Swedish Solution for Reconditioning, Transport, Interim Storage and Final Disposal of Failed Fuel – 17024

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ABSTRACT

Despite today's increasingly more reliable operation of nuclear power plants, failed fuel rods exist in all Swedish plants. Managing intermediate storage and sub-sequential final disposal of such rods has been a growing problem. The Swedish system for spent fuel management uses the principle of intermediate storage of the fuel in a central intermediate storage facility (CLAB) before disposal in a final repository according to the KBS-3 method. However, the intermediate storage facility does not allow storage of failed fuel and the final repository has limitations on moisture in the deposited fuel and hence failed or broken fuel rods cannot be accepted as-is.

The nuclear power companies in Sweden have jointly established the Swedish Nuclear Fuel and Waste Management Co, SKB, to manage the spent fuel and the operational waste. To find a solution to transport the failed fuel to storage, SKB has established a project with the goal to have all currently failed fuel rods from all the Swedish nuclear power plants reconditioned and transported to the intermediate storage facility before the year of 2020. The project has established the acceptance criteria for reconditioned failed fuel in the final repository and evaluated a number of options for treatment, encapsulation and transportation of the failed fuel rods. Furthermore, two suppliers have developed reconditioning methods fulfilling the criteria and contracts were signed with both suppliers in May 2016.

This paper outlines the details of the Swedish solution for treatment and storage of failed fuel including the technical requirements for the reconditioning method and transportability.

INTRODUCTION

The Swedish Nuclear Fuel and Waste Management Company, SKB, is responsible for taking care of the Swedish nuclear waste and for planning of this work funding. The radioactive waste is divided into different categories: high level waste (spent fuel) and low and intermediate level waste. Spent nuclear fuel is currently placed in interim storage pools at the central intermediate storage facility (Clab) awaiting the Swedish final repository to be in place.

Historically, failed but “leak tight” fuel rods were allowed to be transported to Clab and are today stored there. These failed fuel rods are today of concern since they must be reconditioned before being accepted for final disposal according to the KBS-3 method and recently the shipments of failed but leak tight fuel rods to Clab were stopped. Failed and uranium leaking fuel rods have never been allowed to be shipped to Clab and are hence still stored in the ponds at the nuclear power plants.

Managing intermediate storage and sub-sequential final disposal of failed fuel rods has been a growing problem. Today, a total of 497 failed fuel rods are stored in the spent fuel pools at the 10 units currently in operation. All leakage from failed fuel of fission products with long half-lives and transuranium elements in a nuclear power plant or in an intermediate storage facility, gives unnecessary radiological doses to the personnel, risks with distribution of alpha contamination in systems and facilities, increased volumes of waste with long half-lives and transuranium elements, as well as an increased need of protection measures, personal protection equipment and cleaning. SKB started in 2015 a project with the goal to establish both a short and a long term solution for reconditioning and transportation of failed fuel in order to achieve a sustainable encapsulation for long term intermediate disposal. The decision to close down four units in Sweden for decommissioning made the urgent need for a short term solution even more urgent. The project shall manage to remove all currently failed fuel rods from all the Swedish nuclear power plants before the year of 2020.

CHARACTERISTICS OF THE FAILED FUEL RODS

A fuel rod can be damaged or failed and for the Swedish work with this kind of fuel the following definitions have been established:

damaged fuel	nuclear fuel that has been geometrically altered in form and or shape to a degree that may affect retrievability from a (licensed) storage system or make it unsuitable for transport in a licensed cask.
failed fuel	any breach, such as hairline cracks or holes in a cladding that permits water into a fuel element and includes also broken fuel rods and pieces of fuel rods.

The majority of the failed fuel rods at the Swedish plants have been pulled out from the fuel assembly and placed in open storage canisters. These canisters have collected all the failed fuel rods over the years. The inventory shows a wide range of fuel rod failures.

a. broken
b. top and/or bottom plug missing
c. large cracks > 10 mm length
d. small cracks ≤10 mm length
e. debris fretting
f. pin hole

The failed fuel rods are to be considered as “wet”. They are stored “open” in pools and water ingress is a fact for rods with cracks or being broken. Also fuel with small cladding failures, such as debris fretting and small pin-hole failures can have residual internal moisture.

In addition to the failures listed above, there exists a small number of “difficult cases” that need to be treated case by case. It is not possible to lift these failed fuel rods because they are stuck in the skeleton or in the purpose built canister. Handling of severe failures in the pool should be reduced to a minimum for ALARA reasons.

SKB ACCEPTANCE CRITERIA FOR RECONDITIONED FAILED FUEL

SKB has established the acceptance criteria for reconditioned failed fuel in the final repository as well as for handling, transport and intermediate storage. The fulfilment of the acceptance criteria will be detailed for the selected methods and subject for an extensive approval process.

General requirements

All methods, equipment and procedures shall meet the requirements for work and equipment approval for all units at all Swedish nuclear power plants and Clab.

Handling requirements

The handling requirements include both design requirements and operational requirements. It is essential that a capsule fits within the current facilities and handling equipment, that it is transportable and that it can be encapsulated in copper and nodular cast iron for the final repository together with the rest of the spent fuel from the Swedish power plants. The capsule shall therefore correspond with any fuel assembly, BWR or PWR, already within the Swedish system, in the means of dimensions and weight, handling and criticality.

Material requirements

The nuclear power plants have requirements on what kind of materials that are allowed to be used in their facilities and SKB has requirements on the material properties for items to be stored in Clab and in the final repository. In order to maintain the tightness during long term storage and for the radiation safety of in the final repository SKB has the following acceptance criteria on material.

a. The leak tight parts of the capsules must be manufactured of stainless steel or a material with the same or higher corrosion resistance.

b. The material thickness for the leak tight parts of the capsule shall not be less than 3 mm. For zirconium alloys a minimum material thickness of 0.7 mm is accepted due to the proven high corrosion resistance.

c. The capsule must not contain any organic material.

Dryness requirement

Since the Swedish final repository has limitations of presence of moisture, the failed fuel rods must be dried before they are encapsulated. It must be verified that there are no remaining water in the top and bottom plenum of the fuel rod and the fuel rods shall be dried to a degree of dryness that meets the ASTM C1553 “Standard Guide for Drying Behaviour of Spent Nuclear Fuel” or an equivalent standard. To limit the presence of moisture and oxygen in the capsules and the fuel rod, the dried capsules shall be filled with inert gas before sealing.

Tightness requirements

The capsules with the encapsulated failed fuel rods shall be helium leak tight.

Transport requirements

The reconditioned fuel must be transportable to Clab.

PILOT PROJECT

SKB has completed a pilot project with the aim to test the drying method of vacuum drying according to the ASTM C1553 “Standard Guide for Drying Behaviour of Spent Nuclear Fuel”. Wet failed fuel rods from the Ringhals NPP were transported to the Studsvik Hot Cell Laboratory. Studsvik has an already established and approved procedure to encapsulate cut pieces of examined irradiated fuel for disposal within the SKB system but examined fuel is always dry at the time of disposal and therefore additional drying have never been necessary.
Since no licenced transport package for transport of the needed amount of fuel was available, the transport was performed under Special Arrangement and with the SKB owned INF-3 vessel m/s Sigrid. At the Studsvik Hot Cell Laboratory the fuel

rods were cut in one meter lengths to fit in the Studsvik capsules for transport to storage. Also the plenum was cut to fulfil and verify the acceptance criteria of no water in top and bottom plenum. The vacuum drying could be completed and fulfilment of the criteria in the ASTM C1553 standard could be verified. The capsule was then flushed two times with inert gas before being sealed and helium leak tested.

TRANSPORTATION OF FAILED FUEL

It is worth nothing if you cannot transport it. Transportability is the key factor for success. The Swedish nuclear fuel waste system is designed for the continuous transport of spent fuel to the central intermediate storage. Transportation of leaking failed fuel is mostly a difficult task. Few packages are licensed to carry severe failed fuel and if they are, the risk for contamination must be considered at all steps of the handling; packing, vacuum drying, transporting and unpacking. With a forced time schedule and sites closing down, the option of implementing new packages to solve the short term problem with the failed fuel and the difficult cases is not realistic. SKB has therefore looked at what is available today and already implemented packages or packages that could easily be implemented.

Packages for failed fuel

SKB has got 10 TN17/2 packages for transportation of spent nuclear fuel from the stations to Clab. The certificate for the TN17/2 allows a small number of fuel rods with pin-hole failures to be transported but cracks and broken rods are not allowed to be transported. SKB is currently in the process of acquiring new packages of the HI-STAR 80 type. For this cask type, punctured fuel rods (i.e pin hole and debris fretting) are allowed to be transported as-is and larger failures can be transported if placed in a damaged fuel container. The fleet of new casks will however not be fully implemented before late 2021.

Packages for “difficult cases”

For failures when the fuel rod is not possible to separate from the fuel bundle because it got stuck in the skeleton, it is necessary to remove all intact rods and handle the failed fuel and the skeleton as separate waste. One way to treat this waste is to cut the skeleton in the spent fuel pool at the power plant or to bring the whole piece to a hot cell laboratory for segmentation. For transportation of BWR fuel dimensions, the NCS 45 can be used. This package is implemented in Sweden and holds a license that allows transport of a limited number of failed fuel rods without encapsulation and also together with irradiated material. For PWR fuel dimension the situation is far from optimal. The only implemented package that can transport a PWR skeleton or a PWR sized storage canister to the hot cell is the old 29-ton fuel cask. This package does not fulfil todays licence requirements and can only be transported under special arrangement with compensatory measures.

RECONDITIONING ALTERNATIVES

Reconditioning just before encapsulation for the final repository, KBS-3

Before the spent nuclear fuel is transported to the spent fuel repository for final disposal it will be encapsulated in copper and nodular cast iron. This is planned to take place in an encapsulation plant, to be built next to the interim storage facility. If the failed fuel is transported as-is and stored in that condition in Clab it could be reconditioned in the encapsulation plant just before being encapsulated with the rest of the spent fuel.

Encapsulation on site

A purpose built canister, which can be dried and leak tight sealed, are placed in the spent fuel pool at the power plant. Fuel rods with all kind of failures are loaded into dedicated positions and when the canister is filled it is dried, leak tight sealed and then sent to storage together with the rest of the spent fuel.

Encapsulation off site

A hot cell laboratory is designed to handle failed fuel and has got all the tools needed to recondition a difficult case consisting of fuel rods remaining in a skeleton or a canister. A hot cell has already, or can develop, procedures to encapsulate cut pieces of irradiated fuel for disposal as well as arrange disposal of irradiated material.

Reprocessing

If failed fuel is to be reprocessed, it has to be packed in a way that can be accepted by the reprocessing facility, a licensed cask that can be handled both at the power plants and at the reprocessing facility is needed and a transport route must exist, including the return transport. Reprocessing of fuel is not allowed in Sweden so this option has not been further evaluated for the Swedish spent fuel.

EVALUATION AND SELECTION

SKB has evaluated the different of options available for reconditioning of the failed fuel rods against the acceptance criteria for failed fuel in the final repository. It was decided to select the encapsulation method and to have the encapsulation done in the close future. For the final selection of contractors also the delivery time was important, especially for the reconditioning of fuel at sites with close-down decisions.

Evaluation of reconditioning just before encapsulation for the final repository, KBS-3

It is important to avoid leakage from failed fuel into the intermediate storage pool water and it is also important to maintain safe storage to facilitate safe retrieval and disposal of the fuel. It is a desire that no significant degradation of the fuel cladding or fuel assembly should occur during the intermediate storage. Fuel rods with an open cladding failure in contact with water can give rise to fuel pellet oxidation at the failure. There are bad examples of degradation among the stored failed fuel rods in Sweden.

Evaluation of encapsulation on site

To take the failed fuel and load it on site into a purpose built canister which can be dried and leak tight sealed and then sent to storage together with the rest of the fuel seems to be a convenient alternative since it cuts off the need to transport the failed fuel as-is with all those risks. Encapsulation on site in purpose built, leak tight canisters do not solve the problem with the difficult cases which require a more flexible solution.

Evaluation of encapsulation off site

A hot cell laboratory is designed to handle failed fuel and has got all the tools needed to recondition a difficult case consisting of fuel rods remaining in a skeleton or a canister. A hot cell has already, or can develop, procedures to encapsulate cut pieces of irradiated (including wet) fuel for disposal as well as arrange disposal of irradiated material.

The shipments of large amounts of failed fuel to a hot cell are however demanding. A hot cell is not design to receive and unload the heavy casks used to transport spent fuel from a power plant and not many hot cell adapted packages are designed and licensed to transport reasonable quantities of failed fuel. The fuel has to be divided into smaller portions and shipped in several transports. For the difficult cases with a skeleton or canister and only a few remaining failed fuel rods, there are licensed casks for shipment to a hot cell and the hot cell has got all the tools needed to recondition it.

Evaluation of reprocessing

If failed fuel is to be reprocessed, it has to be packed in a way that can be accepted by the reprocessing facility, there is need for a licensed cask that can be handled both at the power plants and at the reprocessing facility and a transport route has to exist, including the return transport.

Selection

Reprocessing of fuel is not allowed in Sweden so this option has not been evaluated further for the Swedish spent fuel. Waiting is not a good option when the fuel is contaminating the pool water and there is a major risk for degradation hence, it has been decided to not wait with the reconditioning.
After evaluation of a number of options for treatment, encapsulation and transportation of the failed fuel rods against the acceptance criteria for reconditioned failed fuel in the final repository, a contract was signed with Westinghouse Electric Sweden AB for the use of their Quiver concept. The Quiver concept will also be implemented as the long term solution. Quivers will be placed in the spent fuel ponds at the remaining sites in operation to collect potential future failed fuel rods. In addition to this the Swedish hot cell laboratory in Studsvik has been contracted to take care of the difficult cases as well as a number of failed rods in canisters from one of the shutdown reactors with urgent need to get rid of their fuel. Studsvik Nuclear AB has already established and approved procedures to encapsulate cut pieces of irradiated fuel for disposal within the SKB system and has in the pilot project with wet failed fuel shown that they have a working drying method. Studsvik has also experience from reception of a complete skeleton.

TRANSPORTATION

With the selected solution for reconditioning of the failed fuel on site a good portion of the failed fuel currently located at the nuclear power plants will not be transported without a leak tight encapsulation. To manage the transportation of the Westinghouse Quiver within the Swedish nuclear waste transportation system without restrictions, the Quiver needs to be included as a licensed content in the SKB transport cask certificate.

Shipments of failed fuel rods for off-site treatment at the Studsvik hot cell laboratory will require a large number of transports in order to be performed with existing cask license. Studsvik is currently working on an extension of the certificate to include more failed fuel rods which could potentially reduce the number of transports by a factor of three.

The difficult cases from BWR reactors can be performed within the licensed content of the NCS 45, which is already implemented at the Swedish power plants. To enable transports of the difficult cases from PWR reactors, the authority plays an important role in setting up the conditions for a transport under special arrangement.

CONCLUSIONS

Looking at the failed fuel issue it is obvious why it is important to have solutions for treatment of the waste that are produced at a power plant at an early stage, preferably before it is even produced.

Leakage from failed fuel stored in spent fuel ponds gives unnecessary radiological doses to the personnel, risks with distribution of alpha contamination in systems and facilities, increased volumes of waste with long half-lives and transuranium elements, as well as an increased need of protection measures, personal protection equipment and cleaning. A solution should focus on taking care of the source of the problem instead of installation of filter systems and storage facilities for an increasing amount of operational waste.

It takes time to establish waste solutions and time is money, especially when you have a shut-down reactor and the failed fuel prevents you from getting into service operation.

SKB has established the acceptance criteria for storage of failed fuel in the Swedish final repository. To recondition the several hundreds of failed fuel rods stored in the spent fuel pools, including the difficult cases, Studsvik Nuclear AB and Westinghouse Electric Sweden AB have been contracted. The Westinghouse Quiver concept has also been chosen as the long term solution should any additional fuel failures occur during the remaining lifetime of the reactors. The Quiver will enable new failures to be taken care of immediately.

For a successful implementation of a failed fuel reconditioning solution, logistics planning and cask licensing issues are critical parts of the project from the very beginning.