Transactions of the Korean Nuclear Society Autumn Meeting
Busan, Korea, October 27-28, 2005

Spent Fuel Dry Storage Cask Thermal Test

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1. Introduction

Most nuclear power plants maintain their spent fuel discharged at a reactor in wet storage pools. However, after several years of use, many pools are filled to capacity. Therefore, finding a sufficient capacity for storage is essential because of the continued delays in obtaining a safe, interim storage facility if nuclear power plants are to be allowed to continue to operate.

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 structure strength part of the over-pack is made of carbon steel, and the inner cavity of the structure 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 the 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. Thermal Test

2.1 Description of the Thermal Test model

The thermal 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.

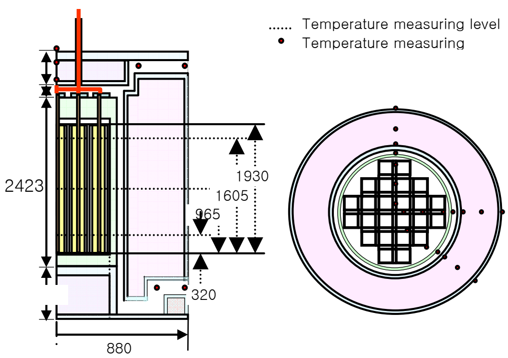

Figure 1. Cross Section of Thermal Test Model.

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 the swage lock.

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 conduction, convection, and radiation. This heat is transferred from the surface of the canister to the inner surface of the over-pack through convection and 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 convection and radiation, and the air, which is heated in the annular area, is vented to the ambient atmosphere through 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 a 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 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 △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 thermal 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 Thermal Test

As shown in figure 2, the thermal tests were carried out in a thermal test house with dimensions of 5.0 m x 5.0 m x 5.0 m. The thermal test house was made of a sandwich panel to decrease the influence of a fluctuation of the ambient temperature. During the thermal test, the test model is located in the center of the thermal test house, and the cold air enters the thermal test house through the six louvers and the heated air goes out through the roof of the thermal test 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 as shown in figure 1. Also, 26 thermocouples were installed to measure and monitor the ambient temperature of the thermal test 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.

Figure 2. Test Model and Thermal Test House.

2.4 Test Results and Discussion

Table 1 lists the maximum temperatures measured under normal conditions. Thermal equilibrium of the test model was reached after about 120 hours, and that state was maintained for a period of 2 days. The average ambient temperature in the thermal test house was maintained at 21°C approximately during the thermal test. A flow did not occur inside the canister because the gap between the lid of the canister and the basket was quite small at 4 ㎜ approximately. In the basket, therefore, the temperature of the upper and the middle part appeared similarly. In the 135° direction, the temperature of the canister surface and the over-pack was higher than that in the other direction. It showed that the basket was contacted with the canister body.

Table 1. Summary of the Thermal Test Results

Location		Maximum temperatures(°C)					
		Basket	Canister	Over-pack (Inside)	Over-pack (Outside)	Inlet	Outlet
0°	Upper	284	110	45	28		70
	Middle	285	106	38	26		
	Lower	212	84	31	24	21	
90°	Upper	283	120	47	28		65
	Middle	286	108	40	26		
	Lower	214	85	32	24	21	
135°	Upper	263	126	47	29		63
	Middle	263	114	40	27		
	Lower	171	87	32	24	21	

The difference of the temperature between the inlet and the outlet was considerably large. The velocity at the inlet in the 0° and 135° direction was measured at 0.59 m/s and 0.43 m/s respectively, the mass flow rate of the air was calculated as 0.0091 ㎏/s and 0.0066 ㎏/s respectively. The measured velocity at the outlet was 0.75 m/s in the 0° and 135° direction, the mass flow rate of the air was calculated as 0.0098 ㎏/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.

3. Conclusion

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

ⅰ) The difference of the temperature between the inlet and the outlet was considerably large. The heat transfer rate transferred to the ambient atmosphere by the air reached 83 %. Accordingly, the passive heat removal system was designed well.

ⅱ) To prevent a local temperature rise, the cavity between the canister and the over-pack as well as that between the basket and the canister has to be designed so as to maintain the same distance.

ⅲ) The gap between the lid of the canister and the basket must have an appropriate space to ensure that the flow can happen inside the canister.

4. Acknowledgments

This paper was prepared under contract with KHNP. The authors thank to all members of the KHNP.

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