TRANSPORT OF IRRADIATED NUCLEAR FUEL BETWEEN REACTOR SITES FOR FURTHER USE

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ABSTRACT

Late 2020 the Ringhals 1 BWR on the Swedish west coast will be shut down and after several months of cooling the spent nuclear fuel will be transported to the Swedish national interim wet storage facility (CLAB). The once and twice burned fuel (12-month cycles) will have a significant residual fissile content, and could potentially be operated for several more cycles in another BWR.

The feasibility of transporting partly burned fuel for further use in the Forsmark BWRs on the Swedish east coast is being assessed and will be described in the paper.

The transport will be by sea in dry transport casks using the existing spent fuel transport infrastructure. The existing design basis for the operation of the fuel does not cover such a transport, so possible impacts need to be evaluated. For instance, acceleration forces and the temperature history during the transportation are being addressed.

1. Introduction

1.1. Background: Shutdown of Ringhals 1 NPP

Ringhals 1 started operation 1975 and will shut down 2020 after 45 years of operation. The last cycle will be operated with an extended coast-down to utilize the final batch of Nuclear Fuel efficiently. Even with an extended coast-down for the last cycle the last two batches of Nuclear Fuel will have significant residual fissile content.

Residual energy and value				
	Enrichment	BU	Design EOL BU	Residual energy
	w/o	MWd/kgU		%
2-year	3	23	40	43
1-year	3,5	13	48	73

Table 1, residual value estimate

The last reload batch has an increased enrichment mostly due to logistical considerations when shutting down Ringhals 1.

1.2. Spent Nuclear Fuel in Sweden

Spent Nuclear Fuel is transported and stored by SKB in the TN17 cask. The transport goes by sea using a special ship “Sigrid” from the respective harbours in both Forsmark and Ringhals to CLAB in Oskarshamn for interim storage or by land only from the Oskarshamn Nuclear Power Plant. The Nuclear Fuel has to wait at least 9 months at the Nuclear Power Plant before it can be transported to CLAB in order to fulfil the licensing of the CLAB facility. CLAB currently stores about 6500 tonnes of Nuclear Fuel waiting for transport to the final repository to be built in Forsmark. Maximum capacity in CLAB is 11000 tonnes of Nuclear Fuel.

2. Transport of Irradiated Fuel for further Use

Transporting spent Nuclear Fuel to CLAB by SKB has been done with extensive experience and success. The logistical network is working, transport means and other equipment and routines are suitable for transporting Irradiated Nuclear Fuel. Transporting Irradiated Nuclear Fuel between Ringhals NPP and Forsmark NPP using SKB’s transport system and their cask but reversing the routines between CLAB and Forsmark should solve most problems associated with the transport and receiving logistics. There are a few issues however with regards to the different needs of storing Nuclear Fuel after transportation and reusing Nuclear Fuel after transportation. The main concerns identified so far are acceleration forces and temperature during transport and handling.

Acceleration forces is important to consider when transporting irradiated Nuclear Fuel in the same way as for fresh Nuclear Fuel but with stricter limits. High temperatures during transport may damage the cladding and is limiting with regards to cooling before transport.

2.1. Acceleration Forces

A Nuclear Fuel rod has a plenum spring located above the fuel column which sole purpose is to keep the fuel column in place during transport of fresh Nuclear Fuel. If the fuel column can freely move the fuel column could be separated into smaller column parts during transport leading to small gaps. Small pellet pieces may thereby relocate, which may result in higher stresses on the cladding during operation and finally leading to so called Pellet Cladding Interaction (PCI) fuel failures.

Another critical component that could be damaged during transport is the spacer which helps distribute water during operation and improves dryout margins. The spacer has springs and contact points with the cladding. Spacer springs could bend if exposed to high acceleration forces, which may result in grid-to-rod fretting during re-use.

When transporting fresh Nuclear Fuel, the maximum acceleration force during transport is limited, typically to a few g. No specific limitations are defined when transporting spent Nuclear Fuel to CLAB by SKB. When Nuclear Fuel was previously transported between Barsebäck 1 and Barsebäck 2 reactors the acceleration was limited to no more than 0.1 g in the axial direction and 0.3 g in the lateral directions.

A test transport has recently been carried out between CLAB and Forsmark as the above mentioned limits from the Barsebäck case are not expected to be fulfilled for a transport between Ringhals and Forsmark. During the test transport acceleration forces were measured outside the TN17 cask (Figure 1) and inside the TN17 cask using a dummy fuel assembly (Figure 2) and a custom built holding device for accelerometers (Figure 3). The dummy fuel assembly was instrumented with six accelerometers to be able to measure any axial variations inside the fuel bundle. The outside measurement was performed with two different accelerometers, one continuously logging accelerometer and one which only logged above a certain threshold value.

Figure 1, mounting of two different accelerometers outside the TN17 cask

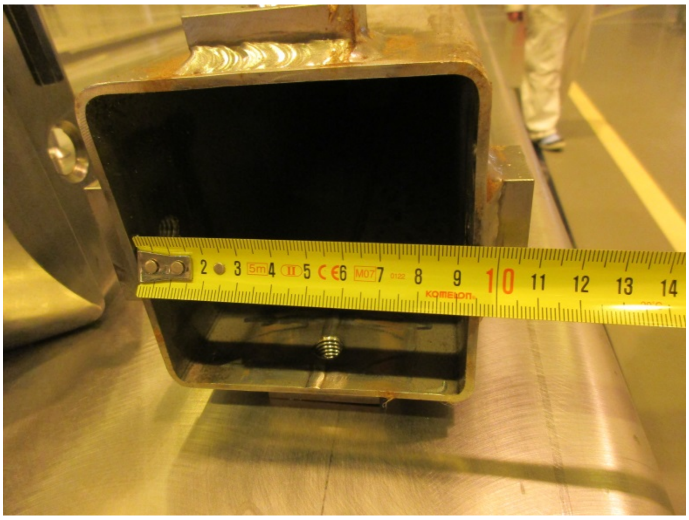


Figure 2, dummy fuel assembly inserted into the TN17 cask

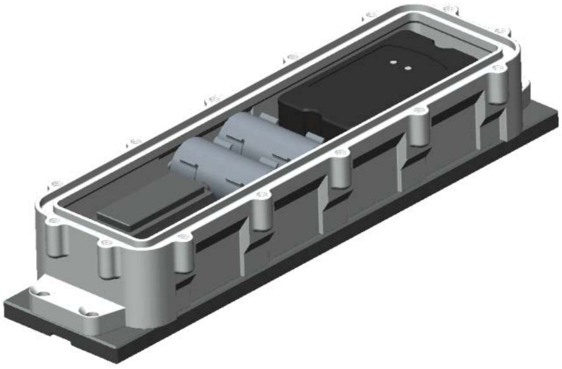


Figure 3, holding equipment for two accelerometers inside the square tube of the dummy fuel

The test-transport indicated that bumps outside Forsmark NPP give acceleration forces slightly above 0.3 g, figure 4, and a possible sliding event when tilting the transport container gave somewhat larger acceleration forces inside the transport container, figure 5. There were also logged events of handling the dummy assembly outside the cask but these events are not part of the transport route. The coordinate system in figure 6.

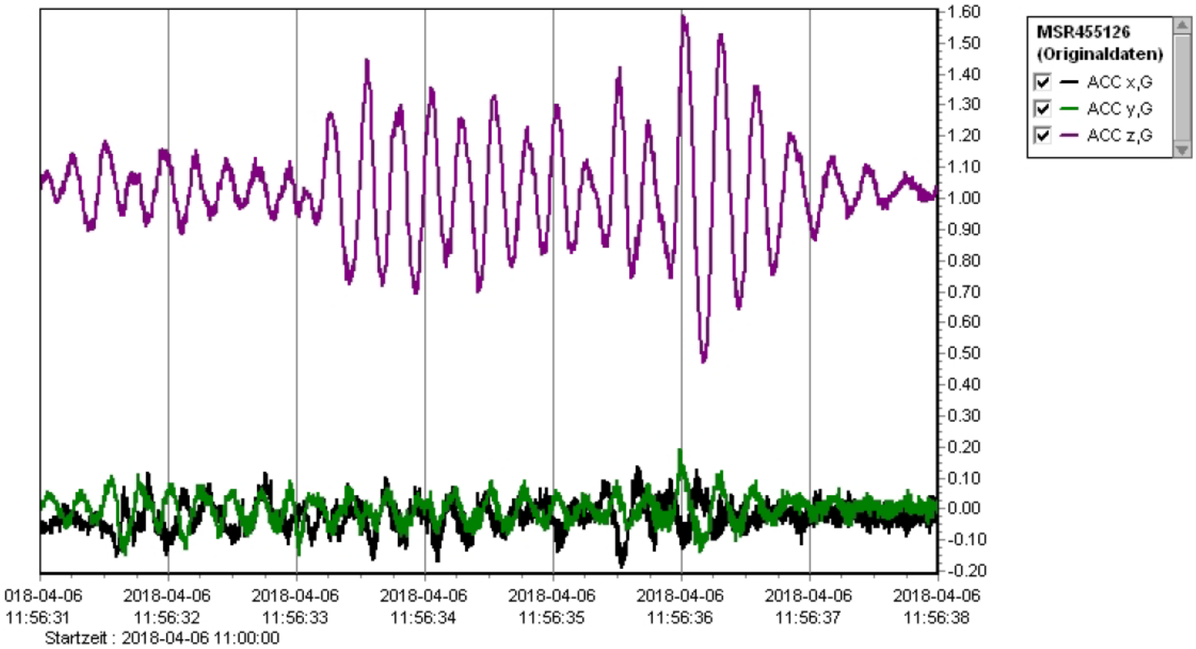


Figure 4, bump in the road outside Forsmark NPP

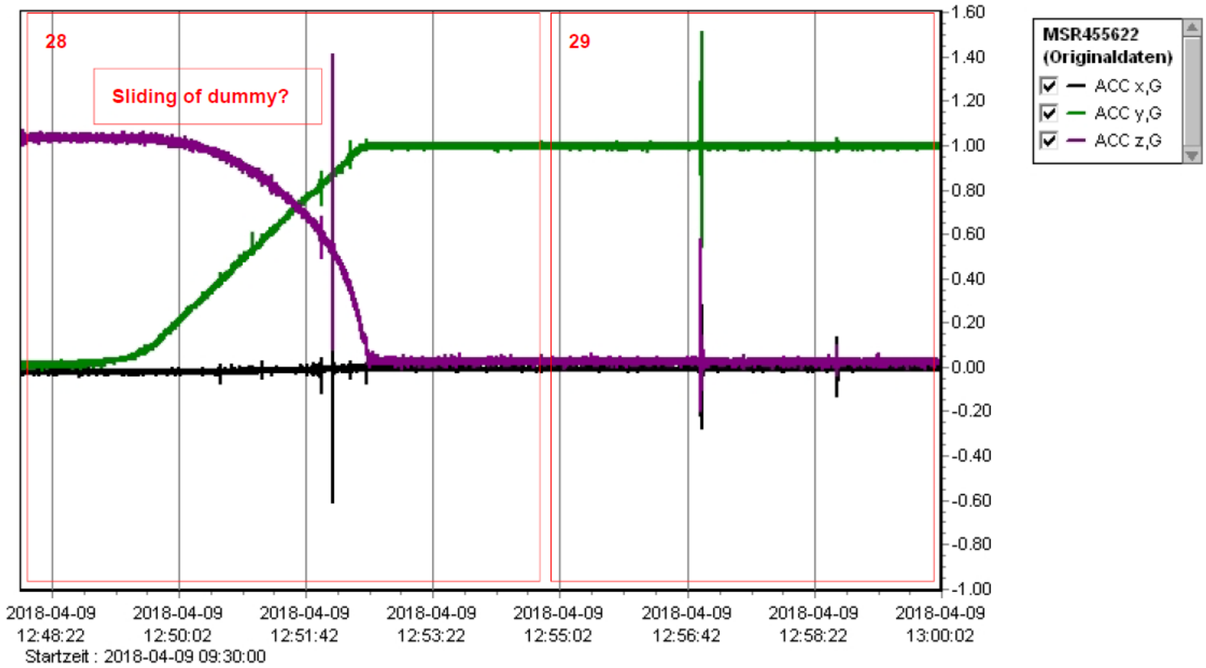
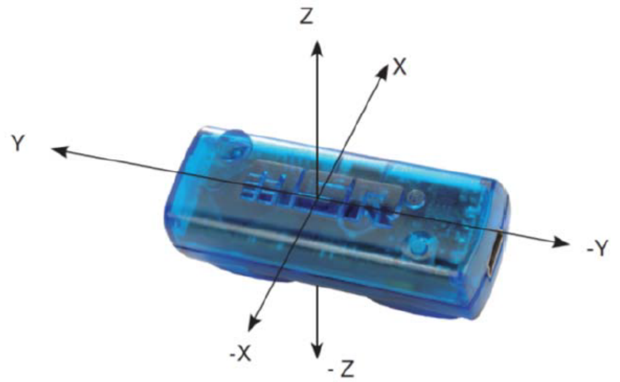


Figure 5, possible sliding of the dummy inside transport cask



MSR axis colors		
x	black	lateral
y	green	axial
z	purple	lateral

Figure 6, axis directions, y-axis is along the fuel-rods, z-axis is the up direction away from the fuel-rods

To determine the maximum allowed acceleration force, detailed studies will be performed by the Nuclear Fuel vendor. A hot cell study will also be performed on a fuel rod from Forsmark after two years of irradiation. The main goal is to try to determine the effect of two years of irradiation on the plenum spring. The plenum spring is expected to relax, however, some residual spring force will be present. This relaxed spring force determines the force available to keep the pellet column in place during transportation and handling. A secondary goal is to study the fuel column to determine the effective column length that can freely move. It is expected that some fuel pellets will have no gap between the pellet and the cladding at some exposure, and thus be stuck. Due to the considerably lower exposure at the top of the fuel column the top column part can probably freely move. This effective fuel column height is an important parameter together with the reduced performance of the plenum spring to determine whether the plenum spring can hold the fuel column at bay.

2.2. Long-Term Increase in Temperature during Transport

One of the goals during operation of Nuclear Fuel is to assure sufficient cooling. Increased temperatures of the cladding due to insufficient cooling will have negative effects on the cladding material. The mechanical strength and the creep resistance of the material will be reduced, which may compromise the further unlimited use of the fuel. In a worst case scenario the onset of corrosion may lead to a fuel failure. For BWRs the sufficient cooling is maintained by protection against dry-out via keeping a certain margin against a critical bundle power.

In recent years studies have shown that acceptable cladding conditions are maintained for moderate absolute temperature increases or for very short dry-out times. The most limiting effects are annealing of the cladding, followed by creep of the cladding (as the second most limiting). The potential impact of cladding creep on the cladding diameter increase in this case is small due to the low rod internal pressure. Even the creep bending of the fuel rods in the spans between spacers is being addressed. It has been shown that no detrimental effects will occur at temperatures below approximately 320 °C [1], Figure 4.

The curve denoted Sigma-A in Figure 4 is a cumulative annealing parameter [2] that was found to predict annealing in hot cell data for cases of post dry out operation where unlimited further operation of the cladding is not impaired.

The thermal loads on Irradiated Nuclear Fuel during transport can be characterised in a similar way as loads during a dry out. Therefore the concept of the annealing parameter, where the time at (elevated) temperature during transportation is considered is judged to be an appropriate concept to use for this transport of irradiated Nuclear Fuel.

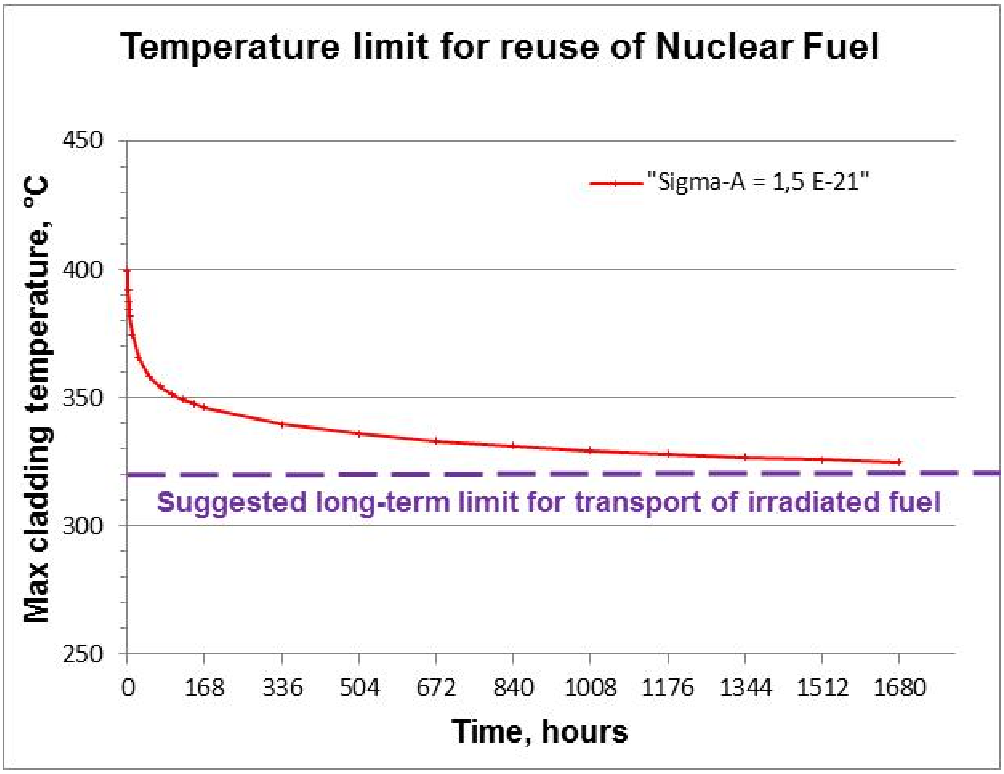


Figure 7, temperature limit for reuse of Nuclear Fuel

The TN17 cask is licensed for operation below a certain temperature threshold and the transport between Ringhals/Forsmark and CLAB has been shown not to violate this threshold. Using the estimated residual heat for a twice burned fuel after 9 months of cooling of approximately 1.6 kW per fuel assembly, it should be possible to stay below the limit shown in Figure 4.

2.3. Short Term Temperature Disturbances

Before transporting the spent Nuclear Fuel, the TN17 cask is dried using a vacuum technique before filling the container with helium. The vacuum in the cask could, during a limited time, cause the fuel temperature to rise. This is normal operating procedure for transporting spent Nuclear Fuel to CLAB and not seen to have any negative effects on storage of spent Nuclear Fuel.

In case of transportation of Irradiated Nuclear Fuel for intended reuse, the small temperature rise has to be evaluated with respect to possible detrimental effects during operation. The expected temperatures and the short duration should allow to analyse the issue by applying the annealing parameter concept described above.

2.4. Cool Down Effects after Transport

When the spent Nuclear Fuel arrives in CLAB the cask is cooled using water before being inserted into the fuel pool. This cooling as well as the final flooding of the cask before unloading the fuel introduces thermal stresses in the fuel cladding, possibly leading to detrimental effects. The cooling procedure and the loads on the cladding have been analysed from a storage point of view and all gathered experience shows that the cooling operation has never resulted in an immediate fuel cladding failure in CLAB.

The reuse of Irradiated Nuclear Fuel assemblies has, however, not yet been analysed with respect to maximum cooling rates for the fuel cladding.

3. Conclusions

When shutting down any Nuclear Power Plant a considerable amount of fissile material/energy will still be left in the Nuclear Fuel. Transporting this Nuclear Fuel to another Nuclear Power Plant has been performed a few other times successfully but transporting irradiated Nuclear Fuel by sea to another Nuclear Power Plant for further use is not common place. This paper shows, however, that it should be possible while still ensuring safe further operation of the fuel. With the planned shutdown of several Nuclear Power Plants in the near future there is potential for both economic and environmental gains.

References

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