DEMONSTRATION TEST FOR A SHIPPING CASK TRANSPORTING HIGHT BURN-UP SPENT FUEL -Drop Test and Analysis-

C.Ito(1), O.Katoh(1), S.Komatsu(1) and H.Ohnuma (1), (2)

(1)Central Research Institute of Electric Power Industry,
1646 Abiko, Abiko-shi, Chiba-ken,270-11 JAPAN
(2)After 1997, Hokkaido University,
13-8 Kita-ku, Sapporo-shi, Hokkaido

SUMMARY

The drop tests stipulated in the IAEA Transport Regulation and analysis against the tests were carried out for a test package which has the same structural features as a package used for the actual transportation from nuclear power plant to the reprocessing plant at Rokkasho-mura in Aomori-prefecture in JAPAN.

The cask used in the drop tests was NFT-14P which contains 14 fuel assemblies for PWR. A structural features of the cask is that some part of the impact energy at the Drop test I are absorbed not only by the impact limiters but also by its external surface fins to remove decay heat. Electric heaters were put into the cask to simulate the heat generation of real spent fuels.Strains and accelerations were measured during the tests.

The test results showed that the measured strains are within the allowable limit at all drop tests and the leakrate at the sealded parts are also within the allowable limit after the drop test.
Using DYNA-3D structural analysis code, the drop test analysis were carried out. The external surface fins were modeled by shell ellement one by one. The deformation mode of the fins at the analysis was not coinsident with the one of the test result exactly. However, the analysis can give good agreement with the measured strains and accerelations.

INTRODUCTION

The reprocessing plant has been constructed at Rokkasho-mura in Aomori-prefecture and will start its operation near future. Transportaion of spent fuels from nucler power plants to a storage pool affiliated to the reprocessing plant will start before the operation of the reprocessing plant. The majority of the spent fuels are expected to be high burn-up fuels. High burn-up spent fuels have characterization of higher enrichment , radioactivity and decay heat compared to current spent fuels. To transport such spent fuels, the high performance shipping casks have been designed and consturucted. In order to investigate the integrity of the casks a series of the regulatory tests were carried out by Central Research Institute of Electric Power Industry (CRIEPI) under the sponsorship of Scietific and Technology Agency of Japan. This paper presents the results of the regulatory drop tests (Free Drop Test, Drop Test I and Drop Test II) in the IAEA Transport Regulation and analysis against the drop tests.

TEST CASK

The cask used in the drop tests was NFT-14P which contains 14 fuel assemblies for PWR. The and external view of the cask used for the drop tests are shown in Fig.1.

A structural features of the cask is that some part of the impact energy at the drop test I in horizontal orientation are absorbed by not only the impact limiters but also its external surface fins for removing decay heat.

TEST METHOD

0.3m and 9m drop tests 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 of absorbing impact energy by the fins in the horizotal drop test is relatively new and has not been fully clarified yet. Electric heaters were put into the cask to simulate the heat generation of real spent fuels. The strains and accelerations at various points in the cask body and inner structure resulting from the impact at the drop test were measured using strain gauges and accelerometers. Leak tests (vacume method) for the sealded parts were carried out before and

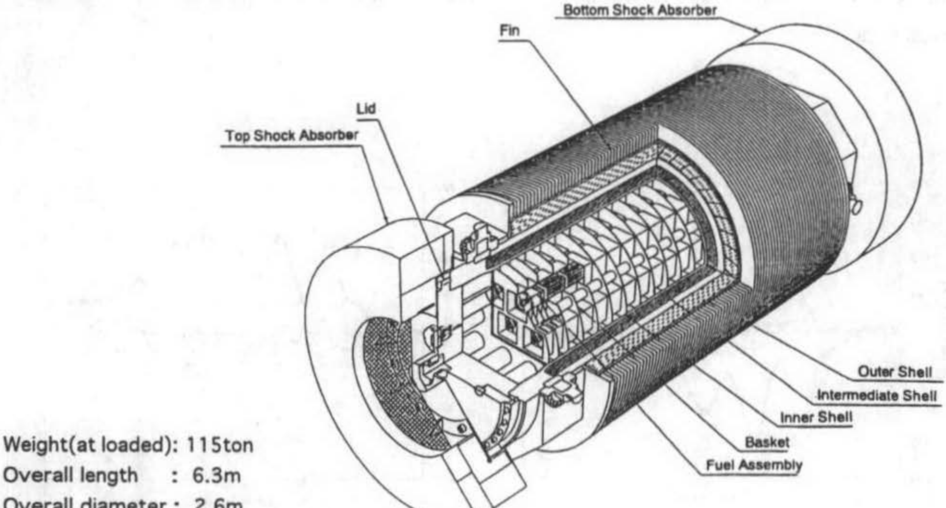

Fig.1 Outview of the Test Cask

after each drop test to evaluate the leak tightness.The drop tests were carried out at the Yokosuka laboratory of CRIEPI.

TEST RESULTS

The maximum acceleration and stress measured in the drop tests are summarized in Table 1. Examples of the time histories of strains measured in the 0.3m and 9m drop tests are shown in Fig.2 and Fig.3 respectively.

As seen from Fig. 2, the cask as a whole deformed like a beam supported at its both ends and free bending vibration with the frequency of about 120Hz was superposed on that. As shown in Table 1a), the maximum stresses yielded in the cask body at the 0.3m free drop are within the elastic range.

At 9m drop test, the impact limitters comes in contact with the targe at first. Shortly after , the heat transfer fins do. Then, impact force was applied to the cask body along the contact zone as a line load. The time histories measured at the 9m drop test show that the hoop strains are larger than the axial strains. This is because the cross section of the cask body was deformed into a hemisphere by applying an impact force in the radial direction. The maximum stress calculated by the measured strains at 9m drop test are within the allowable limit .

At drop test II, maximum stress occured at the vicinity of the contact point was 134MPa. This value was less than the allowable limit. The pin was deformed in its axis by about 38mm.

The measured leak rates are shown in Table 2. The leak rate did not change before and after each drop test at any part and are within the allowable limit stipulated in the IAEA regurltions. Therefore it can be concluded that the integrity of the cask was maintained under the regulatory drop test conditions.

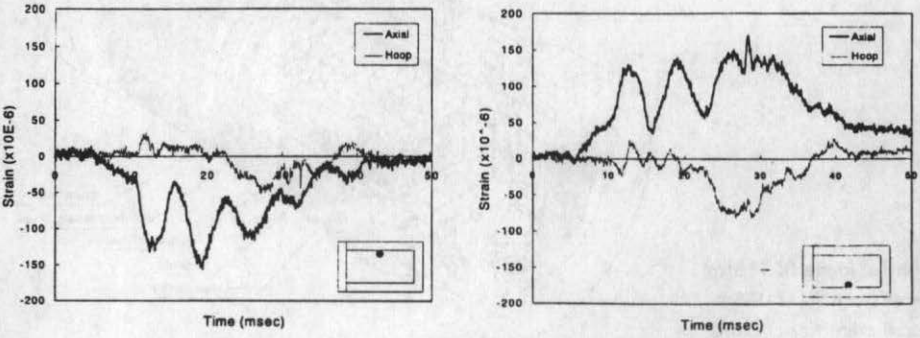

Fig. 2 Strain Histories Measured at the Free Drop Test

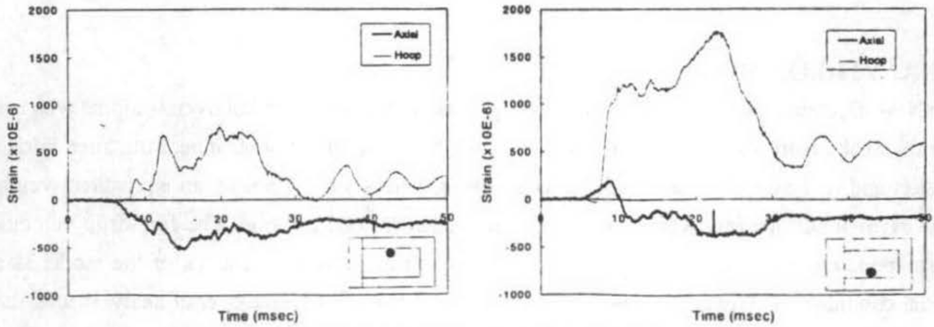

Fig. 3 Strain Histories Measured at the Drop Test I

Table 1 Test Results of the Drop Tests

a) Free Drop Test

Items	Section	Location	Parts	Direction	Max.Strain (x10^-6)	Intersectional strain (x10^-6)	Calculated Stress(MPa)	Allowable Limit
Body	Center	0°	Intermediate	Axial	-227	54	-44	Intermediate Shell:
			Shell	Hoop	67	-154	4	σy=230MPa
			Inner	Axial	-156	-0.236	-32	σu=422MPa
			Shell	Hoop	-51	-94	-16	(160℃)
		180°	Intermediate	Axial	268	-19	54	Inner Shell:
			Shell	Hoop	57	148	21	σy=150MPa
			Inner	Axial	136	-73	23	σu=413MPa
			Shell	Hoop	-81	132	-8	(170℃)
Basket	Center	0°	Basket	Axial	-119	–	-23	Grid : σy=228MPa
		180°	Grid	Axial	194	–	38	(180℃)

b) Drop Test I

Items	Section	Location	Parts	Direction	Max.Strain (x10^-6)	Intersectional strain (x10^-6)	Calculated Stress(MPa)	Allowable Limit
Body	Center	0°	Intermediate	Axial	-945	-910	-252	
			Shell	Hoop	-957	-937	-256	
			Inner	Axial	-519	351	-84	Intermediate Shell:
			Shell	Hoop	767	-398	132	σy=230MPa
		90°	Intermediate	Axial	423	1051	153	σu=422MPa
			Shell	Hoop	1057	421	245	(160℃)
			Inner	Axial	452	-743	47	Inner Shell:
			Shell	Hoop	-781	423	-133	σy=150MPa
		180°	Intermediate	Axial	......	......	–	σu=413MPa
			Shell	Hoop	......	......	–	(170℃)
			Inner	Axial	-389	919	-23	
			Shell	Hoop	1765	-377	278	
Basket	Center	0°	Basket	Axial	-664	–	-130	Grid : σy=228MPa
		180°	Grid	Axial	909	–	178	(180℃)

c) Drop Test II

Items	Section	Location	Parts	Direction	Max.Strain (x10^-6)	Intersectional strain (x10^-6)	Calculated Stress(MPa)	Allowable Limit
Body	Center	0°	Intermediate	Axial	-47	-34	-12	Intermediate Shell:
			Shell	Hoop	-71	-34	-17	σy=230MPa
			Inner	Axial	-16	6	-3	σu=422MPa
			Shell	Hoop	65	1	13	(160℃)
		180°	Intermediate	Axial	......	......	—	Inner Shell:
			Shell	Hoop	......	......	—	σy=150MPa
			Inner	Axial	192	534	72	σu=413MPa
			Shell	Hoop	621	117	134	(170℃)
Basket	Center	0°	Basket	Axial	-194	–	-38	Grid : σy=228MPa
		180°	Grid	Hoop	259	–	51	(180℃)

Remarks
1) Strain: + tention, - Compression
2) Stress is caluculated considering tri-axial condition (neglecting radial strain)

Table 2 Results of Helium Leak Test

Test	Parts	Leak Rate (Pa.m^3/s) Before	Leak Rate (Pa.m^3/s) After	Allowable Limit (Pa.m^3/s)
Free Drop Test	Seal	3.49E-05	5.05E-05	2.00×10E4*
	Vent	5.88E-06	6.14E-06	
	Drain	7.55E-06	7.88E-06	
Drop Test I	Seal	5.05E-05	5.04E-05	2.00×10E5**
	Vent	6.14E-06	6.13E-06	
	Drain	7.88E-06	7.87E-06	
Drop Test II	Seal	5.04E-05	5.85E-05	
	Vent	6.13E-06	5.66E-06	
	Drain	7.87E-06	7.81E-06	

*Corresponding to the leak rate calculated from the A1 value per hour
**Corresponding to the leak rate calculated from the A2 value per week

ANALYTICAL MODEL

DYNA-3D code was used to analyze the drop tests. A half-symmetrical overall model was used for the analysis to calculate the strains in the cask body. In this model, inner structures such as basket and fuel assembly are modeled as a homogeneous structure with an equivalent weight. The external surface fins were modeled by shell ellement one by one. The free-drop velocities corresponding to the drop height were input into each node of the elements of the model as an initial condition. The maximum acceleration obtained from the above overall analysis was then put into the basket model to calculate the strains in the basket. Figures 4 and 5 show the half-symmetrical overall model and the basket model, respectively. The mechanical properties of the materials used in the analysis are shown in Table 3.

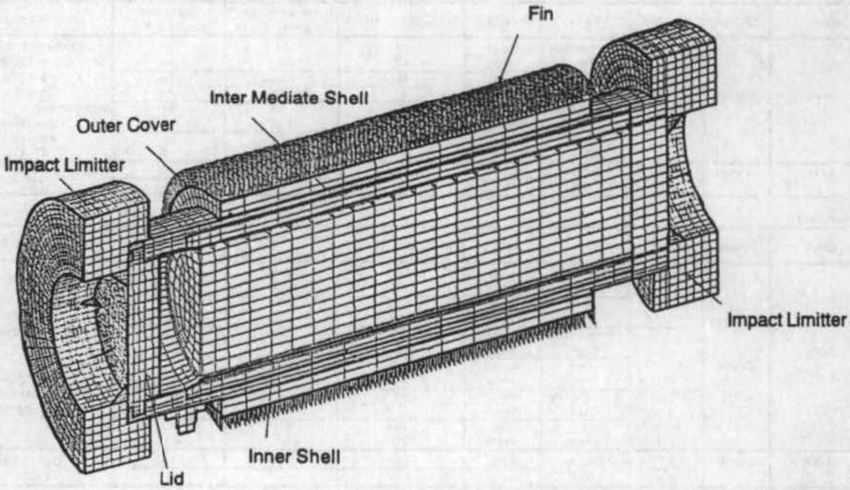

Fig. 4 Half-symmetrical Model for Overall Analysis

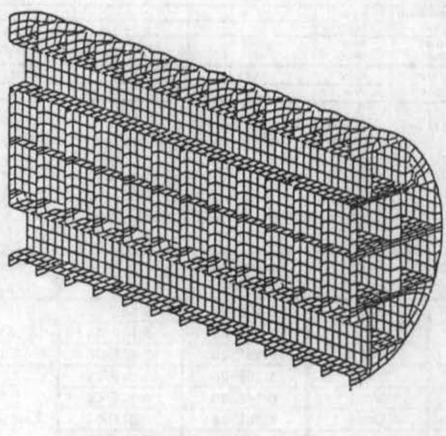

Fig. 5 Basket Model

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 test results. The analysis using Dyna-3D code can thus be used to evaluate the impact phenomenon of casks when a complicated structure is used as the shock absorber.

Table 3 Material Properties

Part	Young's Modulous N／mm2	Poisson's Ratio	Temperature ℃
Inner Shell	1.85E+05	0.28	170
Fin	1.92E+05	0.27	70
Lid	1.89E+05	0.27	120
Support Ring	1.85E+05	0.28	170
Trunnion	2.01E+05	0.3	70
Intermediate Shell	1.88E+05	0.3	160
Outer Shell	1.89E+05	0.27	120
Bolts	1.92E+05	0.3	120
Neutron Shielding	3.14E+03	0.3	R.T.
Gamma Shielding	9.00E+02	0.49	150
Basket Grid	1.85E+05	0.27	180
Impact Limiter	6.00E+02	0.09	R.T.
	6.00E+02	0.09	
	1.68E+03	0.15	

Table 4 Comparison Between the Test and Calculated Results

a) Free Drop Test

Items	Items	Section	Location	Parts	Direction	Caluculation	Test
Strain (x10^-6)	Body	Center	0°	Intmediate Shell	Axial	-291	-227
	Body	Center	180°	Intmediate Shell	Axial	319	268
	Basket	Center	180°	Basket Grid	Axial	267	194
Accelelation (g)	Body	Center	0°	———	Vertical	14	11
Deformation (mm)	Impact	——	Top	———	Vertical	14	15
	Limiter	——	Bottom	———	Vertical	17	15

b) Drop Test Ⅰ

Items	Items	Section	Location	Parts	Direction	Caluculation	Test
Strain (x10^-6)	Body	Center	0°	Inner Shell	Hoop	1280	767
	Body	Center	90°	Inner Shell	Hoop	-998	-781
	Body	Center	180°	Inner Shell	Hoop	1850	1765
	Basket	Center	180°	Basket Grid	Axial	983	909
Acceleration(g)	Body	Center	0°	———	Vertical	85	77
Deformation (mm)	Fin	——	180°	———	Vertical	85	99
Deformation (mm)	Impact	——	Top	———	Vertical	136	150
	Limiter	——	Bottom	———	Vertical	135	150

c) Drop Test Ⅱ

Items	Items	Section	Location	Parts	Direction	Caluculation	Test
Strains (x10^-6)	Body	Center	180°	Inner Shell	Hoop	648	621
	Basket	Center	180°	Basket Grid	Axial	341	259
Acceleration(g)	Body	Center	0°	———	Vertical	14	6
Deformation (mm)	Pin	——	——	———	Vertical	46	38

CONCLUSION

The integrity of the cask for shipping high burn-up spent fuels against the regulatory drop test was confirmed by the drop test. The applicability and accuracy of the DYNA-3D analysis was benchmarked by comparing with the test results.