Development of Transport and Long-Term Storage Casks for Spent Fuel with High Enrichment and High Burn up

R. Diersch, R. Gartz, K. Gluschke, D. Methling

GNB Gesellschaft für Nuklear-Behälter mbH, Essen, Federal Republic of Germany

INTRODUCTION

GNB is introducing two representatives of the new CASTOR cask generation based on the proved, tested and already licensed CASTOR base concept. The main characteristics of this concept are:

1) Cask body made of ductile cast iron with machined fins for heat dissipation
2) The neutron moderator material is integrated inside the cask wall.
3) In order to fulfill the storage requirements the design of the lid system is based on the detectable double-lid principle
4) Shock absorbers to limit stresses caused by type-B-tests

With the new generation of the CASTOR casks, the following aims are pursued:

1) Transport and storage of uranium and MOX-fuel assemblies with maximum enrichment, maximum burn-up and acceptable cooling time, to consider future demands of fuel assembly characteristics
2) Maximum capacity of the cask while guaranteeing safe handling in nuclear power plants and casks interim storage sites as well as transport on public routes.
3) Meeting the requirements for the Type-B packages and the requirements for interim storage sites in Germany.
4) Using the upper bound values for the outer dimensions and a reasonable handling weight the cask concept is an optimised relation between costs and fuel masses per cask.

CASTOR V/19

The CASTOR V/19 cask (see fig. 1) has been designed to accommodate 19 uranium fuel assemblies from the German PWR power plants, having an initial enrichment up to 4.0 % U235, a burn-up up to 55000 MWd/tHM and a cooling time of at least 5 years. A loading of up to 4 MOX-fuel assemblies (4.6 % Pu-fissile, 55000 MWd/tHM, cooling time 10 years) is possible by replacement of the corresponding uranium fuel assemblies (mixed loading).

Table 1 shows the concept-determining nuclear parameters of the casks for the two loading scenarios. With a total mass of 120 t, an outer diameter of 2436 mm and a total length including the shock absorbers of 6782 mm, the maximum allowable values are reached with respect to handling and transport.

The values for the dose rate, also compiled in table 1, show that the allowable values for transport and storage are observed. With respect to the maximum fuel rod cladding temperature, for this reason the construction of the fuel basket and the cask has been designed with a sufficient capacity for heat removal. Due to this reason, radial heat transfer plates made of aluminium are part of the basket (see fig. 2) and lead along the cask wall. The basket individual pieces are mechanically decoupled. This design decreases the thermal stresses resulting from the temperature gradient between the basket centre and the inner cask wall. To guarantee criticality safety, the basket-supporting structural elements are manufactured with borated steel, and supplementary flux traps between the fuel assemblies are provided. Moreover, fuel positions are arranged in such a way that the impact forces resulting from 9-m-sidewall drop are respectively transmitted via nodal connections. As a result of this, the stresses caused by the decelerations are reduced to values below allowable values. This has been demonstrated for different drop positions using the FEM-program-system ANSYS (e.g. Swanson, 1992), whose suitability for benchmark-calculations has been proved (e.g. Robert 1984, 1985, 1988). The results of the stress analysis for the selected structure show that maximum stress (209 N/mm²) is lower than allowable stress (444 N/mm²).

The structural analysis for behaviour of the cask body under the stress conditions of a 9-m-drop test and of a 1-m-pin drop test has been performed with the FEM-program-system ADINA (ADINA, version 5.6, 1990).The results show that the elongations appearing in both tested impact positions are lower than the allowable limit value of 2%.

The fracture toughness analysis has been performed in assuming a semi-elliptical surface crack at the location of the maximum tensile stress. The maximum tensile stress occur during the 9-m-side drop. According to a recommendation of IAEA (e.g. IAEA, 1992), the fracture toughness analysis has been performed with the aid of the linear-elastic fracture mechanics:

$$K_I = \sigma_M \times M_M \sqrt{\pi \times a/Q} + \sigma_B \times M_B \sqrt{\pi \times a/Q}$$

The results show that the safety against instable crack propagations is guaranteed.

The results of the calculations of the steady-state temperature distribution in the cask had been performed with a two-dimensional calculation program (e.g. Lawrence Livermore National Laboratory, July 1986). The steady-state maximum temperature of the fuel rod cladding amounts to 373°C for reference loading.

CASTOR 440/84

The CASTOR 440/84 cask (see fig. 4) has been especially designed for the transport and the long-term interim storage of fuel assemblies from reactors of the type VVER 440. These reactors are in operation in the former USSR and in Eastern Europe. Cask dry storage using the CASTOR 440/84 is planned at Dukovany (Czechoslovakia) and Greifswald in the former GDR.

The CASTOR 440/84 can accommodate 84 fuel assemblies with an average initial enrichment of 3.5% U235, an average burn-up of 33000 MWd/tHM and a cooling time of 5 years.

Taking into account the nuclear fuel data indicated in table 2 and the dimensions and the weight of this CASTOR type, we see that the limits for handling in nuclear power plants, cask interim storage sites and during transport are optimally utilised. The observance of the allowable dose rates is guaranteed (see table 2).

The hexagonal geometry of this type of fuel assemblies and their large number required a special construction for the fuel basket. The chosen design guarantees heat dissipation and criticality safety under normal and accident conditions (see fig. 3). The hexagonal tubes made of borated steel in the fuel basket have a honeycombed arrangement. Between the fuel positions of this arrangement, aluminium plates are adapted to the contours. In the radial direction, the plates have different lengths and assure sufficient heat dissipation. The residual free spaces are filled with small aluminium plates to guarantee sufficient strength. Because there is no connection between the hexagonal borated steel tubes and the aluminium plates, the thermal stresses have only an effect on the single positions of the fuel basket.The calculation of sufficient strength of the basket after a 9-m-drop onto the side-wall has also been performed by the program ANSYS for different drop positions.

The maximum stresses demonstrate that the allowable values are respected and thus the criticality safety is guaranteed under the 9-m-drop test conditions (σ_{max} = 314 N/mm² < σ_{all} = 470 N/mm²). The stresses calculated in the cask body after a 9-m-drop and after a 1-m-pin drop are limited by the sufficient dimensioning of the shock absorbers. Because of that, the allowable stresses are not exceeded. The calculation has been performed with FEM, using ANSYS and ADINA. The fracture toughness calculations have been performed similar to the CASTOR V/19. It could be shown that fracture toughness is guaranteed under conservative assumptions.

The two-dimensional temperature calculations gave as result a maximum fuel rod cladding temperature of 284°C in transport situation and 306°C during the fire test. The allowable limit for the long-term interim storage is 350°C. The maximum temperature appearing in the moderator material during the fire test of 212°C is well below the temperature of decomposition (350°C). Also the function of the metallic seals will not be impaired during the fire test.

SUMMARY

With the casks CASTOR V/19 and 440/84, GNB has developed cask types based on positive experiences in handling, transport and interim storage of fuel assemblies from LWR reactors with CASTOR casks.

This concept has been optimised with the introduced casks so that

- the global handling is guaranteed also for high loading masses
- the mechanical, thermal and nuclear requirements of the transport regulations are safely respected
- the specific requirements for cask storage sites are met
- the existing storage capacities are optimally utilised
- and an optimum is reached for the known safety, financial and technical advantages of the cask storage with respect to the cask costs per ton of heavy metal.

The presented CASTOR V cask is suitable as base type for a series of further cask modifications for BWR fuel assemblies as well as for other PWR fuel assemblies from the German nuclear power plant's. The CASTOR V as well as the CASTOR 440/84 will be further optimised with respect to their mechanical and thermal characteristics, while guaranteeing nuclear safety.

References

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Fuel Assembly Type		19 Uranium-FA	15 Uranium-FA 4 MOX-FA
Weight of Heavy Metal per Cask	(tHM)	10.203	10.167
Burn-up	(GWd/THM)	55	55
Cooling Time	(a)	5	5 (Uran)/10 (MOX)
Photon Source Strength	(Gamma/s)	1.495 E + 17	1.330 E + 17
Neutron Source Strength	(n/s)	1.55 E + 10	3.36 E + 10
Thermal Power	(W)	3.48 E + 04	3.80 E + 04
Activity	(Bq)	3.42 E + 17	3.49 E + 17
	(Ci)	(9.25 E + 06)	(9.44 E + 06)
Gamma Dose Rate at Distance from Surface			
0 m	(μSv/h)	133	118
1 m	"	73	64
2 m	"	50	44
Neutron Dose Rate at Distance from Surface			
0 m	(μSv/h)	77	133
1 m	"	39	67
2 m	"	27	48

Tab. 1: CASTOR V/19 Transport and Storage Cask Design Data

Fuel Assembly Type		84 Uranium-FA
Weight of Heavy Metal per Cask	(tHM)	10.080
Burn-up	(GWd/tHM)	33
Cooling Time	a	5
Photon Source Strength	(Gamma/s)	8.37 E16
Neutron Source Strength	(n/s)	3.23 E9
Thermal Power	(W)	1.93 E4
Activity	(Bq)	2.28 E17
	(Ci)	
Gamma Dose Rate at Distance from Surface		
0 m	(μSv/h)	81
1 m	"	46
2 m	"	30
Neutron Dose Rate at Distance form Surface		
0 m	(μSv/h)	77
1 m	"	53
2 m	"	38

Tab. 2: CASTOR 440/84 Transport and Storage Cask Design Data

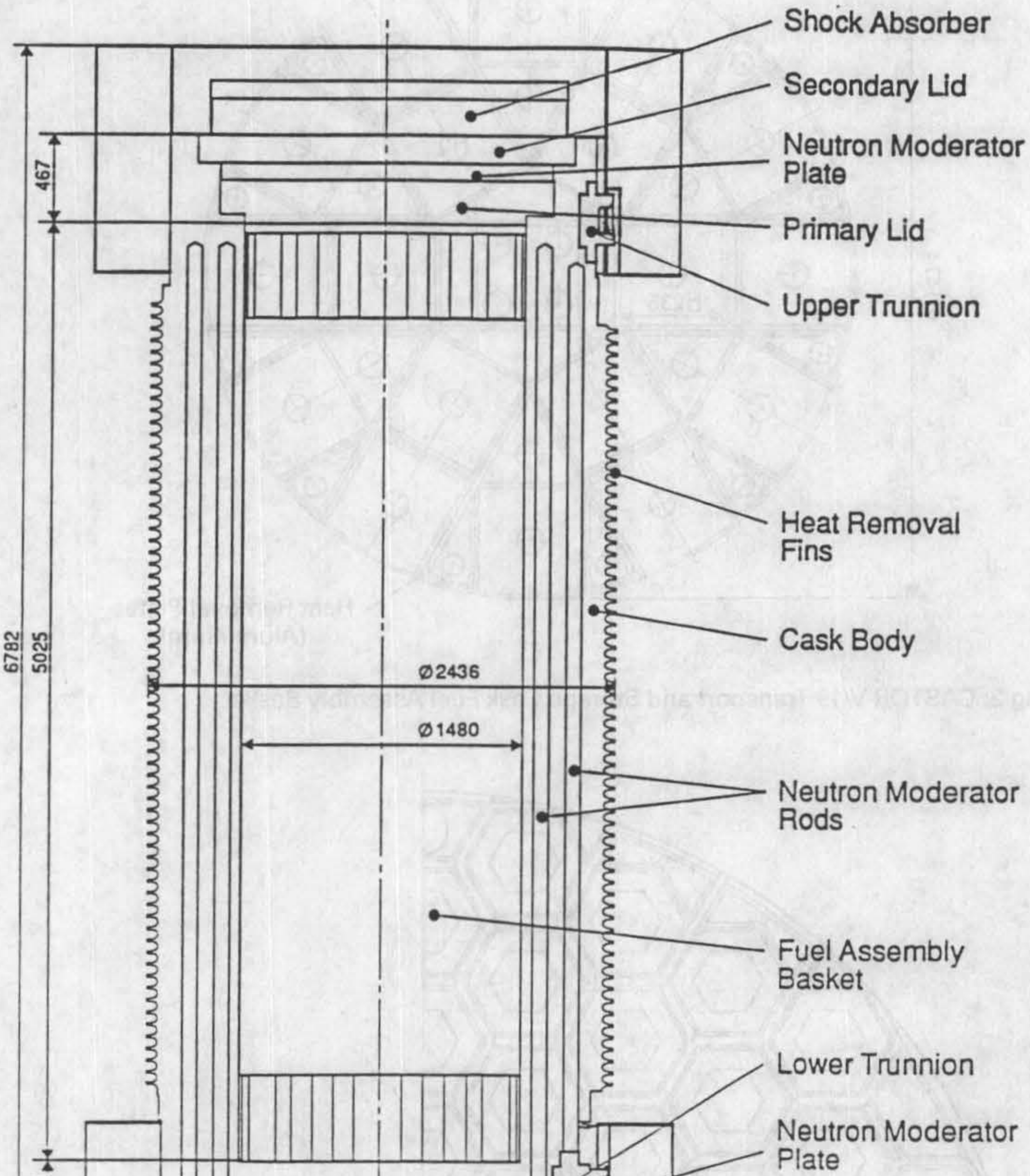


Fig. 1: CASTOR V/19 Transport and Storage Cask Longitudinal Section

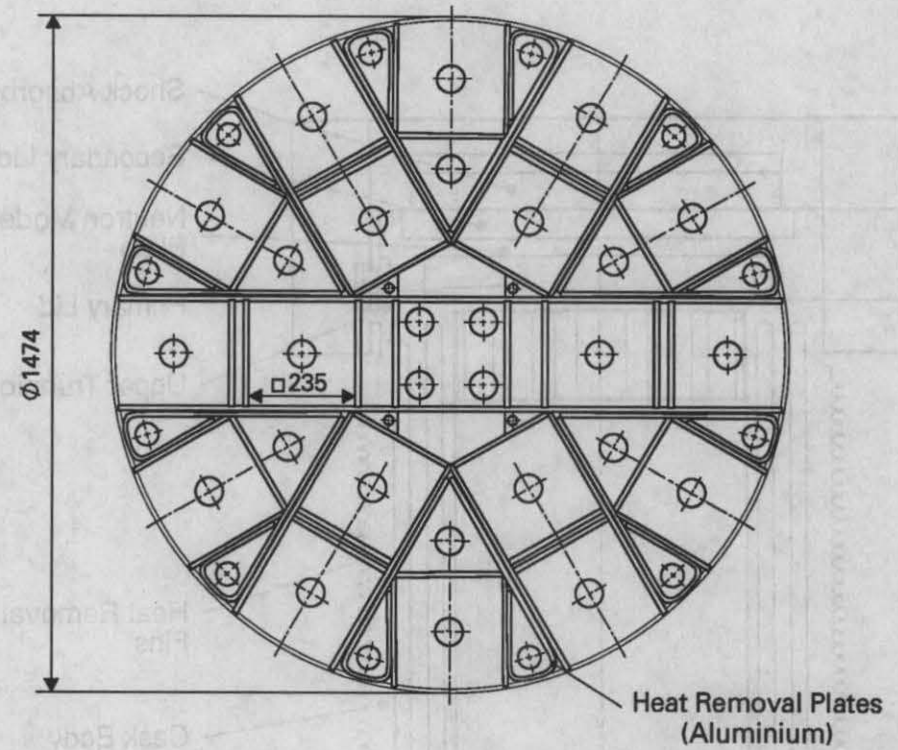


Fig 2: CASTOR V/19 Transport and Storage Cask Fuel Assembly Basket

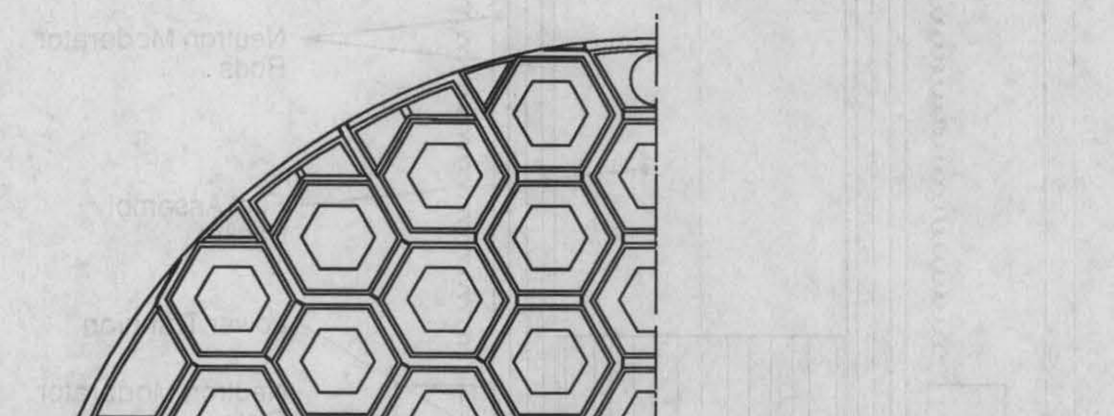
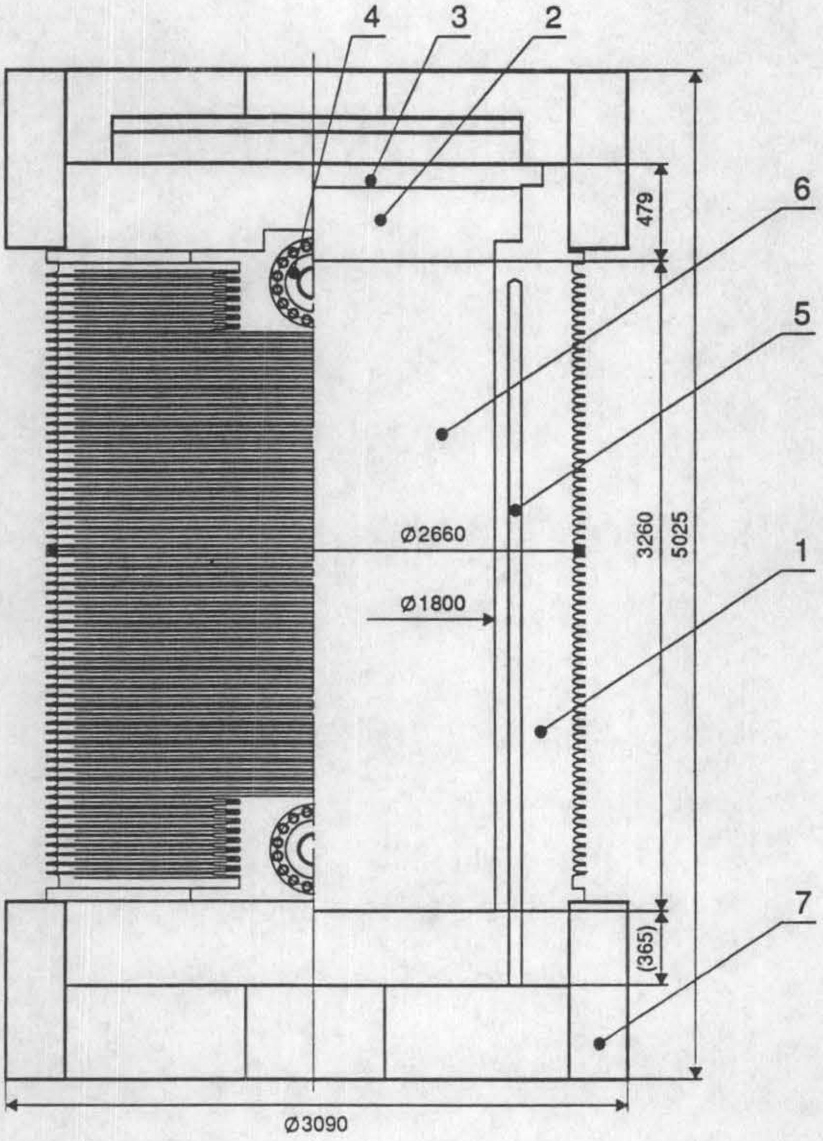


Fig 3: CASTOR 440 / 84 (WWER 440) Transport and Storage Cask Fuel Assembly Basket



1 Cask Body
2 Primary Lid
3 Secondary Lid
4 Trunnion
5 Moderator Rod
6 Basket
7 Shock Absorber

Fig. 4: CASTOR 440/84 (VVER 440) Transport and Storage Cask Longitudinal Section

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