Experimental Verification for the Thermal Analysis of Spent Fuel Storage Cask

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1. Introduction

A spent fuel dry storage system is designed for the long-term storage of the spent nuclear fuel. Thermal test has been performed in order to verify the analysis result for the storage cask under normal operation condition. The storage cask is designed to store 24 PWR spent fuel assemblies. One half scale model has been fabricated and thermal test has been performed to compare the analytical results. The finite volume computational fluid dynamics code FLUENT[1] was used for the thermal analysis. The measured temperatures were compared with the analysis results from computer models of the same condition and configuration as the test.

2. Description of the Storage Cask

Fig. 1 shows the overview of the storage cask[2]. The cask consists of the structural material, a concrete shielding, and a natural cooling system. Heat is transferred from the cask to the environment by a passive means only. Eight air inlet and outlet ducts are installed at the top and bottom for a natural cooling system. The main structural function of the overpack is provided by carbon steel, and the main shielding function is concrete. The overpack is enclosed by cylindrical steel shells. The outer diameter of the storage cask is 3,550 mm and the overall height is 5,885 mm. The gross weight of the cask is approximately 135 tons. The storage capacity of the cask is 24 PWR spent fuel assemblies with a burn-up of 55,000 MWD/MTU and a cooling time of 7 years. The decay heat load from the 24 PWR assemblies is 25.2 kW.

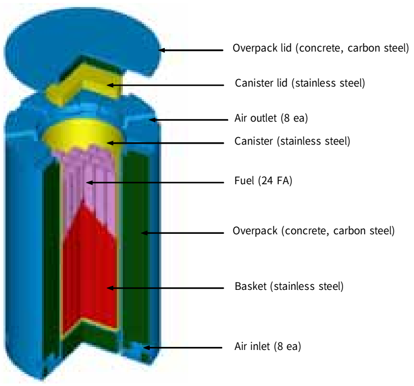

Fig. 1. Overview of Storage Cask.

3. Thermal Test of the Cask

Thermal test model was located in the test house. Fig. 2 shows the test model and house. The house has the outer wall and insulated inner wall to decrease the influence of fluctuation of ambient temperature. During the thermal test, the test model is located in the center of the house, and the cooling air goes inside through the windows with louvers and the crevice between the base concrete and the wall and goes outside through the ventilators attached on the roof.

(a) Test model (b) Test house

Fig. 2. Thermal Test Model and House.

Fig. 3 shows the cross section of the thermal model. There are 24 holes for heaters and several holes for measurements in the canister lid. The dummy heaters simulating spent-fuel assemblies are housed within the fuel baskets. Total thermal power from the dummy heater rods was applied with 6.3 kW, which is a quarter of the real cask.

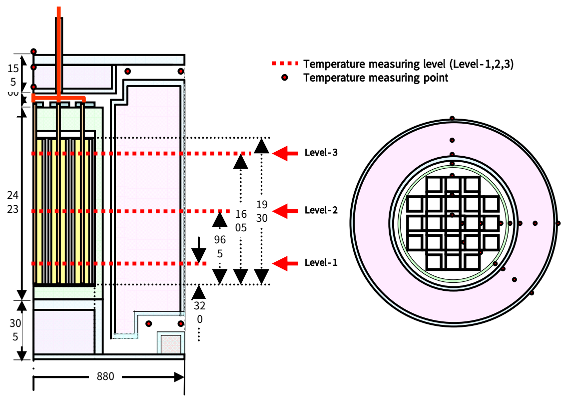

Fig. 3. Cross Section of Thermal Test Model.

To measure the temperature of the cask, K-type thermocouples are installed at various points in the direction of 0, 90, and 135 degrees. Thermal test was conducted under normal condition with an environment temperature of 15℃. The inside of the canister was filled with air instead of helium during the test.

Table 1 shows the summary of thermal test results. There are large temperatures between the upper and lower parts of the cask because the air temperature of the upper part is considerably affected by the hot air going along the canister surface by buoyancy force.

Table 1. Summary of Thermal Test Results

Location		Maximum temp.(℃)				
		Fuel basket	Canister surface	Overpack (inside)	Overpack (outside)	Air (outlet)
0°	Upper	333	128	45	25	76
	Middle	352	125	36	22	-
	Lower	276	103	27	19	-
90°	Upper	333	142	48	25	71
	Middle	356	127	38	22	-
	Lower	278	101	28	19	-
135°	Upper	314	150	49	26	69
	Middle	325	137	38	23	-
	Lower	212	103	28	19	-

4. Thermal Analysis of Storage Cask

Thermal analyses have been performed for the test condition. The analyses were carried out in two stages. In the first stage, the model consisted of the overpack, and the storage canister with a heat flux from the spent fuel. This model calculates the steady state temperature distributions of the overpack, ventilated air and canister wall. In the second stage, the canister with the fuel baskets and fuel assemblies is modeled. The canister wall temperature is applied as a boundary condition calculated from the first stage. It was assumed that the inside of canister was filled with air and helium gas. Fig. 4 represents the temperature contours of the storage cask.

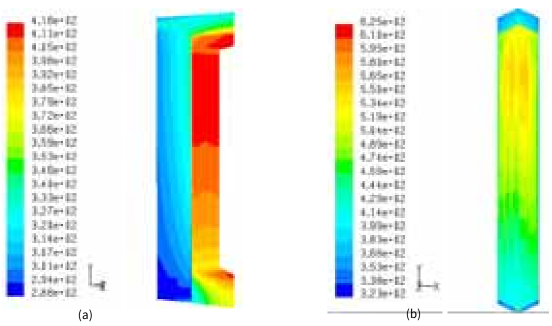

Fig. 4. Temperature Contours for Storage Cask.

The analysis results were compared with the test results as shown in Table 2. The overpack temperatures of the analysis results are slightly higher than the test results. But the general trends of temperature distributions are very similar between two results.

The maximum fuel temperatures were calculated as 352 ^{o}C and 304 ^{o}C in the air and helium cavity. The fuel cladding temperature limit is about 345 ^{o}C for a 7 year cooled PWR fuel assembly[3]. Maximum concrete temperature was calculated as 64 ^{o}C, which is lower than the allowable value of 93 ^{o}C. ACI-349[4] specifies a normal operating concrete temperature limit of 66 ^{o}C, except for local areas which may not exceed 93 ^{o}C.

Table 2. Comparisons of Temperatures between the Thermal Test and Analysis

Item	Maximum temp. (℃)		Allowable value (℃)
	Test	Analysis	
Fuel rod	-	352 *(304)	345
Fuel basket	356	350 *(302)	-
Canister outer surface	150	145	-
Overpack inner surface	49	64	93
Overpack outer surface	26	30	93
Air outlet	76	63	-

* ( ) is the analysis results of helium cavity

5. Conclusions

There were good agreements between the test and analysis results. Therefore, it was shown that the thermal analysis method and procedure were successfully established to estimate the temperature distribution of the storage cask. The maximum temperatures of the fuel rod and concrete overpack were lower than the allowable values. Therefore, the thermal integrity of the dry storage cask will be maintained under the normal conditions.

REFERNCES

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[3] PNL-4835. Technical Basis for Storage of Zircalloy-Clad Spent Fuel Inert Gases, PNL, (1983).

[4] ACI-349, "Code Requirement for Nuclear Safety Related Concrete Structures," American Concrete Institute.