Conceptual Thermal Analysis of a Hot Cell Transportation Cask

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1. Introduction

A hot cell transportation cask is being developed to safely transport spent nuclear fuels and high level radioactive wastes generated from the pyroprocess. A cask to transport the radioactive materials is required to withstand the hypothetical accident conditions as well as normal transport conditions according to IAEA[1] and domestic regulations. The regulations require that the cask should maintain the shielding, thermal and structural integrities to release no radioactive material. The objective of a thermal analysis is to verify that the thermal performance of the cask. The cask must remove the decay heat from the spent fuel to the environment without exceeding the operational temperature ranges of the cask seals or other components important to safety. The accessible surface temperature of a cask in still air at 38 ℃ will not exceed 85 ℃ under normal transport condition. In this study, Thermal analyses of the hot cell transportation have been carried out for conceptual design of the cask.

2. Description of Hot Cell Transportation Cask

The hot cell transportation cask is classified with type B(U)F package in accordance with the requirements of IAEA and domestic atomic regulations.

Fig. 1 shows the configuration of the cask. The cask consists of a cask body, a lid, an inner container and shock absorbers. The cask body consists of lead shield, K-resin as a neutron shield and stainless steel shells. The gamma and neutron shields have a thickness of 140 mm and 60 mm, respectively. Inner container which constitutes the containment vessel is closed by a sealed cover. Shock absorbers are affixed to the ends of the cask to prevent damage in case of a cask drop accident. Shock absorbers consist of Balsa wood and stainless steel casing.

Table 1 shows a description of the hot cell cask. Design basis of spent fuel has a burn-up of 55,000 MWd/tU and a cooling time of 10 years. The cask is designed to transport 20 kg PWR spent fuel rod-cuts or 21 kg ceramic waste of alkali metals fission product generated from the pyroprocess. Decay heat load from the spent fuel and ceramic waste are 32 W and 397 W. The outer diameter of the cask is 0.80 m and the overall length is 1.15 m. The gross weight of the cask is approximately 3.7 tons.

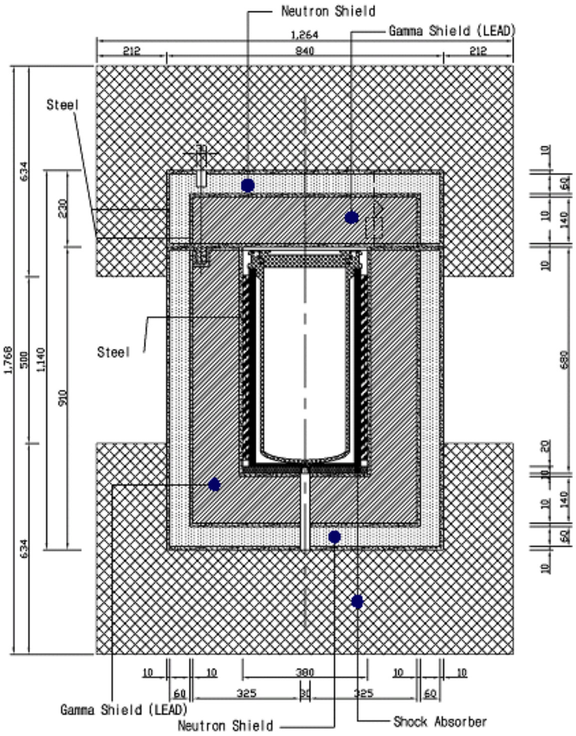

Fig. 1. Configuration of Hot Cell Transportation Cask.

Table 1. Description of Hot Cell Transportation Cask

Item	Description
Package type	B(U)F
Design basis fuel	- Burn-up : 55,000 MWd/tU - Initial enrichment : 4.5 wt% - Cooling time : 10 years
Loading capacity	- Spent fuel : 20 kg - Ceramic waste (AMFP) : 21 kg
Decay heat	- Spent fuel (20 kg) : 32 W - Ceramic waste (21 kg) : 397 W
Weight	3,700 kg
Materials & dimensions	- Cask body : stainless steel . Φ800 x 1,150 mmL . Φ1,270 x 1,763 mmL (including shock absorbers) - Gamma shield (lead) : 140 mm - Neutron shield (K-resin) : 60 mm - Inner container (internal size) . Stainless steel . Φ250 x 595 mmL (30 ℓ)

3. Thermal Analysis Model

Thermal analysis has been performed by using the FLUENT code. Fig. 2 shows a thermal analysis model. In this model, decay heat is removed from spent fuel or ceramic waste to the inner wall by a convection and radiation, and conduction is considered through the cask body. At the cask exterior surface, heat is transferred by a combination of convection and radiation to the ambient air. The decay heat from the spent fuel and ceramic waste are considered with 32 W and 397 W, respectively.

Initially, the cask is assumed to be operating at steady state under normal transport conditions with an ambient temperature of 38 ℃ and insolation of 400 W/㎡. It is then exposed to a 30 minutes, 800℃, fully engulfing fire having a flame emissivity of 0.9 and the cask surface is assumed to have a thermal absorptivity of 0.8[2].

The cask is operated in a vertical position and the convective heat transfer coefficient is derived from the following correlations[3].

- Laminar range(10^4<Ra<10^9) : $h = 1.42(\triangle T/L)^{1/4}$
- Turbulent range(Ra > 10^9) : $h = 0.95\ (\triangle T)^{1/3}$

Heat transfer correlation for a turbulent range was applied to all the outer surface of the cask for a thermal analysis. The surface of the cask was also radiating heat to the environment, and was given an emissivity value of 0.36 for stainless steel.

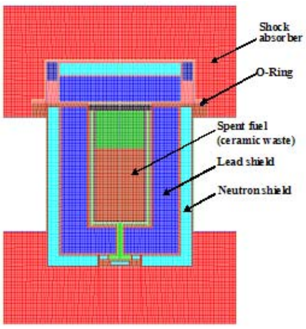

Fig. 2. Thermal Analysis Model.

4. Analysis Results and Discussion

Temperature distributions of the cask taken at various times during the fire and cool phase can be found in Fig. 3. Table 2 shows the thermal analysis results under normal and fire accident conditions for loading condition of ceramic waste. The maximum temperature of the cask surface is calculated as 78 ℃ for normal condition, which is lower than the allowable value of 85 ℃. The results of the analysis show a maximum ceramic waste temperature of 338 ℃, which occurred at 8.0 hours into the transient. This value is maintained below the allowable value of 450 ℃. The viton O-ring seal temperature is lower than the temperature limit of 250°C for the fluorocarbon O-ring. The temperature of the lead shield is lower than the melting point.

Therefore, it is found that the thermal integrity of the cask will be maintained under normal and accident conditions.

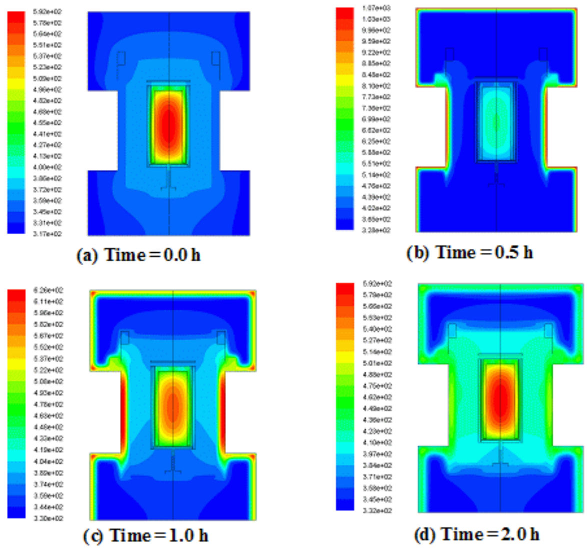

Fig. 3. Temperature Contours for Fire Condition.

Table 2. Thermal Analysis Results for Ceramic Waste

	Maximum temperature (℃)						
	Normal	Fire state		Post fire state (t >0.5 h)			
		0.25	0.5	1.0	2.0	4.0	8.0
Ceramic waste	319	319	319	319	319	324	338
Viton O-ring	80	133	208	204	159	136	132
Lead shield	90	90	102	126	149	146	135
K-resin (core)	83	152	278	298	202	142	130
K-resin (max.)	88	640	715	353	210	146	133
Cask surface	78	794	797	345	202	131	118

5. Conclusions

Conceptual thermal analyses have been carried out for a hot cell transportation cask. The maximum temperatures of the ceramic waste, O-ring seal and lead shield were lower than those of the allowable values. Therefore, it was found that the thermal integrity of the cask is maintained under normal and accident conditions.

Acknowledgement

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REFERENCES

[1] IAEA Safety Standard Series No. TS-R-1, "Regulations for the Safe Transport of Radioactive Material", 2005.

[2] IAEA Safety Standard Series No. TS-G-1.1, "Regulations for the Safe Transport of Radioactive Material", 2005.

[3] J. P. Holman, "Heat Transfer", International Student Edition 4th., 1976.