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DEVELOPMENTS ON MSF CASK FOR TRANSPORT AND STORAGE OF SPENT NUCLEAR FUEL

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ABSTRACT

Cask system for interim storage of spent nuclear fuel (SNF) should have sufficient integrity to comply with both transport and storage regulations. In recent years, cask for higher burnup and shorter cooling time SNFs are needed and economization of interim storage is an important issue as well as its safety. The following developments for the MSF cask fleet have targeted on improving its safety and reducing its manufacturing cost.

SUBCRITICALITY AND HEAT DISSIPATION

New boron containing aluminum alloys manufactured with powder metallurgy process have been developed for basket materials of the MSF cask. The aluminum alloys have high boron content, homogeneous boron distribution, higher toughness and sufficient strength for long-term service. One of the alloys has been registered as ASME Code Case "N-673". The other added mechanical alloy process has higher strength at high basket temperature. The alloys can be formed into various shaped basket assembly parts by hot extrusion, such as square tubes and rectangular hollow plates.

SHIELDING

MHI has developed a new neutron shielding material "®", which has high-temperature stability for long-term service. The material is made of epoxy based resin and filler for refractory. The mixing and filling up facility for the material has also been developed to save manufacturing cost and to improve quality control.

CONTAINMENT AND STRUCTURAL INTEGRITY

The monolithic forging method that forms a cask body shell with its bottom plate in a single process has been developed under joint project with JCFC. This method allows reduction of the manufacturing steps and elimination of structural evaluation and inspections for a plate-to-cylinder weld line. MHI also improved forging low alloy steel based on ASTM A350 which has sufficient fracture toughness and strength under service conditions.

Based on the IAEA regulations, MHI has performed various in-house drop tests to verify the structural integrity including sealing system performance and impact limiter's performance. MHI has also collected a multitude of useful data from drop tests with scale model casks performed by MHI and drop tests with both full size and scale model casks performed by the Bundesanstalt fuer Materialforschung und -pruefung (BAM) in Germany.

1. INTRODUCTION

High performance casks are required for transport and storage due to high burnup of spent fuel with high decay heat from nuclear power plants. The construction of the first commercial spent fuel interim storage facility (Recyclable-fuel Storage) in Japan is in the licensing stage, and a safe and cost-effective cask is desired.

MHI has strategically developed the materials and manufacturing technology to be used for cask manufacturing to ensure full compliance with the requirements of domestic and foreign market environments. The safety of the developed casks has been demonstrated through drop tests with full scale and subscale cask models, based on IAEA Transport Regulations. These technological developments have culminated in the MSF dry type spent fuel transport and storage cask fleet (referred to below as the MSF cask).

In this paper, we report the features of the MSF cask and its technological development.

2. OUTLINE OF THE MSF CASK

The MSF cask has been developed for the safe and cost-effective interim storage of spent nuclear fuel. The cask is designed to comply with the requirements of both transport and storage based on all regulations of the countries where it is used including IAEA transport regulations. Figure 1 gives an overview of the MSF cask and Table 1 lists its main specifications. Its major features are summarized as follows.

- Boron containing aluminum alloy basket made with powder metallurgy
- Forged low alloy steel for main body shell
  (The monolithic forging method is available for manufacturing)
- Double lid closure system with metallic gasket (Tertiary lid system for Japan market)
- Epoxy resin neutron shielding material
- High performance impact limiter

Table 1. Specification of MSF Cask Fleet

	MSF-69BG	MSF-57BG	MSF-21PG	MSF-26PJ
Type	B(U)	B(U)	B(U)	B(M)
Fuel type	10×10 BWR	10×10 BWR	18×18 PWR	17×17 PWR
Payload	69	57	21	26
Cooling period, years	≥9	≥5	≥6	≥15
U-235 Enrichment, %	3.7	5	4.5	4.2
Maximum burnup, GWd/t	45	63	60	48
Thermal power, kW	22	49/33	41	20
Weight, ton	126	122	121	120
Dimensions, m	φ2.5×5.3	φ2.5×5.3	φ2.5×5.7	φ2.6×5.1

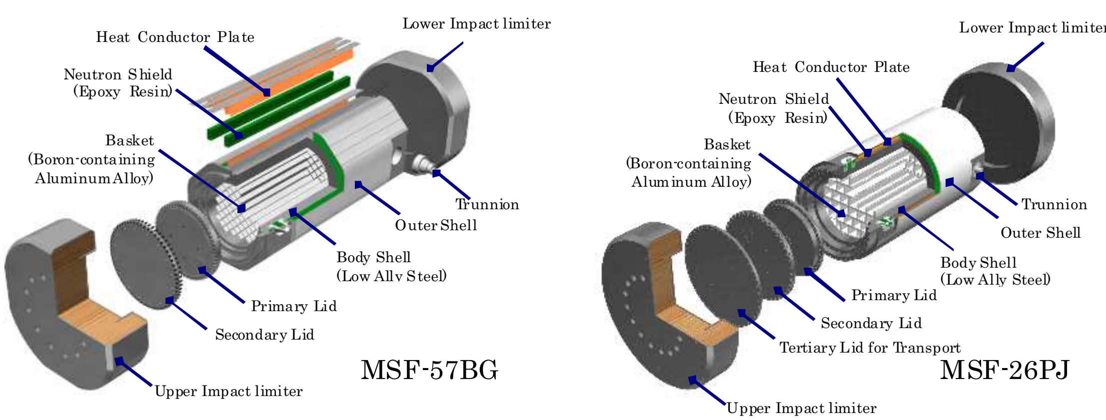


Figure 1. Overview of MSF Cask Fleet

3. TECHNOLOGY DEVELOPMENT PROGRAM

The cask must satisfy four safety functions: (1) containment of radioactive materials, (2) shielding of radiation, (3) prevention of criticality, and (4) dissipation of decay heat. The appropriate structural strength is required to ensure the above safety functions. Furthermore an assumed interim storage period of 40 to 60 years requires the reliable maintenance of the safety functions. From the viewpoint of economy, the cask should accommodate an increased number of fuel assemblies, incorporating safety function enhancements. The simplified cask structure also realizes the reduction of the man-hours required for manufacture and inspection.

Table 2 shows the relation between technology developments and the safety functions, including economical enhancements. The following section gives an overview of the selected development items.

(1) CONTAINMENT

The containment system consists of lids, a main body shell and its flange, and metal gaskets. The performance and structural strength of the containment system must be verified to meet the requirements for both transport and storage. In addition, the aging deterioration due to heat and corrosion needs to be considered from the viewpoint of long term integrity.

(2) SHIELDING

Gamma ray and neutron radiation are shielded with the thick forged steel of the main body shell and the neutron shield installed around the main body. The issue to be verified from the viewpoint of long-term storage will be the aging deterioration of the high polymer materials used for the neutron shielding.

(3) SUB-CRITICALITY

Criticality is prevented by the neutron absorber in the basket and the basket structure maintaining the geometric layout of fuel assemblies. The materials for cask basket are required to possess appropriate strength and toughness and contain the required amount of boron.

(4) HEAT DISSIPATION

The heat dissipation function is maintained by the heat transfer form basket to the outer surface of the cask. In order to obtain excellent heat transfer performance aluminum alloy is the best choice for basket material, and in addition, sub-criticality safety must be satisfied.

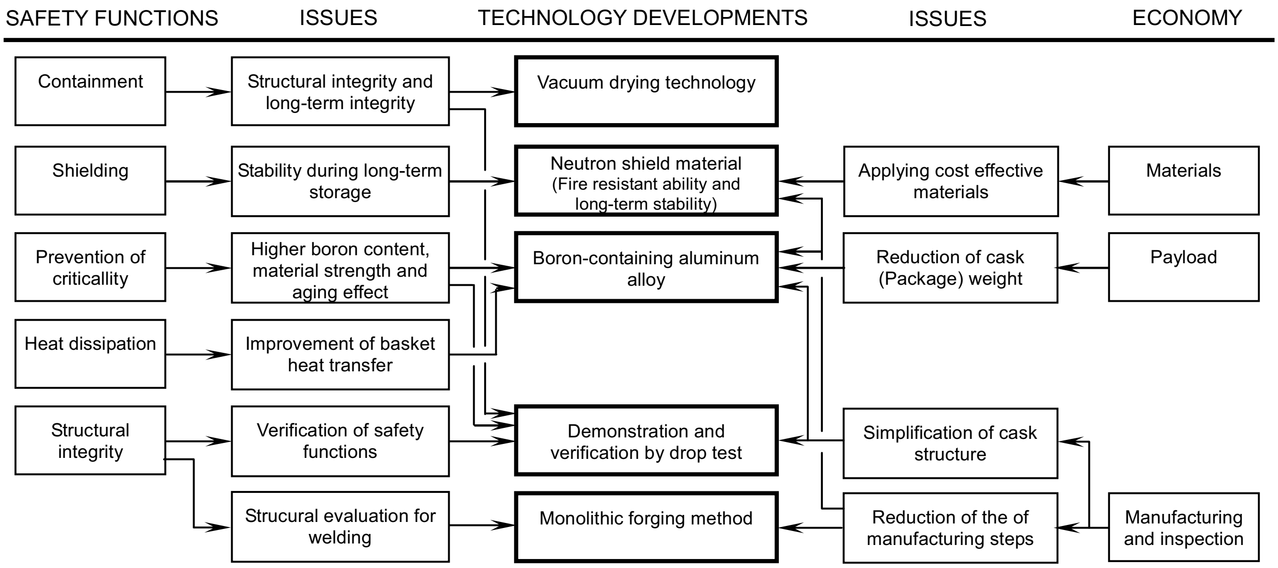
(5) STRUCTURAL INTEGRITY

The cask must be designed to possess the appropriate structural strength in order to maintain its safety functions during transport and storage. Sufficient verification of the structural integrity is required for the containment system and basket.

(6) ECONOMY

The economy of the cask can be improved by reducing the manufacturing and inspection steps and increasing the number of fuel assemblies that can be accommodated. Reduction of package weight is indispensable for increasing the payload. The simplification of the basket structure allows its fabrication steps to be reduced. No welding line in the main body shell contributes to the elimination of inspection and strength evaluations of the welded sections.

Table 2. Technology Developments for MSF Cask Fleet



4. TECHNOLOGICAL DEVELOPMENTS

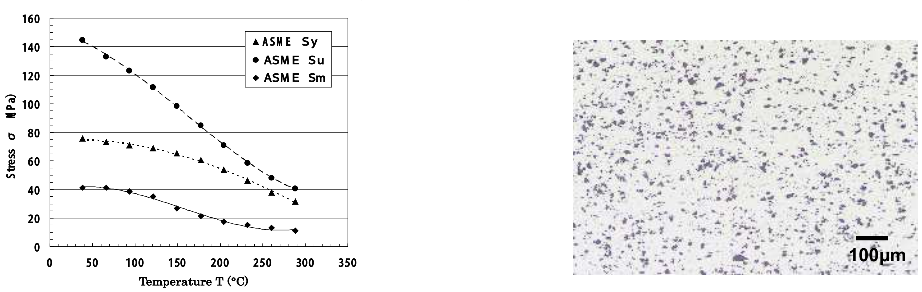
MHI has been developing casks since the 1960s. The MSF cask fleet is the fruit of accumulated MHI cutting-edge technology and its strategic development program. The typical technological developments of the MSF cask fleet are described below.

4.1 BORON CONTAINING ALUMINUM ALLOY

The basket is the key to the prevention of criticality and the dissipation of decay heat, as well as improvements in economy through weight saving and simplified structure. To this end MHI has developed a boron-containing aluminum alloy by powder metallurgy. The developed material has the following features:

- The boron content is 1.5 - 9 wt% B_4C, with uniform boron dispersion.
- Overaging doesn't influence the strength and other mechanical properties, even over long periods of usage at high temperature (up to about 300°C).
- Toughness can be ensured more easily than it can with the melting process.
- The thermal conductivity is equivalent to that of conventional aluminum alloy.
- The material has been already registered in ASME Code Case N-673 as core support structure for storage and transportation of spent nuclear fuel in Section III, Division I.
- Various shapes such as square tubes can be formed by extrusion.

MHI is now applying mechanical alloy technique to realize a boron-containing aluminum alloy with significantly improved strength in high temperature environments.



Mechanical Property **Boron Distribution**

Figure 2. Properties of Boron-containing Aluminum Alloy (ASME Code Case N-673)

4.2 NEUTRON SHIELDING MATERIAL

To enhance the long term stability and the cask fabrication process, MHI has independently developed MREX®, a neutron shielding material. The features of this material are as follows:

- As epoxy resin is the base material, the material specifications such as specific gravity, hydrogen content and B_4C content, are equivalent to those of conventional products.
- The stability under long term high temperature conditions (weight loss characteristics) is equivalent to those of existing products.
- In-house tests have already been conducted to elucidate the material characteristics.
  - Long term stability test for 5,000 Hr x 150°C.
  - Deterioration test by neutron irradiation.
  - Fire testing at 800°C x 30 minutes (50% resin residue or more has been confirmed).
- To improve the traceability, mixing equipment with an automatic material measuring function has been developed.
- The MREX® has been applied to actual transport casks, NFT-14P.

MHI has also developed high performance neutron shielding material with outstanding stability under high temperature conditions for longer periods.

Fire Testing
(Confirmation for 50% Resin residue)

Execution of the Filling up around Cask Body Shell

Figure 3. Testing and fabrication of Neutron Shield Material "MREX®"

4.3 FORGING TECHNOLOGY FOR THE MAIN BODY SHELL

Main body shell is a key factor whose appropriate structural strength is required to assure the safety functions of the cask. The monolithic forging method has been developed in collaboration with the Japan Casting & Forging Corporation (JCFC).

This method is a process where the cask main body shell is forged into a cup shape. The work process to fabricate the main body shell and the results with this process are shown in Figure 4. The features of this method are described below:

- Elimination of welding between the shell and bottom plate, and of welding inspections (RT, etc.)
- Elimination of the fracture toughness evaluation of the weld.

Appropriate toughness of the material for the main body shell also must be maintained under the lowest working temperature, or at –40°C. Thus, quality management technique has been established to ensure the required strength and low temperature toughness.

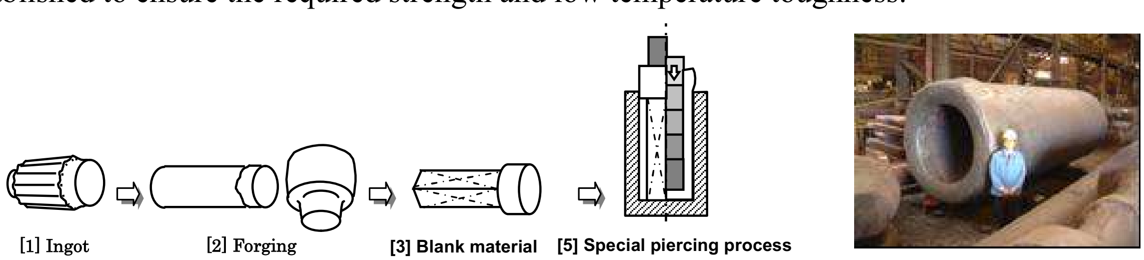


Figure 4. Monolithic forging Method and the Results

4.4 OTHER TECHNOLOGICAL DEVELOPMENTS

Dry type casks with an inner atmosphere of helium are used for interim storage. The water inside the cask is drained and dried up in the power plant. Two important technologies in this drying process must be established: one is a drying procedure which satisfies the temperature limit of the fuel cladding, and the other is a standard of drying up value to avoid corrosion inside the cask. MHI research on these items has led to the establishment of the following techniques:

- Simulation method for vacuum drying process, including the evaluation of the temperature of the fuel cladding
- Countermeasures against corrosion of the sealing system

5. DROP TEST AND STRUCTURE EVALUATION

5.1 DROP TEST

The demonstration by tests and the validation of the calculation are required in order to evaluate the structural integrity of the cask. MHI has carried out a number of drop tests based on IAEA Transport Regulations in the 10-ton class, in-house drop test facility.

For the development of MSF cask fleet, MHI has collected a multitude of useful data from drop tests with both full-size and scale model casks performed by MHI and later by the BAM.

Below is the summary of the drop tests conducted with regard to the development of the MFS cask:

- 1998 - 1999: Tests of a 1/2.35 scale model cask (MHI tests)
- 2003 - 2004: Tests to determine the performance of impact limiters mounted on a 1/2.35 scale model cask (MHI tests)
- 2004 - 2005: Tests on 1/1 and 1/2.5 scale model casks by BAM at the BAM drop test facility in Horstwalde, within the German approval procedure of packages for transportation of radioactive materials.

The full scale drop test model used for the German licensing testing is shown in Figure 5.

In-house Drop Test with 1/2.35-scale Model

Certification Test with Full-scale Model at BAM Test facility in Horstwalde, Germany

Figure 5. Drop Tests for MSF Cask fleet

5.2 DYNAMIC STRUCTURAL EVALUATION TECHNOLOGY

The progress of computing technology has facilitated three-dimensional (3-D) dynamic structural analyses to evaluate the behavior of casks structure under drop test conditions. Appropriate considerations required for the modeling and calculation are shown below.

- Modeling of cask structure and calculation meshes
- Strain rate dependant on mechanical properties
- The friction factor and gaps between elements
- Evaluation of the preconditions such as impact energy

The above items are to be validated (benchmarked) through the tests. Theoretical explanations of the preconditions and assumptions of the analyses based on the test results are required. Now, having executed all of the drop tests outlined in the precedent paragraph, MHI is proceeding with the evaluation and validation of the application of the 3-D dynamic structural analysis code, LS-DYNA.

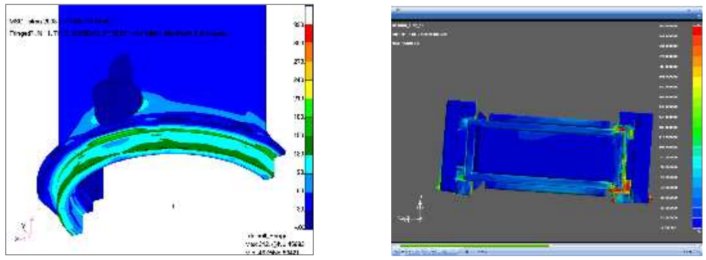


Figure 6. 3-D Dynamic Structural Analysis by LS-DYNA

6. CONCLUSIONS

MHI has continued to develop its technology for improving the safety and economy of interim storage casks for spent nuclear fuel using strategic approaches. The accumulation of this technology has culminated in the MSF cask fleet.

The burnup of fuel has been rising in recent years not only in foreign countries but also in Japan. Following this trend, MHI will continue to promote its policy of developing technology for the supply of optimal products with excellent safety and economy in the future.

ACKNOWLEDGMENTS

MHI expresses our gratitude to the Federal Institute for Materials Research and Testing of Germany (Bundesanstalt fuer Materialforschung und -pruefung; BAM) for allowing us to photograph the BAM drop test facility in Horstwalde, Germany. All remarks about the test results which appear in this report represent the opinions of this writer, not BAM. It should be noted that these results are subject to examination by competent German authorities.

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