LOW WEIGHT CASTOR® CASK WITH HIGH CAPACITY FOR TRANSPORT AND STORAGE OF SPENT NUCLEAR FUEL

Rudolf Diersch
Manfred Weiß
GNB Gesellschaft für Nuklear-Behälter mbH, Hollestr. 7 A, 45127 Essen, Germany

ABSTRACT

The development of storage casks is directed to accommodate a maximum number of fuel assemblies which is possible in accordance with max. cask weight. Some of the elder NPP world-wide have a limited crane capacity of approx. 70 to 80 metric tons. GNB has developed the CASTOR® V/12 S casks for direct dry cask storage, which fulfil both the type B(U)F transport requirements and the criteria for cask storage under normal operation and accident conditions for this special weight definitions.

The CASTOR® V/12 S is designed for 12 PWR fuel assemblies of the type W. H. 14 x 14, 16 x 16 and 17 x 17 with 5 w/o U 235 enrichment, 40 to 60 GWd/MTU and a minimum cooling time of 3 to 7 years.

The cylindrical cask is made of forged carbon steel. Polyethylene rods for neutron shielding are arranged in bore holes of the cask body wall. The lid system is designed as a double barrier system for storage. The two referring lids are metal sealed and bolted (version 1). In version 2 the primary lid is bolted and the secondary lid is welded.

For transport, only the primary lid is necessary. In the transport configuration, wooden-made impact limiters are attached at the lid side and at the bottom side.

The CASTOR® V/12 S cask complies with the requirements of the IAEA and of the 10CFR Part 71 for type B(U)F packages, and meets the requirements of the 10CFR72 for storage casks.

INTRODUCTION

The double purpose cask CASTOR V/12 S is designed for dry transport and for long-term storage of up to 12 intact PWR fuel assemblies (e. g. W. H. 14 x 14, 16 x 16, 17 x 17), used in commercial nuclear power reactors in the United States and in other countries.

The design basis fuel specification is the following:

- initial enrichment of each fuel assembly 5.0 w/o U-235,
- the burn-up is 60 GWd/MTU,
- the minimum required cooling time is 7 years.

The transport and storage of fuel assemblies with other combinations of the above-mentioned fuel parameters can be realized, if the related source terms will not exceed the values of the design parameters.

The cask can be loaded additionally with burnable poison rod assemblies inserted in the fuel assemblies. Depending on the enrichment, some of the fuel assemblies must be equipped with absorber rod modules (ARMs) before loading for criticality safety reasons. Alternative burn-up credit can be used to guarantee the criticality safety.

The CASTOR® V/12 S design meets on the one hand the type B(U)F transport requirements of the IAEA Regulations for Safe Transport of Radioactive Material TS-R-1 and of the U. S. 10CFR Part 71. On the other hand the CASTOR® V/12 S complies with the U. S. 10CFR 72 for long-term storage.

DESCRIPTION OF THE CASK DESIGN

The main components of the CASTOR® V/12 S are:

(1) the containment vessel comprised of:
  - the cask body with the cylindrical shell and the welded bottom
  - the sealed primary lid and the secondary lid

(2) the fuel basket

(3) impact limiters bottom and lid side (for transport only)

The longitudinal and the cross sections of the CASTOR® V/12 S are shown in Figure 1. The main dimensions of this cask can be seen in Figure 1 as well.

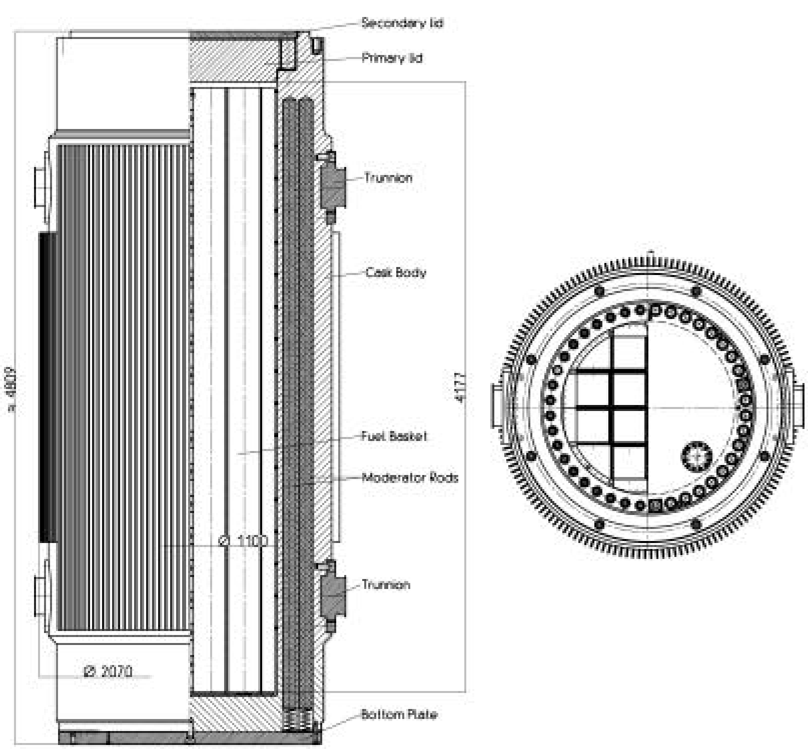

Figure 1, CASTOR® V/12 S cask (without impact limiters)

The handling weight for storage loaded is 76,000 kg and the weight loaded for transport with impact limiters is 86,000 kg.

1. Containment Vessel

The CASTOR® V/12 S concept has been developed in two different versions. Version 1 is the original CASTOR® cask concept with a carbon steel body and with a bolted primary and secondary lid and with pressure monitoring of the interlid space during storage. Version 2 is similar to the version 1 but has a welded secondary lid, no pressure monitoring of the interlid space during storage and no metal O-rings.

The containment vessel for the CASTOR® V/12 S consists of a forged carbon steel cylinder with an integrally-welded carbon steel bottom as well as a bolted primary lid made of stainless steel with a metallic O-ring seal and a vent and drain opening closed by a lid with a metallic O-ring seal. A secondary lid is arranged over the primary lid. This secondary lid is different for Versions 1 and 2 and is described later in this presentation.

The cask cavity surfaces and the O-ring sealing surfaces are overlaid with stainless steel by welding to provide corrosion protection. The cladded sealing surfaces are machined to provide the necessary finish for the seating of the O-ring seals (see Figure 2).

The secondary lid for Version 1 is made of stainless steel. It is fastened to the cask body by bolts. The interspace between the primary lid and the secondary lid is utilized as part of the cask monitoring system (see Figure 2).

The secondary lid for Version 2 is made of forged carbon steel (like the cask body) and is attached to the cask body with a multipass narrow groove weld (see Figure 3). There are no penetrations of the lid in Version 2 and the pressure in the interspace between the lids is not monitored.

The fuel assemblies are confined inside the cask in a dry, inert, helium atmosphere.

Decay heat is removed via the cask surface with fins to the environment by natural convection and radiation.

The CASTOR® V/12 S provides the containment of the fuel assemblies for all design basis normal, off-normal, and postulated accident conditions. The containment function of the CASTOR® V/12 S is verified through helium leak testing and weld examinations performed in accordance with the acceptance test program.

A containment monitoring is necessary for the bolted lid version 1 only. The interspace between the primary and the secondary lid is filled with helium and is utilized as part of the cask monitoring system. The initial pressure of the interspace is set to a pressure of 0.7 MPa (100 psi). A pressure switch is mounted in the secondary lid and is wired to an alarm system in the Interim Storage Facility.

2. Shielding

The Gamma Shielding is provided by the thick-walled steel cask body and by the steel lid system.

Neutron shielding on the cask is provided in both the radial and axial directions.

Neutron shielding in the radial direction is provided by polyethylene rods set into two concentric rows of axial bore holes in the wall of the cask body. Each concentric row contains 36 bore holes for a total of 72 bore holes. The bore holes in the two concentric rows are offset to provide an unbroken line of neutron shielding for radiation from the cask cavity.

Neutron shielding in the axial direction at the lid and bottom areas during transport is provided by the wood and by the polyethylene inserted in the impact limiters. During storage, protective caps made of concrete are attached at the top of the CASTOR® V/12 S cask.

3. Fuel Basket

The fuel basket provides support of the fuel assemblies, control of criticality, and a path to conduct heat from the fuel assembly to the cask body.

The fuel basket is designed to accommodate up to 12 intact PWR fuel assemblies. Fuel receptacles are manufactured by the welding of stainless steel plates to enclose and secure the fuel assemblies. The stainless steel fuel receptacles are assembled together with the borated aluminum plates and gusset plates for additional shielding (see Figure 1).

The borated aluminum plates of this basket gridwork provide heat conductivity. The boron content of these plates assures safety of nuclear criticality.

The closely fitting borated aluminum plates of the basket gridwork fix the square-shaped stainless steel fuel receptacles in a central position inside the cask cavity. This compact close-tolerance arrangement is intended to minimize the movement of the fuel assemblies relative to each other and to the cask body under normal, off-normal, and accident conditions.

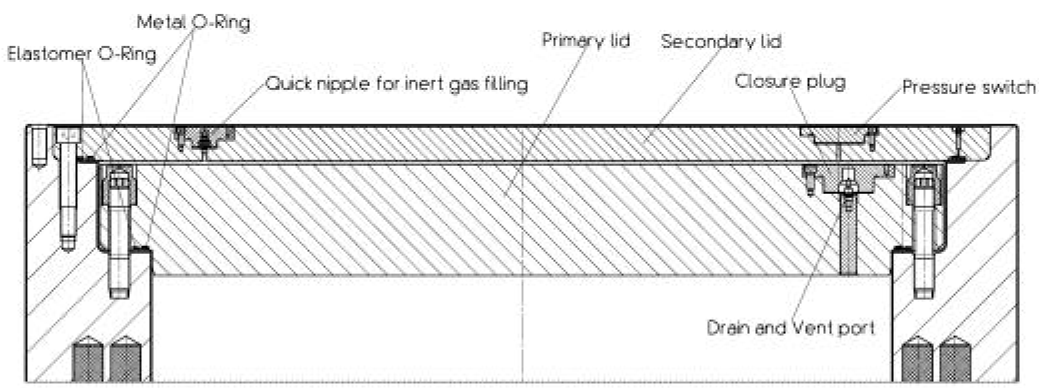

Figure 2, Lid Assembly, Version 1

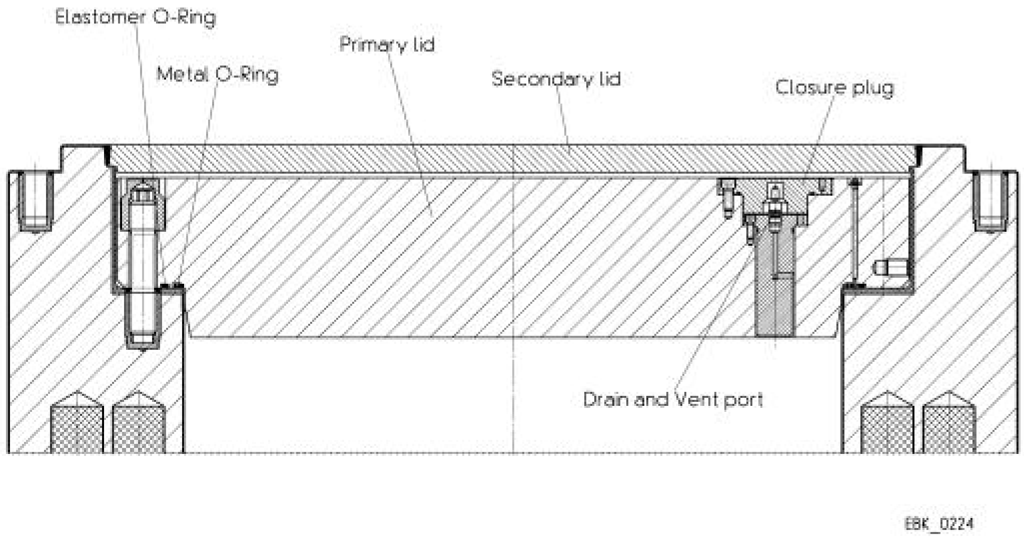

Figure 3, Lid Assembly, Version 2: Welded Closure (Secondary Lid)

4. Impact Limiters

The bottom and lid side bolted impact limiters are made of wood for energy absorption, arranged in a carbon steel structure and encapsulated by a stainless steel shell.

CASK MATERIALS

The CASTOR® V/12 S materials are selected in such a way that their degradation will not occur during the service period of transport and of storage.

The basic material of the cask body and of the secondary lid (Version 2) is forged carbon steel. The cask lids, the bottom plate, the bolts and the trunnions are made of forged stainless steel. Polyethylene is used for neutron shielding.

The structural material of the basket is stainless steel. The material of the heat removal plates and of the ARMs is a composite of aluminum and boron.

During the long-term storage, the CASTOR® V/12 S is subjected to both internal and external influences of different characteristics.

External influences:

- external corrosion caused by the humidity of the ambient air,
- fatigue effects caused by temperature changes.

Internal influences:

- effects of the ionizing radiation,
- corrosive effects of the inventory,
- fatigue effects of the cask components.

The design of the CASTOR® V/12 S as well as the chosen materials like steel, stainless steel, polyethylene, stainless steel coating of the cask cavity, epoxy coating, and the metal seals have been examined regarding the special requirements during an interim storage period of at least 50 years.

CASK SAFETY EVALUATION
Through its design, the CASTOR® V/12 S cask ensures structural integrity, heat removal, subcriticality shielding and retention of radioactive materials. The structural design was made in accordance with the ASME Code application.

1. Structural

The structural performance of the cask was evaluated for the load conditions defined in the U.S. 10CFR 71 for normal operation and for hypothetical accident conditions during transport.

The CASTOR® V/12 S is designed also for storage to withstand all normal, off-normal, and postulated accident loadings as well as the effects of severe environmental conditions and natural phenomena such as earthquakes, tornadoes, lightning, hurricanes and floods.
The structural analyses were made with the LS-DYNA 3D explicit finite element code. The stress limits for the containment structure and bolts according to ASME, Sect. III, Div. 3, were met.

2. Thermal

The thermal evaluation was made for a total heat load of 15 kW per cask. The heat is transferred between the cask with attached longitudinal fins and the environment by passive means only. For transport conditions, the impact limiter and the transport hood covering the cask is considered.

A three-dimensional finite element model was used to simulate the heat transfer in the cask, and a two-dimensional finite element model for simulation of the heat transfer in the fuel assemblies. The calculations were carried out with the MSC/NASTRAN code, version 70.5.2. The maximum allowable temperatures of the components and of the fuel cladding were met.

3. Shielding

The source terms were calculated with the ORIGEN-2.1 code for the W. H. 17 x 17 basis design fuel assembly. The three-dimensional MCNP-4B Monte Carlo transport code was used for the shielding analyses.

The analyses have shown that for normal operation the design limits of 2 mSv/h at any point of the cask surface and of 0.1 mSv/h at 2 m distance from the transport hood are met.

The maximum allowable dose rate will not exceed 10 m Sv/h in 1 m distance under the hypothetical accident conditions.

4. Criticality

The CASTOR® V/12 S provides criticality control for all design basis normal, off-normal, and postulated accident conditions. The effective neutron multiplication factor is limited to $k_{eff} < 0.95$ for intact Zircaloy-clad UO_2 fuel assemblies with optimum unborated water moderation and close reflection, including all biases, uncertainties, and manufacturing tolerances.

Criticality control is maintained by:

- the geometric spacing of the fuel assemblies,
- the absorber rod modules (ARMs) inserted in some guide tubes of the fuel assemblies,
- the fixed borated neutron absorbing materials incorporated into the fuel basket,
- burn-up credit.

The minimum specified boron concentration is further reduced by 25 % for criticality analysis.

The criticality analysis was performed by the three-dimensional Monte Carlo code KENO-Va which was selected for performing the criticality analysis because it has been extensively used and validated.

The results show that $k_{eff} < 0.95$ is met for both normal operational and hypothetical accident conditions.

CONCLUSION

The CASTOR® V/12 S is a new design of a low-weight, double-purpose cask intended for dry storage and transportation of up to 12 spent nuclear fuel assemblies from pressure water reactors. The low cask weight of less than 80 metric tons allows to use it for direct storage of spent nuclear fuel from elder NPPs with a limited crane capacity. The cask safety has been evaluated in accordance with IAEA TS-R-1, U.S. 10CFR 71 and U.S. 10CFR 72.

The cask provides containment, radiation shielding, structural integrity, criticality control and passive heat removal for transport and for storage under both normal conditions and accidental conditions.

REFERENCES

[1] IAEA, IAEA Safety Standards Series TS-R-1, “Regulations for the Safe Transport of Radioactive Material”, 1996

[2] U.S. NRC, 10CFR Part 71, “Packaging and Transportation of Radioactive Material”, 1997

[3] U.S. NRC, 10CFR Part 72, “Licensing Requirements for the independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste”