Demonstration Test for Transporting Vitrified High-Level Radioactive Wastes: Drop Test

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INTRODUCTION

The national policy on the nuclear fuel cycle is based on the "Long-Term Plan for Utilization" drawn up the Atomic Energy Commission of Japan, and the basic policy on the nuclear fuel cycle is that spent fuels from light-water reactors (LWR) should be reprocessed.

In line with this policy, some spent fuels have been reprocessed overseas and high-level radioactive wastes (HLW) have been generated by such reprocessing. Some of the high-level radioactive wastes have been returned by surface transport. In order to ensure the safe transport of high-level radioactive wastes, demonstration tests stipulated by the IAEA transport regulation were carried out in the Central Research Institute of Electric Power Industry (Tamaki et al.1992). This paper describes the drop test. This work was conducted under a contract from the Science and Technology of Japan.

TEST CASK

The test cask is designed as a Type B package and the design combines the specific structural features of both the COGEMA and the BNFL (planned) casks, which are used for shipping HLW from France and the U.K. respectively.

The specifications and external view of the cask used for the drop test are shown in Figure.1.

The cask is characterized structurally as follows: (a) The cask body is covered with a neutron absorber enclosed by a thin steel plate; (b) Impact energy is assumed to be absorbed mainly by inelastic deformation of the neutron shielding material.

In each canister, instead of vitrified high-level waste, glass or mortar was packed to model the weight, and electric heaters were installed in each canister to simulate the real heat conditions of the canister.

TEST METHOD

A 9m drop test onto an unyielding target and a 1m drop test onto a steel bar as stipulated by the IAEA transport regulation were carried out.
A horizontal orientation was chosen for the drop tests because this gives the maximum acceleration compared to other orientations according to the design base analysis, and because the mechanism for absorbing impact energy in the horizotal drop test is relatively new and has not been fully clarified yet.

The strains and accelerations at various points in the cask body and inner structure resulting from the impact caused by the drop were measured using strain gauges and accelerometers. Leak tests for the lid gasket were carried out before and after the drop test to evaluate the tightness of the gasket.
The drop tests were carried out at the Yokosuka laboratory of CRIEPI.

TEST RESULTS

Examples of the strain time histories measured in the 9m drop test are shown in Fig.2. The hoop strains are larger than the axial strains at the parts of the cask body, because the cross section of the cask body was deformed into a hemisphere by applying an impact force in the radial direction. The maximum acceleration and stress measured in the drop tests are summarized in Table 1. The measured leak rates are shown in Table 2.
The test results were as follows: (a) The maximum stress in the cask body as a result of the impact force caused by the free drop are in the elastic range; (b) The leak rate did not change before and after each drop test.

We therefore conclude that the integrity of the cask was maintained under the drop test conditions.

Table 1. Summary of Test Results

Item		0.3m	9.0m	1.0m	Allowable Limit
Acceleration (G)		50	300	10	—
Stress (MPa)	Body	66.6	244.0	104.8	274 (Sy) 413 (Su)
	Basket Segment	38.2	119.6	6.9	71.5 (Su)
Racial Deformation of Outer Shell (mm)		13.0	58	—	—

Table 2. Results of the Leak Test

	Item	0.3m	9.0m	1.0m
Leak Rate	Before Drop Test	4.12×10^{-4}	8.41×10^{-5}	1.35×10^{-4}
	After Drop Test	3.95×10^{-4}	9.95×10^{-5}	8.75×10^{-5}
Allowable Limit		1.88×10^{4} *1)	8.39×10^{5} *2)	

*1) Corresponding to the Leak rate calculated from A_1 value/hour (atm・cc/sec)
*2) Corresponding to the Leak rate calculated from A_2 value/hour

ANALYTICAL MODEL

We used the DYNA-3D and NIKE-2D codes to analyze the drop test. A half-symmetrical model was used for the overall analysis to calculate the strains in the cask by DYNA-3D. In this model, inner structures such as canisters and basket segments are modeled as a homogeneous structure with an equivalent weight. The maximum acceleration obtained from the above overall analysis was then put into the plane strain model for the section model of the cask normal to the longitudinal axis to calculate the strains in the basket by NIKE-2D. Figures 3 and 4 show the half-symmetrical model and the plane strain model, respectively.

The impact energy was absorbed mainly by the inelastic deformation of the neutron shielding material and the thin shell plate, therefore, the mechanical properties of the neutron shielding material play an important role in the analysis. As the structure of the neutron shielding material is rather complex because it contains materials such as silicone gum and heat transfer fins, etc., it is difficult and not suitable to model such a complicated structure by DYNA-3D. Therefore, a partial model of the neutron shielding material including a heat transfer fin was used in the structural analysis to obtain the stress-strain relationship of the model. Then, assuming that the shielding material has the stress-strain behavior of a homogeneous material, overall analysis was performed by DYNA-3D. The procedure to obtain the stress-strain relationship of the neutron shielding material for analysis is shown in Figure 5 and the stress-strain relationship obtained is shown in Figure 6. The mechanical properties of the analyzed materials are shown in Table 3.

Table-3 Mechanical Properties for analysis

Item	Cask body	Neutron shielding material		Silicone gum		Heat transfer fin	
Young's modulus (MPa)	1.95×10^5	581.0		100.0		120.0	
Poisson's ratio	0.3	0.343		0.4		0.3	
Stress (MPa) \ Plastic strain		σ	εp	σ	εp	σ	εp
		0.057	0.0	0.0	0.0	20.580	0.0
		0.606	1.8610E-05	1.036	0.048943	96.04	0.1825
		22.421	1.5045E-03	9.976	0.239820	274.40	34.9825
		4.476	0.0492	13.940	0.335776		
		16.014	0.2472	14.021	0.535692		
		21.296	0.3463				
		21.405	0.5462				

The free-drop velocities corresponding to a fall of 9m and 1m were input into each node of the elements of the model.

ANALYTICAL RESULTS

The test results and calculated results are compared in Table 4. The comparison shows that the analysis gives the same or conservative values compared to the experimental results. The present analytical procedure can thus be used to evaluate the impact phenomenon of casks when a complicated material is used as the shock absorber.

Table 4. Comparison Between Test and Calculated Results (Half-Symmetrical Model)

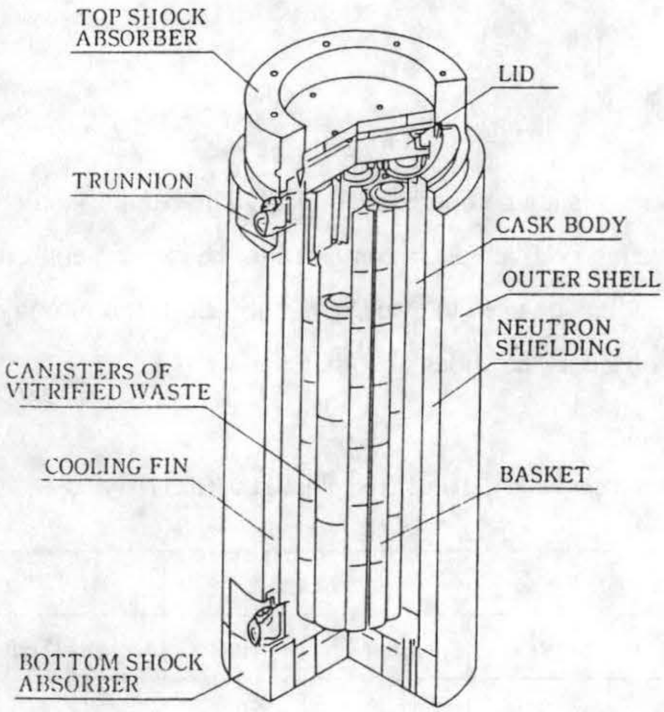
Item	0. 3m		9. 0m		1. 0m	
	Calculated	Test	Calculated	Test	Calculated	Test
Acceleration (G)	68	50	320	300	14	10
Stress (MPa) Cask Body	103. 9	66. 6	380. 2	244. 0	159. 7	104. 8
Stress (MPa) Basket Segment	60. 8	38. 2	158. 8	119. 6	6. 9	6. 9

CONCLUSION

The structural integrity of the cask for shipping high-level radioactive waste was confirmed by the drop-test method. The applicability and accuracy of the analysis by DYNA-3D was benchmarked by comparing the test results and the analytical results.

REFERENCE

H.Tamaki et al. *Demonstration Test for Transporting Vitrified High-Level Waste,* PATRAM 92, 1992.



SPECIFICATIONS

Total Weight : 115 ton

Total Length : 6800 mm

Diameter of Cask : 2400 mm
(including outer Shell)

Thickness of Cask Body
: 254 mm

Thickness of Outer Shell
: 20 mm

Total Number of Canisters
: 28

Quantity of Heat
: 1.46 kW/canister

Fig.1 Concept and Specifications of Demonstration Test Cask

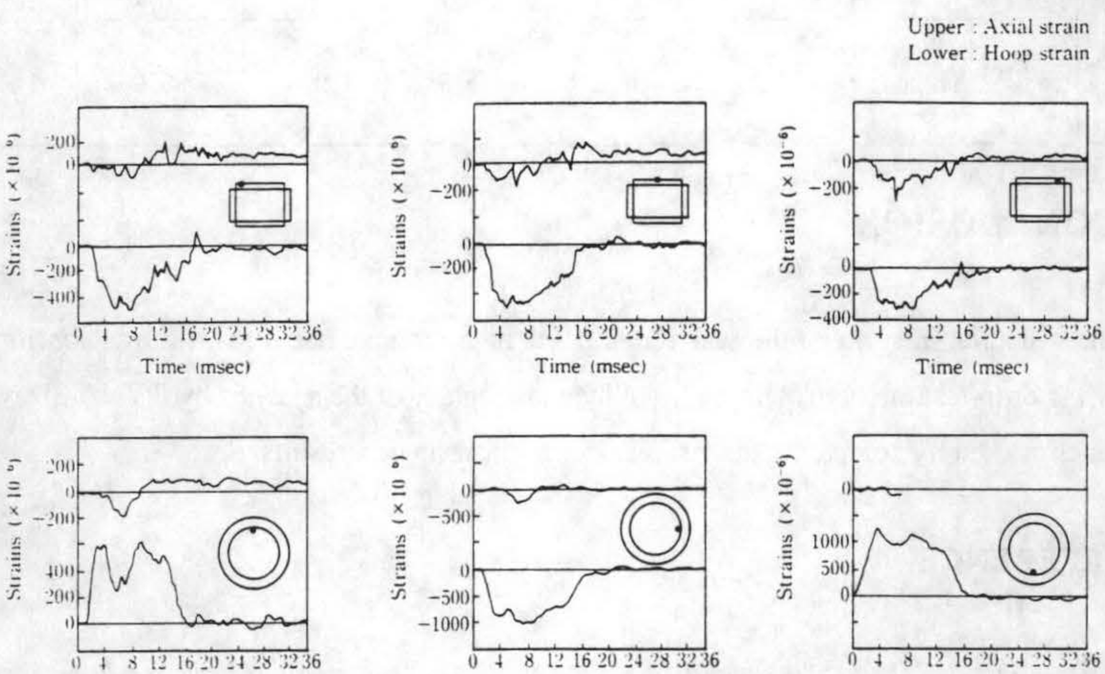


Fig.2 Time histories of strain measured from cask body in 9m drop test

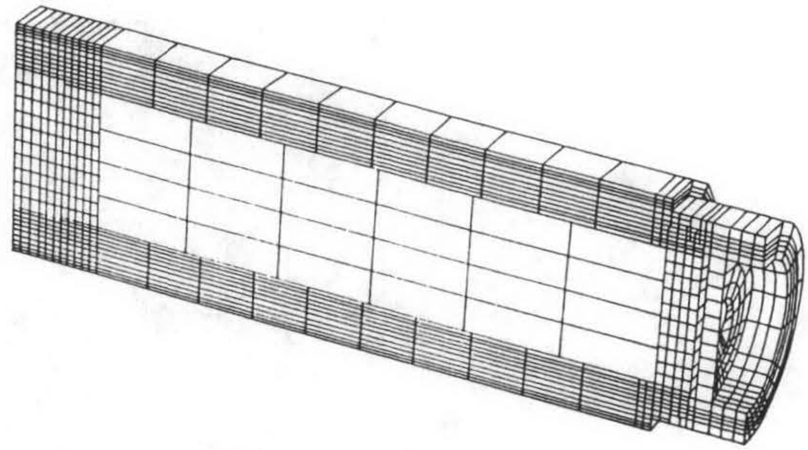


Fig.3 Half-Symmetrical Model

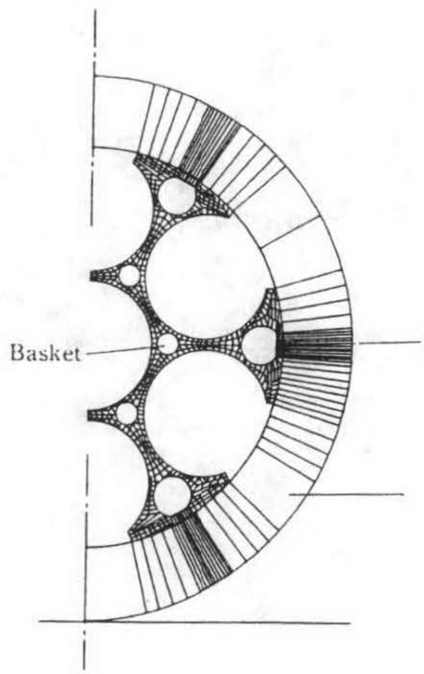


Fig.4 Plane-Strain Model

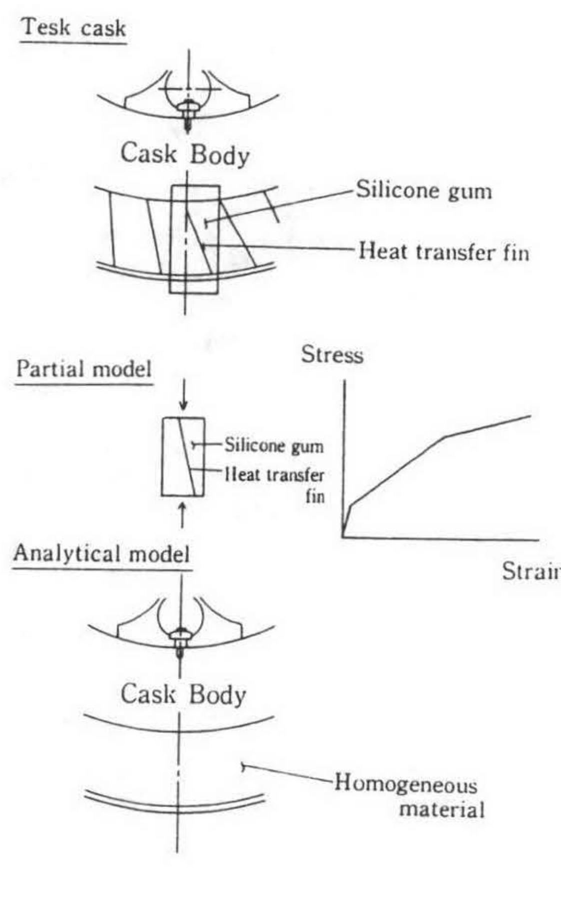


Fig.5 Procedure for obtaining stress-strain curve of neutron absorber

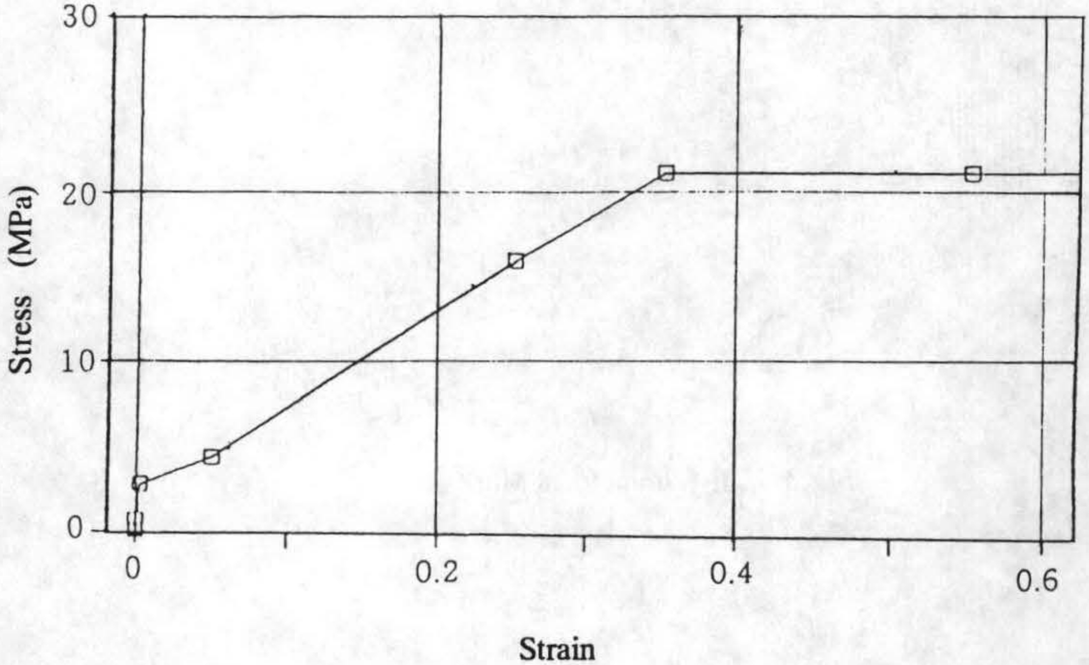


Fig.6 Stress-strain relationship of neutron shielding materials for analysis