DEVELOPMENT OF HIGH PAYLOAD METAL CASKS FOR TRANSPORTATION AND STORAGE OF SPENT NUCLEAR FUELS

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ABSTRACT

The first interim storage facility away from reactor sites will be constructed around 2010 in Japan. Metal casks will be used to transport the spent fuels from nuclear power plants to the storage facility and to store the spent fuel. Hitachi Ltd. has been developing metal casks for the dual-purpose of transportation and storage of spent fuel.

This paper outlines the development of Hitachi’s dual-purpose metal casks. Hitachi’s cask basket is made of plates cross-inserted into each other without welding. There are gaps between the plates and they complicate the heat transfer characteristics. Thus, a heat transfer test was carried out using a full-scale prototype of HDP69B which is representative of Hitachi’s dual purpose cask. The HDP69B was verified to have sufficient heat removal performance for the stored fuel assemblies.

Development of innovative materials for the metal cask used with high burn-up fuels is also described briefly.

INTRODUCTION

Spent nuclear fuels discharged from nuclear power plants in Japan are expected to be reprocessed at the Rokkasho reprocessing plant. Since the generation of spent fuels exceeds the predicted reprocessing capacity, they will have to be properly stored until the reprocessing plant is able to accept them.

The first interim storage facility away from reactor sites will be constructed around 2010. Metal casks will be used in the interim storage system. The guidelines and standards for these casks are being established by the Atomic Energy Society of Japan (AESJ) and the Japan Society of Mechanical Engineers (JSME). Hitachi has been developing dual-purpose metal casks to comply with the guidelines.

Outline of Dual-Purpose Metal Cask

The dual-purpose metal cask is used for the transportation of spent fuel from a power plant to a storage facility, to store the fuel for some decades (about 50 years), and then to transport it from the storage facility to the reprocessing plant.

The metal cask must satisfy various conditions when it is used for the transportation of spent fuels. These are as follows.

1. Sealing of cask lids must be maintained even in a drop accident
2. Dose rate 1m from the cask surface must below 100μSv/h (except in the event of a fire)
3. Criticality of nuclear fuel must be prevented under all conditions
4. Temperature of fuel crud must be kept lower than the criterion for the soundness of stored fuels

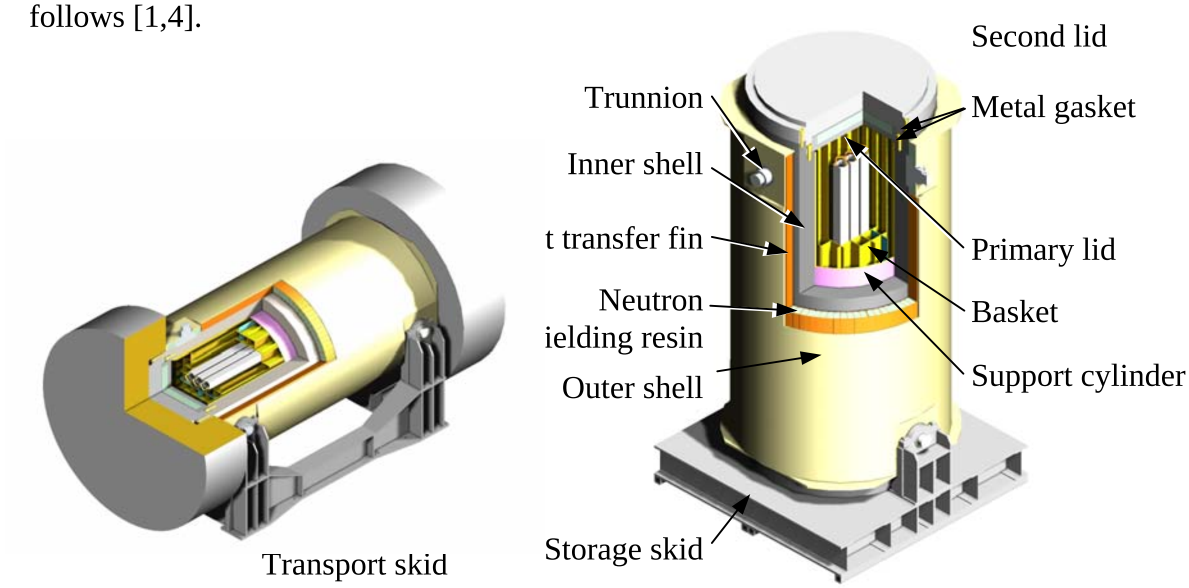
When the metal cask is used for the storage purpose, the properties of some components may change during the storage period due to heat and radiation from the spent fuel. After the storage period, the metal cask will be used to transport the fuel from the storage facility to the reprocessing plant and must satisfy the criteria for transportation use. Thus, the degradation of components should be minimized in the dual-purpose cask.

The metal cask with a high payload of fuel assemblies is desirable to reduce the costs of fuel transportation and storage facility construction. But increasing the payload of fuel assemblies might result in a high cask cost. The goals of Hitachi's development are a dual-purpose metal cask with a high payload and low manufacturing cost.

Hitachi's Dual-Purpose Metal Cask

Basic Concept of Hitachi's Dual-Purpose Metal Cask

The dual-purpose metal cask is shown schematically in Fig.1. Its structural features are as follows [1,4].



(a) Transport stage (b) Storage stage

Fig.1 Outline of Dual-purpose Metal Cask

1) The hybrid basket structure: The fuel basket is assembled with two kinds of metal alloy plate as shown in Fig. 2. Main basket plates are made of a borated alloy such as borated stainless steel. The basket plates are cross-inserted to each other like the dividers in an egg carton. The basket plates support the fuel assemblies and ensure non-criticality of stored fuels. Other plates (heat conduction plates) are made of an aluminum alloy and inserted along with the borated alloy plates to enhance heat removal ability. Assembling the basket without welding makes it easier to manufacture.

2) Heat resistant neutron shielding resin: A highly durable resin developed by Hitachi is used for neutron shielding of the cask. The loss of hydrogen of the developed resin during storage is very small even when it is used at high temperature. The developed resin contributes to the increased payload of fuel assemblies.

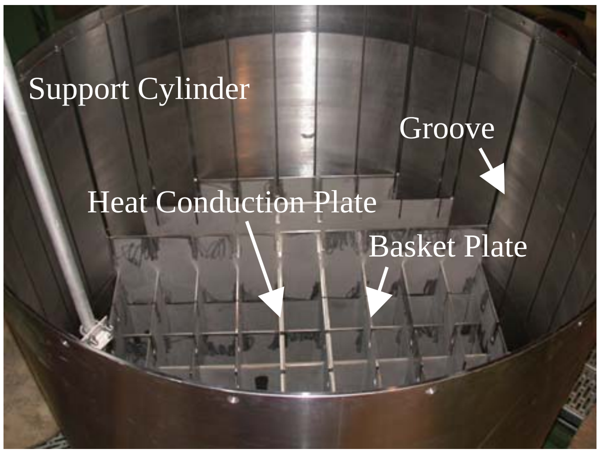


Fig. 2. Structure of Fuel Basket

Development of Dual-Purpose Metal Cask

The development flow for the dual-purpose metal cask is shown in Fig.3. The basic safety functions are containment, prevention of criticality, shielding, heat removal and structural integrity. Several element tests on these functions were carried out in the development and a method to evaluate safety was established.

In the shock absorber element test, a 1/15 scale-model shock absorber was used to develop the actual absorber, which would effectively reduce impact acceleration when accidentally dropped while being transported. Various kinds of wood properties were accumulated to design a shock absorber. An analytical method was established to simulate the deformation behavior on dropping.

A seal-ability test was carried out under conditions in which displacement of the lid was simulated when a cask was dropped during transportation. Seal degradation due to heating the metal gasket which seals the lid was also simulated. In this test, a sufficient margin of seal-ability for the metal gasket versus lid displacement was confirmed.

A method to evaluate the heat transfer in the hybrid basket was established fundamentally using a model of part of a cask basket.

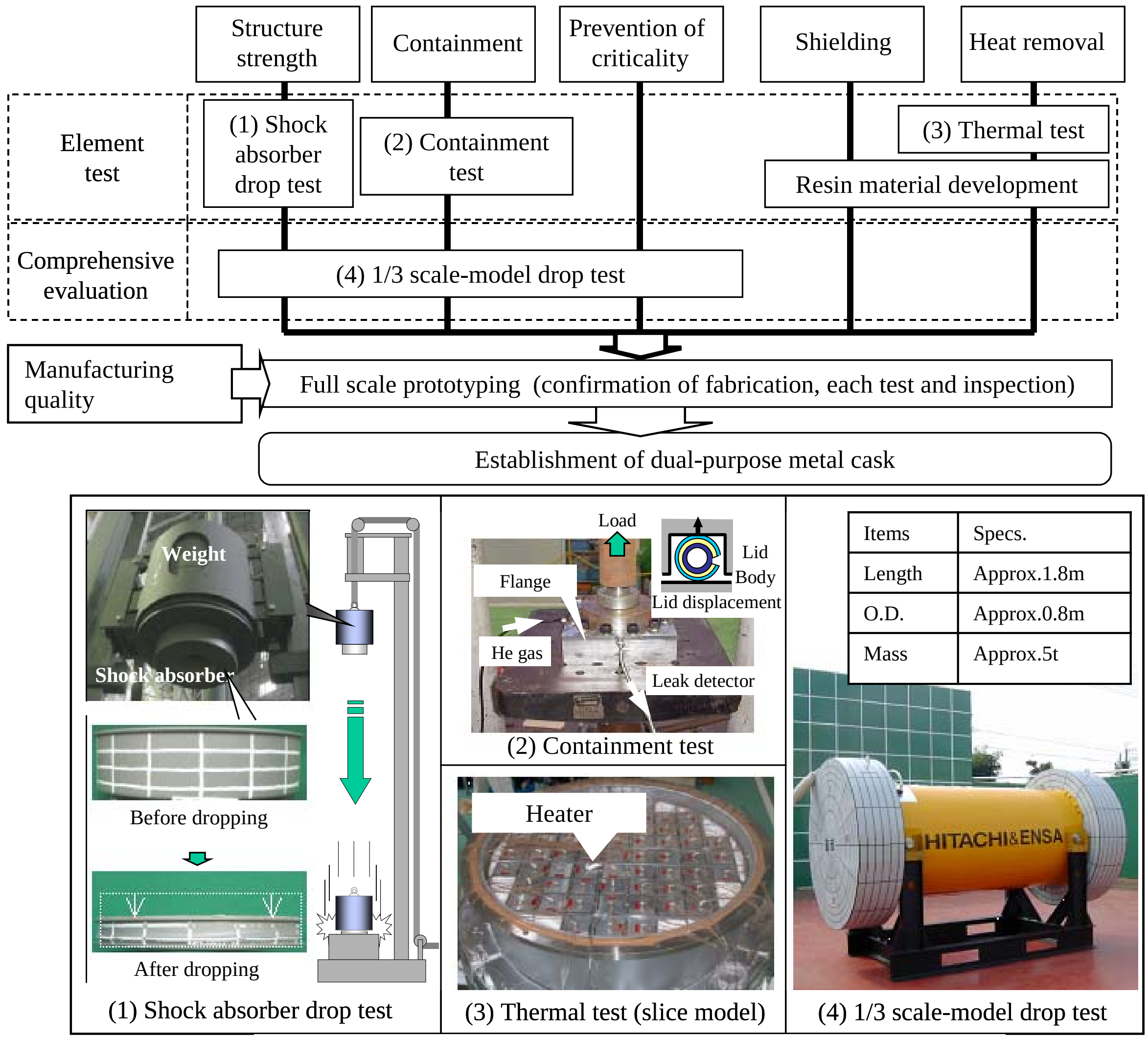


Fig. 3. Development Flow for Dual-Purpose Metal Cask

Based on these element test results, a 1/3 scale-model was designed, fabricated and used for the 9 m drop test. The test data were comprehensively evaluated from the following viewpoints.

1) Design of shock absorber

  (a) Reduction of impact acceleration

  (b) Deformation behavior of shock absorber

2) Soundness of cask

  (a) Seal-ability by metal gasket

  (b) Deformation behavior of inner lids

  (c) Soundness of basket towards impact force

From these evaluations, a design was set and an evaluation method for the shock absorber was developed and high-shock absorbance of the shock absorber was confirmed [2].

Full-Scale Prototyping of HDP69B and Heat Transfer Test

HDP69B is designed to store 69 BWR fuel assemblies of an average burn-up of 34 GWd/MTU which have been cooled for more than 10 years [1.4]. The hybrid basket made of borated stainless plates and aluminum alloy plates is expected to realize both high structural strength and good heat transfer performance. The borated stainless steel plates and the aluminum alloy 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 basket structure and reduced cost and shorter manufacturing time become possible.

A full-scale prototype was fabricated to improve the quality of the developed HDP69B and to ensure the design was optimal. The test and inspection items performed, assuming the actual product, are shown in Table 1. As a representative test item, details of the heat transfer test are described below.

Table I. Test and Inspection Items for Full-scale Prototype

Safety function	Test and inspection items for full-scale prototype
Structural strength	Materials, dimensions, visual inspection, welding, hydrostatic properties, leakage, trunnion [illegible]l, and weight
Containment	Helium leaks
Prevention of criticality	Materials, dimensions and visual inspection
Shielding	Gamma shielding test, materials, dimensions, and visual inspection
Heat removal	Heat transfer test, materials, dimensions and visual inspection

Purpose of the Heat Transfer Test

One of the most important issues for the weld-less basket of the HDP69B is to verify its heat removal capability. The gaps between the basket plates complicate the heat transfer characteristics. Thus, verification of the heat removal ability is essential to realize the HDP69B design [5].

Equipment and Procedure for the Heat Transfer Test

The test used the actual size prototype cask, except for the lid part, and heaters were placed inside the basket.

A special lid was made for the test through which the heater lines and the thermocouple lines could be run between the cask core and the outside. 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.

The heaters were installed in the basket. Their heating power was set to 280 W, which is equivalent to what fuel with an average burn-up of 34 GWd/MTU would produce after cooling for 10 years.

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 around an axial center. In addition, the measurement points were arranged on cross sections which were 300 mm above and below the cross section including the axial center to evaluate heat transfer quantity to the axial direction.

Test was implemented indoors in a controlled environment. Before the test, the air inside of the cask was removed under vacuum, and then the cask was filled with helium to approximately atmospheric pressure. After that, the heater power was turned on, and temperature data were recorded every 15 minutes.

Test Results

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. This state was considered to be the static state. There was a small influence from the change of the environment temperature on the lid temperature but for the others, no influence was seen.

Regarding the temperature of the static state, the average temperature at each measurement point 24 hours before the test ended is shown in Fig. 4. In the test, the basket center temperature was about 194 °C. From this the fuel crud temperature was estimated to about 205 . The target temperature of the fuel crud was less than 275 °C when the ambient temperature was 20 °C. From the result, HDP69B was verified to have sufficient heat removal performance for fuel assembly storage.

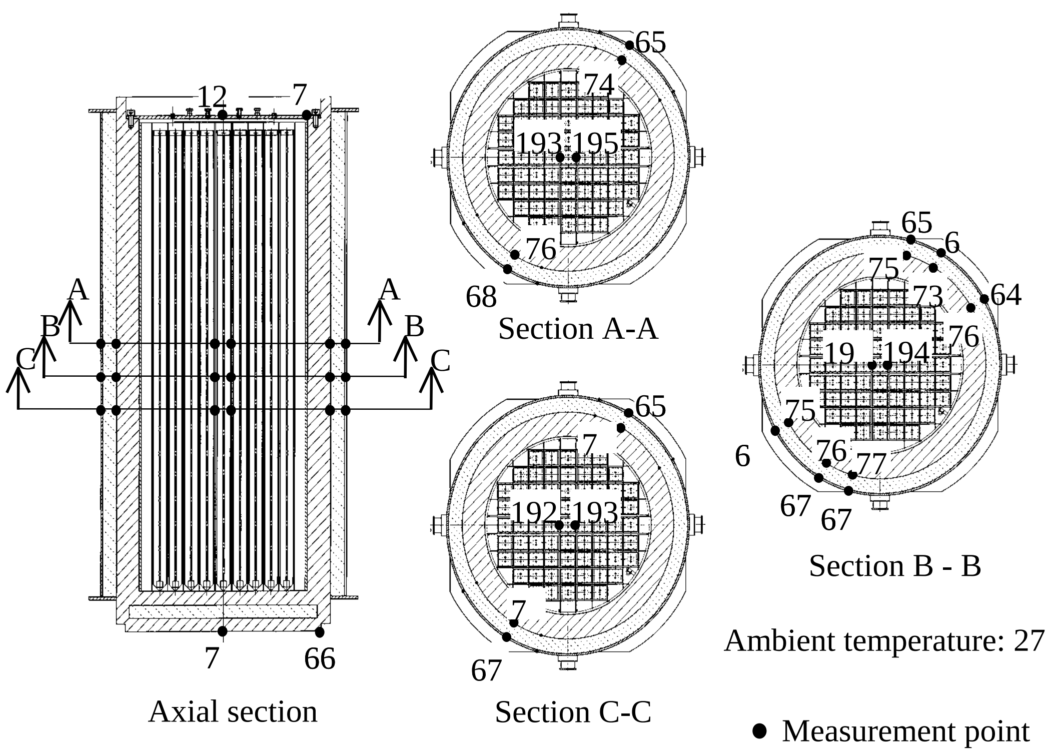


Fig. 4. Temperature of Each Measurement Point in the Static State

Developments for the Innovative Metal Cask for

High Burn-up Fuel

A metal cask for high burn-up fuel will be necessary in the future. High burn-up fuel generates a large amount of heat and emits intense radiation. Hitachi has been developing advanced materials to realize the high payload and low cost metal cask for high burn-up fuels. One is a borated aluminum alloy, and the other is a heat resistant neutron shielding material.

Borated Aluminum Alloy

The borated aluminum alloy has high heat conductivity, so that it is a suitable material for the basket and it was used for the cask for large heat release fuels. Hitachi has also been developing a new borated aluminum alloy for the basket plates of metal cask for high burn-up fuels.

Both high heat conductivity and high mechanical strength are required for the fuel basket material. The borated aluminum alloy is prepared by mixing tetra boron carbide into the aluminum base alloy by powder metallurgy. When the composition of the aluminum base alloy is optimized, the material meeting the above requirements can be realized.

The mechanical strength was measured for representative samples of borated aluminum alloy under development. The borated aluminum alloy possesses good strength over a wide temperature range.

Heat Resistant Neutron Shielding Material

One of the factors limiting the payload of fuel assemblies in a cask is temperature of the neutron shielding material. Since the shielding material is composed of a polymer, attention should be paid to its thermal degradation. The conventional shielding material is applicable below 150 °C.

Hitachi developed a highly durable neutron shielding material by applying a thermosetting epoxy resin [3]. The thermal degradation of this material is negligible even when it is used at 160-170 °C in the cask.

A fabrication process for the shielding unit of the metal cask has been developed for the new resin. In the conventional process, liquid resin is poured into the section between the inner and outer shells and cured at ambient temperature. The quantity of the poured resin is not measured directly. In the new fabrication process, a solid resin block is manufactured and fitted to the cask. Epoxy, curing reagent, catalyst, fire retardant and B_4C are mixed completely, and the mixture is subjected to reduced pressure to remove air bubbles. The liquid resin is poured into the mold in which aluminum case is inserted. After the resin is cured at elevated temperature (about 80°C) in a furnace, the mold is disassembled. The block of cured resin and aluminum case is fitted to the inner shell.

The merits of this new fabrication process are as follows.

1) Neutron shielding ability is assured directly by measuring the size and weight of the resin block.
2) Fabrication of the cask main body and the resin block can be done in parallel, so that the production period can be shortened.
3) Cost of the resin block may be decreased by mass production.

Hitachi has been developing another heat resistant resin, which is curable at ambient temperature. The main composition of the new resin is similar to that of the developed resin. Catalytic reagent is added to the resin system to accelerate the hardening process at room temperature. Both the conventional direct molding process and the above resin block fitting process are applicable to fabrication of the newly developed resin.

From the thermal degradation test, the weight loss of the resin during storage is lower than 1%.

CONCLUSION

Development of a high payload metal cask was described.

1) The heat transfer test was carried out using a full-scale prototype of HDP69B. The HDP69B was verified to have sufficient heat removal performance for the stored fuel assembly.
2) Hitachi has been developing advanced materials such as borated aluminum alloy and heat resistant neutron shielding resin. In the near future, a metal cask for high burn-up fuel will be introduced which uses these materials.

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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