THE ESBB PACKAGE FOR THE TRANSPORT AND INTERIM STORAGE OF MOX FUEL ASSEMBLIES AND PINS

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SUMMARY

The 205 fuel assemblies manufactured for the SNR 300 fast breeder reactor are currently stored at different locations in Germany and abroad. Due to various reasons the fuel has to be moved to a single storage in Germany. Furthermore, 271 fuel pins of SNR 300 type and approx. 800 MOX fuel pins are to be stored at the same place. Following requirements were specified for the packaging:

- licensed as type B(U) package
- a high level containment for the assemblies and pins;
- interim storage must not affect the type B(U) quality of the package;
- transports to be carried out with the NCS security vehicle;
- easy handling at current and future storage facilities;
- option to load a high number of packages into a heavy interim storage cask.

The ESBB (single SNR fuel assembly container) developed by NCS fulfills these requirements. It can contain a single SNR 300 fuel assembly, max. 91 SNR 300 fuel pins or 40 MOX fuel pins. The Plutonium content may be up to approx. 10 kg.

The ESBB consists basically of a stainless steel tube, a welded bottom and a plug at the top side which is welded after loading. All welding seams are checked using the Helium leak tightness check method. Stainless steel parts and the welding seams connecting them define the containment.

The main dimensions of the package are: length 4538 mm, diameter 159 mm, useful length 3708 mm and useful diameter 139 mm. The mass of the loaded package is approx. 340 kg.

The type B(U) license for the ESBB was issued by the German competent authority in December 2000 and validated in the U.K. in July 2001. The safety expertise was based on tests with three prototypes and calculations with approved codes. Currently (September 2001), 230 ESBBs are being fabricated of which 85 are completed and approx. 50 packages are loaded and ready for transportation.

This paper will provide an overview of the design of the package, the loading and handling procedures and the safety analysis and summarizes the tests results.

INTRODUCTION

The 205 fuel assemblies manufactured for the SNR 300 fast breeder reactor are currently stored in Hanau, Germany, and in Dounreay, U. K. Because the SNR project was not pursued further since 1991 the assemblies are not irradiated. Due to various reasons the fuel has to be moved to a single storage in Germany. Additionally, there are 271 surplus fuel pins of SNR 300 type from the fabrication which are to be stored in the same storage. Furthermore, from residues in the shutdown MOX plant Hanau some 800 MOX storage pins are being fabricated which need to be stored in the same manner.

EARLIER CONCEPTS

In a series of studies it was established that the handling of heavy transport and storage casks at the current storage locations as well as the transport of these casks to an interim storage facility is not feasible [1]. Furthermore, it was shown that unloading of a lightweight transport container and handling of an unpacked fuel assembly is not within the scope of the license of an interim storage facility.

REQUIREMENTS FOR THE PACKAGE

Based on the results of the above mentioned studies, requirements were specified for the packaging. Due to the high radioactivity of the content a type B(U) package is required which provides containment for the assemblies and pins. In order to satisfy storage requirements the quality of this containment must be very high and must not be affected by environmental conditions to be expected during interim storage. After interim storage transport must be possible without repacking the fuel, i.e., it must be guaranteed that the package still fulfills type B(U) requirements after some decades in an interim storage. With respect to physical protection requirements transport must be possible with the NCS security vehicles, thus limiting the size and gross weight of the package. Naturally, the handling of the package at current and future storage facilities should be as easy as possible. Furthermore, there should be an option to load a high number of packages into a heavy interim storage cask. The goal of this last requirement is to reduce requirements on the storage facility by adding safety through the heavy storage cask.

CONTENT

As content following material is specified:

- 1 SNR 300 fuel assembly
- max. 91 SNR 300 fuel pins
- max. 40 MOX fuel pins

The SNR 300 fuel assembly has a length of 3700 mm and its hexagonal cladding box has a maximum diameter of 131 mm. The length of the active zone is 950 mm, the breeder zones at each end are 400 mm. Each assembly consists of 166 fuel pins with a diameter of 6 mm. The maximum mass of Plutonium is 10.1 kg per assembly with a Pu_{fiss} content of 7.1 kg. There is up to 1 kg Am-241 present. The thermal power is limited to 225 W and the total mass is 140 kg per assembly. In total there are 205 fuel assemblies containing approx. 1600 kg of Plutonium.

The SNR 300 fuel pins are residues from the fabrication of the assemblies. The length is 2475 mm, the maximum mass of Plutonium is 62 g per pin with a Pu_{fiss} content of 53 g. There are up to 8 g Am-241 present. The thermal power is limited to 1.6 W and the total mass is 0.5 kg per pin.

The MOX fuel pins have a length of 3680 mm, a diameter of 10.75 mm and the length of the active zone is 3530 mm. The fissile content can consist of U-235 and/or Pu_{fiss} and is limited to a maximum of 10% of the total heavy metal. The cladding material is Zirkaloy. The thermal power per pin is 2.5 W and the mass is 3 kg.

THE DESIGN OF THE ESBB

The design of the ESBB with its content is shown in Figure 1. It consists of a stainless steel tube (1), a welded bottom (2), a welded main plug (3) at the top side and shock absorbers (4, 5) at both ends of the container. The plug is equipped with a valve (6) for filling the cavity with Helium after loading. This coupling is covered by a valve plug (7) when presented for transport.

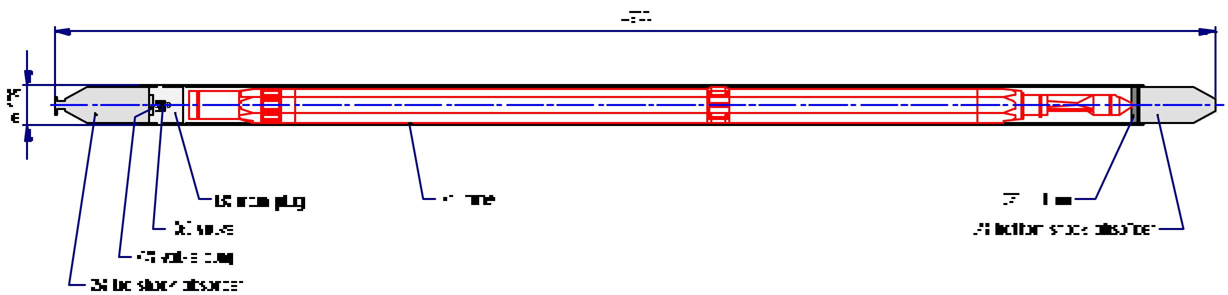

Figure 1: The Design of the ESBB

The containment consists of the steel tube (1), the welded bottom (2), the welded main plug (3) and the welded valve plug (7). The stainless steel parts and the welds are technically leak tight. The quality of this containment is superior to containments based on gaskets. In dry conditions the duration of the interim storage has no influence on the quality of steel and welds. It can therefore be assumed that even after some decades in interim storage the type B(U) quality of the package is maintained. For the transport with the NCS security vehicles a special transport frame was designed which allows easy loading and unloading as well as adequate tie-down of the packages in the vehicles. Due to its low gross weight handling of the package is easy and can be accomplished by simple means. For horizontal operation the package can be handled with slings or fork lifter. In vertical orientation specially designed tools are used for the empty and loaded containers. With respect to the optional loading into a heavy interim storage cask, it is foreseen to load 52 ESBB packages into one cask.

SAFETY ANALYSIS

The analysis of the mechanical safety comprised normal and test conditions. For normal conditions handling, loading and unloading as well as transport were analysed. All calculated results were well within the acceptable range. The analysis of the tests for demonstrating the ability to withstand accidental conditions of transport was compared to test results described below and found to be in good agreement.

The thermal analysis was carried out with the computer code HEATING [2]. All results were within the limits given by the Regulations. The temperatures are so low that interim storage does not affect the properties of the packaging and the content. For packages loaded with SNR 300 fuel assemblies with a thermal power as high as the certified limit, the surface temperatures may exceed the limit of 85°C specified in the Regulations for exclusive use. A transport frame is then required which prevents the access to the surface adjacent to the active zone of the fuel. The transient calculations for the analysis of the thermal test showed that the temperature of the outer surface of the package rises to almost 800°C and the temperature of the cladding to approx. 600°C. Leak tightness of container and pins is not affected by these temperatures.

Due to the welded containment activity release is of no concern.

Dose rates were calculated with the computer codes QADS [3] and SAS2H [4]. The calculations show that the total dose rates are well within the limits for exclusive use transports. However, for packages loaded with SNR 300 fuel assemblies additional shielding at the vehicle is required to keep the limits specified in the Regulations for the vehicle.

The criticality analysis with the computer code SCALE [5] comprised the analysis of the single package, an array of five times “N” of undamaged packages and an array of two times “N” of damaged packages. “N” was derived to be 18. With respect to Table X of TS-R-1 max. 36 packages can then be transported under exclusive use.

TESTING OF THE PACKAGE

Drop testing of the package was carried out by the "Bundesanstalt für Materialprüfung und -forschung (BAM)" in its test centre in Lehre. The test program is listed in Table 1.

Test No.	Drop Height	Drop Orientation	Target	Prototype no.
1	9 m	vertical onto bottom side	IAEA	1
2	9 m	vertical onto plug side	IAEA	2
3	9 m	horizontal	IAEA	3
4	9 m	slap down, primary impact onto plug side	IAEA	2
5	1 m	horizontal, impact at package centre	IAEA/bar	2
6	1 m	oblique, impact at plug welding seam	IAEA/bar	2

Table 1: Test Program for the ESBB

For the tests 3 prototypes were used. Prototype 1 was used for tests no. 1, prototype 2 for tests no. 2, 4, 5 and 6 and prototype 3 for test no. 3. As the instrumentation failed during the first 9 m horizontal drop, a second 9 m horizontal drop was carried out with the same prototype 3 in the same orientation.

The design of prototype 1 was in the plug section different from the final design. It was closed with a threaded plug and sealed by a metallic O-ring. The bottom section and the container body were identical to the final design. The vertical 9 m drop onto the bottom shock absorber resulted in a symmetrical deformation of 100 mm, a maximum deceleration of 350 g and a rigid body deceleration of 150 g, which was well in agreement with analytical calculations. Visual inspections and measurements showed that there was no deformation of the container body. The decelerations measured at the foot of the fuel assembly were much higher and reached some 1600 g. This was caused by relative movements of the fuel with respect to the container due to a gap of approx. 10 to 20 mm. Visual inspection of the assembly showed a deformation of approx. 70 mm of the foot. The pin section of the assembly showed no deformations at all. The bottom was tested for surface cracks and leaks. A standard helium leak rate not exceeding 10^{-8} Pa m^3 s^{-1} was established. The sealing of the plug side did not comply with the requirements. Therefore the design was modified as described above.

The vertical 9 m drop onto the plug shock absorber with prototype 2 resulted in a symmetrical deformation of 120 mm, a maximum deceleration of 1100 g and a rigid body deceleration of 160 g. Although the maximum deceleration is much higher than for the bottom the rigid body deceleration is almost the same. One reason for the higher maximum deceleration may be the different mechanical properties of the assembly foot and head. Visual inspections and measurements showed no deformation of the container body, the same result as after the drop onto the bottom. The decelerations measured at the foot of the fuel assembly reached some 1500 g. Visual inspection of the assembly showed no deformation.

Figure 2: Prototype 3 before the 9 m vertical drop test

The horizontal 9 m drop onto the container side with prototype 3 was repeated twice because the instrumentation failed during the first drop. As measurements after the first drop showed only small deformations of the container body it was decided to repeat the drop in the same orientation. Thus, results from the second drop could be used to estimate the results of a single drop. The circular cross section of the container body had become elliptical by 4 mm, measured in the centre of the packaging. The elongation measured was less than 0.4% compared to the breaking elongation of at least 40%. Decelerations measured where up to 9000 g as expected from the very small deformations. The visual inspection showed except of the change of the shape of the cross section and a marked line at the line of impact no other indications of the strain. Prototype 3 is shown in Figure 2 before the 9 m drop test and in Figure 3 after the test. The inspection of the assembly established deformations of the cladding box of 4 mm in drop direction.

Figure 3: Prototype 3 after the 9 m vertical drop test

Prototype 2 was used for the 9 m slap-down drop after the vertical drop. The primary impact was on the plug side. The test resulted in a bending of the longitudinal axis of the container. The deviation of the centreline to a straight gauge was maximum 30 mm. The cross section of the container body changed from no change at the plug end to 4 mm elliptical at the bottom side. The elongation measured in the centre of the container was less than 0.2%. Decelerations were 900 g at the plug end for the primary impact, 8500 g for the secondary impact at the bottom side and 1900 g for the third impact at the plug side. The visual inspection of container and assembly showed less damage than after the horizontal 9 m drop.

After the 9 m drops two penetration tests were carried out with prototype 2. As expected, the strain caused by these tests was much less severe than by the 9 m drops. Additional local deformations were in the range of 1 to 2 mm. The oblique drop onto the welding seam between plug and container body – the edge of the bar hit the seam exactly – resulted in no visible deformation of the weld.

After each drop test the welding seams of the containment were tested for leaks and surface cracks. A standard helium leak rate not exceeding 10^{-8} Pa m^3 s^{-1} was established in all cases.

LICENSING

The certificate of package approval for the content SNR 300 fuel assemblies was issued in December 2000, the current revision expires end of 2003. This certificate was validated in U.K. in July 2001. For the SNR 300 fuel pins and the MOX pins the certificate of package was applied for in January 2001 and is expected to be issued in fall 2001.

MANUFACTURING AND LOADING

The ESBBs are manufactured in 4 individual parts container body (1 + 2 + 4), main plug (3 + 6), valve plug (7) and lid shock absorber (5). These parts are packed separately and shipped to the loading station. The loading can be in vertical or horizontal orientation. After the fuel is loaded into the cavity the plug is welded to the container body. For this welding operation an orbital welding head for high quality welds is used. This welding operation is shown in Figure 4. The welding seam is then allowed to cool down which may take several hours. For the leak test the cavity is filled with helium and an adapter is used to provide the test space. For the helium leak test of the closure disk a special test piece has been designed which fills up the space between closure disk, plug and valve and releases continuously a small stream of helium. The helium filled test piece is inserted, the closure disk screwed in and welded with a special welding head. An adapter is then used for the helium leak test. The final examination is a check for surface cracks on the welding seams by using the dye penetration method. After installation and fixation of the plug shock absorber the package is ready for the contamination and dose rate checks before transport as well as for the application of the required labels.

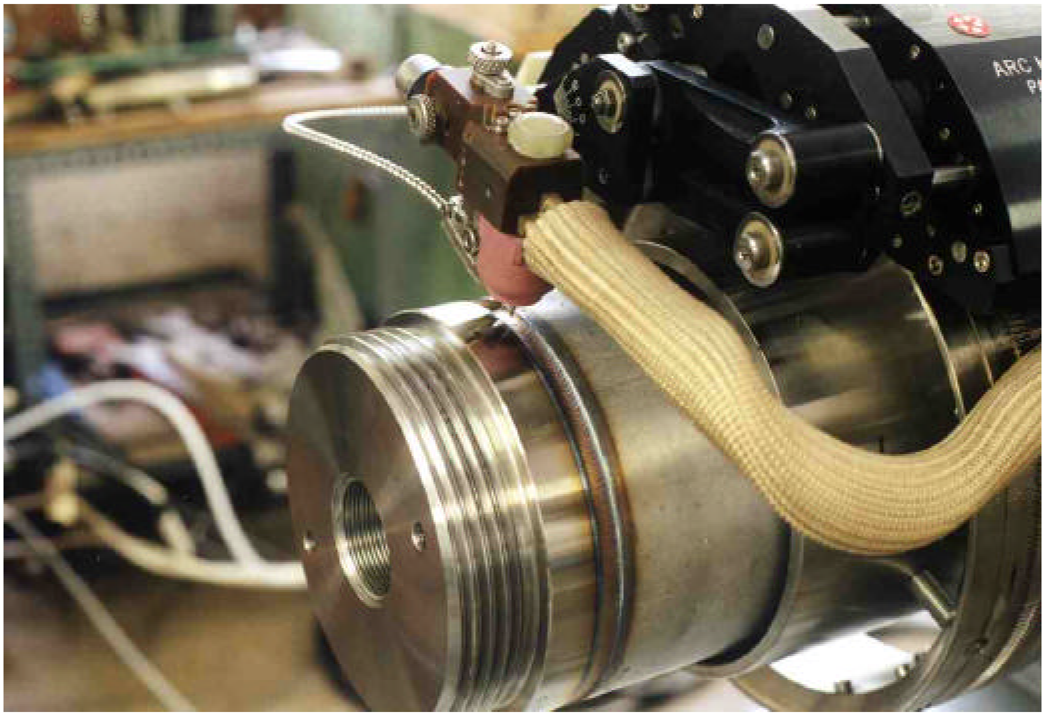

Figure 4: The main plug is being welded to the container body

According to current contracts in total 230 ESBB will be manufactured. 85 of these are already finished. Loading commenced in July 2001 and at the time of PATRAM 2001 approx. 50 packages are ready for transport.

QUALITY ASSURANCE

Quality assurance (QA) is a central part in the development, manufacturing and loading of the ESBB. All documents required are written, checked and released in accordance with the QA system of NCS. This QA system is regularly updated and certified by external certification agencies to comply with ISO 9001 and KTA 1401.

The QA documents filed together with the application for package approval are checked and released by BAM. These documents include drawings, specifications and procedures for manufacture and handling. Based on the specifications manufacturing plans are set up by the manufacturer which are pre-checked by NCS and the expert of BAM. These manufacturing plans are the checklist for the inspections before and during manufacture and before commissioning and are the basis of the final documentation. Use of the packaging is only permitted after the expert of BAM has issued a final examination certificate.

FUTURE DEVELOPMENTS

Recently, the use of the ESBB package design for PuO_2 powder packed in primary cans was studied. This study showed that the design could be used for such content. Depending on the specification up to 35 kg of Plutonium could be transported. With respect to handling restrictions in the facilities the length of the packaging could be reduced. The package has to be opened by cutting. Reuse of the major part is possible if the small loss during each cut is taken into account in the initial length of the container body and the adaptation of spacers. In comparison to other designs, the package design ESBB has advantages with respect to capacity and hence transport frequency and costs. However, further work is necessary to finalize the safety analysis of the package.

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