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STRUCTURAL INTEGRITY OF MSF-57BG TRANSPORT AND STORAGE CASK BASED ON FULL-SCALE AND 1/2.5-SCALE DROP TEST RESULTS

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ABSTRACT

Transport and storage cask for spent fuels is used for transport and storage of spent fuels. Integrity of containment system and confinement system during transport has to be demonstrated by drop tests and/or numerical simulations in accordance with IAEA transport regulations [1].

This paper describes results and evaluation of drop tests with Full scale model and 1/2.5 scale model of MSF-69BG, which is representative of "MSF cask (Mitsubishi Spent Fuel Cask)" developed as transport and storage cask. In addition, outline of structural evaluation of MSF-57BG, which can accommodate 57 BWR fuels, are described on the basis of these drop test results.

INTRODUCTION

MHI has developed MSF-57BG cask for transport and storage of higher burn-up and shorter cooling time BWR 57 fuels. The MSF cask is now in the licensing stage in Germany.

A series of drop tests based on the IAEA transport regulations [1] has been conducted by the German Federal Institute for Materials Research and Testing (BAM) to prove the structural integrity of MSF cask. A full-scale model and a 1/2.5 scale model based on MSF-69BG type, which can accommodate 69 BWR fuels, were used as drop test models. These tests have been finished successfully, and the followings were confirmed by measurement results of leakage rates at each lid system and deformation amounts at each part before and/or after the tests.

(1) The leakage rates of Helium gas after the drop tests satisfied the criteria based on IAEA transport regulations [1].
(2) No significant deformation of basket was observed. (sub-criticality)
(3) No severe damage to cask body excluding shock absorbers was observed. (shielding performance)

In addition, static compression tests of shock absorber have been conducted under supervision of BAM to obtain load-displacement characteristics at room temperature and high temperature.

Based on these results, an FE analysis model was developed and verified, and a numerical simulation method was established to evaluate dynamic behavior of the cask body, especially behavior at lid parts. Next, based on the established simulation method, structural integrity of a different type of MSF-57BG was confirmed at -40°C as well as at maximum design temperature.

SPECIFICATION OF MSF-57BG CASK

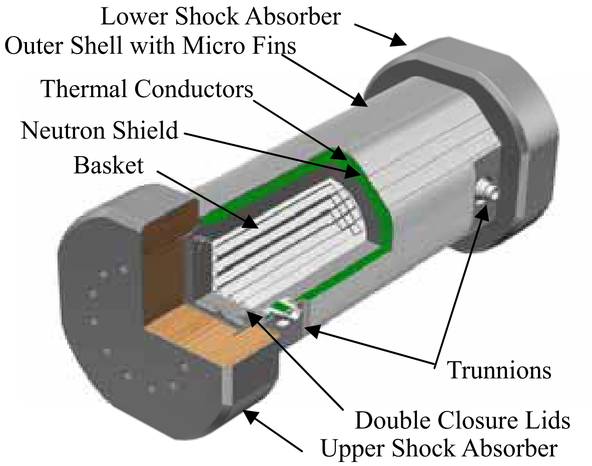
Specification of MSF-57BG is shown in Table 1. Features of MSF-57BG are shown below.

- Low-alloy steel body shell manufactured by the monolithic forging process [2]
- Boron containing aluminum alloy basket consisting of 57 separate square pipes [3]
- External fins (micro fins) with high heat dissipating performance in vertical position (storage)/in horizontal position (transport)
- Epoxy-resin based neutron shield (MREX®)
- Double closure lids with metallic O-rings
- High performance shock absorbers using oak/red cedar/balsa

Table 1. Specification of MSF-57BG

Type	B(U)
Fuel Type	BWR
Payload	57
U-235 Initial Enrichment (%)	5
Burnup (GWd/MTU)	63
Thermal Power (kW)	33
Weight (metric tons)	122(*) / 141
Dimensions (m)	ϕ 2.5 x 5.3(*) ϕ 3.2 x 7.3

(*) Without Shock Absorbers



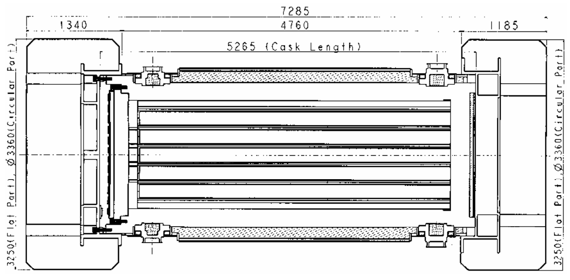
DROPT TESTS

Drop Test Models

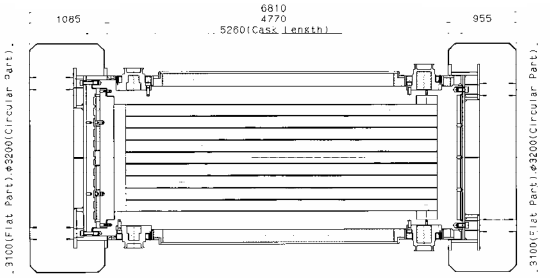
Drop tests were conducted with two drop test models (a full scale model and a 1/2.5 scale model) to prove the following two technical issues.

(1) Verification of the structural integrity of the cask
(2) Demonstration of the closure system performance

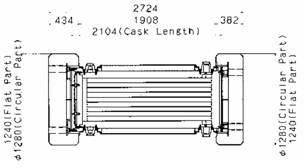
The drop test models were designed and fabricated based on the same concept as MSF-57BG, and they have similarity to MSF-57BG in geometry. Comparison of weight and dimensions between MSF-57BG and the drop test models is shown in Figure 1and in Table 2.



a. MSF-57BG



b. Full-Scale Drop Test Model



c. 1/2.5 Scale Drop Test Model

Figure 1. Outline of MSF-57BG and Drop Test Models

Table 2. Comparison between MSF-57BG and Drop Test Models

	MSF-57BG	Full-scale Model	1/2.5 Scale Model
Payload	57	69	69
Weight (metric tons)	122(*) / 141	113(*) / 127	7.2 (*) / 8.0
Dimensions (m)	ϕ 2.5 x 5.3(*) ϕ 3.2 x 7.3	ϕ 2.5 x 5.3(*) ϕ 3.1 x 6.8	ϕ 1.0 x 2.1(*) ϕ 1.2 x 2.7

(*) Without Shock Absorbers

Drop Tests Sequences

According to the IAEA transport regulations [1], the specimens shall drop onto the target in such a way that it will obtain the maximum damage. In order to realize the regulation's requirement, 13 drop tests (full-scale: 5 tests, 1/2.5 scale: 8 tests) were performed under the drop test conditions shown in Table 3.

Table 3. Drop Test Conditions

Model	BAM Test No.	Seq. No.	Condition	Drop Height
Full-scale model	III.3/0995	1(*)	Slap down (10 degree)	9.3m
	III.3/0996	2(*)	Horizontal	1.0m Penetration
	III.3/0997	3	Vertical	9.3m
	III.3/1004	4-1	Slap down (10 degree)	0.3m
	III.3/1007	4-2	Slap down (10 degree)	9.0m
1/2.5 scale model	III.3/1020	1-1	Vertical	9.3m
	III.3/1021	1-2	Vertical	1.37m Penetration
	III.3/1019	2	Horizontal	9.3m
	III.3/1015	3-1	Oblique (Corner)	9.3m
	III.3/1016	3-2	Oblique (Corner)	1.39m Penetration
	III.3/1029	4-1	Slap down (10 degree)	0.3m
	III.3/1030	4-2	Slap down (10 degree)	9.0m
	III.3/1031	4-3	Horizontal	1.25m Penetration

(*) Seq. No2 was conducted following the test of Seq. No.1.

A main purpose of the full-scale tests was to demonstrate containment integrity. Therefore, slap down and vertical drop, which were evaluated as severer drop conditions to containment system, were applied to the drop test conditions for full-scale models. The slap down test with the full-scale model (Seq. No.1) was conducted as an open test during the PATRAM technical tour in 2004 [4][5].

Drop Test Results

(1) Containment system

Table 4 and Table 5 respectively show the Helium leak test results before and after the drop tests using the full-scale model and the 1/2.5 scale model. The leakage rates after the drop tests, some of which increase two or three orders more than those before the tests, satisfy the criteria based on the IAEA transport regulations. The reason why the leakage rate of secondary lid for the 1/2.5 scale model increased significantly after Seq. No.4 drop test is a specific effect due to instrumentation grooves in the lid and accumulated impact by repeating tests several times.

(2) Sub-criticality and shielding performance

Basket cells of the full-scale model and those of the 1/2.5 scale model were removed from cask cavity inside to inspect the basket cells after all of the drop tests. As a result, no significant deformation was observed. Basket cells after the series of drop tests with a full-scale model are shown in Figure 4. Theses tests results proved that integrity of confinement system is maintained.

In addition, condition that shock absorbers were fixed on the both ends of the cask was maintained in all of the drop tests, and there was no damage of shielding materials.

Figure 2. Slap down Drop Test with Full-Scale Drop Test Model

Figure 3. Oblique (Corner) Drop Test with 1/2.5 Scale Drop Test Model

Figure 4. Basket Cells for Full-Scale Model after Series of Drop Tests

Table 4. Leakage Rates after Each Drop Test Sequence (1/1 Scale Model) (Unit: Pam^3/s)

Seq.#	ORIENTATION	PRIMARY LID		SECONDARY LID	
		Before	After	Before	After
1	9.3m slap down	$< 1\times10^{-11}$	$< 1\times10^{-11}$	7.4×10^{-9}	1.6×10^{-6}
2	1m puncture(following Seq.No.1)	$< 1\times10^{-11}$	2.0×10^{-11}	1.6×10^{-6}	7.8×10^{-7}
3	9.3m vertical drop	1.0×10^{-8}	3.9×10^{-6}	2.0×10^{-11}	1.7×10^{-11}
4-1	0.3m slap down	2.5×10^{-11}	1.0×10^{-11}	1.5×10^{-11}	$< 1\times10^{-11}$
4-2(*)	9.0m slap down	1.0×10^{-11}	$< 1\times10^{-11}$	$< 1\times10^{-11}$	3.0×10^{-7}

(*) Seq.No.4-2 following Seq.No.4-1 was conducted without a change of metallic O-rings.

Table 5. Leakage Rates after Each Drop Test Sequence (1/2.5 Scale Model) (Unit: Pam^3/s)

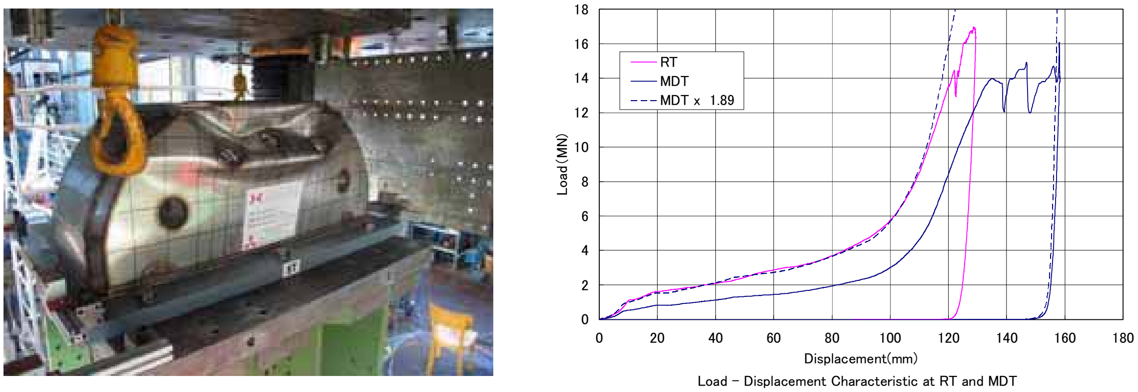
Seq.#	ORIENTATION	PRIMARY LID		SECONDARY LID	
		Before	After	Before	After
1	9.3m vertical drop+1.37m puncture	1.2×10^{-9}	3.6×10^{-8}	2.4×10^{-7}	8.4×10^{-7}
2	9.3m horizontal drop	7.3×10^{-9}	1.4×10^{-8}	$< 1\times10^{-11}$	8.9×10^{-9}
3	9.3m oblique drop+ 1.39m puncture	1.5×10^{-9}	7.8×10^{-9}	$< 1\times10^{-11}$	4.4×10^{-8}
4-1	0.3m slap down	1.8×10^{-8}	5.0×10^{-9}	2.0×10^{-8}	5.0×10^{-8}
4-2/3	9.0m slap down+ 1.25m puncture	5.0×10^{-9}	4.0×10^{-7}	5.0×10^{-8}	2.8×10^{-3}

(*) Seq.No.4-2/3 following Seq.No.4-1 were conducted without a change of metallic O-rings.

SHOCK ABSORBER COMPRESSION TESTS

Wood strength is known to have temperature dependency and to decrease at high temperature [6]. To identify the load-displacement characteristics and the their temperature dependency of shock absorber as component, static compression tests of shock absorber were conducted at room temperature and high temperature (100°C). These tests were also conducted under supervision of BAM with their test equipment (25MN press machine).

The tests results (load-displacement characteristics) are shown in Figure 5. The results proved that shock absorber compression strength at high temperature (100°C) reduced to approx. 53 % of that at room temperature. Therefore, strength degradation of shock absorbers at maximum design temperature is considered for design of MSF-57BG.



Load - Displacement Characteristic at RT and MDT

Figure 5. Shock Absorber Compression Test Results

DROP TEST ANALYSES

FE Analysis Model

In order to simulate the drop test results, dynamic FE analyses were performed using LS-DYNA code. Figure 6 shows an FE analysis model, and Figure 7 shows verification procedure of the analysis model. Shock absorber analysis model was established based on load-displacement characteristics obtained from shock absorber compression tests, and then a cask body model with this shock absorber model was established.

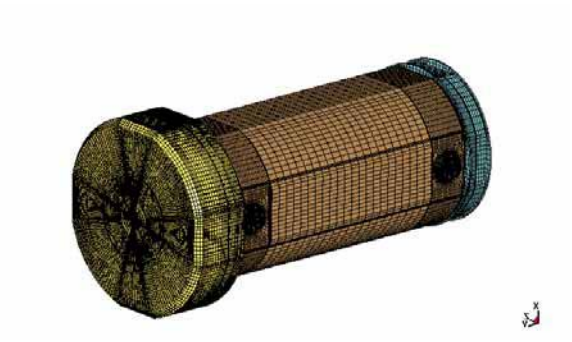


Figure 6. Drop Test Analysis Model

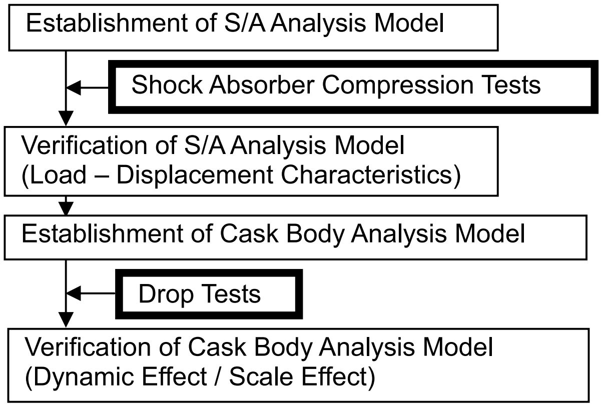
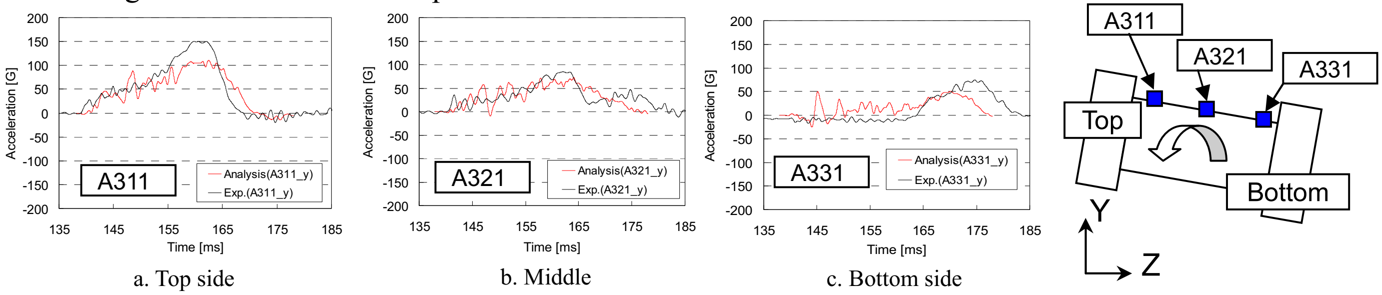


Figure 7. Verification Procedure

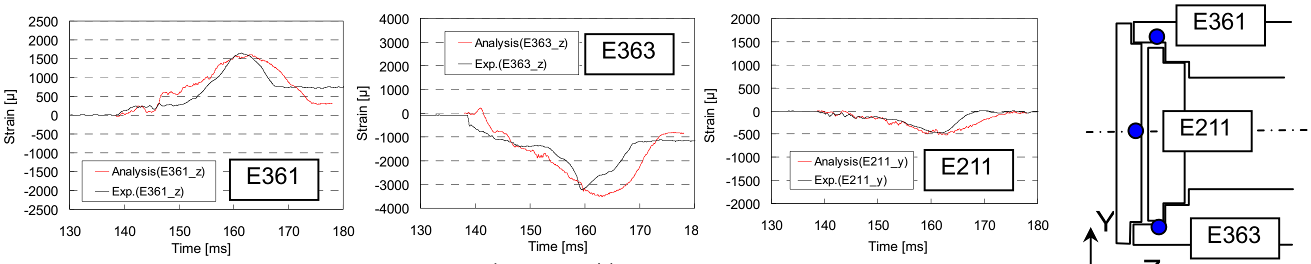
Analysis Results

Analysis results for slap down are shown as an example. In this analysis, only a secondary impact behavior under slap down was simulated and an initial velocity of secondary impact was calculated based on the analytical equation [7]. Figure 8 shows comparison of decelerations on cask body between analytical and experimental results, and Figure 9 shows comparison of strains on body flange root and on secondary lid between analytical and experimental results. These figures show that deceleration time histories and strain time histories of the analytical results well agree with those of the experimental results.



a. Top side b. Middle c. Bottom side

Figure 8. Comparison of Deceleration between Analytical and Experimental Results



a. Opposite side b. Impact side c. Secondary lid (center)

Figure 9. Comparison of Strain between Analytical and Experimental Results

MSF-57BG STRUCTURAL INTEGRITY EVALUATION

FE Analysis Model

An MSF-57BG analysis model was established on the basis of the verified drop test analysis model. Figure 10 shows an MSF-57BG analysis model.

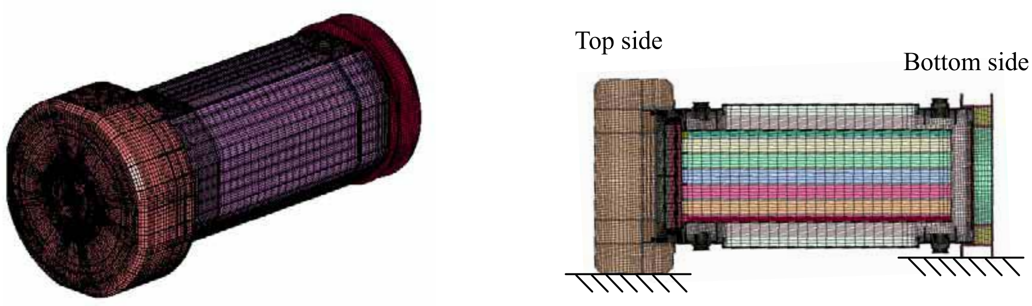


Figure 10. FE Analysis Model of MSF-57BG

Analysis Results

(1) Slap down

Slap down analysis of MSF-57BG was conducted at a maximum design temperature with heat load of 33kW. 0.65 times strength of shock absorber at room temperature was applied taking into account the wood strength degradation due to temperature increase up to an average 80°C. As an example of the analyses results, Figure 11 shows comparison of strain on body flange root between MSF-57BG and the drop test model. Slap down analysis of MSF-57BG at -40°C was conducted with 1.4 times strength of shock absorber at room temperature as well.

The analyses results proved integrity of MSF-57BG because the strain is much smaller than that caused to the drop test model.

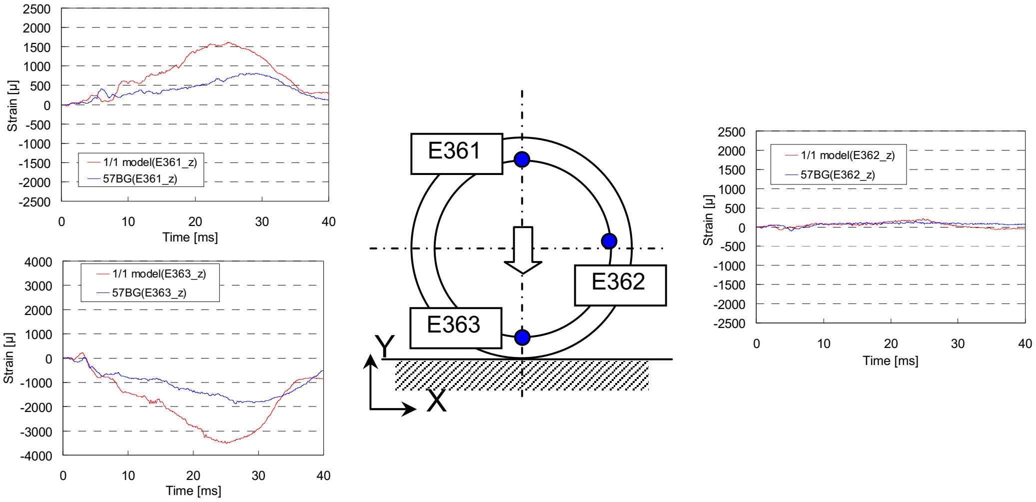
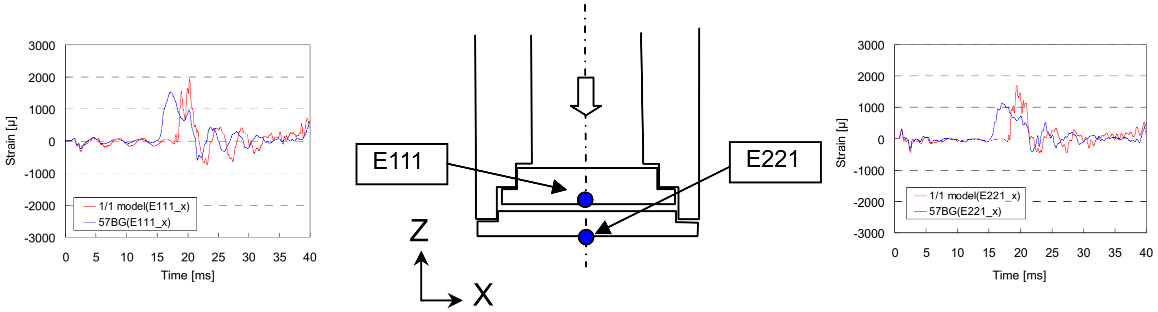


Figure 11. Comparison of Strain on Body Flange Root (Analytical Results) between MSF-57BG (Max. Design Temp.) and Drop Test Model (RT)

(2) Vertical Drop

Vertical drop analyses of MSF-57BG were also conducted at a maximum design temperature with heat load of 33kW and at -40°C. As an example of the analyses results, Figure 12 shows comparison of strain on primary lid and secondary lid between MSF-57BG and the drop test model at -40°C. The analyses results proved integrity of MSF-57BG because the strain is smaller than that caused to the drop test model.



a. Primary lid (center)

b. Secondary lid (center)

Figure 12. Comparison of Strain on Primary Lid and Secondary Lid (Analytical Results) between MSF-57BG (-40 ºC) and Drop Test Model (RT)

CONCLUSIONS

The drop test results show sufficient integrity of containment and confinement system. Furthermore, the drop test analysis model was established and verified by the drop test results and shock absorber compression test results, and then structural integrity of MSF-57BG was proved with FE analyses on the basis on the drop test analysis model.

ACKNOWLEDGMENTS

MHI thanks BAM for giving MHI the opportunity to present pictures taken on the BAM test facilities in Germany. Statements in this presentation concerning test results reflect MHI’s point of view only; MHI’s statements do not represent the official BAM point of view, and are subject to further investigations within the German licensing procedure.

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