# Development of high performance transportable storage cask For interim storage

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## ABSTRACT

Mitsubishi Heavy Industries, Ltd. (MHI) has established transportable storage cask design "MSF series". Overall external view of the MSF transport and storage cask is illustrated in Fig. 1. MSF series cask employs new-developed design and materials, and realizes the increase of accommodation of fuel assemblies and the improvement of reliability. The following key technologies are applied to the MSF series.

- Main body

A main body of the MSF cask consists of seamless vessel. It is effective for improving ability to eliminate a weld seam between cylindrical parts and base plate part of the main body. Therefore unique forging method has been developed and employed for manufacturing main body.

A shape of main body is polygonal configuration because this shape provides close contact between external surface of the basket cell and internal surface of the body, and heat dissipation performance is greatly improved by enabling to enlarge heat transfer area.

- Basket

MSF series cask uses a simplified basket cell that consists of individually not jointed square pipes made of boronated aluminum applied by powder metallurgy. This basket cell has good heat dispersion property and powder metallurgy provides higher boron content in boronated aluminum.

- Neutron shielding material

MSF series cask uses the new-developed neutron shielding material. As our investigation, purity of refractory material, which shielding material consists of, influences durability of shielding material. Therefore the purity has been improved.

## INTRODUCTION

It is one of the realistic solutions against increasing demand on interim storage of spent fuel assemblies arising from nuclear power plants in Japan to apply dual purpose (transport and storage) metal casks. Since 1980's Mitsubishi Heavy Industries, Ltd. (MHI) has been contributing to develop metal cask technologies for utilities, etc. in Japan, and have established transport and storage cask design "MSF series" which realizes higher payload and reliability for long term storage.

MSF series transport and storage casks use various new design concepts and materials to improve thermal performance of the cask, structural integrity of the basket, durability of the neutron shielding material and so on. This paper summarizes an outline of the cask design that can accommodate BWR spent fuel assemblies as well as the new technologies applied to the design and fabrication.

## OUTLINE OF THE CASK DESIGN

Overall external view of the MSF transport and storage cask is illustrated in Fig. 1, and its specification as a sample is shown in Table 1. Cylindrical part and base part of main body that function as a primary gamma shield are made of forged carbon steel. Primary lid and secondary lid also made of forged carbon steel are screwed to the top of main body in order to allow continuous monitoring of pressure variation of the inter-space between the two lids during storage.

Specially developed neutron shielding material is installed in the concentric space between the main body and the external shell. Inner fin made of copper are longitudinally welded along with the main body and external shell through the neutron-shielding layer. Inside the cask cavity, basket cell consisting of 69 separated square pipes made of boronated aluminum is inserted to space spent fuel assemblies, and has the functions of accommodating them and of sub-criticality control. A pair of shock absorber made of wooden material covered with stainless steel plate is installed at both ends of the cask to absorb impact energy and alleviate the impact force imposed on the cask and its content in a drop accident.

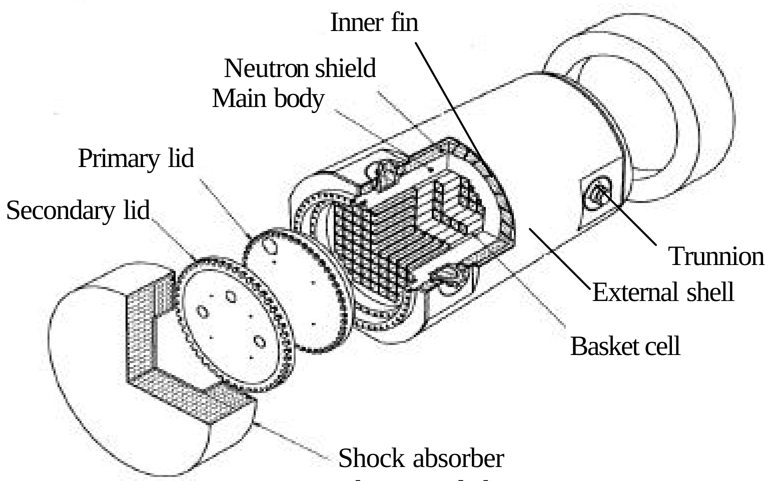


Fig. 1 Cask external shape

Table 1. MSF cask specification (a sample)

| Item | Specifications |
|---|---|
| Type of fuel assembly | BWR 8x8 |
| Initial enrichment | 3.2 % |
| Burn-up (max.) | 40 GWd/t |
| Cooling time | 10 years |
| Number of fuel assemblies | 69 fuel assembly with channel box |
| Design decay heat power | 19kW |
| Weight of cask | 119ton (Including lids, basket and fuel assemblies) |
| Size including shock absorber | 3.6m(W) x 6.6m(L) |
| Size excluding shock absorber | 2.6m(W) x 5.5m(L) |
| Materials | |
| Body | Carbon steel forging |
| Neutron shielding | Epoxy resin |
| Basket | Boronated aluminum by powder metallurgy |
| Containment device | Metallic gasket |

## KEY TECHNOLOGIES

The following key technologies for design and manufacturing are applied to the MSF series. Purposes of technologies used in cask design are shown in Table 2.

Table 2 Purposes of key technologies

| Item | Purpose<br>Improve reliability | <br>Increase payload | <br>Simplify fabrication |
|---|---|---|---|
| New manufacturing method | | | |
| - Monolithic forging | | | O |
| New structure | | | |
| - Polygon shaped body | | O | |
| - Basket assembly | | | O |
| New material | | | |
| - Boronated aluminum alloy | O | O | |
| - Neutron shielding material | O | | |
| - Metallic gasket | | | O |

- Monolithic forging

With regard to the manufacturing method, main body forging of the cask is using "monolithic forging method", which means that heated steel is shaped into vessel by only forging technique.

Circumferential welding between cylindrical part and base part is required to fabricate main body in the ordinary process of cask manufacturing. And heat treatment and inspection on the welded seam are also required after welding. This radical new method eliminates any welding work. This also eliminates in service inspection on the welded seam during long-term storage. Accordingly MSF cask has gained improved reliability by the elimination of welding.

Fig. 2 Monolithic forging for MSF cask

-Basket cell

The simplified basket assembly consists of individually not jointed square pipes that are inserted into the body and directly supported by the internal face of the body. Assembling to structure form plates is required to fabricate basket in the conventional process but the new structure eliminates this process. The validity of this structure is verified by the 9-meter drop demonstration test.

- Shape of main body

Monolithic forging is shaped into polygonal configuration by machining. The body forging after machining is illustrated in Fig 3. Temperature of the basket should be kept low when aluminum is used for the basket structural material. For meeting the mentioned above object, internal face of the body forging is machined to make "steps" in its cross section in order to fit the external shape of basket cell which consists of individual square pipes. This provides close contact between external surface of the basket cell and internal surface of the body forging, thus heat dissipation performance is greatly improved by enabling to enlarge heat transfer area. As a result of the design, it is possible to get lower temperature of basket than conventional configuration of the cylindrical body that gives a larger gap between the basket and the body internal surface. External surface of the body forging is also machined in a polygonal shape to provide optimized configuration for gamma shielding with minimum weight. Inside and outside machining of body forging make the body compact to maximize the number of fuel assembly to be housed within weight and dimensional limits imposed on the cask design.

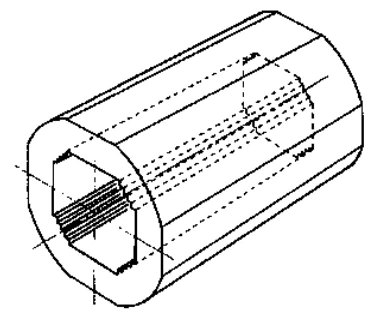

Fig. 3 Shape of body forging of MSF series cask after machining

-Basket material [3]

MSF series cask uses boronated aluminum without heat treatment. Powder metallurgy is adopted for its manufacture process. Several types of aluminum alloys usually reinforced by heat treatment are used for many types of basket in order to increase accommodation of fuel assemblies. The usual manufacturing process of boronated aluminum alloy (subcritical credible sheets) is to dissolve boron in molten aluminum alloy to pour the ingot case, then form the ingot into plate by rolling. However, the strength of aluminum reinforced by heat treatment is lowered during use in high temperature condition because of over-aging (growth of $Mg_2Si$ crystal). And because there is a tendency for segregation of boron in the ingot while the molten aluminum is being solidified it is necessary to add separation element (e.g. Ti) to obtain homogeneous boron distribution. As some boride element ($TiB_2$, $AlB_2$) has needle shape crystal, usual boronated aluminum are brittle material. It was difficult to have high toughness.

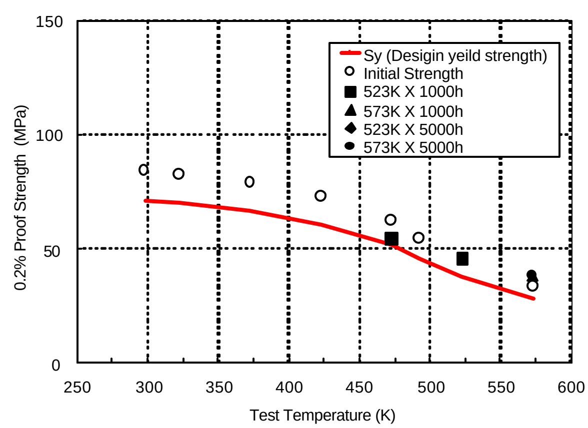


Fig. 4 Design yield point of boronated aluminum

The over-aging problem can be resolved by the boronated aluminum without heat treatment. Design yield point and tensile strength have been verified to envelop the result of long term heating tests. (Shown in Fig. 4) Powder metallurgy solves the homogeneity problem of boron distribution and brittleness problem. Manufacturing method of powder metallurgy excludes coagulating process of molten aluminum and provides boronated aluminum with small precipitation and good homogeneity of boron distribution.

- Shielding material[2]

MSF series cask uses high durability neutron shielding material.

In order to maintain shielding performance of the cask for long-term storage, it is extremely important to maintain the integrity of neutron shielding material at its service temperature. However, the usual neutron shielding material deteriorates and its hydrogen content is reduced when the material stays in high temperature condition for a long time.

For MSF series casks, components of the refractory material, which are added for providing neutron-shielding material with fire-extinction-property, were investigated. And a better neutron shielding material with improved refractory material so as to minimize hydrogen loss even during service has been used.

For this reason, our purpose was to develop a high durability epoxy base neutron shielding material which has the same self-fire-extinction property, high hydrogen content and so on as conventional

Therefore the new-developed neutron shielding material has been added with refractory material of which impurity is 0.1wt% or less. It has been predicted that its moisture loss is 1% or less even at 170 C for 60 years. Besides, the new-developed neutron shielding material has also self-fire-extinction property and its extent of damage after fire accident is small. As the result of demonstration test, flame on the material has been eliminated and approximately 78% of neutron shielding material have remained after the fire resistance test at 800 C for 30 minutes.

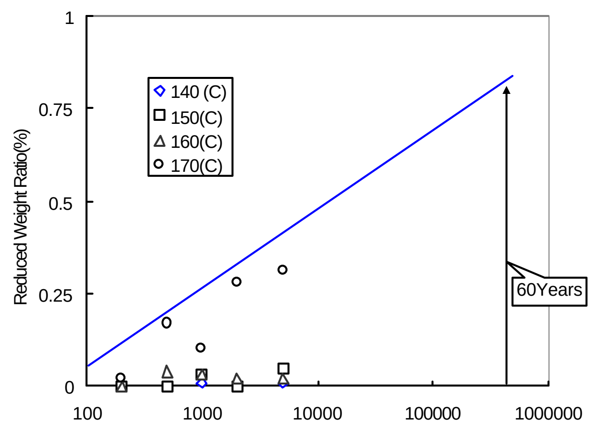

Fig.5 Results of long-time heating test

Specifications of the developed neutron shielding material are shown in Table 3.

Table 3 Specifications of neutron shielding material

| Type | Item | Specifications |
|---|---|---|
| Composition of neutron shielding material | Main agent | Epoxy resin |
| | Refractory material | Aluminum hydroxide |
| | Neutron absorbing material | $B_4C$ |
| Properties of neutron shielding material | Density($g/cm^3$) | 1.67 ±0.05 |
| | Hydrogen content ($g/cm^3$) | 0.096 or more |
| | $B_4C$ content ($g/cm^3$) | 0.194 or more |

-Metallic gasket

MSF series casks adopt metallic gasket for dual purpose of transportation and storage as containment device. With regard to transportation situation, it is delicate to maintain containment integrity after a drop accident with a metallic gasket because too much displacement of lid breaks containment integrity. MSF series cask has been designed so that movement of lid is limited by mechanical structure of lids and flange. Validity of cask design and integrity of containment are confirmed by the 9-meter drop demonstration test.

**VERIFICATION**

It has been confirmed by analysis and demonstration tests that MSF series casks satisfy with IAEA regulations[1]. Outline of demonstration test is shown in the following:

- Heat transfer test

Heat transfer analysis method and heat dispersion performance of inside structure of cask has been confirmed by demonstration. Fig 6 shows that the temperature of basket parts analyzed by ABAQUS code is on the conservative side.

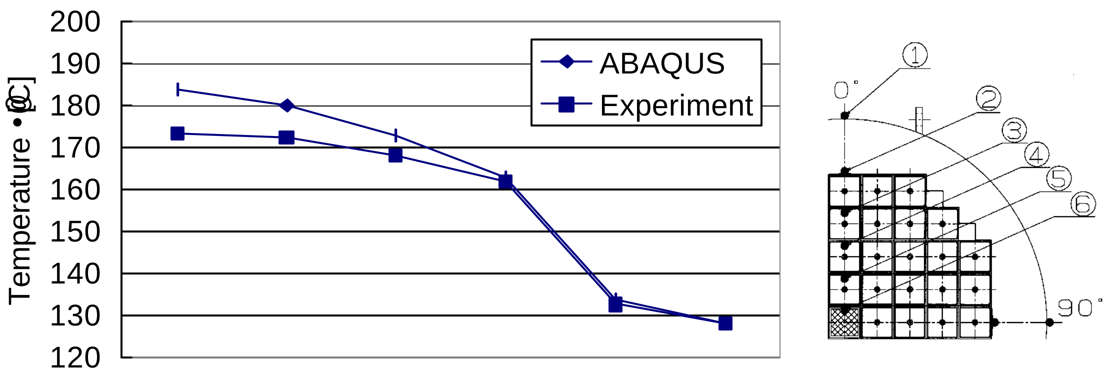


Fig. 6 Comparison between heat transfer test and experiment for the slice model

- Structural integrity

Using 1/2 scale model, drop test has been performed as shown in Fig 7 in order to verify the containment integrity, validity of the cask and compliance with the regulation requirements.

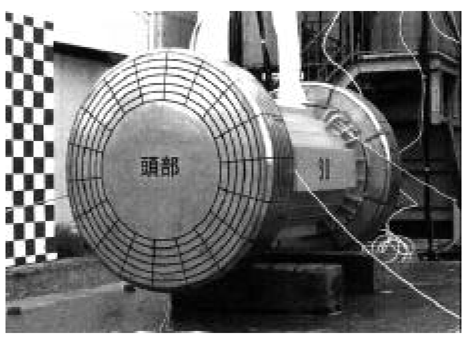


Fig.7 1/2 Scale model for drop test

- Confirming the containment integrity

It has been confirmed that the containment integrity has been kept and leakage rate could be kept under its test criteria.

- Conforming the fuel clad integrity

It has been confirmed by analysis, that the fuel element has been kept integrity during drop testing. In case of horizontal 9m drop testing, maximum dynamic stress on fuel cladding was evaluated less than its allowable value.

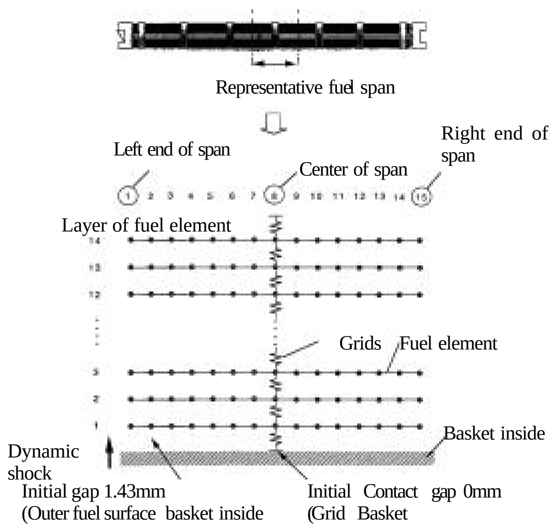


Fig.8 Analysis model of fuel element

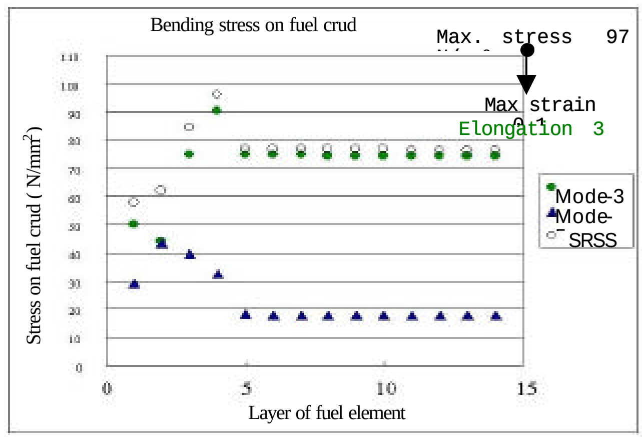


Fig.9 Analysis result of strain on fuel crud

Fuel elements were modeled as shown Fig.8 that are verified with several kinds of experimental data. Dynamic shock waves that were detected from 1/2 cask drop testing put into this model. Response characteristics of fuel elements were analyzed as shown Fig.9. Horizontal axis of Fig.9 is number of fuel element layer (14*14 type fuel). Maximum stress was indicated on layer No.4. On layer No.4, maximum stress has been occurred, during rebound fuel element in the cask. The evaluated strain on fuel cladding is lower than the allowable strain with sufficient margin.

**SUMMARY**

This cask features new technologies for:

a) Structure (main body, basket, and shock absorber); and,

b) Materials (boronated aluminum, neutron shield, and body forging); thus, the storage capacity has been improved by nearly 10% as compared to the conventional design.

And these new technologies have been confirmed by demonstration tests.

**REFERENCES**


[1] IAEA Regulations for the safe transport of radioactive material, 1996 safety series No.6

[2] K. Najima, et al, 'Development of neutron shielding material for cask', ICONE9, Nice, (2001).

[3] Y. Sakaguchi, et al, 'Development of Boronated aluminum ally for basket of metal cask for nuclear spent fuel', ICONE9, Nice, (2001).