FROM SHUTDOWN TO START OF DISMANTLING
Experiences from the FiR 1 TRIGA Reactor and VTT's Radioactive Materials Laboratory in Finland

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Abstract

In summer 2021, the Government of Finland granted to VTT Technical Research Centre of Finland Ltd a decommissioning licence for the FiR 1 research reactor, which was operated in 1962–2015. The paper summarises the lessons learned in planning, licensing, contracting and preparatory measures from shutdown until start of dismantling in spring 2023. In January 2023, the Finnish regulator STUK approved the final decommissioning plan and the final safety analysis report for decommissioning, which summarise a relatively large set of decommissioning and waste management planning documentation completed in co-operation with VTT's main contractor Fortum. The preparation for decommissioning involved also complete revision of the management system of the reactor: Organization, quality management practices in particular concerning subcontracting, and site arrangements including radiation protection, site and information security, emergency preparedness and nuclear safeguards. During the preparatory phase, the waste handling process including packaging, characterization and transport has been refined to fulfil Fortum's Loviisa NPP´s requirements for waste handling and final disposal of the waste. Dismantling planning including work instructions, radiation safety and site arrangements (such as controlled zone boundaries, logistics and security aspects) has been carried out to meet Finnish regulations. Dismantling works are to start in April 2023.

1. INTRODUCTION

In this paper we present the current state of the decommissioning project of FiR 1 TRIGA Mark II reactor, which was operated in Espoo, Finland, in 1962–2015 by VTT Technical research Centre of Finland Ltd. The contract between VTT and Fortum, signed in March 2020, encompasses the planning of decommissioning, dismantling of the reactor, and the transfer of the waste management obligation from VTT to Fortum when the dismantling waste has been transported to Loviisa NPP for final disposal. FiR 1 is the first nuclear facility to be decommissioned in Finland and thus frequent updates of the project's progress have been given, for example in the RRFM conference series [1–3] and elsewhere [4]. In particular, the paper [3] summarises the spent fuel removal and transport to further use that was completed at the end of 2020. In addition to the reactor, a research facility for radioactive materials testing (the old hot cells at VTT Reactor Laboratory) was operated from 1970's to 2017, when the operation moved to new premises. Hot cell decommissioning is being carried out in parallel and scheduled to complete in spring 2023. This project has served as a valuable pilot for the decommissioning of the research reactor.

VTT applied a license for decommissioning of the reactor from the Government of Finland in June 2017, and the license was obtained in June 2021. While VTT as the licensee remains to be responsible for the nuclear and radiation safety of the reactor and the decommissioning site, Fortum as the main contractor will take significant responsibility on implementing the decommissioning.

By the end of 2022 the detailed planning had been completed. During 2022 VTT had performed initial on-site preparations for non-activated material for initiating the actual dismantling work at the site in the first half of 2023. For on-site preparations Fortum has finalized necessary procurements, and the licensing process of the final disposal of FiR 1 waste to Loviisa LILW repository is ongoing.

2. PROJECT MAIN PHASES AND SEQUENCES

Now that the preliminary planning phase and detailed planning of dismantling has been completed, the remaining main phases of the project are preparations for waste management, worksite preparations, dismantling, waste management and clearance of the site. The planned schedule is presented in Fig. 1.

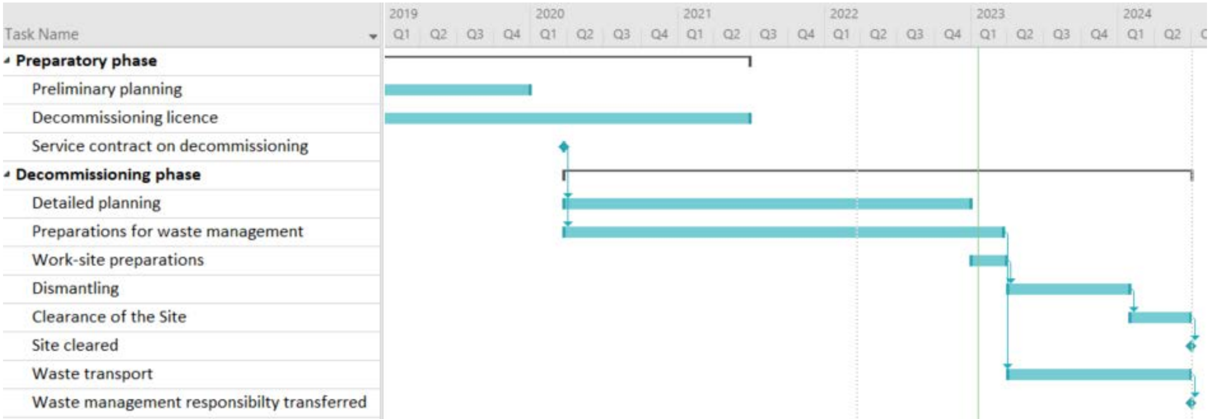

FIG. 1. Planned schedule of the decommissioning project, including dismantling LILW disposal.

3. DISMANTLING PLANNING AND SITE PREPARATIONS

Dismantling plans have been refined so that they include all practical aspects regarding to the dismantling work. Dismantling, waste management, nuclear safeguards, site logistics, radiation protection and conventional safety operations are integrated to fully support the actual dismantling actions. A lot of planning has also been done to ensure that requirements (e.g., waste acceptance criteria) placed by the Loviisa LILW repository are met. Several modern tools have been utilized during the planning. These include radiation modelling with MCNP and HVRC VRdose®, remote planning with eSiteview and precise CAD modelling. MCNP modelling and HVRC VRDose® have been used to optimize the working process in terms of the ALARA principle. MCNP models have also been used to estimate the radiation levels inside and outside the building, supporting efficient layout planning and specifying the decisions to construct additional radiation shielding.

The site preparations are performed in the beginning of 2023. The preparations include working personnel licensing process, trainings, and worksite arrangements. The site yard is prepared for arrangements for security, safety and working areas. The facility is equipped by new shoe boundaries and personnel and radiation measurement equipment.

4. CHARACTERIZATION AND ACTIVITY INVENTORIES

Activity characterization provides the basis and waste management planning, cost estimation and radiation safety planning. Characterization of research reactors can be especially challenging because their operating history typically contains different applications and modifications to the reactor structures. Moreover, things that are relevant in decommissioning are not as relevant in construction phase and some this data may not be available (or even false) in construction time documentation. Therefore, sampling and validation are required to measure, e.g., the amount of activating impurities in material composition and the accuracy of old documentation.

As the licence holder, VTT has been responsible for activity characterisation of reactor structures and components. In the preliminary phase, VTT conducted activity calculations using a model that combined several MCNP neutron flux models representing different reactor operation phases to ORIGEN-S point-kinetic calculations to consider the operation hours in each configuration. The ORIGEN-S calculations were repeated for all the reactor main components and structures separately, assuming the flux and material composition being homogeneous for each target (Fig. 2) [5–7]. For some components and structures, the target volume was further divided into smaller pieces, to reach the homogeneity assumption. These results were used in the preliminary waste estimates and dismantling plan.

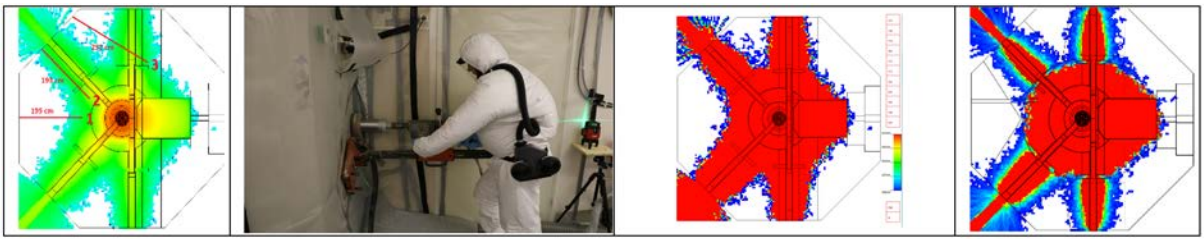

FIG. 2. Conservatively calculated preliminary estimates of concrete waste volumes were validated via sampling. This enables reducing the amount of activated waste by around 5 tons.

VTT's waste management is based on nuclide vectors and the scaling matrix approach. This enables efficient activity measurements during dismantling (Fig. 3). Characterization work in 2015–2020 has focused on validating the calculated results by collecting samples from different materials. An important limiting factor has been that since the spent fuel was still in the reactor core in 2015–2020, samples could be drilled only from the low active outer areas of the reactor, to avoid damaging the tank or core structures.

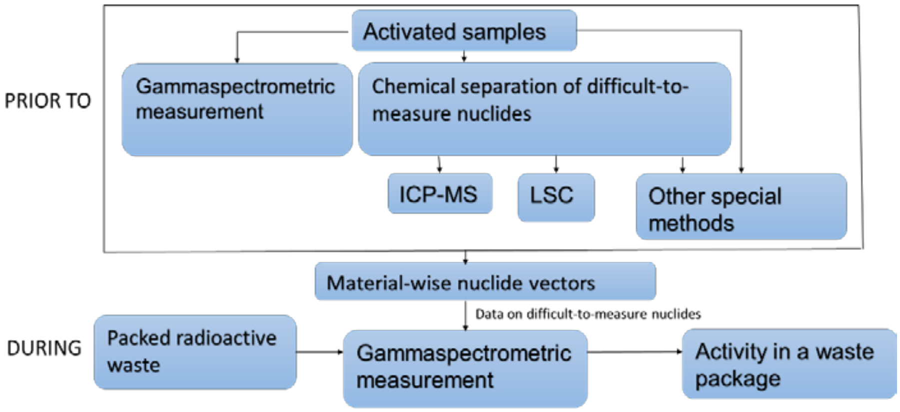

FIG. 3. Flow chart on nuclide vector formation prior to dismantling and use in waste management during dismantling.

Characterization by sampling and measurements is especially important to estimate the safety of long-term final disposal of decommissioning waste. In this case, the long-lived beta active nuclides (e.g., ^{14}C, ^{36}Cl, ^{59}Ni etc.) have the highest safety significance. These are often called difficult-to-measure (DTM) since their measurements requires destructive analysis and radiochemical methods. Along with the decommissioning project, VTT has developed systematically the methods to measure DTM in decommissioning waste. Having samples from a real nuclear facility (instead of just laboratory standards) has been extremely important, since the biggest challenges are related to e.g., sample matrix destruction, separating different nuclide fractions and handling gamma nuclide interference in measuring beta active nuclides. Method development has also included international collaboration via sample intercomparison exercises between several Nordic laboratories [8–10].

VTT–Fortum contract in 2020 has enabled setting Loviisa NPP waste acceptance criteria as boundary conditions to waste management planning. Therefore, forming the validated nuclide vector has been set to follow ISO 21238:2007 standard, and special challenges related to especially waste final disposal can be discussed directly with the final repository facility owner. It has been identified that altogether VTT will need 15 nuclide vectors. It is a relatively large number but illustrates the special challenges in a research reactor with various material and structural modifications throughout the facility operating history.

5. RADIATION SAFETY PLANNING

Along with validating the nuclide vectors, characterization work in 2015–2020 has also included applying the results in especially radiation safety planning and waste final disposal safety assessment. VTT–Fortum agreement has also been essential to set the boundary conditions for this planning. Practical questions include e.g.

- — Intermediate waste storage in the research reactor facility area (a couple of months at a maximum) is a challenge because the reactor is located in a university campus area, and radiation dose limits to public are very low. Building an MCNP virtual model of the reactor building has enabled estimating direct doses through the building walls [11]. The current plan is to use dismantled free-released heavy structures from the reactor to provide extra shielding.
- — Special materials and certain long-lived nuclides must be considered in the safety assessment of final disposal (which barriers are needed, do the packages have to provide a barrier in waste final disposal).
- — Validating all the methods used in waste classification and sufficient environmental safety procedures.

6. DECOMMISSIONING OF THE HOT CELL LABORATORY

The hot cell laboratory is decommissioned under the Radiation Act unlike the reactor, which is governed by the Nuclear Energy Act with different licensing processes. In any case, there are many synergies between the parallel projects. A preliminary waste inventory of the laboratory was estimated during the licensing process, and final disposal for the waste had to be arranged. The agreement between VTT and Fortum also covers the disposal of the radioactive waste from the decommissioning waste from the laboratory. Practical arrangements of the laboratory decommissioning have required development of working procedures and processes. Structural changes of the buildings were made to enable routes for material flow for interim storage and free release. Decontamination methods and methodology for estimating the free release of material have been developed. Main challenge ahead will be free release of the premises and HVAC to show fulfilment of free release limits. A significant challenge has been the lack of information and knowledge, e.g., incomplete information on history of stored radioactive samples and waste. Practices for waste management had to be developed during the project, and a lot of effort was used to return some legacy waste to original owners.

7. NUCLEAR WASTE MANAGEMENT

Fortum has included the disposal of FiR 1 and laboratory decommissioning waste to the license process of lifetime extension of Loviisa NPP LILW repository. Fortum carried out the EIA (environmental impact assessment) process in 2020–21 and submitted the license permit application to the Ministry of Economic Affairs and Employment of Finland in March 2022 [12].

Nuclear waste management planning has been included all needed measures for securing safe and efficient waste management in the FiR 1 decommissioning project. The packaging plan covers all waste generated at the site during decommissioning but also earlier waste from the operation of the reactor. Generated waste is sorted by three main attributes: activity, material, and applicable nuclide vector. Waste package selection is often a compromise between several factors. E.g., the packages must provide enough shielding, but reactor hall crane and doorways set limitations to package size and weight. Logistics and requirements in both public road transportation and final repository site also need to be considered.

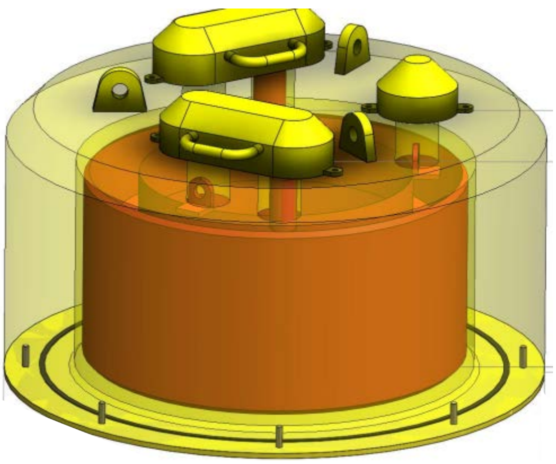

FIG. 4. An illustration of the radiation shield for the irradiation ring.

The standard package is a 200-litre barrel, but some larger components also require customised packages. A larger waste container is designed for bigger waste items. The most active reactor internals (irradiation ring, graphite reflector and small active steel parts) will be packed to specifically tailored radiation shields which will be further shielded with concrete disposal packages. Waste database maintenance has been planned so that the data collected at the dismantling site can be reliably and mostly automatically transferred to the waste database used in Loviisa NPP as the waste is disposed. The designed radiation shield for the irradiation ring is presented in Fig. 4. Final disposal has been planned in terms of final disposal repository, long-term safety, and logistics. The waste from FiR 1 decommissioning will be disposed to existing waste halls of Loviisa NPP's LILW repository.

8. SUMMARY

FiR 1 has been a key nuclear energy training and research facility for almost two generations. Now it serves as a pilot facility also in decommissioning, being a forerunner in using virtual visits in the planning, detailed activity inventory characterization, radioactive waste management between licensees, and development of free release of materials, including methods to estimate difficult-to-measure nuclides.

The review time of VTT’s application for FiR 1 decommissioning was relatively long, about four years. The main reason is that VTT’s nuclear waste management solutions are based on commercial contracts, which were not yet in place upon the submission of the licence application. The licensing phase of the project tested both VTT’s capability to fulfil the requirements and liabilities, but also the Finnish nuclear legislation, regulations, and authorities’ guidelines. Exchange of experiences between VTT and authorities has led to improvements in the Nuclear Energy Act and the YVL guides issued by the Radiation and Nuclear Safety Authority STUK. Lessons learned can be applied to the preparations for the decommissioning of nuclear power reactors (see also [13]).

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