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The use of the CONSTOR® cask concept for light water reactor fuel

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Abstract

The company GNB has developed a new dual-purpose cask concept – the CONSTOR® – which fulfills both the safety criteria for storage and for transport. Two variants of the CONSTOR® cask are designed for 32 PWR or 69 BWR spent fuel assemblies (SFA) with high burnups (up to 60 GWd/MTU) and high heat loads (up to 32 kW/cask).

The CONSTOR® consists of a thick-walled cylindrical sandwich cask body, including an inner liner fabricated from stainless steel, and an outer liner fabricated from fine-grained steel. The liners are welded to a massive stainless steel head ring to form a double barrier containment. For additional gamma and neutron shielding, the cavity between the liners is filled with CONSTORIT consisting of iron aggregate and cement. Heat-conducting elements are arranged inside the CONSTORIT layer, and on the outer cask surface there are fins improving the dissipation of the decay heat. A double lid-system is available in a welded or a bolted version. Depending on the fuel type, two different baskets are designed for the CONSTOR® cask.

To fulfill the hypothetical accident condition requirements for transport, an overpack and two impact limiters are attached to the loaded cask to form the transport package.

"Design by analysis" is used to demonstrate regulatory compliance. Analyses are performed using IAEA- and NRC-accepted codes and conservative assumptions.

In a special experimental programme, the mechanical and thermodynamical properties of CONSTORIT were verified and the reference values required for the safety analyses were determined. The thermal and mechanical behaviour of the CONSTOR® design has been tested by an extensive test programme using a ½ scale model. A full-scale prototype drop test series will be performed in the near future. At PATRAM, a prototype CONSTOR® transport package consisting of a cask with dummy basket, an overpack and two impact limiters will be subjected to 9-meter free drop test at Horstwalde near Berlin.

1. Introduction

The CONSTOR® (CONtainer for Storage and Transport Of Radioactive Material) is a steel-sandwich cask with concrete as additional shielding material. It is a new generation of casks for transport and storage of SFA and has been developed as a cost-effective design by using conventional mechanical engineering technologies and commonly available materials. The CONSTOR® concept complies with the international regulations of the IAEA for type B(U)F package designs. It also fulfils the requirements of the US-NRC for long-term interim storage according to 10 CFR 72 and for transport according to 10 CFR 71.

The CONSTOR® cask is designed for the transport and storage of 32 spent fuel assemblies from pressurized water reactors (CONSTOR® V/32) or 69 spent fuel assemblies from boiling water reactors (CONSTOR® V/69). The CONSTOR® V/32 and the CONSTOR® V/69 are a further development of the CONSTOR® RBMK. The basic design which was used there, was adapted with a modified concrete formulation and a modified wall structure.

2. Overview

2.1 Dimensions of the CONSTOR® V

The dimensions of the CONSTOR® V are given in table 1.

	CONSTOR® V/69	**CONSTOR® V/32**
Total length	5 180 mm	4 960 mm
Outer diameter (incl. fins)	2 452 mm	2 452 mm
Cavity length	4 525 mm	4 305 mm
Cavity diameter	1 752 mm	1 752 mm
Cask weight loaded: Storage	110 000 kg	113 000 kg
Cask weight loaded: Transport	181 000 kg	184 000 kg

Table 1: Cask dimensions

2.2 Cask contents

The CONSTOR® cask concept is designed to accommodate spent fuel assemblies with the following specifications:

	CONSTOR® V/69	**CONSTOR® V/32**
Number of SFA per cask	69 from BWR (incl. channels)	32 from PWR (incl. control components)
Enrichment in U-235	= 5,0 wt-%	= 5,0 wt-%
Maximum average burnup	= 60 GWd/MTU	= 60 GWd/MTU
Cooling time	= 5 years	= 5 years
Total heat output per cask	= 32 kW	= 32 kW

Table 2: Cask contents

3. Design features of the CONSTOR®

3.1 Cask body

The cask body of the CONSTOR® V/32 and the CONSTOR® V/69 consists of the following components:

- Outer liner: ferritic steel
- Inner liner: austenitic steel
- Bottom plate (outside) ferritic steel
- Bottom plate (inside) austenitic steel
- Wall structure: CONSTORIT® (iron aggregate and hardened cement paste) including copper heat conducting elements
- Head ring: forged austenitic steel

The longitudinal section of the CONSTOR® cask is shown in Fig. 1.

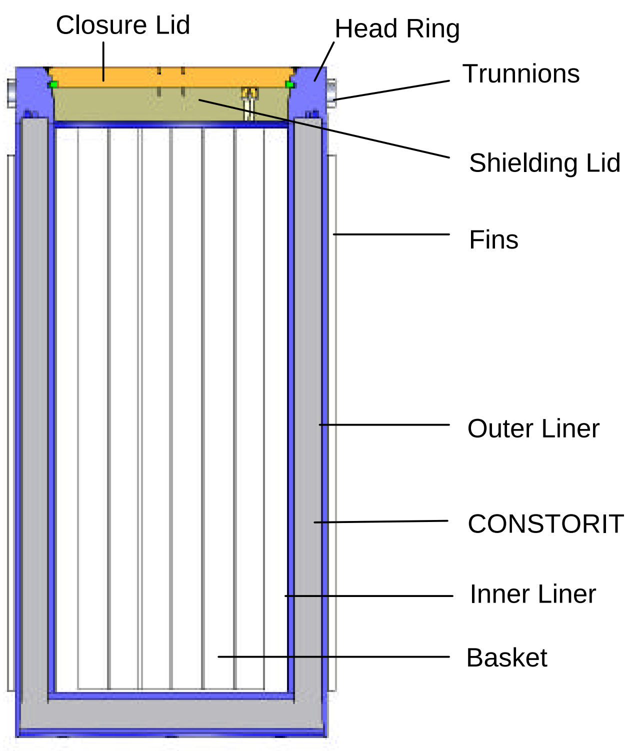

Figure 1: Cask components

3.2 Cask lid system

The primary lid is a shielding lid and retained by a retaining ring. Two lid systems are available for the secondary lid of the CONSTOR® cask:

- Variant A: secondary lid bolted and sealed with 2 metallic gaskets or
- Variant B: secondary lid welded, sealing ring welded across the welding seam.

3.3 Basket

For PWR fuel assemblies the basket consists of welded steel cells which provide accommodation for the fuel assemblies and mechanical strength. Between the cells borated aluminium plates are arranged in an egg-crate structure which provide sufficient heat removal and criticality control.

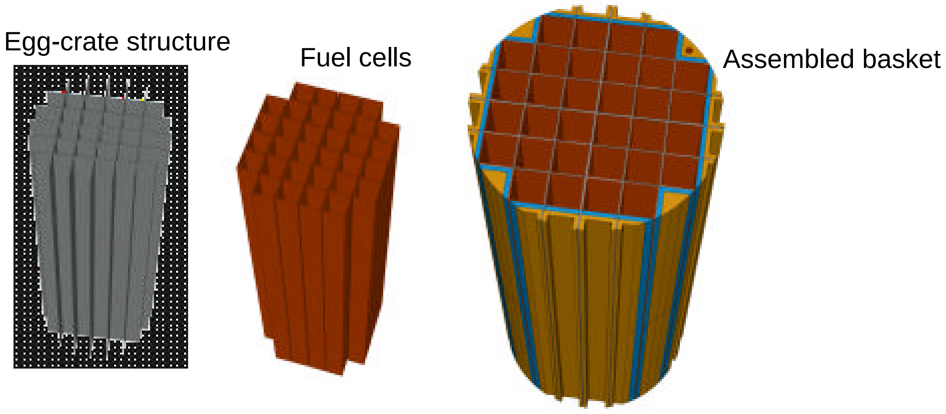

Figure 2: Basket design for the CONSTOR® V/32

For BWR fuel assemblies the basket consists of steel disks for mechanical strength and a borated aluminum egg-crate structure between the disks for heat removal and criticality control. Each egg-crate structure component and the area between the bottom plate and the lowest basket disk are surrounded by steel rings to improve the shielding of γ-sources. Analogous to these there is a steel shielding ring above the top basket ring.

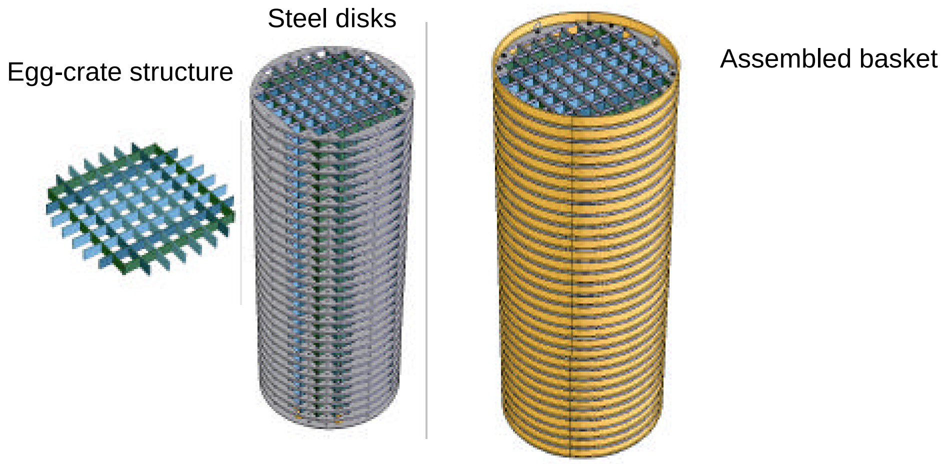

Figure 3: Basket design for the CONSTOR® V/69

3.4 Transport package features

The transport package consists of the loaded cask, an overpack and two impact limiters. The transport package is mounted on the transport cradle with tiedown devices.

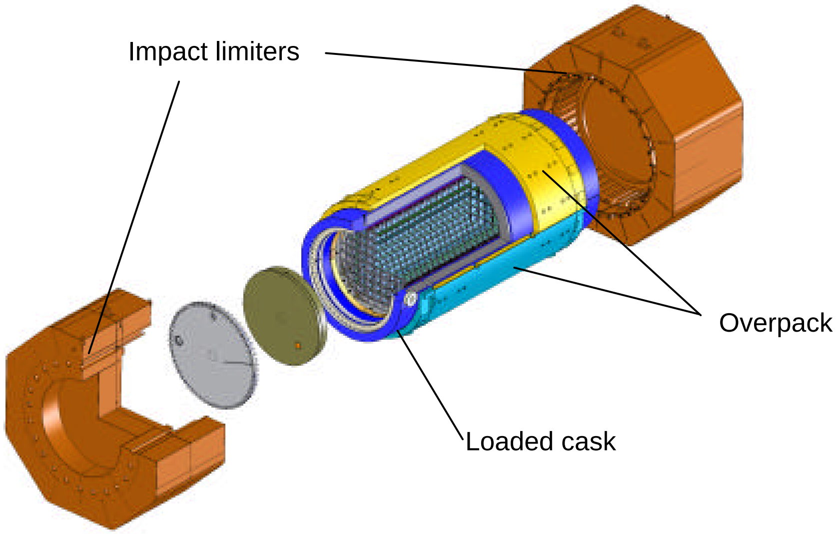

Figure 4: Transport package CONSTOR® V

4. Safety Analysis

"Design by analysis" is used to demonstrate regulatory compliance. The analyses are performed using IAEA- and NRC-accepted codes and conservative assumptions for boundary conditions, tolerances and material properties. The codes are appropriately benchmarked and verified. The drop analysis will be confirmed by a full-scale prototype drop test program.

The structural safety analysis was carried out by codes ANSYS and LS-DYNA. Conservative assumptions are:

- Consideration of gaps,
- Minimal material properties,
- Enveloping temperatures,
- Effects of dimensional tolerances,
- No structural credit for borated aluminum material for the basic design of the basket. Bearing compression strength only will be considered,
- No structural credit for CONSTORIT. Only sufficient bearing compression strength will be required.

Scenarios of possible drop orientations are considered to determine the worst case:

- 9 m:
  - End drop (both ends)
  - Side drop, including trunnion region
  - Corner drops (both ends, CG over corner)
  - Slap down drops (multiple angles)
- 1 m pin drops:
  - Lid and bottom end drop
  - Side drop at CG
  - Side drop near lid end.

The fuel assembly load distribution in the basket was considered.

The thermal safety analysis was carried out by the FEM-code ANSYS. Therefore the heat transfer mechanism inside the basket is considered by radiation and conduction, no convection in the cavity is assumed. Gaps and heat conductivities will be set to their maximum or minimum values respectively to get the worst results during stationary thermal and transient fire analyses. The influence of the fission gas release from the fuel rods on the conductivity of the inert gas atmosphere was accounted for.

The shielding safety analysis was carried out by code MCNP. Conservative assumptions are:

- bounding source terms,
- minimum material properties, e. g. densities,
- detailed modeling of the copper heat removal elements,
- assumption of free water loss in the CONSTORIT for HAC fire,
- cobalt content activation of the end fittings,
- subcritical neutron multiplication effects and secondary gamma production is handled by MCNP.

The subcriticality safety analysis was carried out by the code KENO Va. For PWR spent fuel assemblies burnup credit and conservative axial profile are applied. The “Upper Subcriticality Limit” (USL) code bias determination methodology (NUREG/CR-6361) was used. Additional conservative assumptions are:

- optimum moderator density,
- effects of dimensional tolerances,
- post accident fuel assembly geometry changes.

5. Material testing programmes

The material testing programmes focus on:

- Long-term studies for CONSTORIT (thermal behaviour, irradiation behaviour including radiolysis),
- Material compatibility in the three-material system steel-hardened cement paste-copper within the CONSTORIT filling for the CONSTOR® V/32 and CONSTOR® V/69 casks (investigation of corrosion behaviour),
- Compression strength of CONSTORIT under different long-term conditions,
- Investigation of borated Aluminum.

6. Thermal and drop testing programmes

Since the beginning of the development of the CONSTOR® design, several thermal performance tests and fire tests using half-scale cask model were carried out. Furthermore two drop test series with a half-scale cask model have already been performed.

A demonstration test program with a full-scale model CONSTOR® V/TC is being planned to start in 2004. Aspects of this items will be presented in a separate paper at PATRAM 2004.

7. Summary and Conclusions

Using detailed analyses and tests, it has been shown that the CONSTOR® cask concept can be used for the safe transport and storage of spent nuclear fuel from boiling water reactors and pressurized water reactors. The concept can be flexibly adapted to different kinds of spent fuel specifications.

On Tuesday, September 21, 2004, the German Federal Institute for Materials Research and Testing (BAM) will perform a 9-meter free drop test on a full-scale cask of the type CONSTOR® V on behalf of GNS/GNB. The CONSTOR® V, developed by GNB, is a new generation of casks for transport and storage of spent fuel assemblies.