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KN-18 Spent Nuclear Fuel Transport Cask

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ABSTRACT

KN-18 cask as shown in Fig.1 was designed to transport up to 18 PWR spent nuclear fuel assemblies in compliance with the requirements of Korea and IAEA regulations for Type B(U)F package. It provides containment, radiation shielding, structural integrity, criticality control and heat removal for normal and accident conditions of transportation. CE 16x16 fuel with maximum enrichment of 5.0 wt.%, maximum burnup of 60 GMWD/MTU and minimum cooling time of 9 years can be loaded and transported under both dry and wet conditions. Cask body of a thick forged carbon steel inner shell, a neutron shielding layer and a stainless steel outer shell is closed by two stainless steel lids. Neutron shielding material is installed surrounding the inner shell in the external shell with longitudianl aluminum heat trasnfer fins. Stainless steel fuel basket with neutron absorbing plates to accommodate 18 PWR fuel assemblies provides support of the fuel, control of criticality and path to dissipate heat. Impact limiters to absorb the impact energy under hypothetical accident conditions are attached at the top and bottom side of the cask during transportation. Carbon steel surfaces were covered by stainless steel cladding for corrosion protection and external cask surfaces were treated by buffing to facilitate decontamination work. Handling weight loaded with fuel is 104 tons and total transportation weight including impact limiters is 126 tons. The cask was licensed in accordance with Korea Nuclear Safety Act. Total four casks were fabricated in accordance with ASME Sec.III Div.3 and legal fabrication examination was undergone.

Fig.1 KN-18 cask on a special heavy-haul trailer

INTRODUCTION

KN-18 cask was designed and evaluated to transport up to 18 spent nuclear fuel assemblies in compliance with the requirements of Korea and IAEA regulations for Type B(U)F package. The cask provides criticality control, containment, radiation shielding, heat removal and structural integrity for normal and accident conditions. Maximum allowable initial UO_2 enrichment of fuel is 5.0 wt.%, fuel assembly burnup is limited to maximum average of 60 GWD/MTU and fuel to be loaed must have a minimum cooling time of 9 years. CE 16x16 fuel may be loaded and subsequently transported in the cask. Fuel can be transported alternatively in an inert helium gas atmosphere (dry type) or in a water filling (wet type) inside the cask cavity in order to reduce operationg time. Criticality control features were designed to maintain neutron multiplication factor (k_{eff}) including uncertainties and calculation bias at less than 0.95 under normal and accident conditions. Shielding features of the cask including impact limiters were designed to maintain maximum combined gamma and neutron dose rate to less than 2 mSv/h on surface and to less than 0.1 mSv/h at 2 m distance under normal conditions.

CASK DESCRIPTION

The cask consists of a cylindrical cask body with neutron shielding layer, double cask lids, a fuel basket, two pairs of trunnions and a pair of impact limiters as shown in Fig.2 and Fig.3.

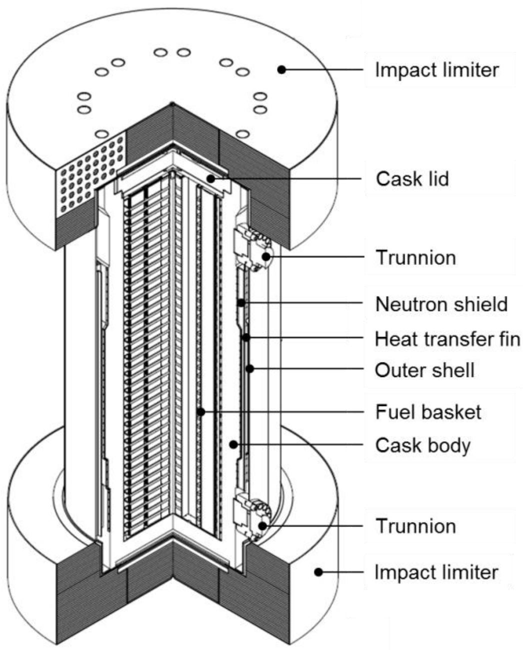

Fig.2 Cask overview

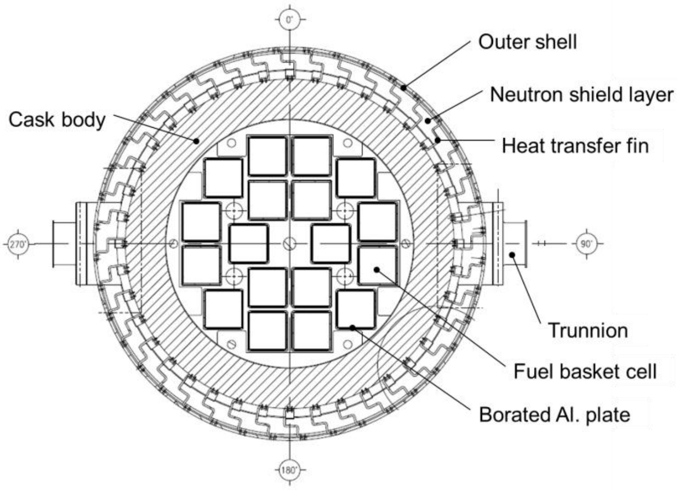

Fig.3 Cask section view

Containment system as defined by a cask body, cask lids, lid bolts and O-ring seals consists of a forged thick-walled carbon steel cylindrical body with an integrally-welded carbon steel bottom, and is closed by two stainless steel cask lids, which are fastened to the cask body by lid bolts, and sealed by double elastomer O-rings. Steel thickness of cask body wall, bottom and cask lids meets dose rate limits of the related regulations together with neutron shielding material. Neutron shielding material of resin is poured surrounding the inner shell in the external shell with longitudinal aluminum heat transfer fins. Fuel basket to accommodate 18 PWR fuel assemblies provides support of the fuel, control of criticality and path to dissipate heat from fuel to the cask body. Fuel receptacles, which are assembled as a grid together with borated aluminum plates, are manufactured by welding of stainless steel plates to form a square tube to enclose and secure the fuel. Each stainless steel receptacle is fully surrounded by borated aluminum plates of the basket grid. Borated aluminum plates of the basket grid provide sufficient heat removal and boron content of borated aluminum plates assures nuclear criticality safety under normal and accident conditions. Two pairs of stainless steel trunnions designed in accordance with the requirements of Korea Nuclear Safety Act and ANSI N14.6 are attached to the cask body for lifting and rotation of the cask between vertical and horizontal positions. A pair of impact limiters filled with woods to absorb impact energy under 9 m free drop conditions as hypothetical accident are attached at the top and bottom sides of the cask during transportation. Impact limiters are manufactured from carbon steel plate inner structure and stainless steel outer shell filled with woods. Carbon steel surfaces were covered by welded stainless steel cladding for corrosion protection and external cask surfaces were treated by buffing to facilitate decontamination work. During transportation, the cask is placed in horizontal position on a specially designed tie-down structure to meet the regulatory requirements. Overall cask length is 5,159 mm with wall thickness of 290 mm and outer diameter of the cask body is 2,351 mm. Each impact limiter is 3,592 mm in diameter and extends 1,075 mm along the side of cask in axial direction. Handling weight loaded with 18 fuel assemblies is 104 tons and transportation weight with impact limiters is 126 tons.

EVALUATION

Structural design of the cask incorporates the criteria based on Korea Nuclear Safety Act and IAEA regulation. Structural performance of the cask was evaluated against load conditions as defined in US 10 CFR 71 and USNRC RG 7.8. Stress limits for containment structure and bolts are as stated in ASME Sec.III Div.3 and are consistent with those stated in USNRC RG 7.6. Non-containment structural members are shown to satisfy essentially the same structural criteria as containment structure, even though RG 7.6 applies only to containment structures. Non-containment structures include all structural members other than containment boundary components, but exclude trunnions and impact limiters. Impact limiters are not stress-limited. While performing their intended function during free-drop impact, impact limiters crush and thereby absorb impact energy. Crushing of woods contained in impact limiters absorbs kinetic energy of the cask while limiting deceleration forces applied to the cask. Structural analyses were performed using an explicit finite element code to evaluate performance of the cask under normal and hypothetical accident conditions. Structural performance was confirmed by demonstration tests using a 1/3 scaled-down model and tests results were used to verify numerical tool and methods used in the analyses. Heat is transferred between the cask and environment by passive means only. In transportation, the cask is fitted with a pair of impact limiters, one at each end. Under normal conditions, the cask must lose heat generated by fuel to environment without exceeding operational temperature limits of cask components important to safety. Demonstration of thermal performance was also carried out by combination of tests using a 1/8 slice model and analyses. The cask loaded with CE 16x16 fuel was analyzed in terms of temperatures in the cask and in fuel assemblies and also in terms of pressure. Analyses considered both water and helium as backfill mediums. One basic three dimensional model was used to simulate normal and accident condition of both dry and wet cask. Radiation shielding features for the cask are sufficient to meet radiation dose requirements in the related regulations and additional KHNP's requirements. The cask shall be designed so that under normal conditions radiation level does not exceed 2 mSv/h at any point on, and 0.1 mSv/h at 2 m from, external surface of the cask, and the cask shall be designed so that, if it were subjected to hypothetical accident conditions, it would retain sufficient shielding to ensure that radiation level at 1 m from surface of the cask would not exceed 10 mSv/h with maximum radioactive contents which the cask is designed to carry. Shielding for the cask is provided by thick-walled cask body and lids. For neutron shielding, resin layer is enclosed in cask body wall and resin plates are inserted in lid side impact limiter and between cask bottom and bottom steel plate. During transportation, impact limiters are installed at the top and bottom of cask end areas. The cask is transported with a special vehicle using a transport hood. For distant locations geometric attenuation enhanced by air and ground provides additional shielding. CE 16x16 fuel with intact zircaloy cladding was determined to be design basis for shielding calculations. Normal conditions were modeled with the cask with impact limiters and accident conditions assumed the absence of impact limiters and neutron shielding. Shielding analysis covers accident conditions in the related regulations in a conservative manner, because impact limiters remain on the cask and complete loss of neutron shielding is not possible. The cask was designed to transport 18 PWR fuel assemblies without any criticality under normal and accident conditions. This is accomplished by controlling neutron multiplication with borated aluminum plates between basket cells. Borated aluminum plates are sandwiched between flux trap and fuel assembly. Flux trap forces physical separation between fuel assemblies and, when filled with water, slows down neutrons so that they can be captured in borated aluminum. Basket assembly within the cask cavity maintains the relative position of fuel assemblies under normal and accident conditions. And the cask design was approved in accordance with Korea Nuclear Safety Act.

Fig.4 9m drop test

Fig.5 Comparison of analysis and test results

FABRICATION

Cask body, bottom and lids were forged, machined and clad, and bottom is attached to the cask body by welding. Aluminum heat transfer fins and outer shells were attached the cask body, and resin was poured in the space between the cask body and outer shells. Basket structure was assembled and installed inside the cask. And two cask lids were placed on the top of cask body. Cask body and bottom made of low alloy carbon steel, SA350LF3 were forged using mandrel bar forging method like nuclear reactor forging, and heat treated, machined twice and examined non-destructively. Internal and external carbon steel surfaces of the cask body were clad with stainless steel to prevent corrosion due to contact with water. Bottom was attached to the cask body by automatic narrow gap welding. Neutron shielding layer was enclosed on the cask body wall and aluminum heat transfer fins were attached on the cask body in neutron shielding layer for effective heat removal. Neutron shielding material of NS-4-FR resin was poured into space between the cask body and outer shells. Basket was designed to accommodate 18 PWR fuel assemblies, perforated disks with square holes were stacked, receptacles were welded to square tubes to enclose and secure the fuel and assembled as a grid together with neutron absorbing material of METAMIC and inserted into stacked disks with square holes. Impact limiters attached at the top and bottom sides of cask were cylindrical and filled with absorbing material of laminated spruce and beech woods. And the related equipment to handle and transport the cask was fabricated at the same time. The related equipment consists of a specially designed heavy haul trailer with 8 axles and 64 tires, a tie-down structure and a personnel barrier on the trailer, a cask lifting device, two kinds of cask lid handling tools and a vacuum drying equipment necessary for dry transport condition. Total four casks were fabricated in accordance with ASME Sec.III Div.3.

Fig.6 Forged cask body

Fig.7 NDE

Fig.8 Narrow gap welding

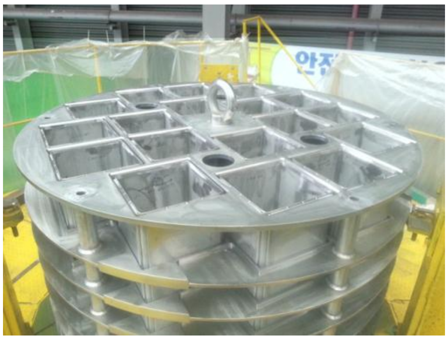

Fig.9 Basket structure

Fig.10 Fin

Fig.11 Cask and related equipment

LEGAL FABRICATION EXAMINATION

In each fabrication process of the cask, legal fabrication examination was undergone by Korea's regulatory body in accordance with the related regulations and codes & standards. Fabrication examination including qualification assurance consists of material inspections, weld inspections, non-destructive examinations, visual and dimensional inspections, hydrostatic test with MNOP, load tests, thermal test to demonstrate heat transfer integrity, helium leakage test to containment system, shielding integrity test and functional tests. All inspections and tests were carried out undergone for each fabricated cask. The most important material test in the cask was for fracture toughness. Forged cask body of SA350LF3 must meet the drop weight test requirement at RTNDT of -107 ^{o}C in accordance with ASME Sec.III Div.3 and USNRC RG 7.12, and was satisfied with the drop weight test requirement at RTNDT of -107 ^{o}C and other test requirements. Weld and machined parts was examined by non-destructive examination of UT, PT, MT and RT. Integral leak test to confirm the integrity of weld part was performed by means of an integral hood test using helium gas. The cask was tested to the test load of 162 ton equal to 150% of cask handling weight in accordance with ANSI N14.6, and NDE evaluation for load-bearing areas were carried out after load test. The cask was hydrostatically tested under test pressure of 1.5 times MNOP in accordance with ASME Sec.III Div.3. Visual and dimensional inspections to verify that the cask was fabricated and assembled in accordance with drawings, applicable codes & standards were carried out. Dimensions and tolerances specified on drawings were confirmed by several kinds of measurement methods. And load tests for cask lifting devices and cask lid handling tools were also carried out. Thermal test using dummy heaters to demonstrate heat transfer capability of cask and helium leakage test to containment system was performed. Radiation shielding integrity test was performed under loading real fuel at the nuclear power plant.

Fig. 12 Material test

Fig. 13 Helium leak test

Fig. 14 Thermal test

CONCLUSION

KN-18 cask was designed to transport up to 18 PWR CE 16x16 spent nuclear fuel assemblies for dry and wet transportation. The cask was evaluated as a transport package that complies with the requirements of Korea Nuclear Safety Act and IAEA Regulations for Type B(U)F package. The cask provides containment, radiation shielding, structural integrity, criticality control and passive heat removal for normal and hypothetical accident conditions. A strong point of KN-18 cask is that it was licensed as a package for international and domestic transportation, optimized for high burnup spent nuclear fuel of maximum 60GWD/MTU and possible to reduce transport time through both dry and wet loading conditions. Design of the cask were approved by Korea's regulatory body in accordance with Korea Nuclear Safety Act. All casks were fabricated in accordance with ASME Sec.III Div.3 and examined in accordance with Korea NSSC Notice.

REFERENCES

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[4] US 10 CFR Part 71, "Packaging and Transportation of Radioactive Material"
[5] ASME BPVC Section III Division 3, "Containments for Transportation and Storage of Spent Nuclear Fuel and High Level Radioactive Material and Waste"
[6] ANSI N14.6, "Special Lifting Devices for Shipping Containers Weighing 10,000 lbs(4,500 kg) or More"
[7] USNRC Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material"
[8] USNRC Regulatory Guide 7.6, "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels"
[9] USNRC Regulatory Guide 7.12, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Wall Thickness Greater Than 4 Inches (0.1m) But Not Exceeding 12 Inches (0.3m)