Solutions for Management of Defective Fuel Assemblies - 15318

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ABSTRACT

Defective fuel management is a major challenge for nuclear operators when the time comes for finding a long-term solution for their used (or spent) fuel assemblies.

This question of defective fuel management can be raised in several cases:

- For optimizing the remaining operating costs of shutdown reactors, the spent fuel pools must be emptied as soon as possible; a solution needs therefore to be found for evacuating all the spent fuel assemblies, defective fuel assemblies and in particular defective fuel rods included;

- Some utilities are today facing a saturation of their reactor spent fuel pool; evacuating the defective fuel assemblies and extracted defective fuel rods allows optimizing the space in the pool.

Whereas the solutions for managing intact used fuel assemblies are well-known, a specific technical solution must be implemented for managing the defective spent fuel assemblies as well.

The purpose of this paper is to describe the existing solutions for the management of all types of defective fuel assemblies.

<u>Interim Dry Storage Solution</u>
Interim dry storage of defective spent fuel assemblies is being implemented for decades in the USA.
Specific operations are performed for preparing the defective fuel assemblies for interim dry storage and they are then stored with intact used fuel assemblies in the dry storage cask. The advantage of such a solution is its short-term cost effectiveness.
The paper presents the existing dry interim storage solutions for defective used fuel rods, the way they are implemented, the associated operational experience.

<u>Long-term Dry Storage Solution</u>
A long-term dry storage solution for defective fuel assemblies is being developed, compliant with direct disposal requirements. The solution is based on the encapsulation of each defective fuel rod into a fuel rod capsule and an associated specific dry storage licensing approach: this is the best available technology regarding long term storage safety requirements.

The paper presents this unique capsule technology, the transport and storage casks that can be used for transportation of defective fuel rods to the storage facility, and the associated transport licensing approach currently used in Europe.

Treatment Solution
The most definitive way to get rid of defective fuel assemblies is their treatment (or reprocessing) in a treatment plant. There is then no need to assess the behaviour of these specific used fuel assemblies as for an interim storage facility or a final repository. The advantage of such a solution is its sustainable approach.
The paper presents the existing transport and treatment solutions, the way they are implemented, the associated operational experience.

INTRODUCTION

Today the organisations in charge of long-term management of all spent fuel assemblies are looking for a solution for managing the defective fuel assemblies along with intact spent fuel assemblies. In the same time, the nuclear industry all around the world, is being confronted with the end of life of some reactors, and the need to evacuate from their pools all - defective as well as intact - used fuel assemblies. On the other hand, for power reactors in operation, the evacuation of the defective fuel assemblies is a way to optimize their spent fuel pool management.

Whereas the solutions for managing intact spent fuel assemblies are well-known, a specific technical solution must be implemented for managing the defective spent fuel assemblies as well.

In order to meet these new needs, safe and sustainable solutions for mid- and long-term management of defective fuel assemblies have been developed and are implemented. Regarding storage needs especially:

- Interim dry storage of defective fuel assemblies is being implemented for years in USA and
- A most efficient technology for long-term dry storage of defective fuel assemblies is being developed, based on robust safety demonstrations for getting the license of the transport and storage cask.

Besides storage solutions, the most definitive way to get rid of defective fuel assemblies is their treatment (or reprocessing) in a treatment plant. There is then no need to assess the behaviour of these specific used fuel assemblies as for an interim storage facility or a final repository.

The purpose of this paper is to describe these existing solutions for the management of all types of defective fuel assemblies.

DEFINITIONS

According to [1], a spent fuel assembly is categorized as either defective or not, based on its ability to perform its designated functions without requiring the fuel assembly to be handled in a non-standard manner. The main safety functions to be performed by a spent nuclear fuel assembly are related to its ability to maintain radiological confinement, to remain subcritical and to maintain structural integrity.

Regarding confinement, defective fuel assemblies are usually classified, in the USA, into two main categories:

Damaged fuel assembly (see figure 1): assembly containing leaking or suspect leaking fuel rods, with cladding that can be breached. A **leaking fuel assembly (rod)** is a certain type of damaged fuel assembly (rod), for which gas is leaking from fuel rod cladding, but for which loss of nuclear material is excluded.

Damaged fuel assemblies (rods) can be handled by normal means

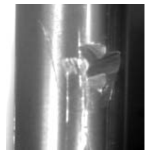

Fig. 1: Damaged fuel assemblies

Failed fuel assembly (see figure 2): assembly containing grossly damaged fuel rods. Grossly damaged fuel rods have breached cladding or parts of cladding and/or **Fuel debris**, e.g., nuclear pellets, fragments of pellets, or fuel powder.
A failed fuel assembly contains damaged fuel rods for which loss of nuclear material cannot be excluded.

Failed fuel assemblies (rods) cannot be handled by normal means

Fig. 2: Failed fuel assemblies

Various types of conditioning exist for defective fuel assemblies or rods:

- **Quivers/Fuel rod canisters** for storing several defective fuel rods together (open or close, all fuel rods in defined positions or fuel rods inserted in tubes with or without end cap common to all tubes) – can be used for wet storage and also for transport
- **Bottles** for wet storage and/or transport of one or several defective fuel assembly(ies)
- **Fuel Rod Capsules** for wet or dry storage or transport of fuel rods (one fuel rod capsule for one fuel rod) with screwed or welded closure (see figures 5 and 9)
- **Capsule canisters** for assembling fuel rod capsules – dimensions are similar to fuel assembly dimensions for easy handling (see figure 6).

SOLUTIONS FOR INTERIM DRY STORAGE OF DEFECTIVE FUEL ASSEMBLIES

Considering interim dry storage of defective fuel assemblies, the US NRC requirements are the following:

- Damaged fuel assemblies shall be stored in a canister’s usual fuel assembly compartment with additional end caps that have multiple holes in order to permit unrestricted flooding and draining; there are designated basket locations for the storage of damaged fuel assemblies;

- Failed fuel assemblies (fuel debris included) shall be stored in a failed fuel can that is placed in a canister’s compartment which is slightly larger than a fuel assembly compartment; there are designated basket locations for the storage of failed fuel assemblies.

AREVA developed and has been implementing for several decades, solutions which are compliant with the NRC requirements. The advantage of such solutions is their short-term cost effectiveness.

For storage of damaged fuel assemblies, AREVA provides the NUHOMS® canisters presented in figure 3:

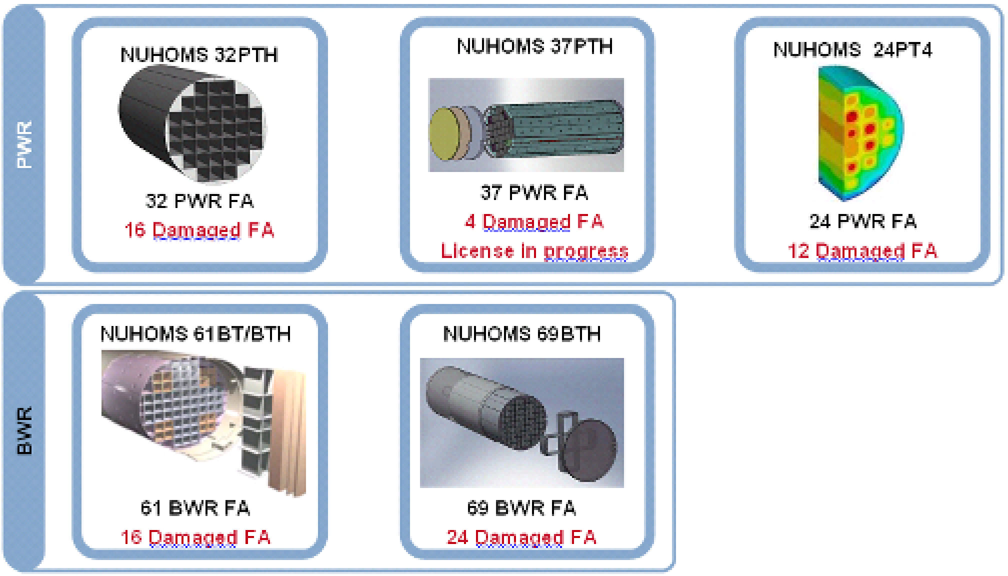

Fig. 3: Canisters having license for storing damaged fuel assemblies

For storage of failed fuel assemblies, AREVA provides the 24PTHF NUHOMS® canister, presented in figure 4:

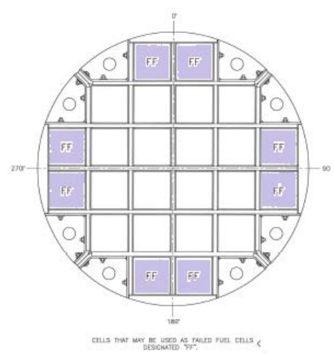

Fig. 4: 24PTHF canister having the license for storing failed fuel assemblies

Operational Experience

➢ Hundreds of defective fuel assemblies are currently stored in interim dry storage casks in the USA.

SOLUTION FOR LONG-TERM DRY STORAGE OF DEFECTIVE FUEL ASSEMBLIES AND RODS

AREVA is developing a new, long-term oriented product for the dry storage of defective fuel rods: the concept is consisting of welded fuel rod capsules (see figure 5), assembled in a capsule canister (see figure 6) that can be loaded in an AREVA transport and storage cask for transportation to and/or storage in a long term dry storage facility (examples of such casks are presented in figure 7). This welded fuel rod capsule concept is based on an existing and experienced screwed fuel rod capsule concept that is already in use (see figure 9).

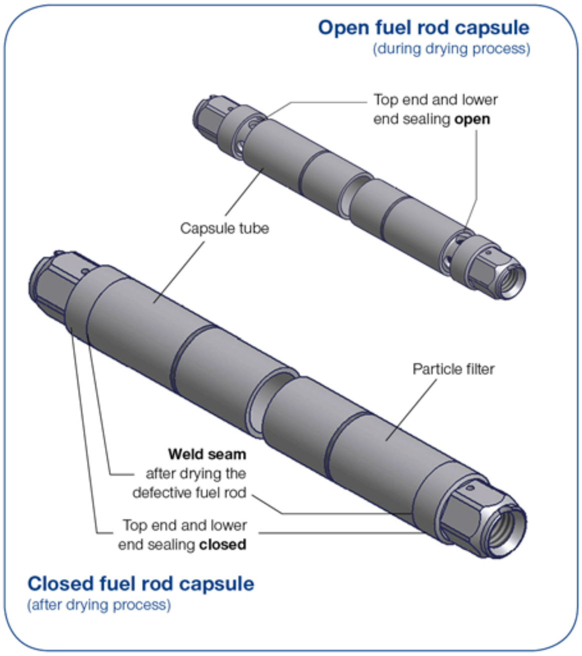

Fig. 5: Welded fuel rod capsule for long-term dry storage of a defective fuel rod

This fuel rod capsule takes the function of a barrier to assure the safe enclosure of radioactive material and is therefore at least equivalent to an intact fuel rod cladding with tight welded end plugs. Two different types of fuel rod capsule are being developed that can be used for any kind of PWR and BWR fuel rods.

The principles of the process are the following:

- Preparation and pre-treatment of the defective fuel rod / fuel debris
- Transfer of the fuel rod or cartridge for debris into the fuel rod capsule in the pool
- Dewatering and drying of the fuel rod / cartridge in the fuel rod capsule
- Gas-tight enclosure of the fuel rod capsule by welding
- Non-destructive testing of the weld
- Transfer of the fuel rod capsule into the capsule canister
- Attachment of the top end piece of the capsule canister
- Handling and transfer of the loaded capsule canister to the cask
- Storage in the same cask of the loaded capsule canister along with intact spent fuel assemblies

All these operations are managed in the spent fuel pool.

This encapsulation technology uses a drying process which allows a physical and reliable demonstration of the remaining amount of residual water within the defective fuel rod.

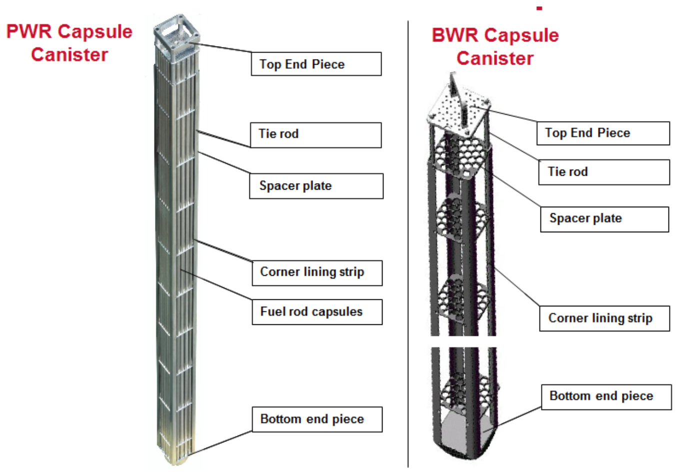

Fig. 6: PWR and BWR capsule canisters

All the equipment and processes described here above are covered by AREVA patents.

Listed below are the main technical topics for a transport cask licensing point of view:

- Qualification of the encapsulation drying process, and estimation of the residual water content
- Mechanical behaviour of a capsule canister, and comparison with an intact spent fuel assembly
- Qualification of the welding process of the fuel rod capsule and non-destructive testing of the weld
- Loading capacity: a compromise between the maximal possible number of fuel rod capsules to be loaded in a capsule canister resp. cask and the easiest way to get the license.

The cask license shall cover:

- Different types and characteristics of defective fuel rods in capsule canisters
- Mix loading of intact and defective spent fuel rods.

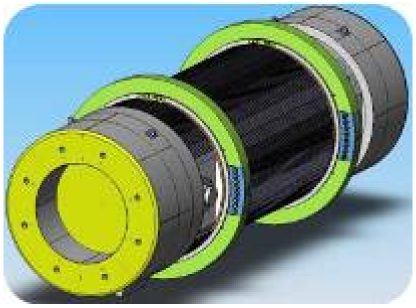

Fig 7: TN®24E and TN®24SH casks that can be used for
transport and dry storage of defective fuel rods loaded into fuel rod capsules

To conclude, the technology developed by AREVA is the most efficient in terms of residual water in the defective fuel rod and allows to obtain a robust safety demonstration for the transport license of the AREVA transport cask and the storage license in the long term dry storage facility: it is the best available technology regarding safety requirements for dry storage.

TREATMENT SOLUTION FOR MANAGEMENT OF DEFECTIVE FUEL ASSEMBLIES

The most definitive way to get rid of defective used fuel rods or assemblies is their treatment (or reprocessing) in a treatment plant like the AREVA La Hague plant. By using this option, nuclear operators do not have to assess the behaviour of these specific used fuel assemblies in an interim storage facility or a final repository.

After the treatment has been performed and according to French law, the reusable material is used by the spent fuel owner or by another party, and the final residues produced by treatment are returned to the spent fuel owner.

Transport of Defective Fuel Assemblies/Rods

For bringing the defective used fuel assemblies/rods to the reprocessing plant, AREVA proposes a comprehensive range of transportation solutions.

The MP197HB transport cask (see figure 8) is licensed in USA for transporting damaged and failed fuel assemblies/rods.

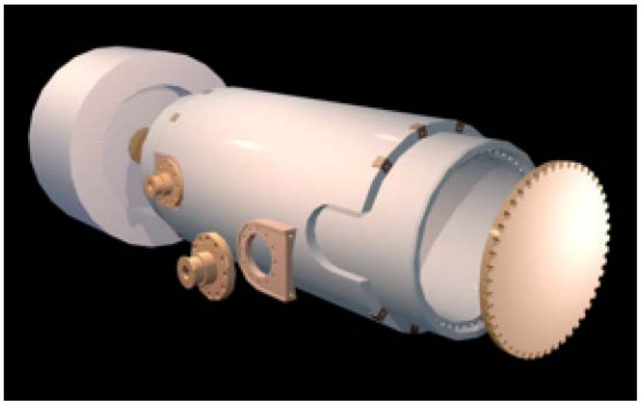

Fig. 8: MP197HB transport cask

The following casks are licensed for transportation of leaking fuel assemblies:

- TN®12 and TN®13, licensed in France, for EDF needs
- TN®17/2, licensed in France and Sweden, for SKB needs
- TN®117, licensed in France and Italy, for SOGIN needs.

Operational Experience

- For EDF needs, AREVA has performed many shipments of leaking fuel assemblies.

In addition, AREVA has a strong international experience in transportation of leaking fuel assemblies: shipments were performed from Germany, Switzerland, Belgium, Japan… to the La Hague plant in France.

In Europe, transportation of failed fuel assemblies and damaged fuel assemblies for which loss of nuclear material can not be excluded, requires the fuel rods or cartridges with debris to be inserted into screwed fuel rod capsules (see figure 9), assembled in capsule canisters to be loaded in the transport cask.

Depending on Safety Authority requirements, the screwed fuel rod capsule can be:

- Either particle-tight only
- Or particle-tight and gas-tight.

Fig. 9: Screwed particle-tight and gas-tight fuel rod capsule for transport of failed fuel rods and damaged fuel rods (with potential loss of nuclear material)

The screwed fuel rod capsules are then put in a capsule canister (see figure 6) which can be handled like a fuel assembly and transported in a transport cask after license extension has been obtained.

Operational Experience

➢ Screwed particle-tight and gas-tight capsules have been provided for conditioning defective fuel rods in two plants in Germany, one plant in Netherlands and one plant in Switzerland. They were then put together in a capsule canister. The TN®17/2 cask (see figure 10) was used for transporting these fuel rods from Germany to the AREVA La Hague plant for treatment.

The TN®12/2 cask has been used for shipments from a French plant and a Swiss plant to La Hague.

Screwed particle-tight but not gas-tight capsules have been provided by AREVA at a German plant and a Finnish plant for wet storage purpose. This design is available for transport of defective fuel rods, if the French Safety Authority so requires.

Fig. 10: TN®17/2 transport cask

Transport of Defective Fuel Rods – Licensing Approach in Europe

The current French Safety Authority approach is that the transport of defective fuel assemblies be performed with the hydrogen content measured once the cask is closed and before shipment, but without specific conditioning. The general licensing approach is the following:

<u>Sub-criticality safety case</u>
In transport accident conditions, analysis considers that all the fissile material of all the spent nuclear fuel assemblies may become free in the cask cavity and that in addition a quantity of water equivalent to the plenum volume of all defective rods may become free in cask cavity. **As a consequence, the number of defective fuel rods per cask loading plan is limited.**

<u>Containment safety case</u>
100% of filling gases and fission gases in defective fuel rods are considered free in the cask with a certain pressure**. As a consequence, the number of defective fuel rods per cask loading plan is limited, and duration transport could be reduced to a few months instead of one year.**

<u>Hydrogen explosion risk safety case</u> (French Safety Authority current requirement)
The measurement of hydrogen content (%) in cavity cask is made at least two days after lid closure. Linear interpolation is made and allows defining a maximum time to reach the Lower Limit of Inflammability (LLI, close to 3%). This time with additional margins, defines a maximum time left between lid closure after loading and lid opening for unloading. **Transport duration could be reduced to a few months instead of one year.**

In conclusion,

- The transportation of leaking fuel rods only requires an extension of the transport license and the application of the hydrogen measurement method, but does not require any preliminary encapsulation
- The transportation of other types of defective fuel rods requires preliminary encapsulation, extension of the transport license and application of the hydrogen measurement method.

Treatment of Defective Fuel Assemblies

The treatment of defective fuel assemblies is performed in the La Hague plant according to the classification presented in table 1.

<table>
<tr><th rowspan="2"></th><th rowspan="2">leaking</th><th rowspan="2">defective with potential loss of nuclear material</th><th rowspan="2">conditioning</th><th colspan="2">authorization status</th><th rowspan="2">reception & treatment procedure</th><th colspan="2">operational experience</th></tr>
<tr><th>French R</th><th>Foreign R</th><th>French R</th><th>Foreign R</th></tr>
<tr><td rowspan="3">unrepaired</td><td>yes</td><td>no</td><td>none</td><td>authorized</td><td>specific authorization required</td><td>standard</td><td>~125 PWR FA</td><td></td></tr>
<tr><td>yes</td><td>no</td><td>bottle</td><td colspan="2">authorized</td><td>specific</td><td>135 PWR FA</td><td>~140 PWR FA
+ ~50 BWR FA</td></tr>
<tr><td>yes</td><td>yes</td><td>bottle</td><td colspan="2" rowspan="7">specific authorization required</td><td>specific</td><td colspan="2">none</td></tr>
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+ 1 BWR FA</td></tr>
<tr><td>yes</td><td>no</td><td>none</td><td>depends on reparation</td><td colspan="2">none</td></tr>
<tr><td>no</td><td>no</td><td>none</td><td>depends on reparation</td><td></td><td>6 PWR FA</td></tr>
<tr><td rowspan="3">c. canister</td><td>no</td><td>no</td><td>none</td><td>specific</td><td></td><td>2 PWR FA
+ 1 BWR FA</td></tr>
<tr><td>no</td><td>no</td><td>bottle</td><td>specific</td><td></td><td>1 BWR FA</td></tr>
<tr><td>yes</td><td>no</td><td>none</td><td>specific</td><td colspan="2">none</td></tr>
</table>

Table 1: Defective fuel assembly classification in the La Hague plant legal framework and corresponding operational experience

The treatment of defective fuel assemblies does not present significant modification compared to the normal process.

Treatment of capsules (see figures 5 and 9) **loaded within capsule canisters** (see figure 6) **in the treatment plant: AREVA operational experience**

➢ AREVA capsule canister design is compatible with La Hague treatment process: the grids and capsules thickness is limited, and when aimed for treatment, the capsules are homogeneously distributed within the capsule canister (not concentrated in the middle nor installed in the periphery only).
AREVA has successfully experienced the treatment of capsule canisters at La Hague, using normal process and tools with specific operating conditions and monitoring.

To conclude, the treatment service proposed by AREVA is a comprehensive solution that can be implemented to manage all types of defective fuel assemblies and rods. It allows not having to assess the behaviour of these specific types of fuel assemblies as for a dry storage facility. One of the main advantages of such a solution is its sustainable approach.

CONCLUSIONS

Today nuclear utilities and organizations in charge of back-end issues have to assess their spent fuel assemblies management policy for all types of fuel assemblies, defective included. Even when implementing new build projects, the stakeholders are asked by the Safety Authorities to present a comprehensive solution for final management of intact and defective fuel assemblies. The defective fuel management is therefore becoming a matter of concern for all nuclear operators. AREVA is continuously developing technologies that meet the customers' needs and the utmost safety requirements.

AREVA proposes qualified and proven solutions for evacuating defective fuel assemblies and rods from spent fuel pools:

- Cost-effective solutions for interim dry storage of defective fuel assemblies

- The best available technology for long-term dry storage of defective fuel assemblies, deriving from existing and experienced fuel rod encapsulation technology

- The most definitive solution for getting rid of defective fuel assemblies, treatment in the reprocessing plant; by choosing this solution, there is no need to assess the behaviour of this specific type of fuel assembly in an interim storage or a final disposal facility.

REFERENCES

[1] IAEA Nuclear Energy Series No. NF-T-3.6: Management of Damaged Spent Nuclear Fuel, issue IAEA 2009