Development of a PIE-Fuel Shipping Cask (MSF-I)

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INTRODUCTION

Mitsubishi Heavy Industries, Ltd. (MHI) recently developed a PIE (Post Irradiation Examination)-fuel shipping cask (MSF- I).

The objective of the development of the MSF- I cask was to provide a cask usable for transporting irradiated fuel from a nuclear power plant to a PIE facility or from there to a reprocessing facility. MHI began the development work in 1982 and obtained the licence approval for the cask from the Japanese competent authority (STA) in 1986. The MSF- I cask is able to transport not only regular fuel but also leak fuel, for both the cases, in the form of either an intact fuel assembly or disassembled fuel rods. The MSF- I cask was designed in consideration of the following:

- Capability of leak fuel transport.
- Capability of high burnup fuel transport after a short cooling time.
- Capability of APWR (Advanced-PWR) fuel transport.

DESIGN REQUIREMENTS

The principal specifications of the MSF- I cask are listed in Table 1. These specifications were determined in consideratioin of the requirements listed below:

Containment Method for Leak Fuel

In the case of transpotation of leak fuel, it should be contained in a canister of leak-tightness to provide double containments together with the leak-tightened cask body.

Cavity Condition

This cask is basically used for PIE-fuel transpotation, so the cavity (fuel loading space) of the cask should be designed to a wet-type, in order to prevent the fuel rods from reaching an excessively high temperature for avoiding as much as possible the thermal effect during transportation.

Cavity Dimension

An adequate size of the cavity should be provided, in order to accommodate not only the current PWR fuel (one assembly) but also the APWR fuel (one assembly) and BWR fuel (two assemblies).

DESIGN FEATURES

The MSF-I cask consists of the cylindrical cask body, lid, fuel container (basket/canister), shock absorbers and the other ancillary devices such as valves, trunnions, etc. Fig. 1 shows a bird's-eye view of the MSF-I cask with a fuel assembly contained in the canister.

Table 1 Specification of MSF- I Shipping Cask

Item	Specification		
(1)Type	B(M) Fissile Class 1		
(2) Total weight of package (MT)	About 45		
(3) External dimensions(mm) (with shock absorbers)	Diameter : 1800 Length : 6220		
(4) Materials	Cask body	Stainless steel	
	Gamma shielding	Lead + Stainless steel	
	Neutron shielding	Silicon rubber + Cooling water	
	Shock absorber (+ Cover)	Wood (+ Stainless steel)	
(5)Cavity condition	Wet		
(6) Specification of fuel to be accommodated (licensed)	Type of fuel	Assembly	Fuel rods
		PWR(14×14,15×15,17×17)	
	Initial enrichment (wt%)	max. 4.2	
	Burnup (MWD/MTU)	max. 45,000	max. 55,000
	Quantity of fuel	1	max. 25 rods
	Minimun cooling time(day)	360	90
	Maximum heat generation(kW)	7.6	
	Maximum mumber of leak rods	3	

Cask Body

The cask body has dimensions of 410 mm ID, 1208 mm OD and 5185 mm length, being composed of a stainless steel inner shell, intermediate shell and outer shell. Between the inner and intermediate shells lead (min. 170 mm thickness) is filled for gamma shielding, and silicon rubber (min. 110 mm thickness) is also filled between the intermediate and outer shells for neutron shielding.

Besides the above, in order to improve the thermal conductivity, 24 pieces of thermal bridges which are made of copper are provided on the inner surface of the intermediate shell to wedge into the lead layer. 18 pieces of internal copper fins are also provided for improving the thermal conductivity between the intermediate shell and outer shell.

The inner shell composes a containment together with the lid fitted on the cask body, functioning as a pressure vessel.

On the outside of the outer shell, 46 pieces of ring-shaped stainless steel fins (6 mm thickness, 100 mm hight) are welded at intervals of 100 mm in order to dissipate the heat generated by the contained fuel. The external surface of the fins and outer shell are buff-polished in order to facilitate its decontamination.

Lid

The lid made of stainless steel has double rubber O-rings for sealing on the part to be coupled with the cask body onto which the lid is bolted.

Fuel Container

Two kinds of fuel containers are available, namely a regular fuel basket and a special canister. The regular basket is to contain a regular fuel assembly or regular fuel rods encased in a fuel rod spacer, and the canister is to contain a leak fuel assembly or leak fuel rods encased in the fuel rod spacer. The canister is a pressure vessel having a sealing boundary secured by a rubber O-ring provided on the coupling part between the canister body and its lid.

Shock Absorber

The shock absorbers are fixed by bolts on both the end parts of the cask so as to protect the cask body, fuel assembly contained therein, etc. against a mechanical impact caused in case of emergnecy that might take place during transportation or handling.
The shock absorbers, each having dimensions of 1800 mm outside diameter and 950 mm length, are made of fir-plywood covered with stainless steel plates.

Valve

Two valves are provided on the top and bottom parts of the cask body, the former being a vent valve and the latter being a drain valve, and these are installed for the purposes of pressure relieving, water level setting, etc., associated with the fuel loading and unloading operations.

Trunnion

There are three couples of trunnions provided on the cask body for lifting and for fixing. One couple of the uppermost trunnions are used for vertical lifting of the cask, while the other two couples are used for fixing the cask to the skid for transportation.

OUTLINE OF SAFETY ANALYSIS

Various kinds of safety analyses were carried out in order to design the MSF-I cask in conformity to the safety requirements not only for the normal conditions but also for the accident conditions in transportation, out of which some major items are described below :

Structural Analysis

- The structural analysis of the cask was carried out in consideration of "Design criteria for the structural analysis of shipping cask containment vessels" (U.S.NRC R.G.7.6), where the design criteria for normal and accident test conditions, are formed by the criteria for Level A and Level D service limits, respectively, given in "Design by Analysis" for Class 1 Components specified in ASME Code Section III.
- The shock absorber deformation and cask body acceleration to be incurred in the 0.3m and 9m free drop tests were analyzed using CASH-II code (Asada et al. 1988).
- The static analysis of the cask body (including the lid) was carried out using AXSAS code, an FEM (Finite Element Method) elastic structural analysis code developed by MHI.

Thermal Analysis

The MSF-I cask was designed, as shown in Table 1, to be suited for transpotation of irradiated nuclear fuel generating a large quantity of heat in conformity with the thermal requirements stipulated by the regulation, that is, the surface temperature of a package under the normal conditions must not exceed 82°C, and the package must be able to withstand the fire condition with a temperature of 800°C for a period of 30 minutes.
A 3-dimensional unsteady-state temperature distribution analysis code, TRUMP, was used in the temperature distribution analysis for each major part.

Sealing Analysis

The sealing analyses of the MSF-I cask were performed for two instances. One was for regular fuel, and the other was for leak fuel assumed to include three leak fuel rods as the maximum.

- Sealing for regular fuel

  Regular fuel is to be contained in the regular basket. In the sealing analysis, it was confirmed that the leak rate of radioactive materials would be far lower than the regulatory values for both liquid and gaseous materials, on the assumption that the concentration of radioactivity of the cooling water inside the cask was 1 μCi/cc.

· Sealing for leak fuel

Leak fuel is to be contained in a canister having a sealing function. The sealing integrity of this canister was evaluated to be maintained under the accident conditions, however, on the safe side, the sealing capability of the canister was neglected in the sealing analysis. Namely, it was assumed that the cooling water inside the canister mixed with the cooling water outside the canister within the cavity. Under the said condition, the radioactivity concentration of the mixed cooling water inside the cavity was analyzed to become much higher than that for regular fuel as described above due to the radioactive nuclides leak from the fuel. In spite of such a conservative and severe assumption, the analysis results verified that the leak rate of radioactive materials would never exceed the regulatory values.

Shielding Analysis

The dose rate of a package under normal conditions is limited to 200 mrem/h or less on its surface and 10 mrem/h or less at 1 m from the surface. To ensure the conformity to these values, the shielding analysis was performed using various analysis codes.

· Source analysis

For evaluating both the intensities of γ-ray and neutron souces, the isotope generation and depletion code of ORIGEN was used, and for the effective multiplication factors to be obtained under subcritical states with various neutron souce intensities calculated above, the multi-group Monte Carlo method code of KENO-IV was adopted to evaluate the total neutron flux to be shielded.

· Shielding analysis

In the shielding analysis for both the γ-ray and neutron sources, the one-and two-dimensional transport equation codes of ANISN and DOT 3.5 (for streaming evaluation) were used.

Criticality Analysis

The KENO-IV was also utilized in the criticality analysis so as to ensure that the subcritical state would be maintained even if an infinite number of the MSF- I casks should congregate under the normal or accident conditions.

MODEL TESTS

In association with the development of the MSF- I cask, the following model tests were carried out for evaluating the validity of the developed design.

1/3-Scale Model Drop Test

In order to confirm the integrity of the package under the drop accident conditions, as required by the regulation, and to verify the validity of the analysis methods, the 9 m drop and 1 m puncture tests were executed using a 1/3-scale model as specified in Table 2.

Table 3 shows the comparison between the safety analysis values and the experimental values converted from the 1/3-scale model test results. Fig. 2 shows the test view. Through the tests, the integrity of the package under the accident conditions and the adequacy of the structural analysis methods were duly verified.

Partial Model Thermal Tast

In order to verify the thermal capability of the cask structure having a multilayer construction and the adequacy of its analysis method, a thermal test (at 800°C for 30 minutes) was executed by the furnace test-II. A partial model having dimensions of 650(W) × 500(H) × 650(L) which simulated the central part of the MSF- I cask was used. Fig. 3 shows the test view, and Fig. 4 shows the results of the thermal test. From the results the thermal performance of the MSF- I shipping cask and the adequacy of its analysis method were verified.

Table 2 Specification of 1/3-Scale Model

Item	Actual construction	1/3-Scale model	Reduction factor
Out sidediameter (mm)	1800	600	3.0
Full lenght (mm)	6200	2073	3.0
Weight (kg)	44220	1540	28.7
Material	Stainless steel		-

Table 3 Comparison between Analysis and Experimental value (Drop test)

Orientation / Evaluation item	Vertical drop test		Horizontal drop test		Corner drop test	
	Test Result	SAR	Test Result	SAR	Test Result	SAR
Acceleration (G)	114	115	117	135	73	138
Deformation (mm)	88	187	73	156	155	381

Remarks 1. Test result = Actual measured values of 1/3-scale model test x R

2. R; The ratio of the analysis value by HOND-II code for the full scale model to that for the 1/3 scale model.

3. SAR (Safety Analysis Report) ; Analysis value by CASH-II code

EXPERIENCE OF TRANSPORTATION AND MAINTENANCE

Transportation

Since the the first practical use of the MSF- I cask for transporting spent fuel was made May 1987, a total of four such occasions have been experienced to date by MHI with the cooperation of the utilities, transportation companies, etc. these shipments have been executed very safely in accordance with the applicable regulations and guidances stipulated by the competent authorities and relevant organizations. Fig 5 shoes a view of the cask handling for shipmant.

External Radiation Level

The external dose rates in actual transportation were measured. The comparison between the measurements and analytical dose rates (Nakata and Ohashi 1988) are shown in Figs. 6, and 7, indicating close agreements to each other with safe-side analyses. From the figures, it can be stated that the shielding design of the MSF- I cask is safe and adequate.

Maintenance and Inspection

The organization responsible for fuel-related services including the operation and maintenance of the MSF- I cask has been established within MHI so as to execute the proper maintenance and inspection needed for each transportation and periodic test to ensure quality of the cask. Incidentally, when the MSF- I cask is off the service, it is located in the exclusive area in our post-irradiation examination facility, i.e., Mitsubishi Hot Laboratory (MHL) in Tokai, Ibaraki Pref.

CONCLUSIONS

- For the purpose of transporting irradiated fuel to undergo a post-irradiation examination (PIE), a PIE-fuel shipping cask, MSF- I , available for PWR, APWR and BWR fuels was developed by MHI through various analyses and tests.
- Employing a double containment system as the case may be, the MSF- I cask can accommodate not only regular fuel but also leak fuel both having a present burnup or future high burnup, in the form of intact assembly or disassembled fuel rods.
- The MSF- I cask has been utilized for the domestic transpotation of PIE-fuel four times to date safely, verifying its designed performance and adequacy of the analysis methods.

REFERENCE

A.Asada, M.Ohashi, et al., "Development of Simplified Analysis Codes for 9-M Drop and 1-M Puncture Tests for a Radioactive Material Transport Cask", Waste Management '88 (1988).

M.Nakata, M.Ohashi, "Comparison Between Measured and Analyzed Dose Rates of MSF- I Cask and Validation of its Shielding Design", 7th International Conference on Radiation (1988).

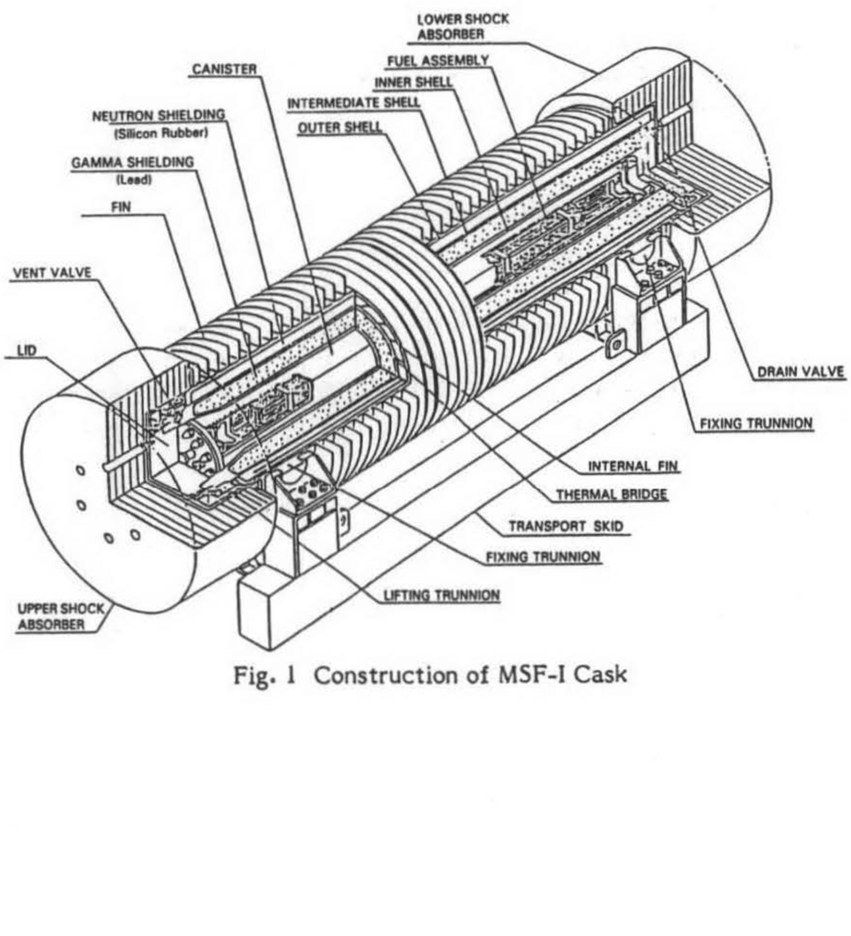

Fig. 1 Construction of MSF-I Cask

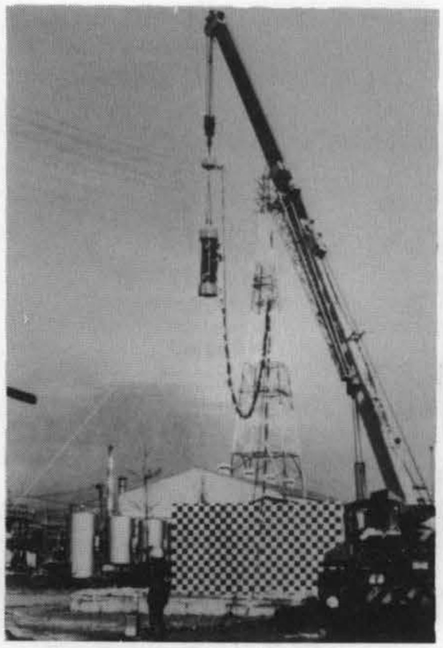

Fig. 2 View of 9m Vertical Drop Test

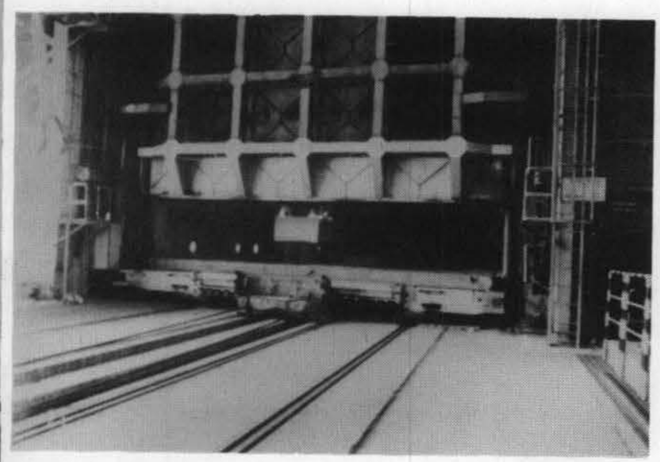

Fig. 3 800°C-30 Minute Thermal Test (Coming out of Furnace)

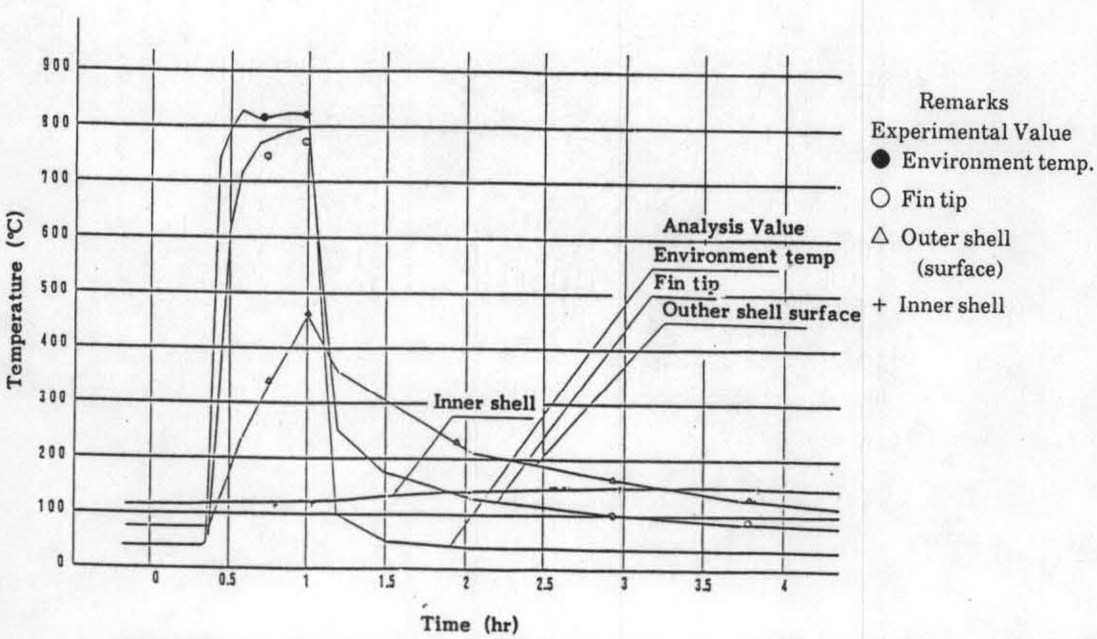

Fig. 4 The comparison between Analysis and Experimental value (Thermal test)

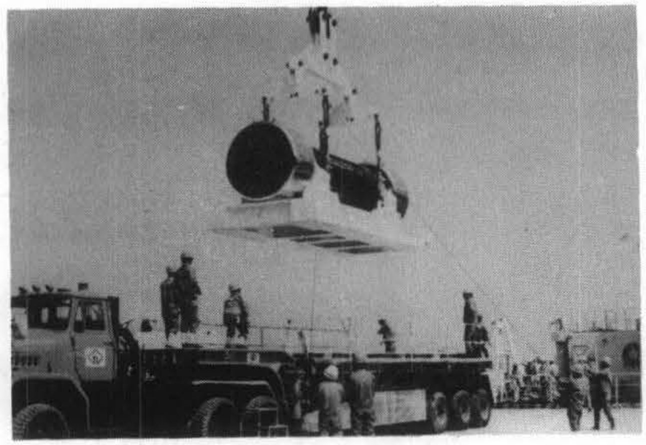

Fig. 5 MSF- I Handling for Shipment

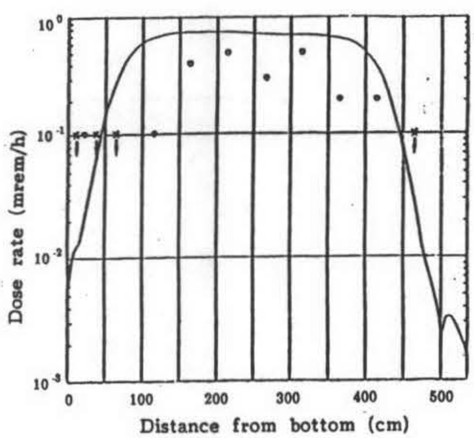

Fig. 6 Example of Analyzed and Measured Surface Dose Rate Distribution(Neutron)

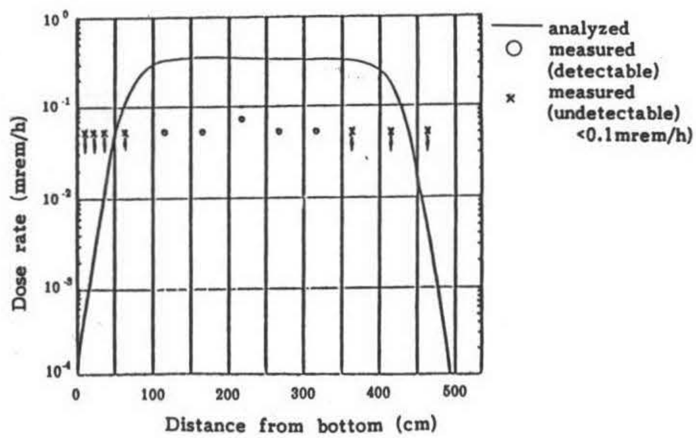

Fig. 7 Example of Analyzed and Measured Surface Dose Rate Distribution(γ-Ray)