Full-Scale Prototyping of the Hitachi Dual-Purpose Metal Cask and Verification of Its Heat Transfer Characteristics

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ABSTRACT

Hitachi has been developing dual-purpose metal casks for transport and storage of spent nuclear fuels. The Hitachi cask, HDP69B can store 69 BWR fuel assemblies. The cask features are as follows. 1) The fuel basket is assembled mainly with plates of borated stainless steel. The plates are not welded, but cross-inserted into each other like the dividers in an egg carton. Since the borated stainless steel has relatively low heat conductivity, aluminum alloy plates are inserted along with some stainless steel plates to enhance heat removal ability. 2) Cured resin blocks are fitted into the inner shell of the cask for neutron shielding of the cask body. The resin blocks are surrounded by an aluminum casing which transfers heat of stored fuel from the inner shell to the outer shell of the cask. The block type shield structure eliminates the need for welding the heat transfer fins to the inner and outer shells. The weldless structures of the HDP69B lead to its enhanced manufacturability, but they complicate the heat transfer characteristics because there are gaps between such components as the aluminum casing and inner/outer shells.

We carried out full-scale prototyping of the HDP69B and ran a heat transfer test using the prototype. The purposes of the heat transfer test were to check the heat removal ability of the HDP69B and to verify the safety analysis model for heat removal. Results of the heat transfer test and optimized analysis model for heat transfer characteristics of the HDP69B are the focus of this paper.

The heat transfer test is summarized as follows. Sixty nine heaters simulating the shape and heat power of spent fuel assemblies were inserted into the fuel basket. After replacing the inner atmosphere with 0.1 MPa of helium, the heat transfer test was started. About 7 days were required to equilibrate the temperature distribution. The temperature at the center of the basket was 194 °C. The results confirmed the HDP69B had sufficient heat removal ability. The three-dimensional calculation model for the heat transfer characteristics of the prototype HDP69B was also established.

1. INTRODUCTION

It is planned to reprocess spent nuclear fuels discharged from nuclear power plants in Japan at the nuclear fuel recycle plant under construction at Rokkasho-mura. The number of spent fuels exceeds that of recycled fuels and the spent fuels have to be properly stored and maintained as a recycled fuel resource until reprocessing begins. The interim storage facilities for spent fuels may be at reactor sites or at some distance from them. Most of the interim storage facilities will be using dry storage and will want to have a dual purpose metal cask to allow both transport and storage. Therefore, we developed the dual purpose transport and storage metal cask.

The metal cask, HDP69B which was developed has a compound material basket structure which combines borated stainless steel plates and aluminum alloy plates with the basket and side neutron shielding consisting of resin block structures. Welding of parts is held to a minimum and the assembly process is simplified as much as possible; these steps help to shorten the manufacturing time needed. However, because the final result is influenced by the size of the gap which is found in the combined part, appropriate modeling is necessary when evaluating the temperature.

We carried out a heat transfer test for cutting into round slices in which we used an actual scale diameter and we were able to verify the heat transfer evaluation method [1] for the HDP69B with the compound basket structure. The model for cutting into round slices is generally used for safe evaluation of the fuel cladding tubes and the side-piece resin. However, because it does not consider heat transfer to the axial direction, the model gives results which have a big leeway. Therefore, we manufactured a full-scale HDP69B type metal cask experimentally and implemented the heat transfer test for it to confirm the heat transfer performance of the HDP69B and to verify the heat transfer evaluation model. This paper gives the evaluation results of the heat transfer performance of the HDP69B in the full-scale heat transfer test and the 3-D heat transfer calculation.

2. FERTURES OF HDP69B TYPE METAL CASK

The structure of the HDP69B type metal cask is shown in Fig. 1. It can hold 69 BWR fuel assemblies which have an average burnup of 34 GWd/t and have been cooled for 10 years. The HDP69B features application of a fit-in type basket structure and a resin block structure.
The structure of the basket is shown in Fig. 2. It is not a single material and it gets its structural strength and good heat transfer performance by combining borated stainless steel plates and aluminum alloy heat conduction plates. The borated stainless steel plates and the heat transfer plates have slits allowing them to be inserted into each other in the support cylinder which is located inside the inner shell. Welding becomes unnecessary with this fit-in structure and reduced cost and shorter manufacturing time become possible.
The structure of the side neutron shielding is shown in Fig. 3. The side neutron shielding has a resin block structure. For the HDP69B, the resin is allowed to cure by pouring it into a case made of aluminum alloy and this attaches to the cask body [2]. In this way, since the main unit and the resin block can be concurrently manufactured, the manufacturing period is shortened. Also, a heat curable type resin can be used for the resin, too.

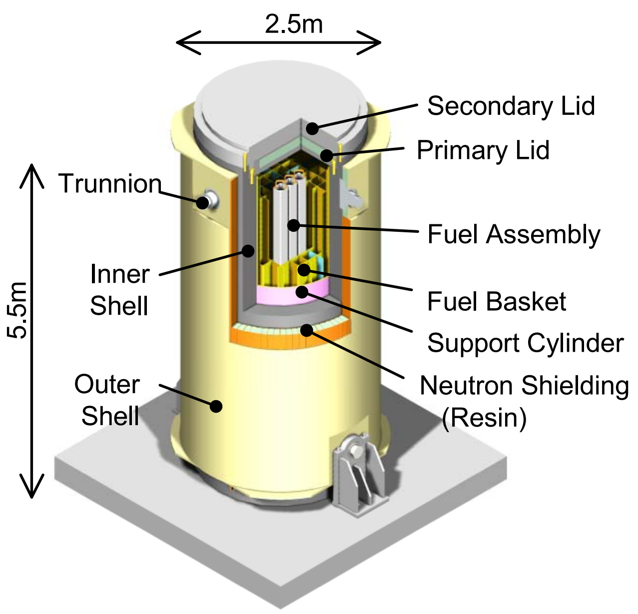


Fig. 1 Cut-away view of HDP69B type metal cask

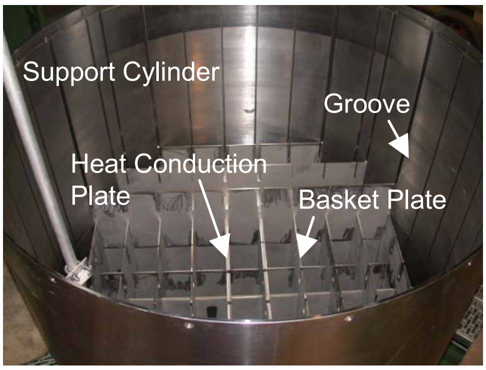


Fig. 2 Structure of fuel basket

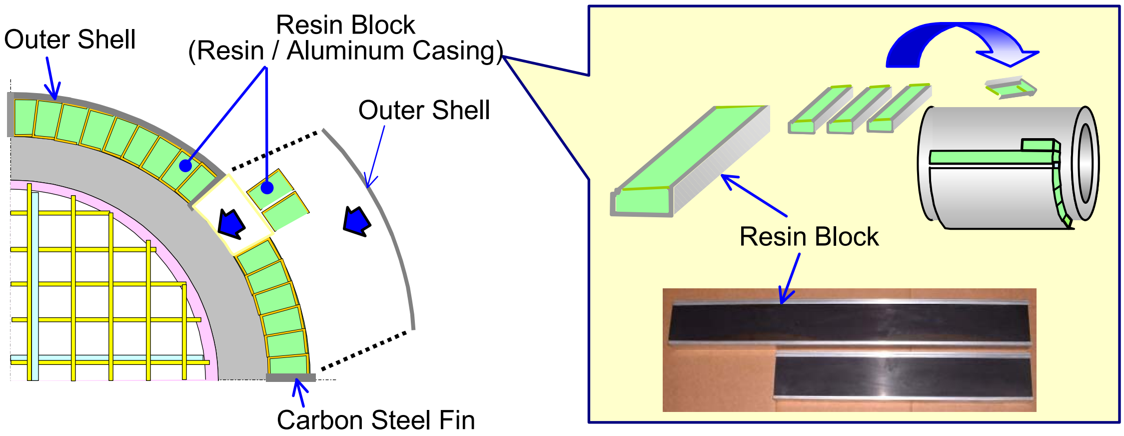


Fig. 3 Structure and alignment of resin blocks

3. HEAT TRANSFER TEST

3.1 TEST EQUIPMENT AND PROCEDURE

The test equipment used the actual size prototype metal cask, except for the lid part, and insertion of heaters. The outward appearance of the cask is shown in Fig. 4. To allow the heater lines and the thermocouple lines to be easily removed, we made a special lid for the test. For the heat resistance in the direction of the thickness to become equal to that of the lid of the actual cask, the test lid surface was covered with an insulator, as shown in Fig. 5. The heaters were installed in the basket to simulate heat generation from the fuel assembly. Heat value was set to 280 W/assembly which is equivalent to what fuel with an average burnup of 34 GWd/t would produce after cooling for 10 years. Two heaters were used per fuel assembly. A 3.7m length at the center was the heat generation part. Square tubes made of aluminum alloy were used around the heater instead of the channel box. The upper part of the square tubes was covered to restrain convection as much as possible. Four steel blocks were put on the room floor surface and the cask was placed vertically on them. The space between the block base and the floor was filled with insulator.

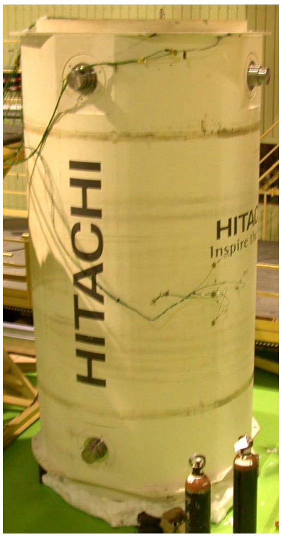


Fig. 4 Outward appearance of HDP69B

A K type thermocouple was used for the temperature measurement. There were 30 measurement points; 6 were on the basket plate near the center, 10 were on the outside surface of the inner shell, 10 were on the outer shell surface and 2 were installed on each base and lid. The temperature measurement points at the basket plate center, the outside surface of the inner shell, and on the outer shell surface were arranged in an axial center section where the fuel was being heated.

A test was carried out indoors. Before the test, the inside of the cask was vacuumized, and then filled with He to approximately atmosphere pressure. After that, the heater power was turned on, and temperature data were recorded every 15 minutes until the static state was reached.

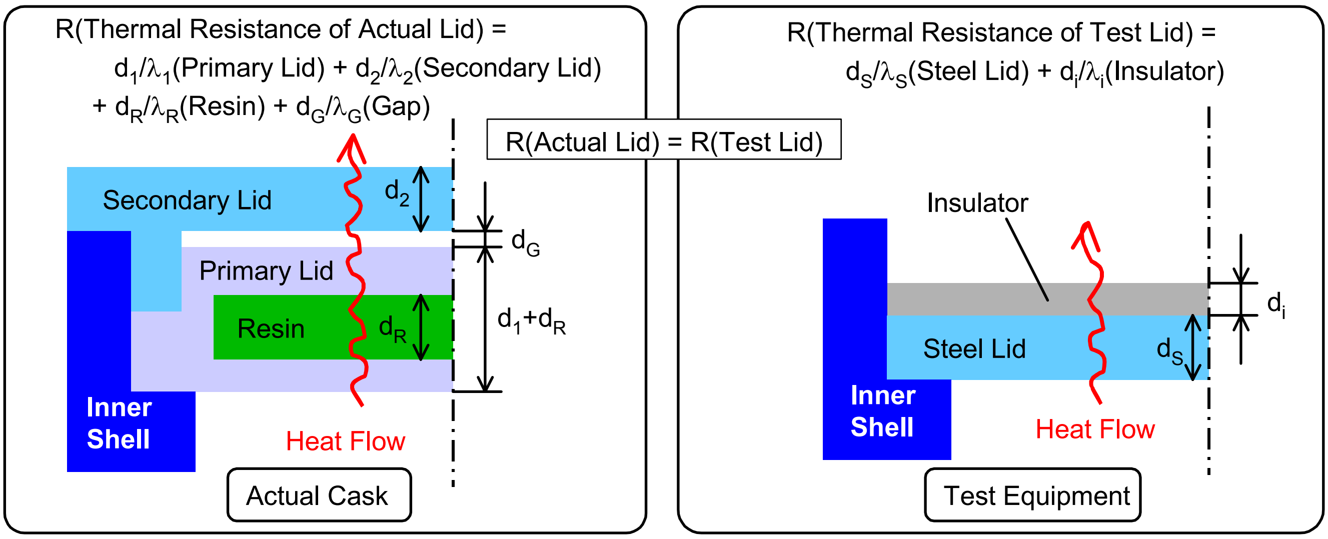


Fig. 5 Viewpoint for setting Insulator thickness on test lid

3.2 TEST RESULTS

Figure 6 shows the temperature change of each measurement point at the basket plate center, the outside surface of the inner shell, and on the outer shell surface. In the 6 days after heating was begun, the temperature rate of rise of each point was less than or equal to 1 °C/day and a static state was reached. Therefore, the test ended within 168.5 hours after turning on the heaters. There was no influence from the change of the environment temperature. As the temperature of the static state, the average temperature at each measurement point 24 hours before the test ended is shown in Fig. 7. In the measurement points on the basket plate center, the outside surface of the inner shell, and on the outer shell surface, no difference with a definite temperature was seen in the axial center section and the position which was shifted by 300 mm at the top and the bottom of the axial center section. In the test, the basket center temperature was about 194 °C. For the HDP69B, the target temperature of the fuel cladding tube is less than 282 °C when the ambient temperature is 27 °C. Because it is considered that the temperature difference between the basket plate and the fuel cladding tube is about 10 °C, the fuel cladding tube temperature which is estimated from the test result is about 204 °C. Consequently, HDP69B had sufficient heat removal performance for the stored fuels.

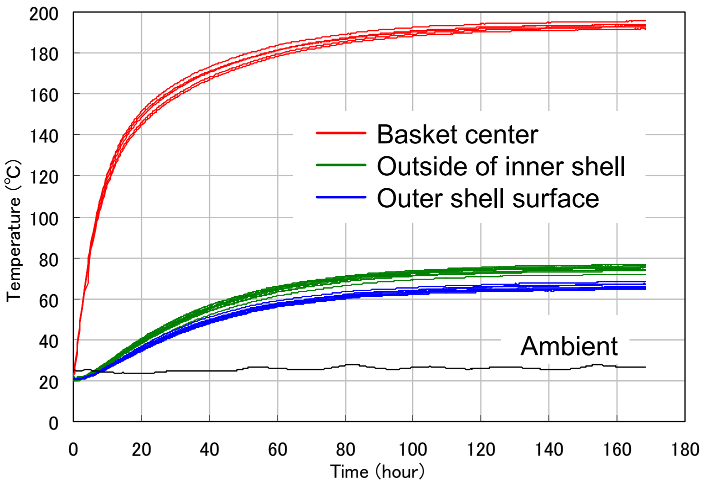


Fig. 6 Temperature change of each measurement point

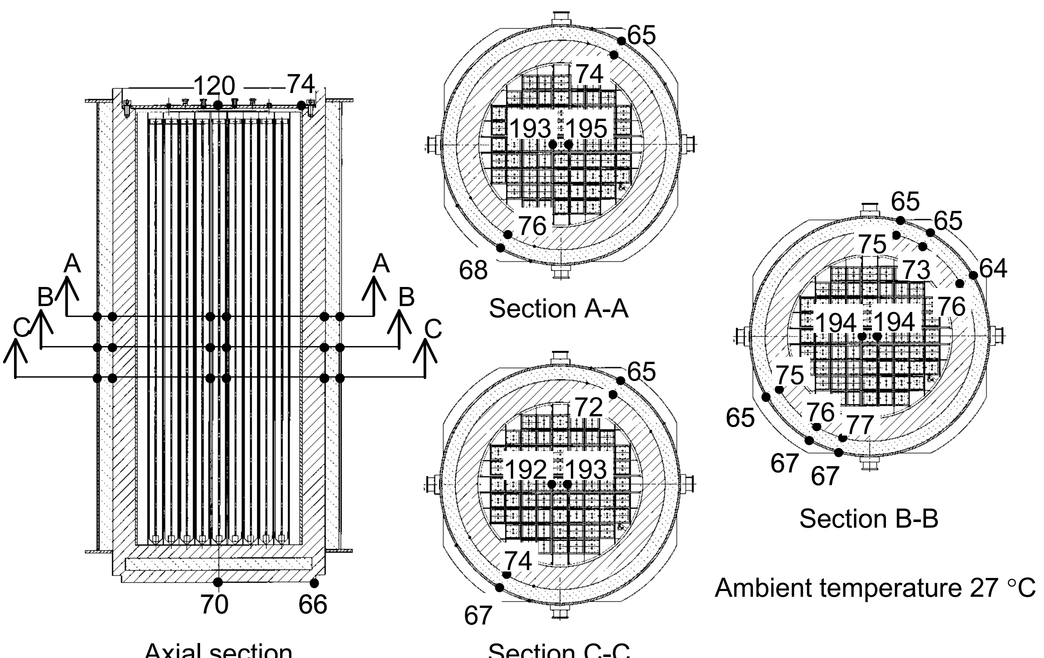


Fig. 7 Temperature of each measurement point at static state

4. THERMAL CALCULATION OF TEST EQUIPMENT

4.1 CALCULATION MODEL AND PROCEDURE

We carried out heat conduction analyses with the test system using the computer software "ANSYS ver.6.1". The analysis model provided a 3-D model of the whole test cask. Then, we assumed symmetry of the cask structure and modeled only a quarter section (90-deg segment). The calculation mesh system is shown in Fig. 8.
The gap width among the parts which are inside the cask was set to the average value of the maximum and minimum manufacturing tolerances, and the change of the gap width by the thermal expansion was not considered. The basket plates and the heat transfer plates were modeled as a unit ignoring the gap which was formed in the joined part. Influence on the heat transfer by the slit was modeled in the following way. The heat resistance of one basket plate or one heat conduction plate which modeled the slit shape faithfully was calculated by the analysis model, and the reciprocal of the heat resistance was set as the thermal conductivity of the basket or heat conduction plates. To reduce the number of the meshes, the inside of the basket cell was replaced by a homogeneous area, and the thermal conductivity of this area was given a value which was equivalent to the heat transfer with the actual shape which consisted of heaters and the aluminum square tube. The heat transfer from inside the cask treated only heat conduction and radiation. The thermal conductivities were values specified in the literature [3]. The boundary condition of the surface of the side and the lid was natural convection heat transfer and radiation, and the bottom surface was adiabatic.

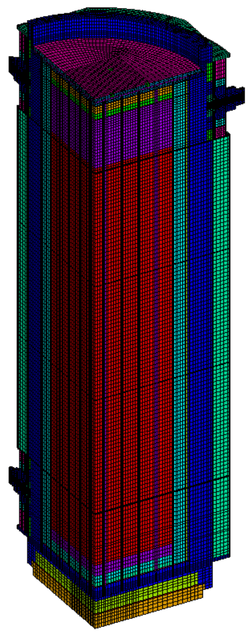


Fig. 8 Calculation meshes of 3-D heat conduction analysis

4.2 CALCULATION RESULTS

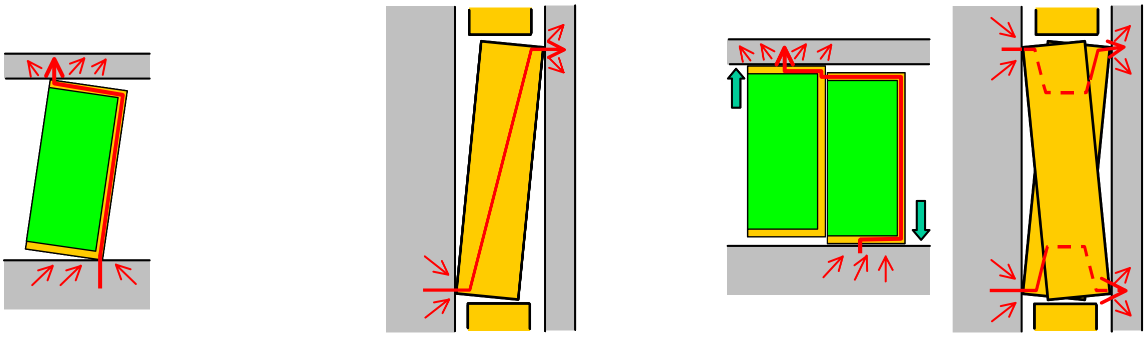
The temperature difference of each section obtained from the 3-D analysis and the test is shown in Table 1. Just as for each part at the basket plate center, the outside surface of the inner shell, and on the outer shell surface, there were 6 or 10 temperature measurement points. However, the deviation among the measurement points in each part was not so big, being less than 5 °C. Therefore, temperature differences in table 1 are using the average in each part.

Table 1 Temperature difference of each section obtained from 3-D analysis and test

Section		Test	Calculation	Calc./Test
Basket Center	- Outside of Inner Shell	119 °C	154 °C	1.3
Outside of Inner Shell	- Surface of Outer Shell	9 °C	27 °C	3.0
Surface of Outer Shell	- Ambient	39 °C	47 °C	1.2

The temperature difference between the inner shell and the basket center obtained as the analysis result was 1.3 times larger compared with the test. We thought that the analysis model was not considering that the change of the gap width by the thermal expansion and the part contact and this caused the difference.
Between the outside surface of the inner shell and the outer shell surface (the side neutron shielding part), in the analysis result, there was a big temperature difference compared with the test result. We thought that this was because the resin case touched the inner shell and the outer shell and it formed a heat transfer path. The gap between the inner shell and the resin block and between the resin block and the outer shell decides the heat resistance in the side neutron shielding part. The analysis model arranges the resin blocks uniformly between the inner shell and the outer shell, and it sets the size of the resin block, the inner shell, and the outer shell to the average value of the maximum and minimum manufacturing tolerances. However, actual size inspection records during

manufacturing show the gap width of this part is approximately half the value used for the analysis model. Also, because the resin blocks are not fixed in position, there is little possibility that they are really arranged uniformly. Therefore, possible heat transfer paths formed between the inner shell and the outer shell through the resin case are shown in Fig. 9.



(a) Contact in cross section (b) Contact in axial section (c) Contact through adjacent block

Fig. 9 Heat transfer paths which are formed by contact

5. CONCLUSIONS

We carried out the heat transfer test of an actual size metal cask to confirm the heat removal performance and to verify a heat transfer evaluation model.

(1) In the test result, the basket plate center temperature was about 194 °C. We confirmed that the target of the fuel cladding tube temperature, less than 282 °C, could be achieved even if it was considered that there was a temperature difference between the basket and the fuel cladding tube.

(2) The temperature difference between the inner shell and the basket center obtained as the analysis result was 1.3 times larger compared with the test. The difference was because the analysis model did not consider the change of the gap width by the thermal expansion and the part contact.

(3) In the side neutron shielding part, the test result had a temperature difference that was about 1/3 smaller than the calculation result. Since the gap width of the resin blocks and the inner/outer shell was small, heat transfer paths were formed in the part by contact.

Manufacturing of the full-scale prototype of the HDP69B and the heat transfer test were carried out by Equipos Nucleares, S.A.,Spain in a partnership with Hitachi.

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