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Heat Removal Performance in accordance with the Location of the Half-blockage of the Inlet Openings of Concrete Storage Cask

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1. Introduction

The management of spent nuclear fuel generated at nuclear power plants has become a major policy issue owing to continued delays in obtaining a safe and permanent disposal facility. Most nuclear power plants store their spent nuclear fuel in wet storage pools. However, after decades of use, most storage pools have reached maximum capacity. For the nuclear industry, finding sufficient capacity for the storage of spent nuclear fuel is essential if the nuclear power plants are to be allowed to continue their operation. Therefore, a concrete storage cask containing 21 spent fuel assemblies is under development by the KOrea RADioactive waste agency (KORAD) in Korea.

The thermal conductivity of concrete is not good, and the allowable temperature of concrete is lower than that of steel. ACI-349 specifies a normal operating concrete temperature limit of 66 °C, except for the local areas, which may not exceed 93 °C, and a short-term or accident temperature limit of no more than 177 °C[1]. Therefore, a passive heat removal system was designed so that the temperatures of the fuel assembly cladding material and the concrete storage cask components remain within the allowable limits. The passive heat removal system consists of four inlets and four outlets.

This paper discusses the experimental approach used to evaluate the heat removal performance in accordance with the location of the half-blockage of the inlet openings of the concrete storage cask under off-normal conditions.

2. Thermal Test

2.1 Description of the Concrete Storage Cask

The concrete storage cask system consists of three separate components: an over-pack, a canister, and a transfer cask. The spent nuclear fuel assemblies are loaded and sealed inside the canister. The canister is then transferred using the transfer cask into a cylindrical over-pack for on-site dry storage. The canister may be removed from the over-pack at any time and transferred into the transport cask for movement to a permanent disposal facility.

Figure 1 shows a schematic of the concrete storage cask. The structural casing of the over-pack is made of carbon steel, and the inner cavity of the casing is filled with concrete, which acts as a radiation shield. The outer diameter of the concrete storage cask is 3,306 mm and its overall height is 6,180 mm. It weighs approximately 148 tons. The concrete storage cask accommodates 21 PWR spent fuel assemblies with a burn-up of 45,000 MWD/MTU and a cooling time of 10 years. The decay heat from the 21 PWR spent fuel assemblies is 16.8 kW.

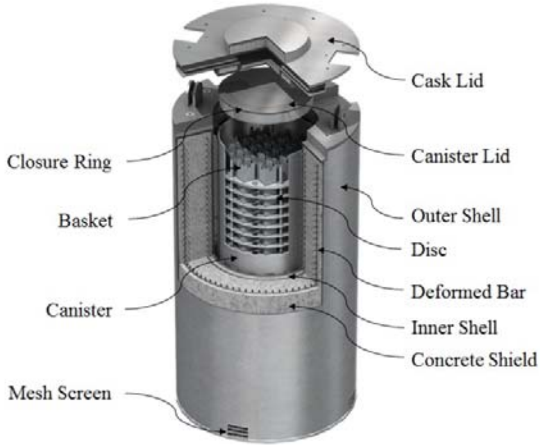

Fig. 1. Configuration of Concrete Storage Cask

2.2 Thermal Test

Under off-normal conditions, thermal tests were carried out in a test house with dimensions of 8 m(W) x 10 m(L) x 10 m(H) for three cases, as shown in table 1. During the thermal test, the test model was located in the center of the house, cold air entered the house through four louvers at the ground level, and the heated air was vented through four exhausts at the upper level.

Table 1. Test Conditions

	Inlet Location			
	0°	90°	180°	270°
1st Case		Blockage		Blockage
2nd Case	Blockage	Blockage	Blockage	Blockage
3rd Case	Blockage			Blockage

2.3 Test Results and Discussion

Table 2 lists the maximum temperatures measured under off-normal conditions in the first case. The thermal equilibrium of the test model was reached after approximately 192 hours, and that state was also maintained for two days. The average ambient temperature in the thermal test house was maintained at approximately 20 °C during the thermal test.

As shown in table 2, the maximum temperature of the canister surface was measured as 136 °C, the maximum temperature of the over-pack inner surface was measured as 59 °C, the maximum temperature of the concrete center was measured as 44 °C, and the maximum temperature of the over-pack outer surface was measured as 34 °C.

Table 3 shows the temperature and velocity from the test results measured at the inlet and outlet openings under off-normal conditions. The average velocity at the inlet openings was measured as 0.86 m/s; however, the average velocity at the outlet openings was measured as 0.76 m/s, which is lower than that at the inlet openings. This is due to the mass flow rate of the air decreasing at the inlet. The mass flow rate of the air was calculated to be 0.271 kg/s. Accordingly, the heat transfer rate into the ambient atmosphere by air was estimated as 87.4% of the heat transferred from the concrete storage cask into the environment. This shows that the passive heat removal system worked adequately under off-normal conditions as well. Therefore, we can know that the half-blockage of the inlet openings has a relatively small effect on the maximum temperature and temperature distributions.

Table 2. Thermal test results in the first case

Level (mm)	Temperature (°C)				Ambient (°C)
	Canister Surface	Over-pack Inner Surface	Concrete Center	Over-pack Surface	
6(4,970)	136	59	44	34	20
5(4,630)	132	58	43	33	
4(4,130)	126	55	41	32	
3(3,630)	121	51	38	30	
2(2,630)	114	44	34	27	
1(1,630)	97	36	28	24	

Table 3. Temperature and velocity at the inlet and outlet

	Inlet			Outlet		
	0°	90°	180°	45°	135°	225°
Temp. (°C)	17.5	-	17.2	67.7	71.7	74.1
Velo. (m/s)	0.81	-	0.91	0.82	0.74	0.71

As can be seen in the temperature distribution, a drift flow in the flow area that could increase the local temperature of the dry storage cask has not occurred. Because the ambient temperature difference between the normal and off-normal conditions in the first case is 4 °C, we can estimate that the temperature increase in the canister and over-pack components is between 3 and 5 °C. Therefore, the influence of the half blockage of the inlet on the temperature appears to be minimal.

Table 4 lists the maximum temperatures measured at level 6 under off-normal conditions of the three cases. The average ambient temperature in the house was maintained at approximately 20 °C in the first case, 23 °C in the second case, and 30 °C in the third case during the thermal test under off-normal conditions. The maximum temperature of the canister surface was measured as 136 °C in the first case, 139 °C in the second case, and 146 °C in the third case. From these results, the temperature difference of the canister surface in the three cases is equal to the ambient temperature difference. Therefore, we can know that the canister surface temperature is directly affected by ambient air flowing in the annulus area between the canister and over-pack inner surface.

Table 4. Comparisons of temperature at level 6

Location (mm)	Temperature (°C)				Ambient (°C)
	Canister Surface	Over-pack Inner Surface	Concrete Center	Over-pack Surface	
1st Case	136	59	44	34	20
2nd Case	139	61	45	35	23
3rd Case	146	68	51	42	30

3. Conclusion

Thermal tests were carried out to evaluate the heat removal performance in accordance with the location of the half-blockage of the inlet openings of the concrete storage cask. The main results were as follows:

(i) The heat transfer rate to the ambient atmosphere by convective air through a passive heat removal system under off-normal conditions reached 87.4 %. Therefore, the half-blockage of the inlet openings has a relatively small effect on the maximum temperature and temperature distributions.

(ii) A temperature difference in accordance with the location of the half-blockage of the inlet openings was not found. Therefore, the influence of the direction of the half-blockage of the inlet openings reaching the heat removal performance was estimated to be minimal.

REFERENCES

[1] ACI 349-13, Code Requirements for Nuclear Safety-Related Concrete Structures(ACI 349-13) and Commentary, American Concrete Institute, Appendix E.4, 2013.