport cask by using the existing TRIGA single fuel element transfer cask and TRIGA fuel handling tool to pick up each fuel element individually from the tank and to lower it into the bundle tubes.

The bundles can also be loaded or unloading in a NPP SNF pool using the TRIGA fuel handling tool. Loading will take place in a situation when the fuel has been stored in a dedicated research reactor spent fuel cask and will be directed into the Posiva repository. Unloading of the FiR 1 TRIGA SNF bundles is needed if the spent fuel is stored in them and the fuel is diverted to the US-DOE path.

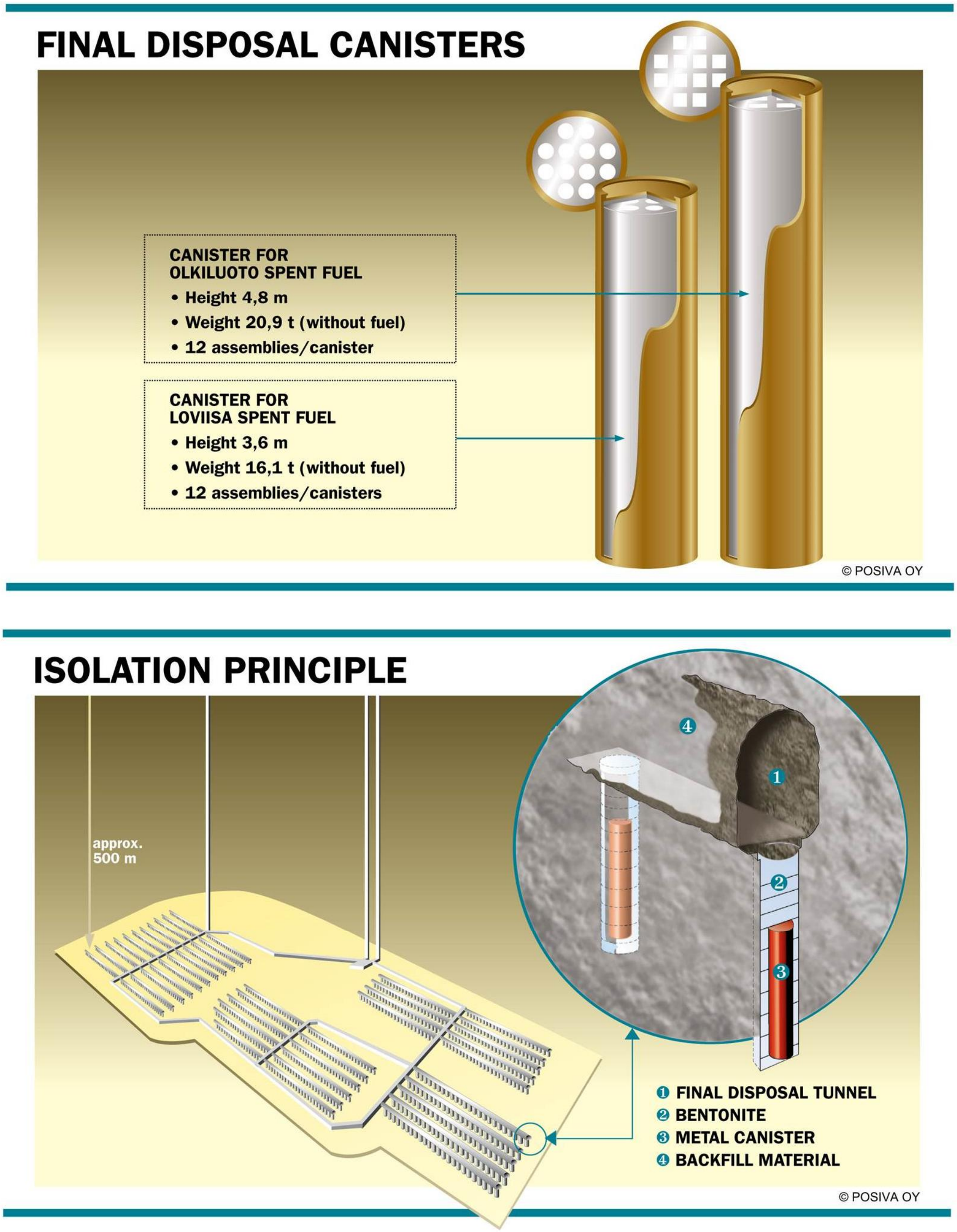


Figure 4. Posiva spent nuclear fuel repository concept. [13].

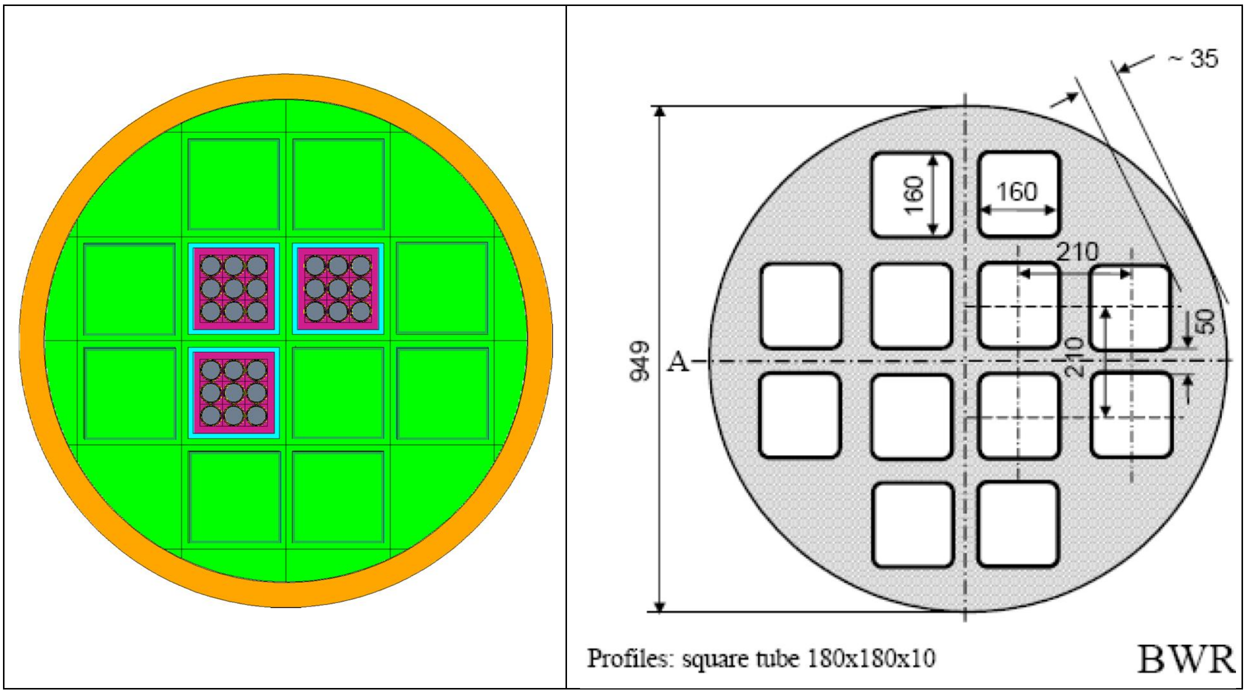


Figure 5. OL1/2 copper canister three holes filled with TRIGA fuel bundles. Grey is the fuel column, purple is inert gas, cyan is the steel lining, green the iron insert and orange the copper shield**.**

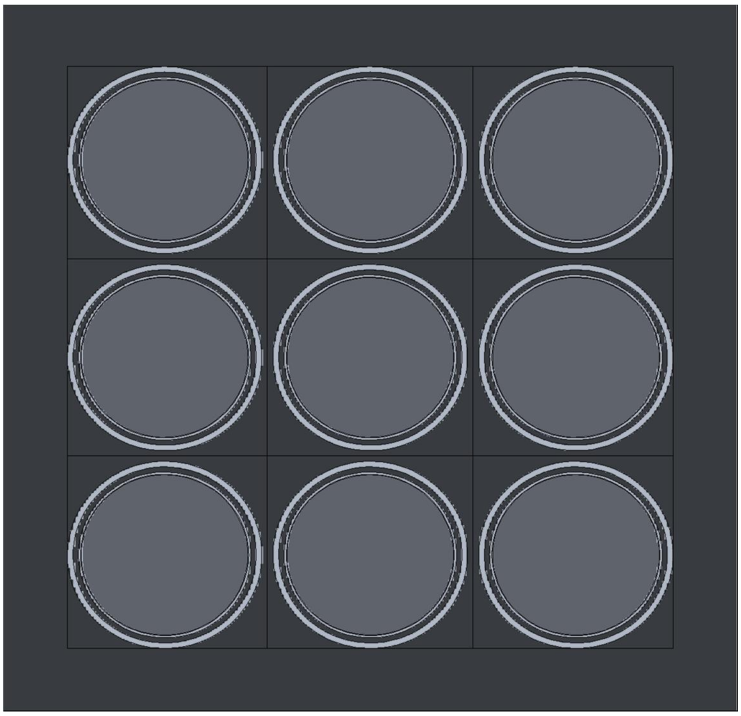


Figure 6. The model of the fuel rods collected into a 3×3 bundle resembling a BWR-type assembly inside a copper canister cavity. Dark grey is the fuel meat, around it in medium grey is the Al (0,75mm) or SS (0,5mm) cladding, light grey are the stainless steel tubes of the bundle [10]**.**

3.2.2 Casks for transport of the FiR 1 TRIGA SNF bundle bottle

The heat load and radiation level from the TRIGA spent nuclear fuel bundles is low compared to spent fuel assemblies from nuclear power plants so a lighter cask would be enough. The total radionuclide inventory of a FiR 1 spent fuel bundle after one year cooling [15] is 5% of the inventory of a 40.4 MWd/kgHM burnup BWR fuel assembly after 37 years of cooling [16] and the heat production (5 W [5]) 4% of that of a BWR assembly.

A transport cask accommodating three bundles would be optimal, but even three transports using a single bundle cask with a weight of about 20 tons like NAC-LWT [12], TN-LC [17] or NCS 45 [18] would be acceptable. Also a standard NPP SNF transport cask can be used, but the large size and weight will cause problems; CASTOR TVO weights about 80 tn and has a diameter of 2 meters.

3.2.3 Transporting the FiR 1 TRIGA SNF bottles in a Posiva copper canister

In Sweden the SNF assemblies are collected from the power plants to the interim storage Clab outside Oskarshamn [16]. After interim storage the spent nuclear fuel will be sealed into canisters in the encapsulation plant to be built at Oskarshamn. From there the copper canisters are transported to the Spent Fuel Repository that SKB plans to construct at Forsmark. The difference in our case would be that the canister would not be welded at the reactor but later at the Posiva encapsulation plant. So the lid of the copper canister has to be separately designed and licenced for this transport. Otherwise the SKB transport system for KBS-3 canisters can be used.

The total radionuclide inventory of the FiR 1 spent fuel after one year cooling [15] is 15% of the inventory of a 40.4 MWd/kgHM burnup BWR fuel assembly after 37 years of cooling [16]. So the inventory of the FiR 1 final disposal canister will be about 1% and the total heat production of 14 W less than 1% of a canister containing BWR assemblies.

3.2.4 Dedicated Research Reactor SNF cask for transport and storage

As another concept for transporting the spent fuel from FiR 1 to an intermediate storage at one of the nuclear power plant sites is to use a research reactor specific transport and storage cask with dedicated TRIGA fuel holders or baskets. That cask would be transported either to Olkiluoto or Loviisa NPP spent fuel facilities (SNF) for intermediate storage.

Transfer of the TRIGA SNF from the transport and storage cask into the bundles to be put into the Posiva canisters could take place in the SNF pools of the Olkiluoto or Loviisa NPP's. From there on the bundles would be handled as regular fuel assemblies when transporting to the Posiva encapsulation plant.

Alternatively, the cask could be transferred from the intermediate storage to the Posiva encapsulation plant where the FEs from the cask would be transferred directly into bundles inside a Posiva canister.

To allow for the diversion into the US-DOE path means have to exist to unload the cask in the NPP SNF pool for transferring the fuel elements into the NAC-LWT TRIGA baskets underwater in the pool. If the transport and storage cask can be lowered into the pool this stage will be simple to arrange.

For an easy access to lift the fuel from the cask using the TRIGA fuel handling tool a short, single layer cask would be suitable. Potential dedicated research reactor spent fuel transport and storage cask for our purpose are for example the Škoda VPVR/M Cask (capacity 36 TRIGA FE) [19], TN-MTR (capacity appr. 70 TRIGA FE) [20], CASTOR® MTR2/3 (capacity

78 TRIGA FE) [21], GNS-16 (capacity 90 TRIGA FE) [21] and BEA Research Reactor (BRR) cask (capacity 19 TRIGA FE) [8]

4. Discussion

In this report, several pathways for the FiR 1 TRIGA spent nuclear fuel from the reactor to two alternative destinations have been described. Several technically feasible options exist. Safety, security, risk and licensing issues will be further analysed and discussed among the parties involved. Owners and operators of the mentioned technologies will be involved; availability of the casks is one of the key issues. None of the technical solutions is yet licensed in Finland and thus require a licensing process with the Finnish Radiation and Nuclear Safety Authority STUK.

Open issues are:

1) Opening of the Idaho facility for foreign TRIGA reactor fuel return. [3,23]
2) Licensing of the TRIGA fuel disposal in the Posiva repository. This option was included in the environmental impact assessment (EIA) of the FiR 1 decommissioning [6,7] but a decision in principle by the parliament and construction licence from the government for this special system are required according to the current legislation. Until now, the facility is licenced only for NPP fuel. VTT has performed criticality safety [10,22] and radiation risk assessment [22] to support the licensing of this solution.
3) Transferring the agreement in principle with Posiva into a detailed contract.

This study was made to support the licence renewal of the FiR 1 reactor.for decommissioning.

5. Conclusions

Several pathways have been identified and described for the FiR 1 TRIGA spent nuclear fuel from the reactor to two alternative destinations. Further process will show which of them are the most potential.

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