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Heat Removal Test by using a 1/2 Scale Storage Cask

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1. Introduction

Dry storage cask will be one solution for solving an interim storage problem. The dry storage cask consists of two separate components: an over-pack, and a canister. The structural strength part of the over-pack is made of carbon steel, and the inner cavity of the structural strength part is filled with concrete, which accomplishes the role as a radiation shield. The outer diameter of the dry storage cask is 3,550 ㎜ and its overall height is 5,885 ㎜. It weighs approximately 135 tons. The dry storage cask accommodates 24 PWR spent fuel assemblies with a burn-up of 55,000 MWD/MTU and a cooling time of 7 years. The decay heat from the 24 PWR spent fuel assemblies is 25.2 ㎾.

This paper discusses the experimental approach used to evaluate the heat transfer characteristics of the dry storage cask.

2. Heat Removal Test

2.1 Description of the Test model

The test model is a one-half scale model of the real dry storage cask. Figure 1 shows the cross section of the thermal test model. The lid of the canister has 24 holes for electrical heaters and 24 holes for thermocouples.

The electric heaters, which are to simulate 24 PWR spent fuel assemblies, are accommodated within the baskets and fixed on the top of the lid of the canister by means of a swage lock.

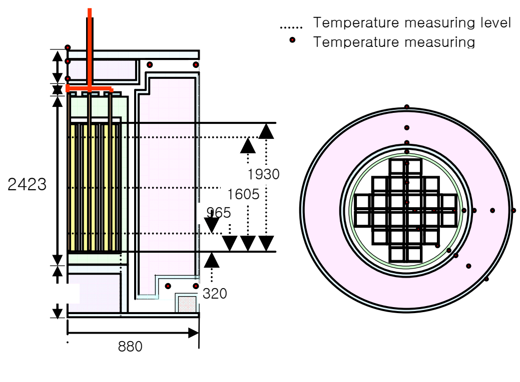

Figure 1. Cross Section of Thermal Test Model.

2.2 Heat Transfer Mode and Measurement System

Heat is generated by the spent fuel assemblies within the canister and it is transferred to the surface of the canister via a conduction, convection, and radiation. This heat is transferred from the surface of the canister to the inner surface of the over-pack through a convection and a radiation. The over-pack is designed to dissipate the heat from the canister through the passive heat removal system. This mechanism is a natural convective air flow through the annular area between the canister and the inner surface of the over-pack. Therefore, the heat transfer from the over-pack to the ambient atmosphere is accomplished through two mechanisms; the heat, which is conducted through the over-pack body, dissipated from the exterior surface of the over-pack to the ambient atmosphere by a convection and a radiation, and the air, which is heated in the annular area, is vented to the ambient atmosphere through the outlet of the passive heat removal system.

The heat transfer from the exterior surface of the over-pack to the ambient atmosphere is [1]

$$q_s = hA(T_s - T_a) + \sigma\varepsilon A(T_s^4 - T_a^4)$$

where q_s is the heat transfer from the exterior surface of the over-pack to the ambient atmosphere, h is a natural convective heat transfer coefficient, A is the surface area, T_s is the temperature at the surface, T_a is an ambient temperature, σ is the Stefan-Boltzmann constant and ε is the emissivity.

The heat transfer to the ambient atmosphere through the outlet of the passive heat removal system is [2]

$$q_A = \dot{m} C_p \Delta T$$

where q_A is the heat transfer to the air, $\dot{m}$ is the mass flow rate, C_p is the specific heat of the air and $\triangle T$ is the differential air temperature from the inlet to the outlet.

In order to evaluate the heat transfer characteristics of the dry storage cask, accordingly, two measurement systems were used in the heat removal test. One is the temperature data acquisition system, which consists of the thermo-couple scanner, the signal conditioner, the A/D converter and the P/C. The other is the velocity data acquisition system, which consists of the anemometer scanner, the data logger, the A/D converter and the P/C.

2.3 Heat Removal Test

The heat removal tests were carried out in a house with dimensions of 5.0 m x 5.0 m x 5.0 m. The house was made of a sandwich panel to decrease the influence of a fluctuation of the ambient temperature. During the heat removal test, the test model is located in the center of the house, and the cold air enters the house through the six louvers and the heated air goes out through the roof of the house. Total heat power from the 24 electric heaters was applied to 4.5 ㎾.

The thermocouples were installed to measure and monitor the temperature of the test model. Also, 26 thermocouples were installed to measure and monitor the ambient temperature of the house.

The sensor to measure the air velocity at the inlet and outlet was two types. Hot wire anemometers were used to measure the air velocity at the inlet duct. As the temperature exhausting from the outlet duct is very high, the air velocity at the outlet duct was measured with vane type anemometers.

2.4 Test Results and Discussion

In the normal condition, a thermal equilibrium of the test model was reached after about 120 hours, and that state was maintained for a period of 2 days. Table 1 lists the maximum temperatures measured under normal conditions. The average ambient temperature in the house was maintained at approximately 27°C during the normal condition test.

The difference of the temperature between the inlet and the outlet was considerably large. The average velocity at the inlet and outlet was measured at 0.49 m/s and 0.72 m/s respectively. The mass flow rate of the air was calculated as 0.0104 ㎏/s. Accordingly, the heat transfer rate transferred to the ambient atmosphere by the air was estimated as 83 %. It shows that the performance of the passive heat removal system is well maintained.

Table 1. Test Results for Normal Condition

Location		Maximum temperatures(°C)					
		Basket	Canister	Over-pack		Inlet	Outlet
				Inside	Outside		
0°	Upper	259	116	53	36		70
	Middle	240	105	46	34		
	Lower	177	-	39	32	27	
90°	Upper	259	121	54	36		76
	Middle	239	110	47	34		
	Lower	176	88	40	32	27	

In the off-normal condition, a half of the inlet was closed. Table 2 shows the temperatures which are compared with the normal condition.

From the test results, as the temperature increase is about 2 °C ~ 8 °C, the influence of the half blockage of the inlet on the temperature seems to be a very small.

Table 2. Test Results for Off-Normal Condition

Location		Maximum temperatures(°C)					
		Basket	Canister	Over-pack		Inlet	Outlet
				Inside	Outside		
0°	Normal	259	116	53	36	27	70
	Off-Normal	263	123	56	38	27	78
90°	Normal	259	121	54	36	27	76
	Off-Normal	263	125	58	38	27	84

In the accident condition, after a thermal equilibrium of the test model was reached, all the inlets were closed. The test was continued for 48 hours. Table 3 shows the temperatures at 12 h, 24 h, 36 h and 48 h after all the inlets were closed. The temperature rose precipitously until 12 hours had lapsed, but the temperature rise became dull after 36 hours.

Table 3. Test Results for Accident Condition

Location	Temperatures(°C)					
	O h	12 h	24 h	36 h	48 h	Amb.
Basket	259	275	282	287	288	31
Canister	116	144	150	154	156	31
Over-pack	43	46	51	55	58	31

3. Conclusion

The heat removal test was carried out to evaluate the heat transfer characteristics of a dry storage cask, the main results were as follows:

i) In the normal condition, the heat transfer rate transferred to the ambient atmosphere by the air reached 83 %. Accordingly, the passive heat removal system was designed well.

ii) In the off-normal condition, the influence of a half blockage of the inlet on the temperature seems to be a very small.

iii) In the accident condition, The temperature rose precipitously until 12 hours had lapsed, but the temperature rise became dull after 36 hours.

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