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MULTIPLE WATER BARRIERS: AN ALTERNATIVE TO THE ASSESSMENT OF THE FUEL ASSEMBLIES DURING ACCIDENT CONDITIONS OF TRANSPORT

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1. INTRODUCTION

Packages for the transport of radioactive material have to comply with national and / or international regulations. These regulations are widely based on the requirements set forth by the International Atomic Energy Agency (IAEA) in the "Regulations for the Safe Transport of Radioactive Material".

In this framework, packages to transport fuel assemblies (including used fuel assemblies) have to meet the requirements for packages containing fissile material. In accident conditions of transport, the applicant for the package design approval has to show that the package remains sub-critical taking due account of the status of the contents in these conditions.

In most cases, considering water ingress in the package, it is not possible to assume that the fissile material included in the fuel assemblies is dispersed in the package with the most severe conceivable distribution regarding criticality. In order to alleviate this difficulty, during the last years, we have provided a significant better knowledge of the conditions of the fuel assemblies to be transported. This was part of the Fuel Integrity Project (FIP), which progress was regularly reported during PATRAM 2001 and PATRAM 2004 symposia.

However, for packages which encounter a large g-load during accident conditions of transport and / or which contain used fuel assemblies with very high burn-up, it can be difficult to demonstrate that the fuel assemblies are not significantly damaged. Then, to make the criticality assessment considering water inleakage into the flask and a large release of fissile material within its cavity will not allow meeting the sub-criticality criteria. For that reason, for our package designs, which use a gas - and not water - as an internal coolant and which fall into that category, we have decided to take credit of the possibilities provided by the sub-paragraph 677 (b) of the Regulations. This paragraph allows not taking into account water in the package, provided that the package exhibits “multiple high standard water barriers”.

The paper describes our experience with the implementation of this paragraph. Two different cases are considered: either a double vessel, or a double lid. It will be explained when each of these solutions is implemented, and give examples of package designs with such features, as well as the approvals which were granted for these designs in various countries.

2. REGULATORY REQUIREMENTS FOR WATER INGRESS

2.1.1 Individual package in isolation

As regards packages containing fissile material, requirements in the 2005 Edition of the "Regulations for the Safe Transport of Radioactive Material" set forth by the International Atomic Energy Agency (IAEA) dealing with water ingress when assessing an individual package in isolation are included in paragraph 677.

It is required that "*For a package in isolation, it shall be assumed that water can leak into or out of all void spaces of the packages, including those within the containment system. However, if the design incorporates special features to prevent such leakage of water into or out of certain void spaces, even as a result of error, absence of leakage may be assumed in respect of those void spaces. Special features shall include the following:*

(a) Multiple high standard water barriers, each of which would remain watertight if the package were subject to the tests in para. 682 (b), a high degree of quality control in the manufacture, maintenance and repair of packagings and tests to demonstrate the closure of each package before each shipment; or

(b) ... "

In short, the Regulations requires to considerer water ingress in the individual package in isolation, whatever its behaviour during the routine, normal or accident conditions of transport, except if the design incorporates "multiple high standard water barriers".

2.2 Package array

It can be pointed out that there is no specific and / or general requirement regarding water ingress for a package array. Water ingress has "only" to be considered as a result of the tests for demonstrating ability to withstand normal and accident conditions of transport.

3. CONFIGURATIONS FOR CALCULATIONS

In the following, the configurations which are considered for the different regulatory situations are detailed. They are focused on the hypothesis dealing with the water ingress and with the conditions of the fuel assemblies, when the package deign includes "multiple high standard water barriers" (and uses a gas as an internal coolant).

3.1 Individual package in isolation - Routine conditions of transport

For this first regulatory situation, the fuel assemblies are intact.

As regards water in the cavity, on a regulatory basis, and since "multiple high standard water barriers" are present, it could be considered that the cavity of the packaging is dry (or almost dry, that is to say with a quantity of water inside the cavity equal to the residual water in the cavity after draining and drying, when the package is loaded in a pond). However, our common practice, at least for packages which are loaded or unloaded with water in the cavity, is to consider the cavity flooded with water. This allows to take into account a human error during the draining and drying operations, or a flaw in the draining and drying system.

3.2 Individual package in isolation - Normal conditions of transport

For this second regulatory situation, the fuel assemblies are almost intact: they present no damage, except the possibility for the fuel pins to slide, until they rest on the top or bottom nozzle of the fuel assemblies.

As regards water in the cavity, the hypotheses are the same as under the routine conditions of transport.

- If all the operations are performed in a dry environment, it can be assumed that there is no water in the cavity since "multiple high standard water barriers" are present.

- If some operations before the transport entails the presence of water, we generally consider that the cavity is flooded with water (to take into account a human error during the draining and drying operations, or a flaw in the draining and drying system), but on a regulatory basis, it could be considered that the cavity of the packaging is dry (or almost dry, that is to say with a quantity of water inside the cavity equal to the residual water in the cavity after draining and drying).

3.3 Individual package in isolation - Normal conditions followed by accident conditions of transport

We design a package with "multiple high standard water barriers" when the package encounters a large g-load during accident conditions of transport and / or when it contains used fuel assemblies with very high burn-up. Then, the condition of the fuel assemblies after the accident conditions of transport (and particularly after the 9 m drop) is difficult to ascertain, or at least the assessment could be considered as controversial by the competent authority which has to approve the package design.

Then, for this third regulatory situation, we consider two sets of hypotheses.

3.3.1 In the first set of hypotheses, the fuel assemblies are considered as intact but the cavity is flooded with water. Whilst the hypothesis about the fuel assemblies can be difficult to demonstrate for such a package design with large g-load during accident conditions of transport and / or containing used fuel with very high burn-up, the second hypothesis (cavity flooded with water) is unduly pessimistic: the presence of "multiple high standard water barriers" would allow to consider a restricted quantity of water as explained in the following.

3.3.2 In the second set of hypothesis, the fuel assemblies are considered as severely damaged. This can go up to considering that the fuel assemblies are completely ruined and in the most critical arrangement (as regards geometry and moderation by the restricted quantity of water in the cavity).

As regards water in the cavity, credit is taken from the “multiple high standard water barriers”. The quantity of water is restricted to:

- the residual water in the cavity after draining and drying, if some operations before the transport entails the presence of water, and

- the water which can leak into the package during the tests for demonstrating ability to withstand accident conditions of transport, that is to say, mainly,

    - a 9 m drop onto a flat and unyielding surface, followed by a 800 °C / 30 minutes fire, and a 0.9 m immersion test during eight hours, on the one hand, and
    - a 15 m immersion test during eight hours, on the other hand.

3.4 Array of packages - Normal conditions of transport

For this fourth regulatory situation, the fuel assemblies are almost intact: they present no damage, except the possibility for the fuel pins to slide, until they rest on the top or bottom nozzle of the fuel assemblies.

As regards water in the cavity, there is no specific and / or general regulatory requirement regarding water ingress for a package array. Therefore,

- if all the operations are performed in a dry environment, it can be assumed that there is no water in the cavity,

- if some operations before the transport entails the presence of water, it can be considered that the quantity of water inside the cavity is equal to the residual water in the cavity after draining and drying.

Having said that, it must be recognized that, for simplification purpose, the hypotheses we consider for an array of packages are very often the same as for an individual package in isolation in the normal conditions of transport. For packaging transporting used fuel, this simplification in the choice of the hypotheses allows to decrease the number of calculations, while inducing no undue burden: in most cases, the neutron interaction between the packages is reduced to an insignificant value because of the large thickness of the wall of the packages.

3.5 Array of packages - Normal conditions followed by accident conditions of transport

Similarly to an individual package in isolation, because of the uncertainties regarding the condition of the fuel assemblies under the accident conditions of transport, the fuel assemblies are considered as severely damaged.

As regards, water in the cavity, and similarly to an array of packages under normal conditions of transport, there is no specific and / or general regulatory requirement regarding water package for an array of package. Therefore, the quantity of water in the cavity is restricted to this which will be "naturally" present subsequent to the tests for demonstrating ability to withstand accident conditions of transport. Consequently, the quantity of water is restricted to:

- the residual water in the cavity after draining and drying, if some operations before the transport entails the presence of water, and

- the water which can leak into the package during the tests for demonstrating ability to withstand accident conditions of transport, that is to say, mainly,

    - a 9 m drop onto a flat and unyielding surface, followed by a 800 °C / 30 minutes fire, and a 0.9 m immersion test during eight hours, on the one hand, and
    - a 15 m immersion test during eight hours, on the other hand.

As a consequence, when the neutron interaction between the packages is reduced to an insignificant value, this configuration is the same as that yielding from the second set of hypothesis for an individual package in isolation under the normal conditions of transport followed by the accident conditions of transport.

3.6 Summary

Two main conclusions can be pointed out.

- When designing a packaging with a gas (and not water) as an internal coolant, taking credit for "multiple high standard water barriers" provides a significant benefit when assessing an individual package in isolation under the normal conditions followed by the accident conditions of transport.

- Whilst the Regulations require to consider five situations (individual package / array of packages, routine / normal / accident conditions of transport), the number of situations can be drastically reduced by an adequate choice of the hypotheses, particularly for packages with thick walls (as it is the case for packagings transporting used fuel). The number of situation can fall down to two, in both cases considering an individual package in isolation.

    - Fuel assemblies are intact (except the possibility for the fuel pins to slide until they rest on the top or bottom nozzle of the fuel assemblies), and
        - if all the operations are performed in a dry environment, it can be assumed that there is no water in the cavity,
        - if some operations before the transport entails the presence of water, it can be considered that the quantity of water inside the cavity is equal to the residual water in the cavity after draining and drying, or - conservatively - it can be considered that the cavity is flooded with water.

- Fuel assemblies are completely ruined, and the quantity of water is restricted to:
  - the residual water in the cavity after draining and drying, if some operations before the transport entails the presence of water, and
  - the water which can leak into the package during the tests for demonstrating ability to withstand accident conditions of transport, that is to say, mainly,
    - a 9 m drop onto a flat and unyielding surface, followed by a 800 °C / 30 minutes fire, and a 0.9 m immersion test during eight hours, on the one hand, and
    - a 15 m immersion test during eight hours, on the other hand.

4. "MULTIPLE HIGH STANDARD WATER BARRIERS": THICK VESSEL AND DOUBLE LID

When transporting used fuel assemblies, there is a need for a significant gamma shielding to control the external radiation level. This can be provided by several means, including multiple "thin" steel walls, a steel-lead-steel wall, a "thick" cast iron wall or a "thick" steel wall.

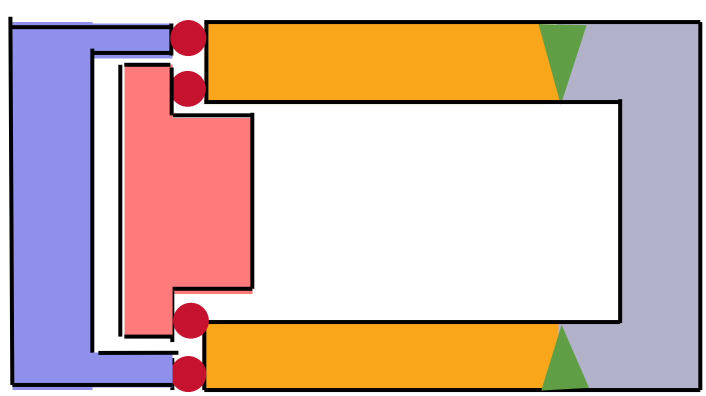
The last type of design - "thick" steel wall - provides an intrinsic high mechanical resistance. In addition, within the concept of "multiple high standard water barriers", it is fair to focus on the "barrier(s)", which is the lid(s). It is based on the fact that the Regulations refer to multiple barriers, not multiple containments, and the sense of "barrier" includes both a fixed obstacle and a moveable obstacle (the barrier). In this field, the fixed obstacle is the body of the packaging, and the moveable obstacle (the barrier) is the lid.

The first designs where we took credit of the "multiple high standard water barriers" were the casks of the TN 24 family. The TN 24 casks are dual purpose casks which have been provided by TN International to Belgian and Swiss utilities for the transport and storage of their used fuel assemblies.

These casks include:

- a thick forged steel shell and a thick forged steel bottom, both being jointed by a large penetration shell / bottom weld,

- a double lid, originally for storage purpose, each lid being fitted with a gasket which can be tested before shipment.



The original designs of the TN 24 family did not take credit of "multiple high standard water barriers". However, later on, an approval against the latest editions of the IAEA Regulations (1996 or 2005 Editions) was needed and burnup of the fuel assemblies increased. Therefore, whilst the use of "multiple high standard water barriers" appeared as a worthwhile option, the challenge was to incorporate those features on the existing design, whilst minimizing the consequences in the packaging and its operations. The idea was then to take credit of both lids, in order to have packages with "multiple high standard water barriers": this solution induces really no modification of the packagings.

We started to discuss this issue at the end of the previous millennium with French competent authority. After getting an agreement on the principle of the recognition that such a concept can meet regulatory requirements concerning "multiple high standard water barriers", we applied for an approval for several package designs of the TN 24 family.

For each package design of interest, it was demonstrated that the leak rate of the two lids after accident conditions of transport was quite acceptable regarding water ingress and subsequent (sub-)criticality. Also, it is specified that the leak rate of the lids have to be checked before each shipment, as well as during maintenance.

Approvals were granted by French competent authorities, and subsequent approval / validation were obtained in Belgium and Switzerland.

5. "MULTIPLE HIGH STANDARD WATER BARRIERS": DOUBLE CONTAINMENT

5.1 Transport of used fuel

As described in paragraph 4, one option for the design of the gamma shielding of a cask transporting used fuel is a steel-lead-steel wall.

In paragraph 4, the need to focus only on the lid(s) when assessing the acceptably of a "multiple high standard water barriers" concept is explained. However, when discussing the implementation for casks whose body is made up of a steel-lead-steel wall with French competent authority, it appeared that this restricted focus would not be accepted, because the body do not exhibit mechanical resistance as large as a thick forged steel shell.

Therefore, we decided to use a double containment for the new TN 9/4 packaging. This cask is used to transport used fuel in Switzerland, as a shuttle from the Mühleberg power plant to the Zwilag storage facility, where the fuel assemblies are transferred in a large payload dual purpose cask of the TN 24 family.

The cask itself is a rather typical cask. The “multiple high standard water barrier” is provided by a watertight canister fitted in the cavity; the fuel assemblies are loaded in a basket (the basket is in the canister).

Both the cask and the canister are designed to be leaktight: the leak rates measured after a series of physical drop tests lead to a water ingress quite acceptable regarding criticality purpose.

In addition, the leaktightness of the cask and of the canister are also checked before each shipment, as well as during maintenance.

Approval was applied for in France, as the country of origin of the design, and granted by French competent authority. Then, the approval was duly validated by the Swiss competent authority.

5.2 Transport of fresh MOX fuel

Transport of fresh MOX fuel requires a package design which meets the requirements for Type B(U) packages containing fissile material.

Transport of this fuel can be made using our FS 65 packaging. This packaging is quite compact. Subsequently, a high g-load is encountered during the regulatory 9 m drop test, and it may be difficult to convince the competent authority that the fuel assemblies are not severely damaged after this regulatory drop test. As a consequence, in order to get an approval against the latest editions of the IAEA Regulations (1996 or 2005 Editions), the use of “multiple high standard water barriers” appeared as a worthwhile option.

However, the original design of the FS 65 packaging did not incorporate such “multiple high standard water barriers”. The challenge was then to incorporate those features on the existing design, whilst minimizing the consequences in the packaging and its operations.

Several such packagings are in operation. These packagings have a single lid and it was not possible, without heavy modification to add a second lid.

In addition, the packaging designs for such material do not need a significant gamma shielding. As a consequence, and as in the example described in paragraph 5.1 for used fuel, due to the level of mechanical resistance which can be provided by the body of such a packaging, a double containment was needed to be in a position to obtain a package design approval based on “multiple high standard water barriers”.

For sub-criticality purpose and in order to assure the integrity of the fuel assembly for its use in the nuclear reactor, the fuel assembly which is transported in the FS 65 packaging is clamped in a basket that is inserted in the cavity of the packaging.

The idea was then to modify the basket to make it watertight and to consider it as one of the “multiple high standard water barriers” (and more precisely as the inner one).

The design of the basket was successfully modified. It was demonstrated that the new package design, including upgraded instructions for operations, meets all the regulatory requirements to be qualified as incorporating “multiple high standard water barriers”. This terminated with a new package design approval granted by French competent authority.

6 CONCLUSION

For this last decade, one of the most challenging raising technical issue in the assessment of the safety of package design containing fuel assemblies is the evaluation of the fuel assemblies. This is of particular importance for the packagings containing fresh or used fuel and encountering high g-load, as well as for those transporting used fuel with high burn-up. Designing packages incorporating “multiple high standard water barriers” allows to alleviate this issue, and then to get package design approvals with a robust technical basis and on a sound administrative ground.

TN International, an AREVA subsidiary, has successfully incorporated such features on both existing designs (without modification of the packaging or with minor modifications of the packaging, and always with limited consequences on the operations) and new designs. Approvals were applied for by TN International: they were then granted by French, Belgian and Swiss authorities.