Proceedings of the 15th International Symposium on the Packaging and Transportation of Radioactive Materials
PATRAM 2007
October 21-26, 2007, Miami, Florida, USA

RETURN OF THE FUEL FROM THE GERMAN COMPACT SODIUM-COOLED NUCLEAR REACTOR FACILITY KNK II WITH THE CASTOR® KNK

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ABSTRACT

The Compact Sodium-Cooled Nuclear Reactor Facility KNK II, located at the German Research Centre Karlsruhe has been operated from 1977 to 1991 as a prototype facility for the Fast Breeder Reactor SNR 300. The fuel of the KNK II consisted of fuel assemblies (FA) with highly enriched Uranium-/Plutonium-MOX fuel.

The FA were transported to C.E.A (France) in 1993 for reprocessing. However, due to the low solubility of the MOX fuel 2413 fuel rods from 27 FA could not be reprocessed. They were encapsulated and stored in a pool of the French research centre Cadarache.

In a project organized by the Research Centre Karlsruhe, these fuel rods will be returned to Germany to be stored for a maximum of 40 years in the interim storage facility ZLN near Greifswald.

For the return and the interim storage of the fuel, 4 transport and storage casks of the type CASTOR® KNK were designed by GNS Gesellschaft für Nuklear-Service mbH especially for this project. Regarding criticality safety, a significant challenge for the cask design was the fuel composition with an uranium enrichment of up to 93 % ^{235}U and a plutonium content of up to 35 % of the total heavy metal mass. Due to these high fissile contents of the fuel, the cask baskets were equipped with additional absorber components (borated aluminium sheets with 20 w/o B_4C) to limit the necessary cask number.

The transport was investigated by Nuclear Cargo + Service GmbH. Since C.E.A. at Cadarache has no railway access, the 4 heavy CASTOR® KNK casks must be transported in one batch by road to a railway station near Cadarache and from there in one batch by rail to the interim storage facility ZLN. Rail transports with nuclear materials of this kind will be performed for the first time in Germany.

The project started in September 2001 and the planned project deadline is at the end of 2008. The paper will give an overview of the actual status of the project, the design characteristics of the CASTOR® KNK and the transport logistics.

INTRODUCTION

The Compact Sodium-Cooled Nuclear Reactor Facility KNK II, located at the German Research Centre Karlsruhe has been operated from 1977 to 1991 as a prototype facility for the Fast Breeder Reactor SNR 300. The fuel of the KNK II consisted of fuel assemblies (FA) with highly enriched Uranium-/Plutonium-MOX fuel.

The FA were transported to C.E.A (France) in 1993 for reprocessing. However, due to the low solubility of the MOX fuel 2413 fuel rods from 27 FA could not be reprocessed. They were encapsulated and stored in a pool of the French research centre Cadarache.

In a project organized by the Research Centre Karlsruhe, these fuel rods will be returned to Germany to be stored for a maximum of 40 years in the interim storage facility ZLN near Greifswald.

In addition KNK II-fuel, which is currently stored at the research centre Mol in Belgium, and fuel from the former German nuclear ship Otto-Hahn, which is currently stored at the German research centre GKSS in Geesthacht, were integretated into this project.

For the return and the interim storage of the total fuel, 4 transport and storage casks of the type CASTOR® KNK were designed by GNS Gesellschaft für Nuklear-Service mbH especially for this project. In the following an overview will be given about the fuel, the fuel cans, the loading and transport logistics and the design features as well as the safety proofs of the CASTOR® KNK.

HISTORY OF THE KNK II-FUEL

After the shut-down of the Compact Sodium-Cooled Nuclear Reactor Facility KNK II in August 1991 the spent fuel of the 1st and 2nd reactor core (9602 fuel rods) was transported to C.E.A (France) for reprocessing.

In February 1996 C.E.A informed, that reprocessing in France was not possible for 2413 fuel rods, because of their low solubility. After some further investigations, i. e. searching for new solvers, C.E.A informed in November 1999, that reprocessing was definitely not possible for these fuel rods. The Forschungszentrum Karlsruhe GmbH and the responsible German ministry decided to return the fuel back to Germany for interim storage without reprocessing.

Currently, most of the KNK II-fuel is stored in a wet storage facility (PEGASE) in the research centre Cadarache, encapsulated in 33 cans of type KfK/CEA.

In addition, KNK II-fuel consisting of 52 fuel rods and a test element with 19 fuel rods is currently stored in two cans of type CEA in a dry storage facility in the research centre Mol in Belgium.

After the start of the project the responsible German ministry proposed to integrate also fuel from the former German nuclear ship Otto-Hahn into the return project. This fuel consists of 52 low enriched fuel rods, some of them with defects, and pellet-fragments of the defective fuel rods. Currently, this fuel is stored in a can of type OH in a dry storage facility in the research centre GKSS in Germany.

FUEL DATA

The main data of the fuel (KNK II and Otto-Hahn) is approx.:

- total heavy metal mass : 620 kg
- total mass U-235 : 170 kg
- total mass Pu : 90 kg
- max. initial enrichment U-235 : 3 - 93 %
- max. Pu-content : 35 %
- max. burn-up : 137 G Wd/tHM
- decay heat : 1600 W
- total activity : 12.5 PBq

QUALIFICATION STATUS OF THE CANS

Since the fabrication documentation of the 35 cans of type KfK/CEA were found to be incomplete and these cans were not designed to withstand the mechanical accident conditions of transport /1/ for the CASTOR® KNK, it was decided to overpack these cans into 35 existing cans of type Phenix.

The Phenix-cans were constructively adapted by GNS (shortening of the can tubes, optimization of the lid system) and requalified by German experts for the transport and the interim storage inside the CASTOR® KNK. Loading and leak-tight welding of the Phenix-cans will be performed in a hot cell facility ("STAR") in the research centre Cadarache.

The one can of type OH (for the fuel of the nuclear ship Otto-Hahn), a new construction under consideration of the transport and the interim storage qualification requirements in the CASTOR® KNK, will be loaded and leak-tight welded in the research centre GKSS.

LOGISTICS OF THE FUEL RETURN

The two cans of type CEA will be transported from Mol to Cadarache with the transport cask NCS 45 to be also loaded and welded there into cans of type Phenix. The transport of the can of type OH from Geesthacht to Cadarache will also be performed with the transport cask NCS 45. Both transports will be organized and performed by Nuclear Cargo + Service GmbH.

After the cans of type Phenix are loaded (with the 33 cans of type KfK/CEA from the wet storage facility PEGASE) and welded in the hot cell facility STAR of Cadarache, they are interim stored in the dry storage facility CASCAD of Cadarache.

Later, 3 casks CASTOR® KNK will be completely loaded with 9 Phenix-cans each in CASCAD, the 4th cask will be partly loaded with 6 Phenix-cans in CASCAD and then completely loaded in STAR with additional 2 Phenix-cans (fuel from Mol) and the OH-can. In the following, the 4 casks will be transported in one batch ("four-pack") to the interim storage facility ZLN near Greifswald. This transport is planned for the end of 2008. Since C.E.A. at Cadarache has no railway access, the 4 heavy CASTOR® KNK casks must be transported in one batch by road to a railway station near Cadarache and from there in one batch by rail to the interim storage facility ZLN. Rail transports with nuclear materials of this kind will be performed for the first time in Germany. The transport will also be organized and carried out by Nuclear Cargo + Service GmbH. A logistic flow chart of the fuel return is shown in Figure 1. The transport vehicles are shown in Figure 2.

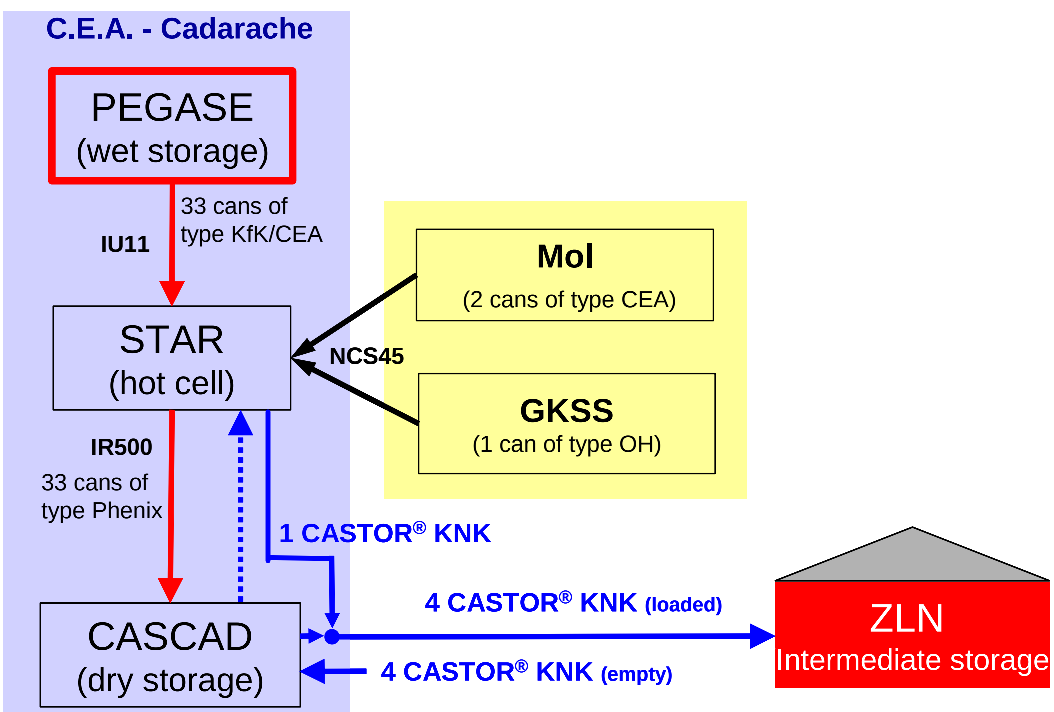
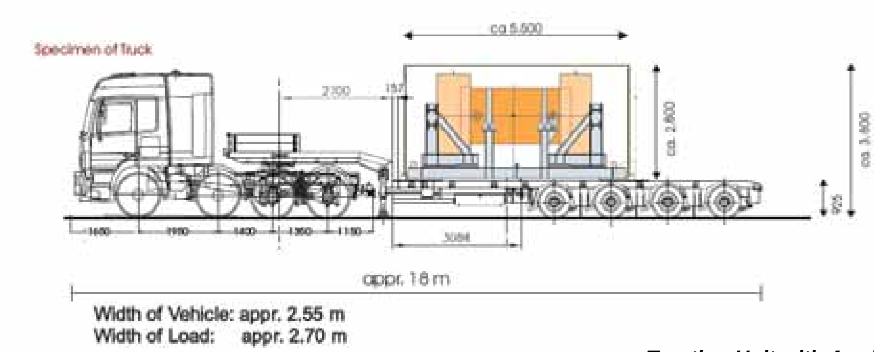


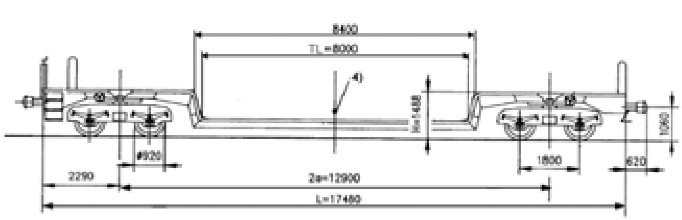
Figure 1. Logistic flow chart of the fuel return

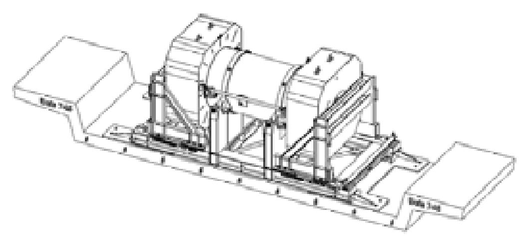
a.) Road Transport



Traction Unit with 4-axle-Semi Trailer

b.) Rail Transport





Railwagen Type Uaai .. ***Rail Transport Configuration***

Figure 2. Transport vehicles

DESIGN FEATURES OF THE CASTOR® KNK

The transport and storage cask CASTOR® KNK consists of a thick-walled cylindrical cask body, which contains a basket (one variant for 9 Phenix-cans or one variant for 8 Phenix-cans and one OH-can) for holding the cans with the inventory and is closed with a primary and a secondary lid with the respective bolts and seals.

The cask body is made of ductile cast iron, the two lids are made of stainless steel. Above the secondary lid a guard plate of unalloyed structural steel is arranged for the protection of the lid system. Both basket variants are provided with nine positions each holding the cans. The cask is a transport packaging and thus equipped with lid side and bottom side shock absorbers. On the means of transport, the cask is covered by a transport hood that constitutes the easily accessible surface in the sense of the transport regulations /1/. Figure 2 shows two 3D-views of the cask.

The main dimensions of the cask are approx.:

- outer diameter (without shock absorbers) : 1380 mm
- width (with shock absorbers) : □ 2090 mm
- height (without shock absorbers) : 2784 mm
- height (with shock absorbers) : 3906 mm
- inner diameter (cask body) : 640 mm
- height of cask cavity : 2014 mm

The maximum mass (loaded, with shock absorbers) is approx. 32,500 kg, the mass without shock absorbers (loaded) is approx. 26,300 kg.

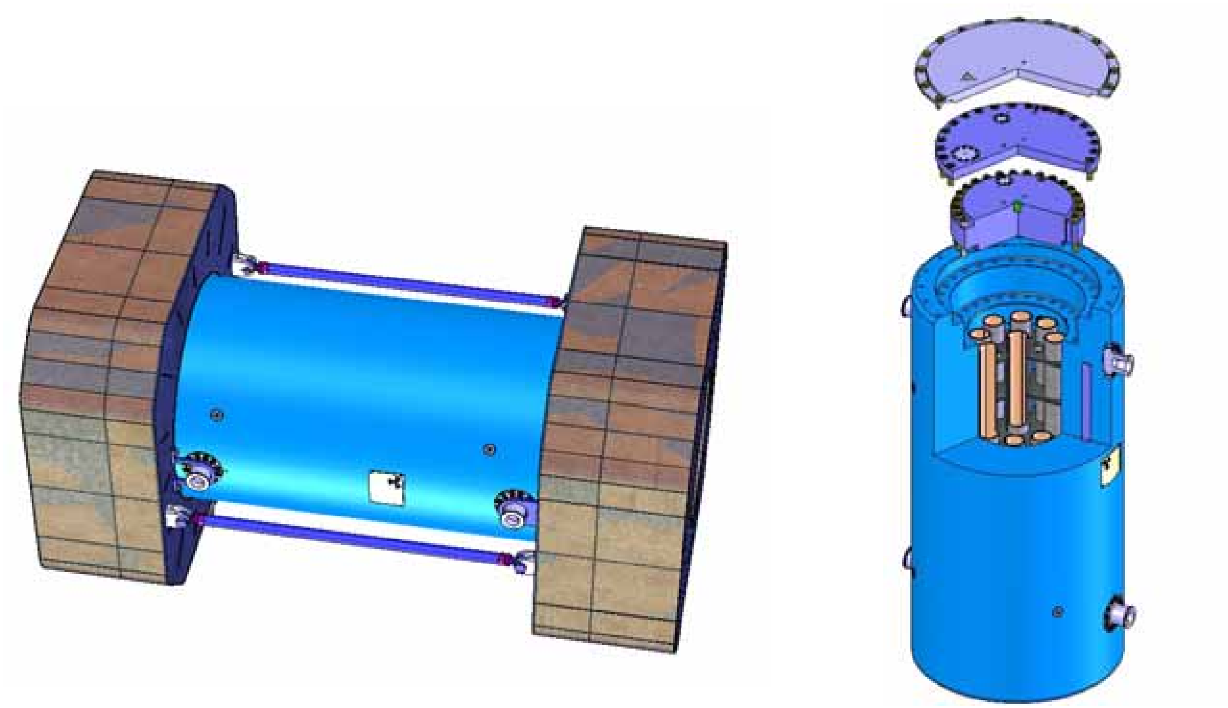


Figure 3. 3D-views of CASTOR® KNK

The applicated main inventory data of the cask (maximum values) are approx.:

- decay heat : 570 W
- total activity : $4.7 \cdot 10^{15}$ Bq
- inventor mass : 500 kg (without mass of cans)
- heavy metal mass : 210 kg
- total mass U-235 : 67 kg
- total mass Pu : 32 kg

SAFETY PROOFS FOR THE CASTOR® KNK

The safety proofs that the design of the CASTOR® KNK meets the requirements for type B(U)F packages /1/ are performed by calculations, by referring to earlier sufficiently similar proofs regarding comparable cask types and by the results of a drop testing programme with a test specimen of the can of type Phenix.

Exemplary for the calculational proofs Figure 3 shows the Monte Carlo calculation model for the proof of the criticality safety. The proof was performed with the programme system SCALE 4.4a /2/ for a covering hypothetical cask loading with 9 cans with the highest fissile content for routine and normal conditions of transport and for the real can loadings under accident conditions of transport.

Beside the limitation of the fissile content and the geometric arrangement and positioning of the fuels in the cask cavity, the subcriticality is ensured by using borated aluminium sheets inside the basket structure as absorber components. These sheets are produced by a powder metallurgical fabrication process and are made of an alloy Al+20 w/o borcarbide B_4C.

A special qualification programme was performed by GNS to develop this material.

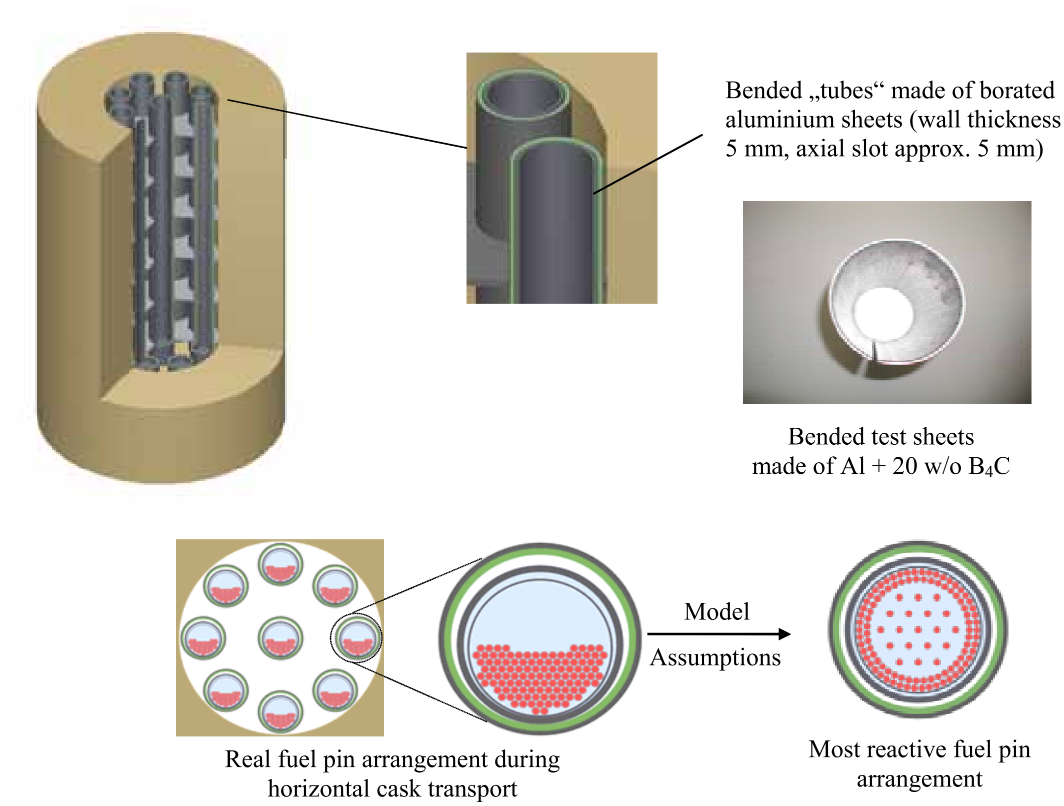


Figure 4. Criticality Calculation Model

The maximum effective neutron multiplication factor results for accident conditions of transport to $k_{eff} + 2 \cdot \sigma + \Delta k_u = 0.9324$ (with k_{eff} and σ as the calculated average of the Monte Carlo result and its standard deviation and Δk_u as a conservative estimate of the combined bias and uncertainties). Concerning the inner and outer (water) moderation, the maximum k_{eff} results for a complete dry cask cavity and water flooded cans.

CONCLUSIONS

The CASTOR® KNK cask is the essential part of the return project for nuclear fuels from the KNK II-reactor facility. The cask is designed for the transport and the interim storage of the fuels and the design meets the requirements of the international regulations for type B(U)F packages.

According to the project time schedule, it is planned to load 4 casks inside the research centre of Cadarache (France) and to transport these casks to the interim storage facility ZLN in Germany at the end of 2008.

The transport organization and the logistics are very challenging and complex under consideration of the tight project time schedule, the requirements of the heavy load road transport, the defined moment of transshipment from road to rail, bundling of transports as well as the requirements for the rail transport to Germany.

REFERENCES

/1/ IAEA Safety Standards Series No.TS-R-1 (ST-1, Revised), Regulations for the Safe Transport of Radioactive Material, 1996 Edition (as amended 2003)

/2/ SCALE 4.4a: Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation for Workstations and Personal Computers Oak Ridge National Laboratory NUREG/CR-0200 ORNL/RSIC, CCC-545, 2000