Development of Transport and Storage Cask for High Burn-up Spent Fuel

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Introduction

Mitsubishi Heavy Industries, LTD. (MHI) has been developing various transport and storage casks (MSF cask fleet) for high burn-up spent nuclear fuel (SNF). This paper outlines the specifications and describes the features of the newly developed casks and the advanced technology that enables the maximize number of the accommodated fuel assemblies of high burn-up and short cooling period.

Development Points

MHI had already developed a transport and storage cask (MSF-69B) for which the Japanese competent authority issued a certificate of compliance as a type BM (F) package in 2000.

This cask had been developed to achieve both high economic feasibility and reliable safety. It was possible to improve the payload efficiency (69 BWR fuel assemblies accommodation), economize the manufacturing steps and assure safety for long-term service without any modification of the conventional cask handling equipment at power stations by applying the following technologies developed by MHI.

- Application of monolithic forging to the body shell and body bottom
  Simplification of the cask structure and economization of the manufacturing steps by eliminating the welding between body shell and bottom plate
- Simplified basket of independent cell structure
  Formed by direct insertion of the cells into cask cavity
  Simplification of the structure and reduction of manufacturing steps
- Application of boron contained aluminum made by powder metallurgy for the material of the basket
  Up to 9% (as B4C) boron addition for improvement of sub-criticality performance
  Foregoing of the heat treatment step in manufacturing in order to eliminate the potential decrease in mechanical properties caused by aging
- Application of large shock absorber
  Reduction of the acceleration in a 9 m drop by half
  (Less than 50 G in 9 m horizontal drop)

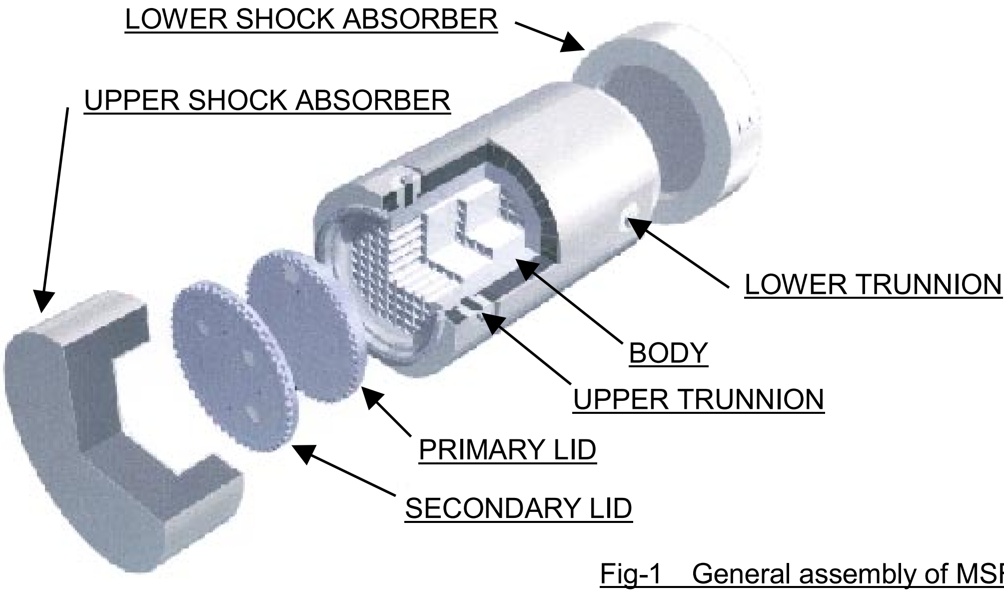

Fig-1 General assembly of MSF-69B

However, the specifications of the accommodated SNF are (1) a cooling period of more than 10 years, (2) maximum burn-up of 40 GWd/t and (3) dissipated heat power of approx. 20 kW. The weight of the cask was limited by the capacity of the handling crane at the power station.

On the other hand, taking into account the core operation, the burn-up is apt to be higher and for example in Europe it reaches more than 60 GWd/t. Besides, if it is considered the termination of the power station, prompt discharge from the spent fuel pond (=accommodation for short cooling SNF) is required and, with respect to the weight and dimension of cask, in order to enable to cope with various transport mode (sea and land), it is preferable the maximum width of the cask including the shock absorbers is less than 3.1 m due to land transportation and the weight limit shall be established due to the capacity of power station cranes.

Of course, the casks not only satisfy the above requirements but also comply with requirements as a type BU (F) package stipulated in IAEA transport regulations (TS-R-1) and for maintaining the safety of spent fuel decentralized storage facilities.

According to the above, it is necessary to consider the following issues because of the requirements placed on transport and storage casks already developed.

- It is not possible to apply the large shock absorber so that it is difficult to control the acceleration below 50 G (490 m/sec^2).
- Depending on the increase in acceleration, it is necessary to design the basket and closure system to ensure containment and nuclear criticality safety
- Because of the high heat power (twice as high as ready developed) caused by short cooling period for fuel accommodation, it is necessary to improve the heat dissipation performance, and, because it is destined for transport and storage, it is necessary to ensure stable performance in both horizontal and vertical position.

Lineup of Cask Fleet for high burn-up SNF

MHI has developed various transport and storage casks for high burn–up SNF. Two representatives (MSF-21P is for PWR and MSF-57B is for BWR SNF accommodation) of the casks are outlined in Table-1. And the description below is a general explanation for them.

Table-1 Outline of casks for high burn-up SNF

Cask type	Type of SNF	No. of accommodated SNFs	Heat power	Fuel specifications		
				Initial enrichment	Burn-up*1	Cooling period
MSF-21P	PWR	21	41kW	4.45%	60GWd/t	6yrs
MSF-57B	BWR	57	49kW	5.0%	63GWd/t	5yrs

*1 Given as the bundle/assembly average burn-up.

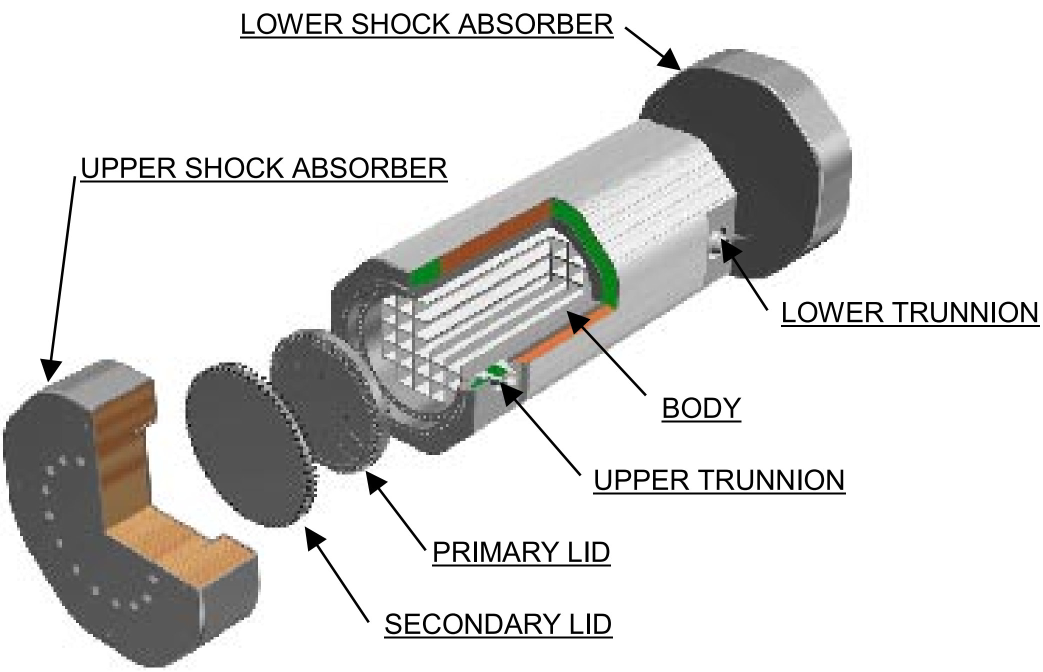

Fig-2 General assembly of MSF-21P

Weight: 138 ton

Whole length 5.7m Width: 2.4 m (without S/A)

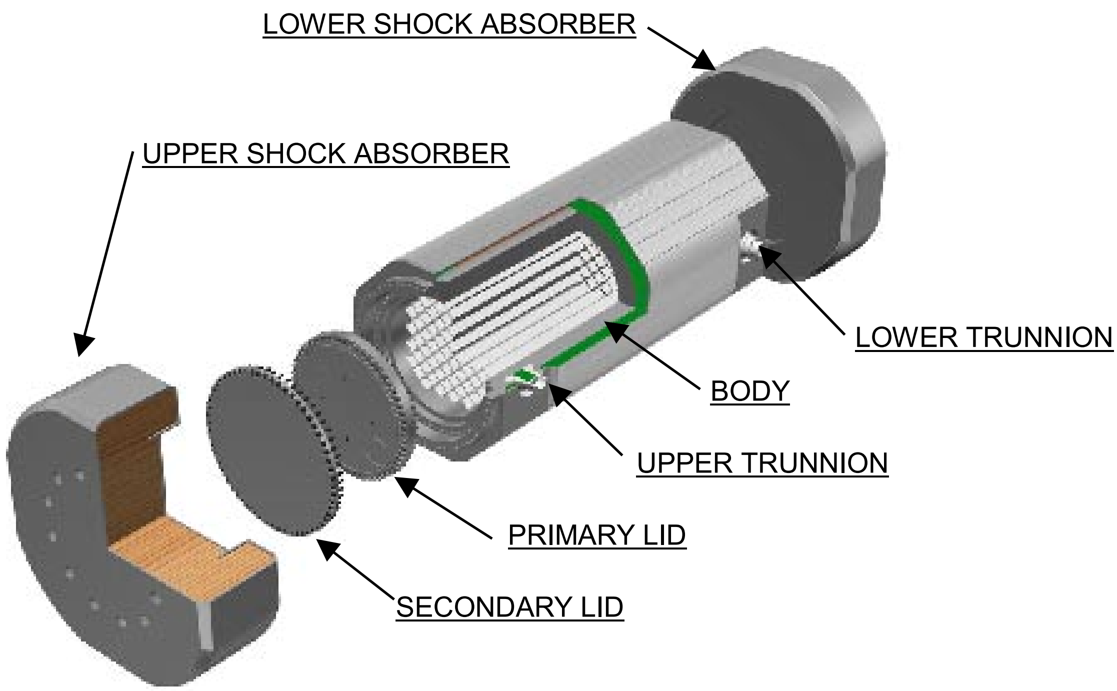

Fig-3 General assembly of MSF-57B

Weight: 140 ton

Whole length: 5.3m Width: 2.5 m (without S/A)

-Cask Body-

The body of the MSF cask consists of a shell, base plate, outer shell, neutron shielding, and two pairs of trunnions.

The body shell and base plate are made of forged low-alloy steel of ASTM A350 Grade LF5. This material has adequate mechanical properties for normal operation as well as normal and accident conditions of the transport considered according to TS-R-1, along with ductility at low temperature. The cavity wall of the body is machined to fit the external shape of the basket. Thus, unnecessary gaps are eliminated and heat transfer from the fuel assemblies to the environment is optimized.

The external envelope is manufactured from rolled carbon steel. Grooves that form Micro Fins are machined longitudinally on the outer surface to provide effective heat dissipation.

A layer of neutron shielding made of resin is enclosed between the body shell and the external envelope. Longitudinal copper plates, functioning as thermal conductors, are welded to the shells and the envelope to provide good heat transfer through the resin. The resin is also installed outside on the base plate and on the primary lid to provide axial neutron shielding. With its high hydrogen content, it has good neutron shielding properties and is stable over a high range of operating temperatures and long-term service.

The cask is equipped with two pair of trunnions, which are used for handling and for anchoring during transport. The trunnions are fabricated from forged precipitation-hardened stainless steel. They are located near the ends of the cask, and each one is fastened to the cask body by bolt to allow easy replacement after repeated use.

For corrosion protection during service, the internal surface of the cask body is coated with metallic spray and the external surface is coated with epoxy paint.

The cask cavity is backfilled with inert helium gas during transport.

-Closure System-

The closure system of the MSF cask consists of the primary and secondary lid and covers for the penetration points incorporated into the lids.

The primary lid is made of forged carbon steel and sealed against the body top flange by double metallic O-rings incorporating a testable interspace. The primary lid is locked to the body flange with bolts made of steel alloy. The primary lid and the bolts are primary components of the cask containment. A penetration that functions as a drain/vent port is recessed into the primary lid. The drain/vent port has a cover plate made of precipitation-hardened stainless steel with double metallic O-rings, which is part of the primary containment.

The secondary lid is made of forged carbon steel with dual metallic O-rings incorporating a testable interspace and provides a redundant containment boundary for the cask. The secondary lid is affixed on the body flange by bolts made of steel alloy. Secondary lid bolt holes are used for fastening the shock absorber during transport. The pressure monitoring port located on the side of the top flange allows continuous monitoring of pressure changes in the interspace between the primary and the secondary lids, which is pressurized with helium gas when used as a storage cask. The vent port for the lid interspace is also located on the top flange. These two ports with cover plates made of precipitation-hardened stainless steel are sealed with double metallic O-rings.

-Basket-

The cask cavity is fitted with a basket designed as a structural support for the fuel assemblies.

MSF-21P. The basket is designed to accommodate 21 PWR fuel assemblies. The fuel compartments are provided by assembling (ref Fig-4) into lattices. The hollow plates are made of boron containing aluminum alloy manufactured by powder metallurgy, which has a low density and good heat dissipation property. The aluminum alloy contains 5 wt% B_4C enriched to 65 wt% B-10 to provide criticality control. The basket fits closely into the machined cask cavity resulting in a very small temperature difference across the gap between the outer surface of the basket and the cavity wall.

MSF-57B. The basket consists of 57 square tubes (Fig-5) that provide compartments for the BWR fuel assemblies with channel boxes. The tubes are made of boron containing aluminum alloy manufactured by powder metallurgy, which has a low density and good heat dissipation property. The aluminum alloy contains 7.0 wt% B_4C consisted of natural boron to provide criticality control. The basket fits closely into the machined cask cavity resulting in a very small temperature difference across the gap between the outer surface of the basket and the cavity wall.

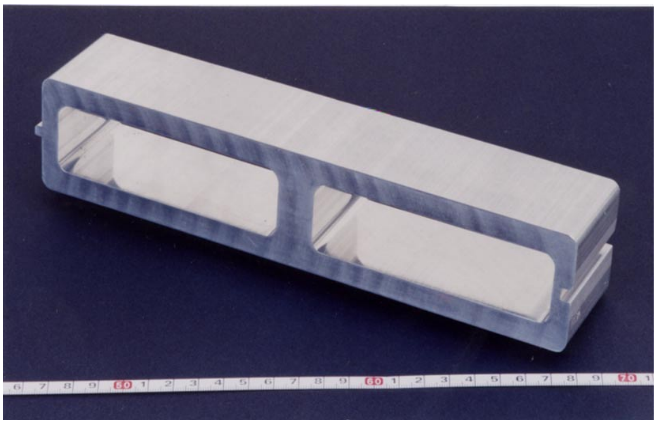

Fig-4 Rectangular hollow plates of PWR basket (Partial model)

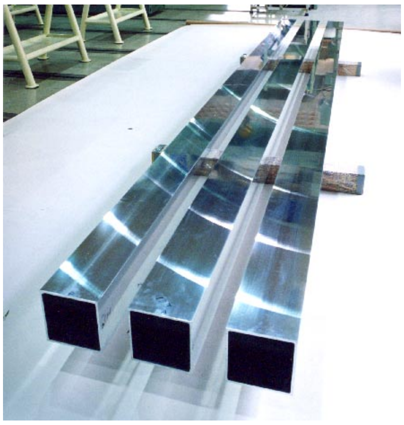

Fig-5 BWR basket cell (Square tube)

-Shock Absorbers-

During transport, shock absorbers are fitted to both ends of the cask. The upper and lower shock absorbers consist of a stainless steel housing, which is filled with wooden materials. They absorb the impact energy with their appropriate deformation and restrict acceleration to an acceptable level during drop tests. The upper impact limiter provides additional protection for the lids during puncture testing and also reduces the heat input into the containment system during a fire accident.

New Technologies Applied to the MSF Cask

The following new technologies are applied to the MSF casks, which accommodate SNF of high burn-up and short cooling period, or in the other words, to ensure their component integrity against high heat power, to comply with the requirements of concerned regulations and guidance, and to keep the size of the casks within the capacity of the facility/equipment of power stations.

-Application of Small Grooves (Micro Fins)**-**

As described previously, the design heat power of the casks reaches approximately 40 kW to 50 kW. For this heat power, it is necessary to control the temperature of all components below their maximum service temperature and, for those to ensure the structural integrity, to control the stress generated in the event of 9 m drop or other impact lower than the yield strength at high temperature. Moreover, the safety functions that the cask possesses must be maintained. A representative safety function of the former is the neutron shielding material (resin). In order not to degrade the shielding function in long-term use as a storage cask, the temperature has to be lower than 150˚C. Boron contained aluminum alloy is used for the basket material described in the next clause. To maintain its mechanical integrity, the temperature has to be controlled lower than 250˚C. For these reason, it is necessary to devise ways to lower the whole temperature, or in the other word, cask surface temperature.

And because of transport and storage, the cask must ensure stable heat dissipation performance in both vertical and horizontal postures. Additionally, it is necessary to comply with the dimensional restrictions derived from the specifications of the pit in the SNF pond, etc.

Taking into account the above, the structure of the external envelope was developed with small longitudinal grooves to function as "Micro Fins", as shown in Fig-6. These fins are formed from grove machining of the outer shell. As the result of our thermal flow analysis, the heat dispersion capacity does not so lower though the cask is placed at horizontal position and it is approximately 1.5 to 2 times as good as finless type.

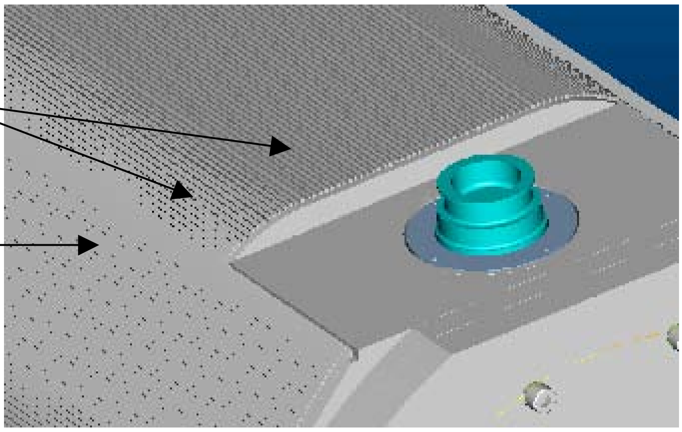

Fig-6 Overview of external envelope for MSF cask

-High Strength Boron Containing Aluminum Alloy Manufactured by Powder Metallurgy-

MHI had already developed boron that contained aluminum alloys (high-toughness B-Al alloy), and registered them as ASME Code Case "N-673" in developing the cask for domestic use in Japan.

However, it has been requested that the basket material have higher strength and stable mechanical properties for long-term service, without reducing toughness, formability and thermal conductivity in the case of a cask for high burn-up and heat power spent fuel, or a cask hat may be highly stressed by impact caused by dropping due to the limited size and weight. MHI has developed novel high-strength B-Al alloys that meet these requirements, based on a new manufacturing process.

Mechanical alloying (MA) has been applied as a key process in manufacturing high-strength B-Al alloy. Raw materials, aluminum alloy powder and boron carbide (B_4C) powder are premixed by a blender in the desired boron content (up to 9 mass% as B_4C to provide the cask with high reliability in sub-criticality safety). Then, the premixed powders are mechanically milled by a high-speed steel attritor with alumina balls in a sealed argon-purged steel chamber. Through this MA process, high-strength metal/ceramic composite materials are obtained by making crystal grains finer and dispersing strengthening particles formed by mechano-chemical reaction during the milling stage. Therefore, the operating condition of the MA process is important towards obtaining the desired mechanical properties. After milling, the powder is consolidated into billets by pressing and sintering. Tubes for baskets are produced by hot extrusion of the sintered billets.

Figure-7 shows tensile properties for high strength B-Al alloys. These alloys have 0.2% proof stress of over

250MPa at room temperature (R.T.), and over 100MPa at 250˚C. These strength levels are twice as high as that of high-toughness B-Al alloy (ASME Code Case “N-673”). Charpy lateral expansion is one of the indices for toughness, and a level of over 0.5 mm is required to register an alloy as an ASME Code Case. Figure-8 shows lateral expansion in Charpy impact tests on high strength B-Al alloy. Although toughness is lowered with the increase in B_4C content, all the alloys meet the Charpy lateral expansion level of over 0.5 mm (at –40˚C).

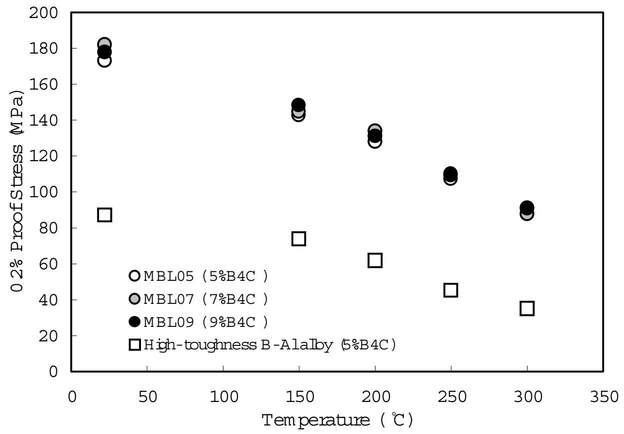

Fig-7 0.2% proof stress of high-strength B-Al alloys

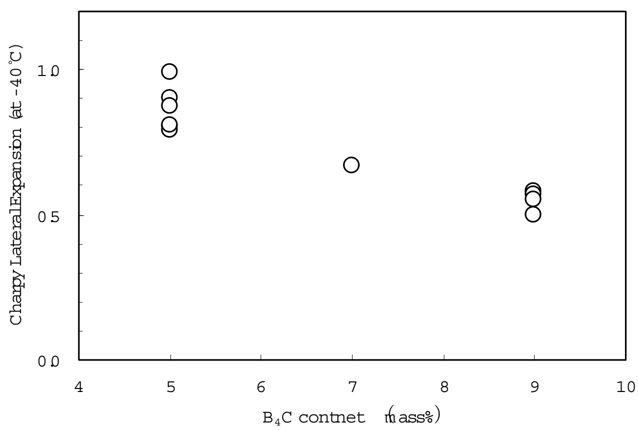

Fig-8 Charpy lateral expansion of high-strength B-Al alloy of various B_4C content (tested at –40˚C)

Conclusion

Mitsubishi Heavy Industries, LTD. has been developing various transport and storage casks (MSF cask fleet) for high burn-up and short cooling spent nuclear fuel (SNF) by applying new technology to the already developed transport and storage cask.

New design and manufacturing technology for the transport and storage cask shall be further promoted in order to propose more reliable and economical casks.