CASTOR® KN-12 SPENT NUCLEAR FUEL TRANSPORT CASK

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ABSTRACT

The CASTOR® KN-12 cask is designed to transport 12 PWR spent nuclear fuels and to comply with the requirements of Korea Atomic Energy Act, IAEA Safety Standards Series No. ST-1 and US 10 CFR Part 71 for a Type B(U)F package. It provides containment, radiation shielding, structural integrity, criticality control and heat removal for the normal transport and the hypothetical accident conditions. W.H 14x14, 16x16 and 17x17 fuel assemblies with maximum initial enrichment of 5.0 wt.%, maximum burnup of 50000 MWD/MTU and minimum cooling time of 7 years being used in Korea will be loaded and transported under dry and wet conditions. A forged cylindrical cask body which constitutes the containment vessel is closed by a cask lid. Polyethylene rods for neutron shielding are arranged in two rows of longitudinal bore holes in the cask body wall. A fuel basket to accommodate up to 12 PWR fuel assemblies provides support of the fuels, control of criticality and a path to dissipate heat. Impact limiters to absorb the impact energy under the hypothetical accident conditions are attached at the top and at the bottom side of the cask during transport. Handling weight loaded with water is 74.8 tons and transport weight loaded with water with the impact limiters is 84.3 tons. The cask will be licensed in accordance with Korea Atomic Energy Act and fabricated in accordance with ASME Section III, Division 3.

INTRODUCTION

The CASTOR® KN-12 cask is a new design of a transport package intended for dry and wet transportation of up to 12 spent nuclear fuel assemblies from pressure water reactors. The cask has been designed by GNB basing on NETEC's requirements and evaluated as a transport package that complies with the requirements of Korea Atomic Energy Act[1], IAEA Safety Stanadards Series No.ST-1[2], US 10 CFR Part 71[3] and for a Type B(U)F package.

The cask provides containment, radiation shielding, structural integrity, criticality control and passive heat removal for normal transport conditions and hypothetical accident conditions. W.H 14x14, 16x16 and 17x17 fuel assemblies being used in Korea will be loaded and subsequently transported in the cask. Maximum allowable initial enrichment of the fuel is 5.0 wt.%, fuel assembly burnup is limited to a maximum average of 50000 MWD/MTU, and the fuel must have a minimum cooling time of 7 years.

The containment system of the cask consists of a forged thick-walled carbon steel cylindrical body with an integrally-welded carbon steel bottom and is closed by a lid made of stainless steel, which is fastened to the cask body by lid bolts and sealed by double elastomer O-rings. The steel thickness of the cask body wall and of the lid meet the dose rate limits of the related regulations together with neutron shielding material. Neutron shielding in radial direction is provided by polyethylene rods arranged in two concentric rows of axial bore holes and in axial direction is provided by polyethylene plates. The fuel basket to accommodate up to 12 PWR fuel assemblies provides support of the fuels, control of criticality and a path to dissipate heat from the fuels to the cask body. The fuel receptacles made of stainless steel to enclose and secure the fuels are assembled as a gridwork together with boronated aluminum plates. Four stainless steel trunnions are attached to the cask body for lifting and for rotation of the cask between vertical and horizontal positions. Impact limiters filled with beech and spruce woods to absorb the impact energy under 9m free drop conditions as a hypothetical accident are attached at the top and at the bottom side of the cask during transport.

The cask will be licensed in accordance with Korea Atomic Energy Act and fabricated in Korea in accordance with the requirements of ASME Sec.III, Div.3[4].

CASK DESCRIPTION
The cask is a cylindrical vessel that is placed in the horizontal position on a specially designed tie-down structure during transport. The cask as shown in Figure 1 consists of a cask body, a cask lid, polyethylene rods, a fuel basket, trunnions and impact limiters.

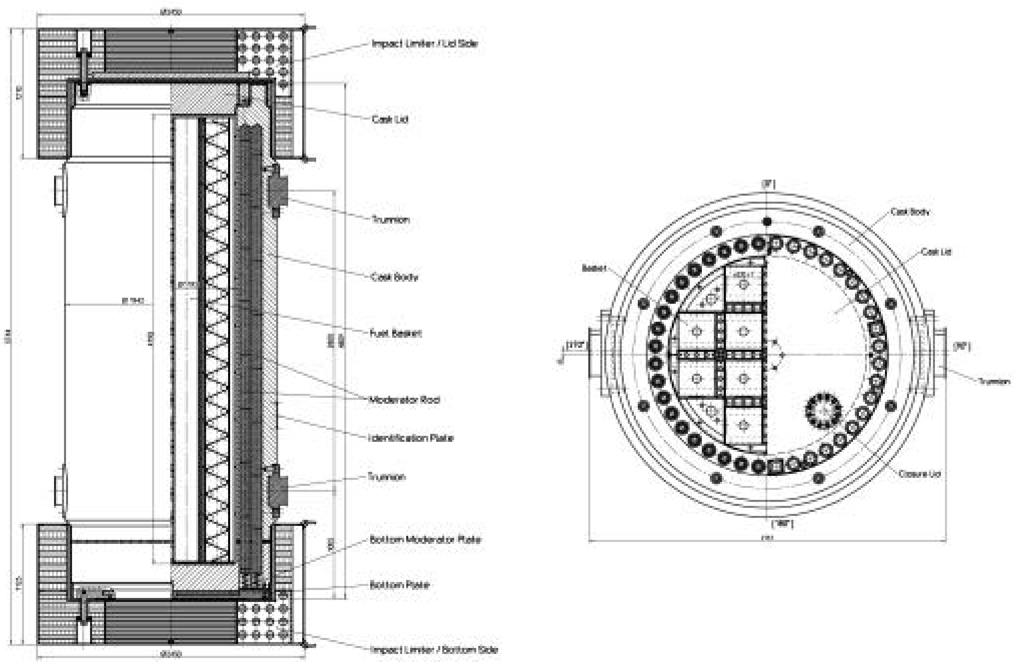

Figure 1, General Arrangement of the CASTOR® KN-12 Cask

A cylindrical thick-walled cask body which constitutes the containment vessel is closed by the bolted cask lid. It provides radioactive material containment within a cavity loaded by spent nuclear fuels inserted in the basket and filled with helium or water. Polyethylene rods for neutron shielding are arranged in two rows of longitudinal bore holes in the cask body wall. A polyethylene plate for neutron shielding is arranged at the bottom side of the cask covered by the bottom plate. A fuel basket that locates and supports the fuel assemblies in fixed positions, provides boron for neutron absorption to satisfy the nuclear criticality safety requirements and to transfer the heat to the cask body wall. Upper and lower pairs of trunnions provide support for lifting and for rotation of the cask between the vertical and the horizontal position. A set of impact limiters manufactured from beech and spruce woods encased in the steel sheeting are bolted at the lid side and at the bottom side of the cask during transport and provide sufficient impact energy absorption to meet the stress limits under the hypothetical accident conditions.

The overall cask length is 4809 mm with a wall thickness of 375 mm and the outer diameter of the cask body is 1942 mm. The cylindrical cask cavity has an internal diameter of 1192 mm and an internal length of 4190 mm. The lid is 290 mm thick. Each impact limiter is 2450 mm in diameter and extends 700 mm along the side of the cask in axial direction. The open dimension of each fuel receptacle is 220 mm x 220 mm to provide a nominal clearance of 3.2 mm around the W.H 17x17 fuel assembly and the free length between basket inside bottom surface up to lower lid surface is 4170 mm. As maximum fuel length is 4132.8 mm to consider the length increase by irradiation and by thermal expansion, a free gap of 37.2 mm is provided.

Weights of cask component are as followings; the cask body of 51.5 tons, the cask lid of 3.3 tons, basket of 7 tons, impact limiters of 11.7 tons, fuel assemblies of 7.9 tons, water filling of 2.2 tons, and cask lifting device of 2.3 tons. Handling weight loaded with water with the cask lifting device is 74.8 tons and transport weight loaded with water with the impact limiters is 84.3 tons.

The main materials used to fabricate the cask are listed in Table 1.

Table 1, Material Specification for the CASTOR® KN-12 Cask

Component	Material	Specification
Cask body	Carbon steel	SA350 Gr.LF3
Bottom plate	Stainless steel	SA182 Gr.F6NM
Neutron shielding	Polyethylene (rod & plate)	WS1 PE-HD-04, Ind.00
Lid	Stainless steel	SA182 Gr.F6NM
Turnnion	Stainless steel	SA182 Gr.F6NM
Basket		
- Fuel receptacles	Stainless steel	SA240 Gr.321
- Neutron absober plates	Boronated aluminium	EP 1100
Impact limiters		
- Impact absorbing material	Wood	Beech & spruce woods
- Gusset plate	Carbon steel	A36
- Case	Stainless steel	SA240 Type 304
Cask outside coating	Epoxy/acryl paint	

The containment vessel for the cask consists of a forged thick-walled carbon steel cylindrical body with an integrally-welded carbon steel bottom and is closed by a lid made of stainless steel, which is fastened to the cask body by lid bolts and sealed by double elastomer O-rings. In the cask lid an opening is integrated closed by a plug with an O-ring seal and covered by the bolted closure lid sealed with an O-ring. The containment system is defined by the cask body, the cask lid, lid bolts, O-ring seals and the bolted closure lid. The inside cask cavity surfaces, the O-ring surfaces and the outer cask region of the lid and bottom side are coverd by a welded stainless steel cladding for corrosion protection. The external surface of the cask between the impact limiters is painted for effective heat transfer and corrosion protection. The steel thickness of the cask body wall and of the cask lid are designed to meet the dose rate limits together with the neutron shielding material.

The neutron shielding is provided in both radial and axial direction. Neutron shielding in the radial direction is provided by polyethylene rods arranged in two concentric rows of axial bore holes in the wall of the cask as shown in Figure 2. 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. The polyethylene rods are firmly secured in the long direction by springs located in the bottom of the bore holes fixed by the bolted bottom plate. Neutron shielding in the axial direction is provided by polyethylene plates and by the woods of the impact limiters. A polyethylene plate at the lid side is integrated in the referring top impact limiter. To provide neutron shielding at the bottom of the cask, a polyethylene plate is inserted into a cavity at the outside of the cask bottom. This plate is secured in place by the steel made bottom plate fixed by cap screws.

The fuel basket is designed to accommodate up to 12 PWR fuel assemblies as shown in Figure 3 and provides support of the fuel assemblies, control of criticality, and a path to dissipate the heat from the fuel to the cask body. The fuel receptacles are manufactured by the welding of stainless steel plates to form a square tube to enclose and secure the fuel assemblies. The receptacles are assembled as a gridwork together with boronated aluminum plates. Each stainless steel fuel receptacle is fully surrounded by the boronated aluminum plates of the basket gridwork. This arrangement is fixed on the bottom side by a welded plate and on the lid side connected by screwing. The boronated aluminum plates of the basket gridwork provide sufficient heat removal. The boron content of the plates assures nuclear criticality safety under the normal transport and the hypothetical accident conditions.

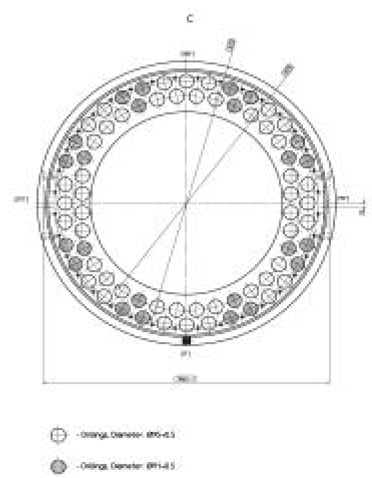

Figure 2, Cask Body Section

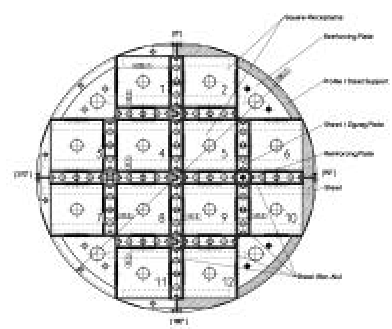

Figure 3, Fuel Basket Section

Impact limiters are attached at the top and at the bottom side of the cask during transport. The impact limiters are designed to absorb the impact energy during 9 m free drop as an hypothetical accident. The impact limiters are manufactured from an inner carbon steel structure and an outer stainless steel shell filled with beech and spruce woods. The outer steel shell is welded water tight to protect the wood against humidity and specially designed to enhance shock absorbing properties of the impact limiter materials.

Four stainless steel trunnions, which are designed in accordance with Korea Atomic Energy Act and ANSI N14.6[5], are attached to the cask body for lifting and for rotation of the cask between the vertical and the horizontal position. The top trunnions are used as attachment points for lifting the cask in the vertical direction and for rotating the cask between the horizontal and the vertical positions. The bottom trunnions are utilized as support points when rotating the cask between the vertical and the horizontal positions**.** The two bottom side trunnions are used as tie-down points during transport of the cask on the transport frame.

During transportation, the cask will be supported by a tie-down structure, which is a specially designed transport frame to meet the requirements of Korea Atomic Energy Act and US 10 CFR 71. The tie-down structure including a hood will provide the support and the weather protection, respectively for the package. Further the tie-down structure including a hood represents a personnel barrier to prevent unauthorized access to the cask. The tie-down structure together with the hood guarantees the free flow of cooling air to the cask.

OPERATIONAL FEATURES

The cask is designed for dry and wet transportation of up to 12 PWR fuel assemblies. The maximum allowable initial UO_2 enrichment is 5.0 wt.%. The fuel assembly burnup is limited to a maximum average of 50000 MWD/MTU. Prior to load in the cask, the fuel must have a minimum cooling time of 7 years. W.H 14x14, 16x16 or 17x17 fuels being used in Korea may be loaded and subsequently transported in the cask Each fuel is assumed to have a maximum decay heat load of 1.05 kW and the cask has a total heat dissipation capability of 12.6 kW. The fuel assemblies can be transported alternatively in an inert helium gas atmosphere or in a water filling inside the cask cavity.

The criticality control features of the cask are designed to maintain the neutron multiplication factor k-effective, k_{eff} including uncertainties and calculational bias at less than 0.95 under the normal transport and the hypothetical accident conditions.

The shielding features of the cask including the impact limiters are designed to maintain the maximum combined gamma and neutron dose rate to less than 2 mSv/h at the surface and to less than 0.1 mSv/h in 2 m distance under the normal transport conditions.

STRUCTURAL EVALUATION

The structural design of the cask incorporates the criteria based on Korea Atomic Energy Act, IAEA Safety SSS No.ST-1 and US 10 CFR 71. Structural performance of the cask has been evaluated for the load conditions defined in US 10 CFR 71 and US NRC RG 7.8[6].

Stress limits for containment structure and bolts of the structure are as stated in ASME Sec.III, Div.3, and are consistent with those stated in US NRC RG 7.6. The non-containment structural members are shown to satisfy essentially the same structural criteria as the containment structure, even though RG 7.6[7] applies only to containment structures. Non-containment structures include all structural members other than the containment boundary components, but exclude the trunnions and impact limiters. The impact limiters, including their cladding structure, are not stress-limited. While performing their intended function during the free-drop impact, the impact limiters crush and thereby absorb the energy of the impact. The crushing of the spruce and beech woods contained in the impact limiters absorbs the kinetic energy of the cask while limiting the deceleration forces applied to the cask.

Structural analyses were performed using LS-DYNA3D explicit finite element code to evaluate the performance of the cask under the normal transport and the hypothetical accident conditions.

THERMAL EVALUATION

Heat is transferred between the cask and the environment by passive means only. It does not rely on any forced cooling and there is no subsystem. In transport, the cask is fitted with two shock absorbers, one at each end. It is transported horizontally under a transport hood. Under the normal transport conditions, the cask must lose the heat generated by the fuel to the environment without exceeding the operational temperature limits of the cask components important to safety.

The temperatures of the cask and components were determined by using finite element methods. Only the cask with W.H 17x17 fuel assemblies was analysed, as this represent the worst case, in terms of temperatures in the cask and in the fuel assemblies and also in terms of pressure. And among the normal transport conditions, only the hot condition was analysed for the same reasoning. Analyses considered both water and helium as backfill mediums. One basic three dimensional finite element model was used to simulate the normal hot condition of transport and the hypothetical accident condition of both the dry and the wet cask, by applying different sets of boundary conditions and material properties. For the evaluation of the cask for the normal hot condition of transport, two dimensional anlaysis to simulate the traverse heat transfer characteristic through the fuel assemblies and to calculate the temperatures in the fuel assemblies was carried out using MSC/NASTRAN, and a steady state analysis was performed using LS-DYNA3D.

SHIELDING EVALUATION

The radiation shielding features for the cask are sufficient to meet the radiation dose requirements in the related regulations and additional NETEC's requirements. The cask shall be so designed that under the normal transport conditions the radiation level does not exceed 2 mSv/h at any point on, and 0.1 mSv/h at 2 m from, the external surface of the cask, and the cask shall be so designed that, if it were subjected to the hypothetical accident conditions, it would retain sufficient shielding to ensure that the radiation level at 1 m from the surface of the cask would not exceed 10 mSv/h with the maximum radioactive contents which the cask is designed to carry.

Shielding for the cask is provided by the thick-walled cask body and the lid. For neutron shielding, polyethylene rods are arranged in the longitudinal boreholes in the vessel wall and polyethylene plates are inserted in the lid side impact limiter and between the cask bottom and the bottom steel plate. Additional shielding is provided by the basket structure. For transport, the impact limiters are installed at the top and bottom of the cask end areas. The cask will be transported with a vehicle using a transport hood. For distant locations geometric attenuation enhanced by air and ground, provides additional shielding.

The source terms for the design fuels were determined using ORIGEN-2.1. The shielding analyses were performed with MCNP-4B, which is a Monte Carlo code that offers a three dimensional combinatorial geometry modelling capability including complex surfaces. W.H 17x17 fuel with intact zircaloy cladding has been determined to be the design basis for shielding calculations. The normal transport conditions are modelled with the cask with the impact limiters and the transport hood, and the hypothetical accident conditions assume the absence of the transport hood, the impact limiters and the neutron moderator. The shielding analysis covers the hypothetical accident conditions in the related regulation in a conservative manner, because the impact limiters remain on the cask and the complete loss of the neutron moderator is not possible. Moderator regions in the shielding model are replaced by air.

CRITICALITY EVALUATION

The cask is designed to transport 12 zirconium cladded PWR fuel assemblies without any criticality under the normal transport and the hypothetical accident conditions. This is accomplished by controlling the neutron multiplication with boronated aluminum plates between the basket cells. The borona ted plates are sandwiched between a flux trap and the fuel assembly. The flux trap forces a physical separation between the fuel assemblies and, when filled with water, slows down the neutrons so that they can be captured in the bor onated aluminum. The basket assembly within the cask cavity maintains the relative position of the fuel assemblies under the normal transport and the hypothetical accident conditions. Fuel for the cask can be loaded with fuel from three plant types, W.H 14x14, 16x16 and 17x17 fueled plants. All of the different fuel designs for these three plant types were analyzed in the criticality analysis.

Three dimensional Monte Carlo code KENO-Va was selected for performing the criticality analysis because it has been extensively used and validated by others and has all the necessary features for this analysis. The criticality calculations were performed with SCALE 4.4a program system.

CONCLUSION

The CASTOR® KN-12 cask is a design of a transport package for dry and wet transportation of 12 PWR spent nuclear fuel assemblies. The cask has been designed by GNB basing on NETEC's requirements and evaluated as a transport package that complies with the requirements of and Korea Atomic Energy Act, IAEA SSS No.ST-1 and US 10 CFR 71 for a Type B(U)F package. The cask provides containment, radiation shielding, structural integrity, criticality control and passive heat removal for the normal transport and the hypothetical accident conditions.

The cask will be fabricated in Korea in accordance with ASME Sec.III, Div.3 after acquiring the certificate of design approval from the Korea regulatory body, KINS, in accordance with Korea Atomic Energy Act.

REFERENCES

[1] Korea MOST, "Korea Atomic Energy Act," 1999

[2] IAEA, IAEA Safety Standards Series No.ST-1, "Regulations for the Safe Transport of Radioactive Material," 1996

[3] U.S NRC, 10 CFR Part 71, "Packaging and Transportation of Radioactive Material," 1997

[4] ASME, ASME B&PV Code, Setion III, Division 3, "Containment Systems and Transport Packagings for Spent Nuclear Fuel and High Level Radioactive Waste," 1998

[5] ANSI, ANSI N14.6, "Special Lifting Devices for Shipping Containers Weighing 10000 lbs (4500 kg) or More," 1993

[6] U.S NRC, Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material," 1989

[7] U.S NRC, Regulatory Guide 7.6, "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels," 1978