

Handling of Reactor Internals at Forsmark Nuclear Power Plant

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ABSTRACT

Forsmarks Kraftgrupp AB initiated preparations for a power uprate on all three BWR reactors several years ago. This modification involved dismantling and replacing the reactor internals, core shroud cover, steam separators and steam dryer, all of which are heavily contaminated. Studies were conducted to analyze the options available for handling and disposing of these components. A strategy was selected and several major projects were initiated to carry out the process. These projects included the construction of an interim storage facility at Forsmark, the design and fabrication of waste containers and handling equipment and a transport system. The system is currently in use at Forsmark 2 where reactor internals are being segmented, packaged and transported to interim storage.

The presentation describes the development of the system for handling the reactor components, including some problems encountered and the solutions applied. The fabrication and testing process are discussed. Actual operation of the system is presented, with illustrations and photographs. Lessons learned that might be of general interest in waste management and decommissioning are presented.

Examples of issues that may be of interest include the importance of considering the entire handling and disposal sequence when evaluating options for managing waste. The tendency to underestimate the complexity of waste handling issues in a major plant modification project may also be addressed. This project has demonstrated that the benefits of a comprehensive fabrication oversight and testing programme are invaluable.

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1 INTRODUCTION

1.1 Background

Forsmarks Kraftgrupp AB (FKA) operates three boiling water reactors that began operation in the 1980's. They were designed and built by ASEA Atom, a Swedish company. Their combined power is about 3160 MW. The Forsmark Nuclear Power Plant is located on the coast of Sweden, north of Stockholm, on the Baltic Sea. Vattenfall AB is the majority owner of FKA.

Forsmark is in the process of modifying the reactor plants to produce 410 more megawatts of electric power. This power uprate requires the replacement of certain components, including components inside the reactor vessel, internals.

The components to be replaced are the core shroud head, which sits on top of the reactor core, as well as the steam separators and steam dryer, which are located above the core shroud head. These components are large, complicated and highly radioactive after they have been in the operating reactor. The portions of the components adjacent the core are subjected to a neutron flux which activates certain substances in the steel, resulting in induced radioactivity. All components are subject to the accumulation of an oxide layer containing radioactive isotopes.

1.2 The problem

The old reactor internals must be disposed of, if possible, or stored away from the reactor hall so they do not interfere with maintenance and fuel handling operations. There existed no integrated system to achieve this goal, as it was not envisioned at the time of construction that the reactor internals would be replaced during the life of the plant.

There are several pools above the reactor in the reactor hall that would be suitable for temporary storage of highly radioactive waste, but space in these pools is limited. There is already waste from previous campaigns stored in the Forsmark pools.

It was already recognized from the start of the power uprate project that it would be necessary to cut up the internals so as to enable packaging, transportation and storage. Westinghouse Electric Sweden AB was contracted to perform this task. They have previous experience in segmenting such components using saws and other tools. This is a time-consuming process.

There is no final repository yet available in Sweden to accept radioactive waste containing long-lived nuclides, which applies to some of the internals. The scheduled start date for operation of the repository is 2045.

There is no transportation cask certified for transporting the internals unless they were to be cut into very small pieces, an operation that is not considered to be justifiable from a cost and safety point of view.

There was no local facility suitable for interim storage of materials with such high dose rates. Storage in a pool would have been an acceptable solution but there are no such pools available at Forsmark. Neither was there a facility suitable for dry storage of these components.

2 INVESTIGATIONS PERFORMED

In order to support the design and safety basis for the handling of these components a number of analyses were performed.

2.1 Waste characterization

While it was not possible to take direct samples of the internals, the radionuclide content could be modelled based on the operation history of the reactor. These calculations were important so that dose rates could be predicted, and so that the radionuclide inventory could be evaluated against the acceptance criteria for SFR, the Swedish final repository for operational waste.

2.2 Waste volume, mass and surface area

Calculation of resulting waste volumes and masses was performed to determine the specific activity and the storage container volume needed. The bulk density of the internal components is relatively low. They consist of tubes and plates designed to maximize surface area so there is a lot of void space. Modelling was performed to optimize the segmenting and packing of the waste.

Estimates of the surface area were needed in order to be able to calculate the parameters for drying the waste as well as the activity per unit area contributed by surface contamination.

2.3 Dose rates

Calculations were performed to estimate the dose rates on the components with the objective of determining the shielding thickness necessary to protect the operators handling the waste.

Further calculations were performed to estimate the wall thickness necessary to meet dose rate limits outside an interim storage facility.

3 ALTERNATIVES EVALUATED

3.1 Packaging alternatives

3.1.1 4-pack SFR waste container (4-kokillslåda)

For steam separators and steam dryer. This alternative was rejected for several reasons. It was not certain that waste could be accepted at SFR without being grouted, which made the system overly complex. As the time available to put the system in operation it proved to be too difficult to and time consuming to develop and operate two entirely different handling systems at the plant.

3.1.2 BFA-tank

The BFA-tank was an existing system already in use at Oskarshamn Nuclear Power Plant for the packaging and transport of reactor components for storage onsite. At Forsmark it was initially intended that this packaging system be used for components with very high dose rates, such as the core shroud head. The BFA-tank is over-engineered for the weights and dose rates of the steam dryers and moisture separators; a lighter and less expensive container would suffice. However, the priority was to have a single system that could be put in operation quickly and would be appropriate for all components that had to be removed, so this was the alternative that was ultimately selected.

3.1.3 Clab storage containers

Clab is the central interim storage facility for spent fuel from Swedish nuclear power plants. The fuel is stored in pools. The facility is located underground near the Oskarshamn Nuclear Power Plant.

The Clab storage containers have dimensions similar to the fuel assemblies so as to be compatible with the handling equipment and storage cells. In order to package reactor internals in these storage containers extensive segmenting work would be required as the components would have to be cut into relatively small pieces in order to fit in the containers. This extra work was not judged to be justifiable from several viewpoints: economic, schedule and radiation protection. Moreover, Clab is designed for the storage of spent fuel and is not intended to store large quantities of other reactor components.

3.2 Storage location alternatives

3.2.1 Interim storage at BFA at Oskarshamn

There was a project HÄRD, carried out as a joint project by the Swedish nuclear power plants and SKB, to identify the optimum packaging and storage solution for the irradiated reactor components. The recommendation of the project was that they be packaged in BFA-tanks (see 3.1.2) at the reactor, transported to Oskarshamn and stored in the BFA until a permanent repository is available.

BFA is an acronym for **B**ergrum **f**ör **A**vfall, which is underground chamber for waste. It was built at the Oskarshamn Nuclear Power Plant for the purpose of storing radioactive waste and has been in use for many years.

Unfortunately, there is at present no certified transport container available to transport the waste from other nuclear power plants. SKB has placed an order for the design, fabrication and certification for such a container, with the designation ATB 1. However, it will not be available for several years. Until that time it will not be possible for any shipment of reactor internals in the BFA-tank to be made on public roads or waterways.

3.2.2 Temporary storage in the pools in the Forsmark reactor halls

There are storage pools in the reactor hall, where fuel and other radioactive components are stored. There is not enough space available in these pools to store the large quantities of components removed from the reactors as part of the power uprate programme. In fact, the initial condition was that all previous waste, currently stored in cassettes in the storage pools, must be removed before the reactor internals could be replaced. It was, however, later decided that there was no immediate need to move this waste. The handling system is designed to deal with this material when it becomes necessary.

It was early recognized that storage of additional segmented reactor internals in the storage pools was not a viable option.

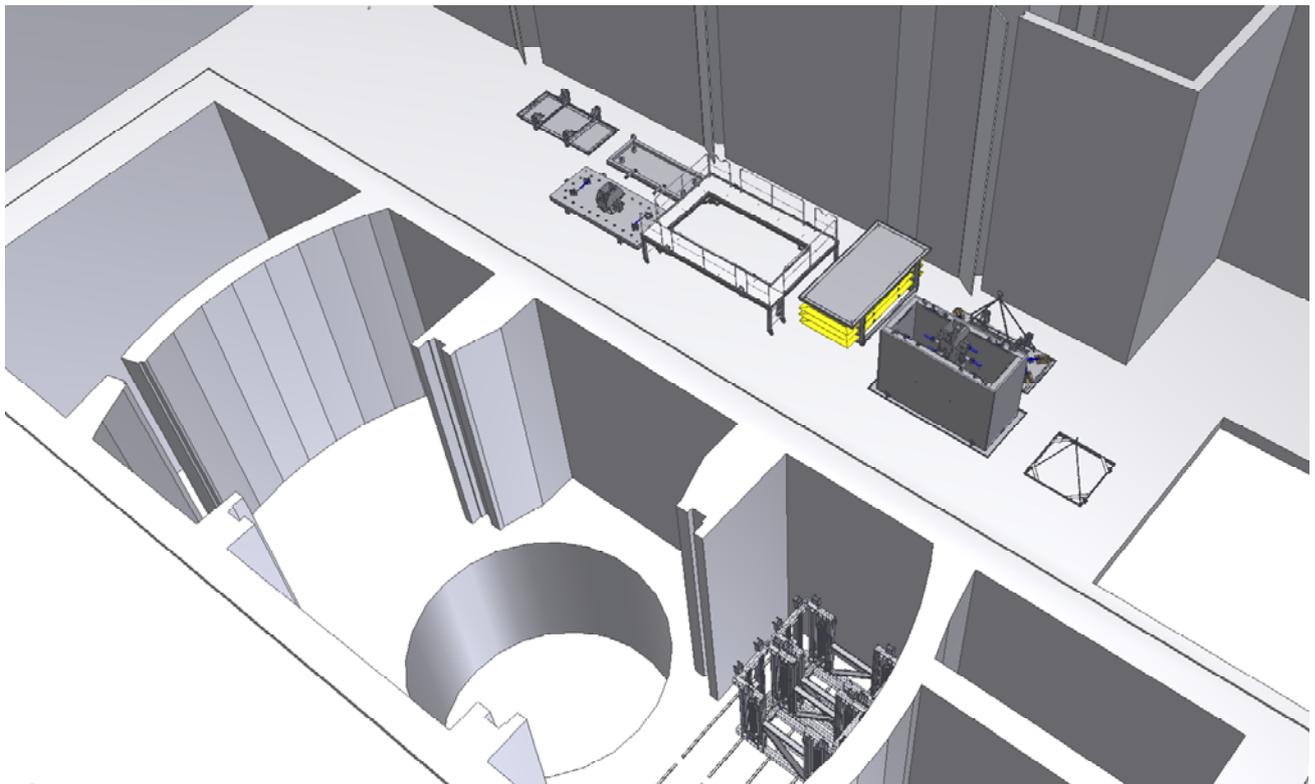


Figure 1 Storage pools in the reactor hall

3.2.3 Interim storage at Clab

As previously mentioned, spent fuel is stored in pools at Clab. The water in the pools serves as a cooling medium as well as shielding. Storage of any reactor internals takes place in the same conditions, that is, underwater. The use of these pools to store reactor internals is a waste of resources; there is no need for water-cooling of this waste. Furthermore, as described in 3.1.3, the dimensions of the Clab containers require extensive cutting operations. This option was eliminated as uneconomical and impractical.

3.2.4 Interim storage at SFR

The interim storage of reactor internals in a tunnel at the final repository for radioactive waste (SFR) was considered. While it was physically feasible it was noted that the current license for the facility does not allow such storage. Authorization would require an act of parliament, which was considered too uncertain and a risk to the project schedule.

This alternative was ruled out for the time being as too uncertain. However, there are studies underway to investigate the possibility of such interim storage, either in existing vaults or in an aboveground facility connected to SFR.

3.2.5 Interim storage in an existing Forsmark facility

Storage in an existing Forsmark facility was considered. There are no pools suitable for wet storage outside the reactor hall. Dry storage of over 50 large, heavy containers with potentially high dose rates imposes rigorous requirements on any storage facility. There were no buildings with the necessary access, floor loading and lifting capabilities.

3.2.6 Interim storage in a new facility at Forsmark

When it became evident that the reactor internals must be stored at Forsmark the alternative of building a new dedicated interim storage facility was evaluated. It was recognized that such an effort would require significant investment and might well become a critical path project.

This alternative was ultimately selected.

4 THE SOLUTION

The agreed solution was to modify Oskarshamn Kraftgrupp's existing handling system and BFA-tanks and to store the tanks in dedicated interim dry storage facility with a remote handling system at Forsmark.

4.1 Modifications to existing system

The BFA-tank handling system has been in use at the Oskarshamn Nuclear Power plant for many years. In order to ensure that the system met the requirements for use at Forsmark several significant modifications were necessary. These included:

- Thicker tank walls for shielding
- Equipment to enable remote handling to minimize dose to the operators
- Provisions for drying the waste inside the tank before sealing to preclude the risk of radiolysis
- Provisions for redundant lifting to preclude damage to the facility
- Use of a transport box between the reactor hall and interim storage facility to provide shielding.

4.2 The new system

The Forsmark handling system consists of a number of components, which are listed below.

Chapter 5 describes the components and operation of the system in detail.

- BFA-tanks
- BFA-Cassettes
- Wet hood
- Transport box
- Special redundant lifting equipment.

4.3 Interesting challenges

The solution to the problem of how to handle the old reactor internals evolved over several years; there was a constant flow of new information and the requirements shifted during the course of the project. Many alternatives were considered and then ruled out.

Some examples of issues that shifted during the planning for the project were the destination of the waste. The first intention was to ship it to BFA near Oskarshamn, until it was discovered that it would take too long (over five years) to produce a certified shipping container for the transport. The possibility of using interim storage at SFR was considered because no public transport would be necessary. As noted, this alternative appeared to be too complicated from a regulatory point of view. As the time available grew shorter it was decided that the approach with the least risk was to build an interim storage facility at Forsmark. Despite the tight schedule the facility was constructed and in operation in time to receive the first BFA-tank when it was loaded in February 2010.

There were some decisions that made the execution of the project easier, or, at least quicker. For example, it was decided that several tons of highly radioactive waste that was already stored in the pools could be left in place. This meant that there was more time available to develop the handling system without risking the schedule for the replacement of the internals.

Another decision that made the project simpler was that to use only one packaging and handling system for all components, even though the steam separators and steam dryers have lower dose rates, and will not be disposed of in SFL (Final repository for long-lived waste). The planned strategy is to decontaminate these components at Forsmark and dispose of the radioactive portion in SFR.

4.4 Sponsors and major stakeholders

The project was carried out within the Forsmark organization.

The design and manufacturing of the equipment was partly financed by Forsmarks Kraftgrupp AB and partly by the Swedish Nuclear Fuel and Waste Management Co (SKB).

Vattenfall Power Consultant AB designed the equipment.

Oskarshamnsvarvet Sweden AB manufactured the equipment.

5 THE EQUIPMENT

5.1 Major requirements and constraints

The radiation levels are of sufficient magnitude that necessitate that the waste be properly shielded. This requirement entails the use of heavy storage containers and handling equipment. Due to the weight of the components, lifting equipment with redundancy was required.

Because the components are radioactively contaminated and are lifted wet from the pool in the reactor hall, a more complex system was required in order to prevent the spread of contamination.

When the most radioactive waste is handled, the operators must be stationed behind radiation shields at certain stages of the operation. During these stages the equipment must be designed to allow remote control of the rotation of the load during lifting.

Special lifting arrangements and manoeuvres were required in order to accommodate the depth of the storage pools relative to the lifting height in the reactor hall.

5.2 Three types/levels of containers - Cassettes, Tanks and Transport Box

5.2.1 BFA-Cassettes

The BFA-Cassettes, which are the innermost containers of the system, are used for transportation of segmented reactor internals from the reactor hall storage pools up to the reactor hall floor and into the BFA-tanks.

The cassettes are manufactured in 4 different sizes (T-50, T-100, T-150 and T-200) corresponding to the four sizes of BFA-tanks. All sizes are dimensioned to carry 12 tonnes of waste. The cassettes weigh from 3 to 6 tonnes and are manufactured in painted carbon steel.

The top of the cassette is fitted with a shielding plate after it is filled.



Figure 2 Cassette

5.2.2 BFA-tanks

The BFA-tanks are used for transportation, shielding and storage of loaded cassettes from the reactor hall floor to and into the Interim Storage Facility.

The BFA-tank is 1,3 m by 2,3 m and 2,3 m high, with a bolted lid. In order to optimize the design with respect to various radioactivity levels of the waste the BFA-tanks have four different wall thicknesses; 50, 100, 150 and 200 mm (same outside dimensions). The tanks weigh from 10 to 33 tonnes and are manufactured in painted carbon steel.

The system is dimensioned for a maximum dose rate of 200 mSv/h on the outside of the BFA-tanks.

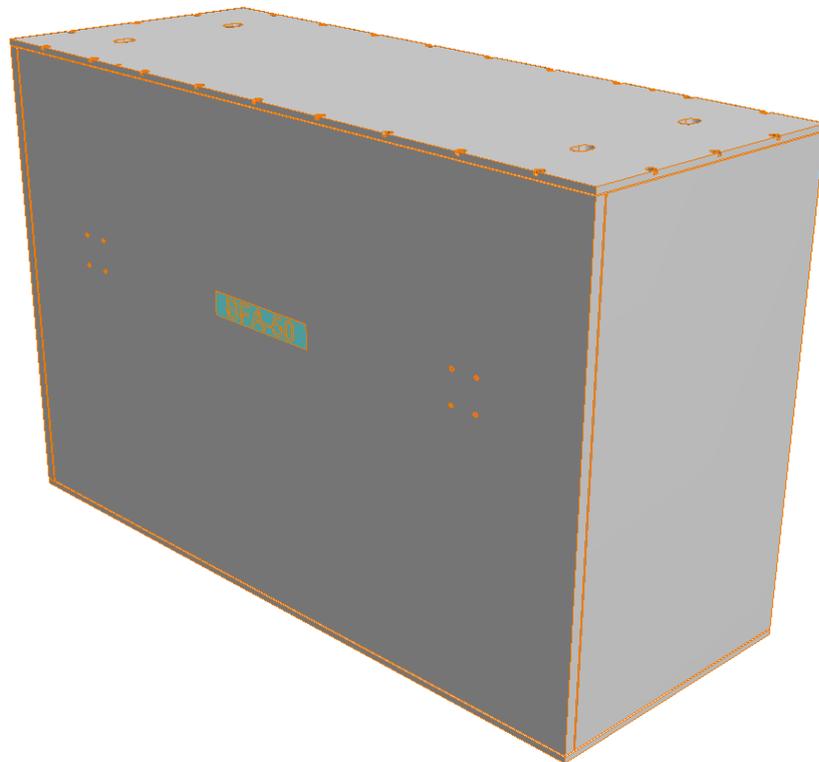


Figure 3 BFA-tank

5.2.3 Transport Box

The Transport Box is used as a carrier of the BFA-tank when it is transported from the Interim Storage Facility to the reactor hall and back. The lifting of the Transport Box is performed with full redundancy. The open/close manoeuvre of the lids is controlled via a main hydraulic unit.

For shielding, the Transport Box has a wall thickness of 200 mm, which allows operators to safely approach it when it is closed. It weighs 58 tonnes and is manufactured in painted carbon steel.

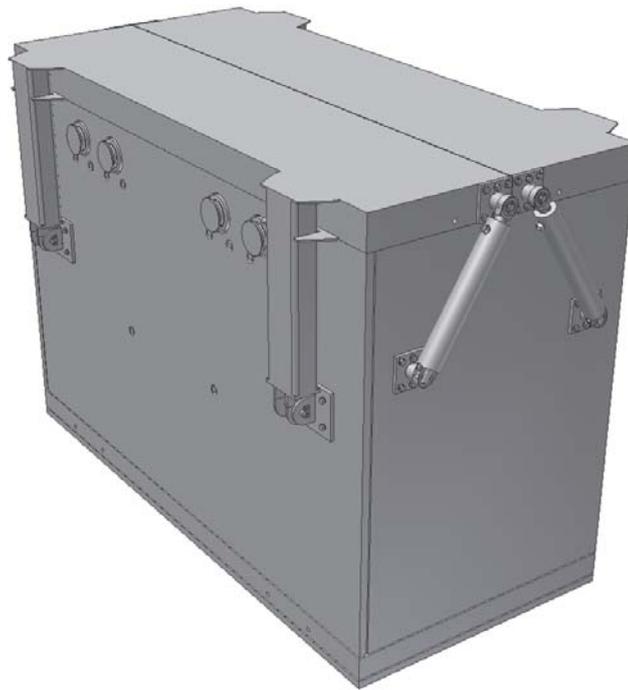


Figure 4 Transport box

5.3 Equipment for Handling Cassettes

5.3.1 Cassette Strongback

The cassette strongback is used for lifting empty cassettes and placing them in the reactor hall pools. The cassettes' shielding plates are also handled with the cassette strongback. The cassette strongback is manufactured in stainless steel.

5.3.2 Cassette Frames

During operation two cassette frames are placed in the reactor hall pool. The function of the cassette frames is to guide and position the cassettes, the cassette strongback and the wet hood. The cassette frames are manufactured in stainless steel.

5.3.3 Wet Hood

The wet hood is a strongback with a surrounding shield, which is used for lifting loaded cassettes from the storage pools and positioning them in the BFA-tanks. The assembly is fitted with three levels of telescopic rods to accommodate the depth of the pool relative to the lifting height in the reactor hall.

The lifting of the cassette with the wet hood is performed with full redundancy. It weighs 47 tonnes and is manufactured in painted carbon steel and stainless steel (telescopic rods).

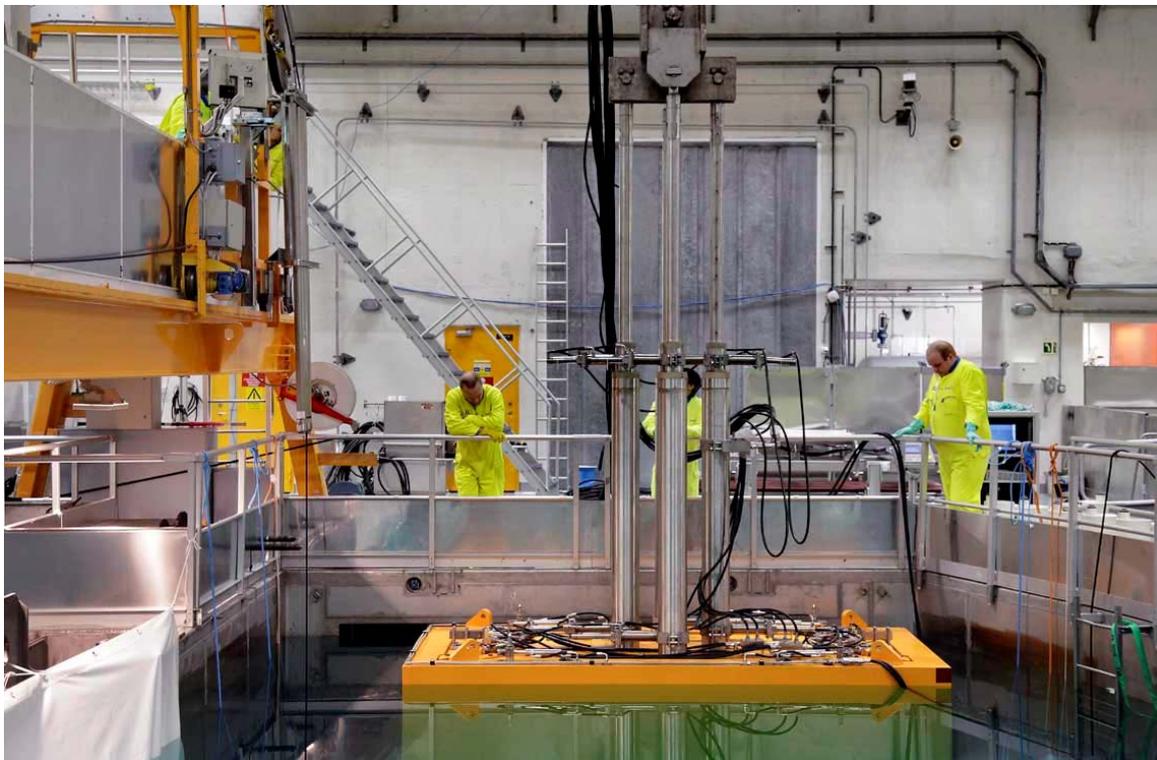


Figure 5 Operation of the wet hood

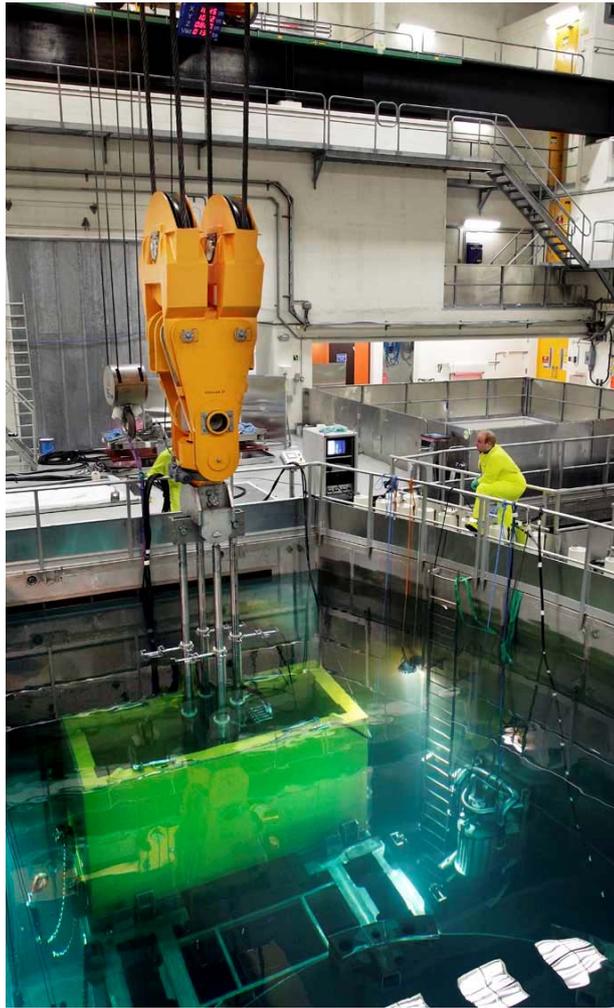


Figure 6 Lowering the wet hood in the storage pool

5.4 Equipment for Handling BFA-tanks

5.4.1 Redundant BFA-tank Strongback

The redundant BFA-tank Strongback is primarily used for lifting the BFA-tanks lids on and off in the reactor hall. It is also used for lifting the vacuum cover (see 5.5.1).

The 200 mm-thick base plate, which is equipped with an array of holes, makes it possible for operators to manually tighten the bolts of the BFA-tank lids. The redundant BFA-tank strongback is manufactured in painted carbon steel.

5.4.2 BFA-tank Strongback

The simplified BFA-tank strongback is used in the handling of BFA-tanks in the Interim Storage Facility. It is designed on the same principle as the redundant BFA-tank strongback but without the radiation shield plate.

5.5 Other Components

5.5.1 Vacuum Cover

The vacuum cover is used for drying the contents of the BFA-tank in order to preclude the production of radiolytic gases. When the drying manoeuvre is performed the vacuum cover is connected to the plant's existing equipment for drying spent fuel. The vacuum cover is manufactured in painted carbon steel and stainless steel.

Drying is not needed for the waste that is to be decontaminated onsite at Forsmark.

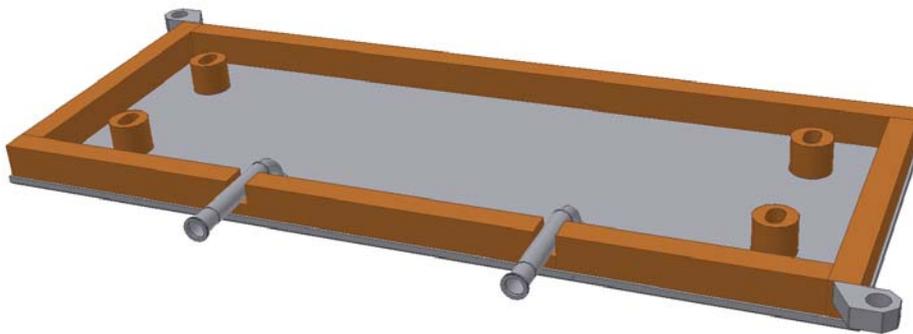


Figure 7 Vacuum cover

5.5.2 Docking Protection Plates

Before docking of the wet hood with the loaded transport box a docking protection plate is placed on top of the transport box with the BFA-tank inside. The plate ensures that any water that drains from the wet hood does not contaminate the transport box or the BFA-tanks' outer surfaces.

The plate is manufactured in four different sizes (T-50, T-100, T-150 and T-200). The material is stainless steel.

5.5.3 Rotatable Crane Hook

The Rotatable Crane Hook enables remote-controlled rotation of load. This is a temporary modification of the existing crane hook that is made before every campaign. The Rotatable Crane Hook is manufactured in painted carbon steel.

6 THE INTERIM STORAGE FACILITY AT FORSMARK

The interim storage facility at Forsmark is essentially a concrete bunker built aboveground. The walls at ground level are one meter thick. The facility is equipped with a fully remote-operated handling system consisting of a crane and lifting yokes.



Figure 8 Interim Storage Facility for Reactor Internals

The facility was originally intended to store 56 BFA-tanks in two layers, stacked on top of each other. The current plan is to store up to 84 BFA-tanks in three layers, in order to accommodate the components from all three Forsmark reactors.

In order to minimize the dose rate outside the facility the tanks are arranged in a specific order inside the facility, so the tanks with the highest dose rates are placed in the middle. This configuration allows the less radioactive tanks to act as shielding.

Transport from the reactor building to the Interim Storage Facility is carried out using existing vehicles owned by SKB and designed to transport waste containers and spent fuel casks. See figure 6. As the Interim Storage Facility is located within the Forsmark security perimeter the transport can be carried out as an internal operation.

7 LESSONS LEARNED AND KEY SUCCESS FACTORS

Major design challenges have resulted from the combination of large components, tight design tolerances and close interfaces between components.

The identification and involvement of Stakeholders at an early stage contributed to a safe and workable system.

The importance of a thorough Factory Acceptance Test (FAT) Programme (as close to the real environment as possible) cannot be overemphasized.

The success of the project depended on a close and positive relationship with the manufacturer. The customer was part of the project, not just a counterpart.

8 ACKNOWLEDGEMENTS

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Bengt Bäversten, SafeTech Engineering AB, was instrumental in developing the BFA-tank handling system. He has been involved in the management of reactor internals waste since before Forsmark decided to implement the power uprate, beginning already with SKB's Hård project.