Conceptual Design for KN-12 Spent Fuel Shipping Cask

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ABSTRACT

The shipping cask to transport spent nuclear fuel assemblies should be evaluated in accordance with the requirements of the IAEA and domestic regulations. The cask should maintain the subcritical, radiation shielding, thermal and structural integrity in any condition of normal transport and hypothetical accident conditions. The NETEC/KEPCO has carried out the conceptual design for the KN-12 shipping cask to transport 12 PWR spent fuel assemblies. In order to meet Type B(U) requirements of the IAEA regulation and Korea Atomic Act and site handling conditions, the subcritical, radiation shielding, thermal and structural integrity for the KN-12 spent fuel shipping cask was evaluated.

INTRODUCTION

As the nuclear power plants increasing, the amount of the spent nuclear fuels discharged from the power plants has been gradually increased. In Korea, the storage of spent fuels will be beyond the capacity, and in particular, the storage capacity of Kori unit 1 will be at the uppermost limit within 3 or 4 years. The KEPCO(\textit{Korea Electric Power Corporation})
considers the on-site transshipment between the neighboring units to be the most useful for the spent fuel storage management at this time. So the NETEC (Nuclear Environment Technology Institute)/KEPCO has been developing the KN-12 spent fuel shipping cask. The shipping cask to transport spent nuclear fuel assemblies should be secured to protect the public and the environment from radioactive dangers. The cask is required to withstand both normal transport and hypothetical accident conditions in accordance with the requirements of IAEA Safety Standards Series No. ST–1[1] and domestic regulations[2,3]. The cask should maintain subcritical, radiation shielding, thermal, and structural integrity not to release radioactive material in any condition of the normal transport and the hypothetical accident conditions.

To comply with Type B(U) requirements of the cask and site handling conditions such as the rated capacity of the cask handling crane, the NETEC/KEPCO has carried out the conceptual design for the KN-12 shipping cask to transport 12 PWR spent fuel assemblies. The criticality, radiation shielding, heat transfer and structural analyses for the KN-12 shipping cask were performed and the cask was evaluated to maintain the integrity in accordance the regulatory requirements.

DESIGN REQUIREMENTS

Basic Requirements

The functional requirement of the KN-12 shipping cask is to transport all spent fuel assemblies discharged from the KEPCO’s operating power plants; Kori unit 1,2,3,4, Yonggwang unit 1,2 and Ulchin unit 1,2. The cask should conform to Type B(U) requirements with approval by Korea competent authority, and comply with the NETEC design criteria. The cask is designed to transport 12 PWR spent fuel assemblies under dry internal cavity transport condition. If wet condition to be water filled in the cask cavity is also acceptable providing it meets requirements, the cask will be designed for both dry and wet cavity conditions in order to reduce the cycle time during on-site transport operations. As the rated capacity of the cask handling crane of Kori unit 1 is 81 tons, the fuel-loaded cask weight does not exceed 70 tons.
Basis Fuel Parameters

Design basis fuel parameters are as follows:

Fuel type all W.H. fuel assemblies
Maximum burn-up 50,000 MWD/MTU
Maximum initial enrichment 5 w/o, and
Minimum cooling time 7 years.

DESCRIPTION OF KN-12 CASK

The KN-12 cask, as shown in Fig. 1, is a right circular cylinder with an impact limiter at each end. A stainless steel, lead and solid resin shielded cask was chosen for the main part of the cask body as it provided maximum shielding efficiency within the weight limits. The approximate dimensions of the cask determined through the conceptual design are as follows:

Cavity diameter 1,130mm
Cavity length 4,170mm
Cask body outer diameter 1,860mm
Gamma shield thickness 135mm
Neutron shield thickness 150mm
Impact limiter diameter 2,400mm
Cask length without impact limiters 4,890mm, and
Cask length with impact limiters 5,690mm.

The maximum gross weight of the cask including the contents and impact limiters is approximately 70 tons. The cask body consists three concentric stainless steel shells; inner shell, intermediate shell and outer shell. The inner shell is 20mm thick and has an inside diameter of 1,130mm. The intermediate shell is 50mm thick and has an outside diameter of 1,540mm. The annular layer between the inner and intermediate shells is filled with lead as a gamma shield. The inner and intermediate shells are welded to stainless steel plates at the top and bottom of the cask. The bottom of the cask consists of two inner
Fig. 1 Overview of the KN-12 cask
stainless steel circular plates, which are 30mm and 50mm thick, respectively, and the bottom end plate is 50mm thick. The spaces between two inner bottom plates is filled with lead and the spaces between the lower inner bottom plate and the bottom end plate is filled with a solid resin neutron shielding material. The cask body is surrounded by a stainless steel outer shell of 10mm thick. The outer shell is 1,860mm in diameter and is supported by longitudinal copper heat transfer fins which are connected to the outer shell of the cask body. The space between the fins is filled with a solid resin, NS4FR, shielding materials. The cask is closed by a stainless steel lid filled with lead and solid resin same as the arrangement of the cask bottom, which is bolted to the top end plate of the cask body. The lid is fastened by 36, 30mm diameter bolts and is sealed by double metallic O-rings. The fuel basket within the cask cavity can accommodate up to 12 PWR spent fuel assemblies. The fuel assemblies are positioned within square sleeves made of stainless steel plates with the thickness of 5mm. Each of the basket sleeves are surrounded by four BORAL sheets with the thickness of 3mm which are held in place by cladding. The sleeves are laterally supported by several stainless steel disks. Four trunnions made of stainless steel forging are welded to the top and bottom ends of the cask for handling and transport, the upper trunnions being required for the cask lifting equipment. The cask is equipped at each end with an impact limiter made of balsa and red wood to withstand the drop impact and fire accident conditions.

EVALUATION BY ANALYSIS

Criticality

In conformance with the regulations, the principal criterion for criticality safety is a maximum effective multiplication factor ($K_{eff}$) of 0.95, evaluated with a 95% probability at the 95% confidence level, including the effect of manufacturing tolerances and calculational uncertainties. Confirmation of the criticality safety of the fuel basket under flooded conditions, when filled with fuel of the maximum permissible reactivity for which it is designed, was accomplished with the SCALE-4.3 system to determine the maximum effective multiplication factor under normal transport and hypothetical accident conditions. Benchmark calculations
were made to compare with experimental data, using critical experiments selected to encompass, in so far as practical, the design parameters of the cask. The 27 group neutron library was used in all calculations, including those used to evaluate the sensitivity of the cask to a range of moderator density and center-to-center spacing. Through the criticality calculations, the center-to-center spacing of the basket which the maximum effective multiplication factor was below the 0.95 criticality safety limit was 258mm or more.

**Radiation Shielding**

The shielding design criteria for the spent fuel cask should meet the requirements of the IAEA and domestic regulations. The dose rate limits specified in the regulation for normal transport conditions are 2mSv/hr (200mrem/hr) on the surface of the cask and 0.1mSv/hr (10mrem/hr) at 1m from the surface of the cask, and the limits for hypothetical accident conditions are 10mSv/hr (1,000mrem/hr) at 1m from the surface.

The radiation protection provided by the KN-12 cask is in the form of solid multi-walled shielding materials which totally surround the fuel. The materials include stainless steel and lead for gamma shielding and a borated polymer, NS4FR, for neutron shielding. The KN-12 cask uses a multi-walled arrangement for radial and axial shields. The arrangement of the radial gamma shielding in the cask body is a 20mm thick stainless steel inner shell and a 50mm thick stainless steel intermediate shell with 135mm lead filled annulus between them. The radial neutron shield is arranged around the intermediate shell with a 150mm thick NS4FR layer which is covered by a 10mm thick outer shell. The bottom of the cask contains a S.S/lead/S.S/NS4FR/S.S shield arrangement with the three stainless steel components providing 140mm of gamma shielding and 100mm neutron shielding. The top of the cask has shields in the form of closure lid. The lid also has a S.S/lead/S.S/NS4FR/S.S arrangement with a 80mm thick stainless steel flanges.

The shielding analyses used the SAS2H sequence of the SCALE-4.3 system to calculate radiation sources. It used the ORIGEN-S code to calculate all of the source strengths and energy spectrum for radiation emitted from the basis fuel assembly. The energy spectrum for neutron and gamma radiation was 27 and 18 energy group structure, respectively. The XSDRNP-M-S and XSDOSE codes were used to calculate the cask does rates for normal transport and hypothetical accident conditions. The
total neutron and gamma dose rates calculated for the normal transport conditions were 0.2256mSv/hr(22.56mrem/hr) on the cask surface and 0.0842mSv/hr(8.42mrem/hr) at 1m from the cask surface. The accidental dose rates occurred in the event of the loss of the neutron shield were 0.3385mSv/hr(33.85mrem/hr) at 1m from the cask surface. The maximum dose rates for both the normal transport and the hypothetical accident conditions were less than the regulatory limits.

Heat Transfer

The heat transfer analyses were performed by the HEATING 7.2 code to demonstrate that the KN-12 cask can safely maintain the design basis temperatures required for the fuel cladding integrity under the range of thermal conditions expected during normal transport conditions, and to demonstrate that the containment boundary system of the cask was maintained within the safe operating temperature ranges. Temperatures for the cask components including the fuel, which were used as the input data for the fire transient analysis, were calculated for normal transport conditions of 12.6kW decay heat load, 38°C ambient temperature and solar insolation. The maximum fuel cladding temperature was 276°C and maintained below 380°C, and temperatures for the cask components were maintained within their safe operating ranges. The hypothetical fire accident condition was evaluated by imposing a 800°C fire temperature for 30 minutes followed by a post-fire equilibrium which was followed for four hours. The temperature time history of several points and maximum cask temperatures during and post-fire accident were calculated. The maximum fuel cladding temperature was also 276°C and maintained within the safe operating ranges, and the maximum lead temperature was 202°C and did not exceed the safe operating range based on preventing the lead from reaching its melting point of 327°C.

Structural

The cask is to maintain the structural integrity not to release radioactive material under normal transport and hypothetical accident conditions. The regulations describe that the cask should withstand a 9m free drop impact onto an unyielding flat surface in a direction causing maximum damage. Because it was difficult to define the impact direction, the 9m
free drop analysis was performed for the vertical, horizontal and corner drop, respectively. The regulations also describe that the package should withstand a 1m drop impact onto a mild steel round bar, which is 150mm in diameter and not less than 200mm long, in an orientation causing maximum damage.

To perform the stress evaluation for the cask, the dynamic analyses under the 9m free drop and the 1m puncture conditions were performed with a three dimensional analysis model using the ABAQUS finite element code. For each 9m free drop, the impact force was linearly jumped and suddenly decreased such that it was absorbed into the crush of the impact limiters made of balsa and red wood. For the 1m puncture, the outer shell and neutron shield layer of the cask impacted onto the round bar were locally and largely deformed, but scarcely any part of the cask body was notably damaged. Any maximum stress intensity on each part of the cask for each condition did not exceed the allowable value prescribed in the regulations. Therefore, the cask was evaluated to maintain the structural integrity under the 9m free drop and the 1m puncture conditions.

CONCLUSION

The conceptual design for the KN-12 shipping cask to transport 12 PWR spent fuel assemblies, which the NETEC/KEPCO has been developing, was performed by the criticality, radiation shielding, heat transfer and structural analyses. The KN-12 shipping cask was evaluated to maintain the integrity in accordance with the regulatory requirements.

REFERENCES