DEMONSTRATION OF THE SAFETY OF SPENT FUEL TRANSPORT CASKS UNDER REGULATORY TESTS AND REALISTICALLY SEVERE ACCIDENT

Chihiro Ito, Hidetsugu Yamakawa, Toshiari Saegusa
Central Research Institute of Electric Power Industry
1646 Abiko, Abiko-shi, Chiba-ken, 270-1194, Japan 471/82-1181

ABSTRACT

The objective of this paper is to demonstrate that casks (NFT type) transporting high burn-up spent fuel not only meet the regulatory requirements, but also keep their integrity in an event of realistically severe accident.

A regulatory 9-m drop test using a full-scale model of NFT-14P cask had been carried out. On the other hand, a drop test of a full-scale model of NFT-32B cask was carried out simulating a realistic drop accident during unloading work at a harbor. The cask with skid was dropped from a height of 7.8-m onto a concrete floor. This would be the most realistically severe accident during transport of spent fuel in Japan. In both cases, it was ascertained that these two casks were found sound according to the results of tests and analyses on the stresses generated in these tests. In addition, it was recognized by measurements and analyses that the stresses generated under the regulatory drop test of NFT-14P cask gave larger values compared with those generated under the accidental drop.

A regulatory fire test (800 degrees in Celsius for 30 minutes) using a full-scale model of NFT-14P cask had been carried out after the 9-m drop test. On the other hand, an analysis was conducted for the NFT-14P cask subjected to a realistic fire accident due to a collision with a tank truck, which was selected as a realistically severe accident during the transport. It was ascertained that in both cases the cask was found sound according to the results of the test and analysis on the temperatures developed in the cask. It was also recognized that the maximum temperature of a sealed boundary at the cask lid reached a more stringent temperature under the regulatory fire test than that under the realistic fire accident.

It was ascertained that the high burn-up spent fuel cask NFT-14P was found sound under the regulatory drop and fire tests and realistically severe accident in Japan. Furthermore, it was recognized that the regulatory drop and fire test dominate realistically severe accidents in Japan.

INTRODUCTION

Demonstration tests on the safety of a transport cask (NFT-14P) transporting high burn-up spent fuel from nuclear power stations in Japan to the reprocessing plant in Rokkasho-mura have been carried out under the regulatory tests conditions to increase public understandings [1], [2]. It is further desirable to demonstrate the safety of the cask under realistically severe accidents during transport. Similarly, demonstration tests on the safety of spent fuel shipping casks under realistically severe accidents during transport have been carried out in USA [3], [4] and UK [5], etc.

PURPOSE

The purpose of this study is to demonstrate that the high burn-up spent fuel transport casks (NFT type) meet not only regulatory tests but also realistically severe accidents during transport. Furthermore, comparison is made for severity between the regulatory tests conditions and realistically severe accidents.

SPECIMES CASKS

A specimen cask used for the regulatory drop test and analysis was NFT-14P type cask. Another specimen cask used for realistically severe accidental drop test was NFT-32B type cask. The use of NFT-32B type cask was due to the weight limit of the drop test facility in CRIEPI. The NFT-14P type cask was analyzed for both the regulatory thermal test and a realistic fire accident. The NFT-14P type cask was chosen to represent the NFT type casks of the same group of a design and their major specifications are shown in Table 1.

Table 1 Major Specifications of the NFT Type Casks Used for Tests and Analyses [6], [7]

Cask Type	NFT•14P	NFT•32B
Type	Wet and Multi-Layered Cylinder with Lead	Wet and Monolithic Layer Cylinder
No. of Fuel Assemblies per Cask	14 PWR	32 BWR
Initial Enrichment Burn-up (Average) Cooling Time After Discharge	4.2 • 44 GWD/tU 21 months	3.7 • 46 GWD/tU 35 months
Decay Heat/Cask Cask Length Cask Diameter Cask Maximum Weight	54 kW 6.3 m 2.6 m 115 t	22 kW 6.4 m 2.4 m 106 t
Regulatory Drop Test (9m) Regulatory Drop Analysis (9m) Accidental Drop Test (7.8m) Accidental Drop Analysis•7.8m• Regulatory Furnace Thermal Test Regulatory Furnace Thermal Analysis Accidental Fire Analysis	* * - * * * *	- - * * - - -

* : Done, - : Not done

Figure 1, NFT-14P Type Cask

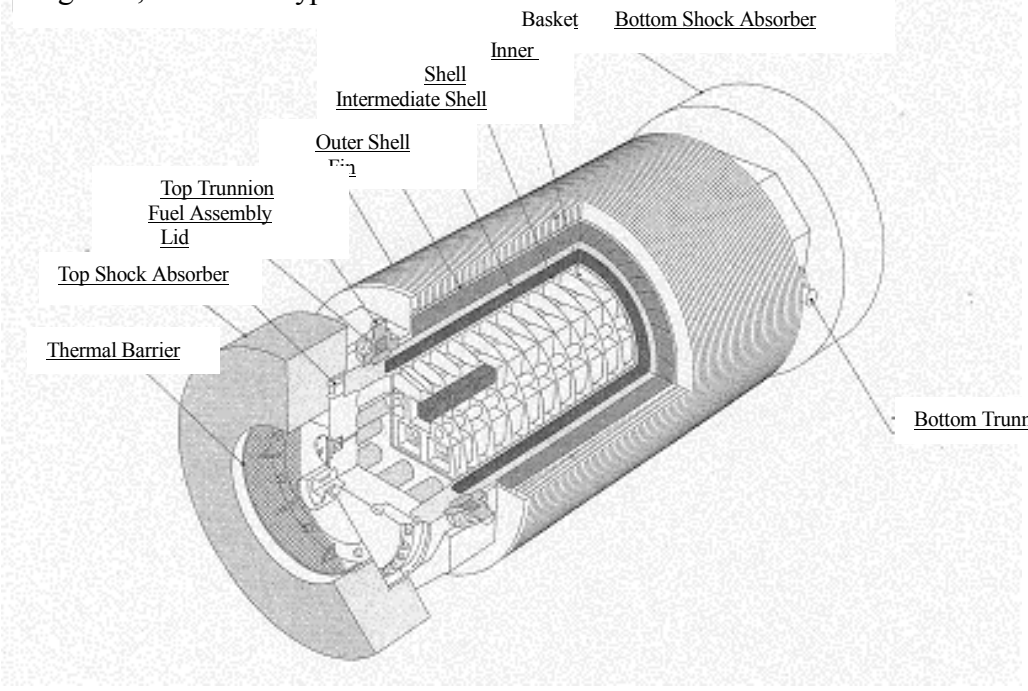
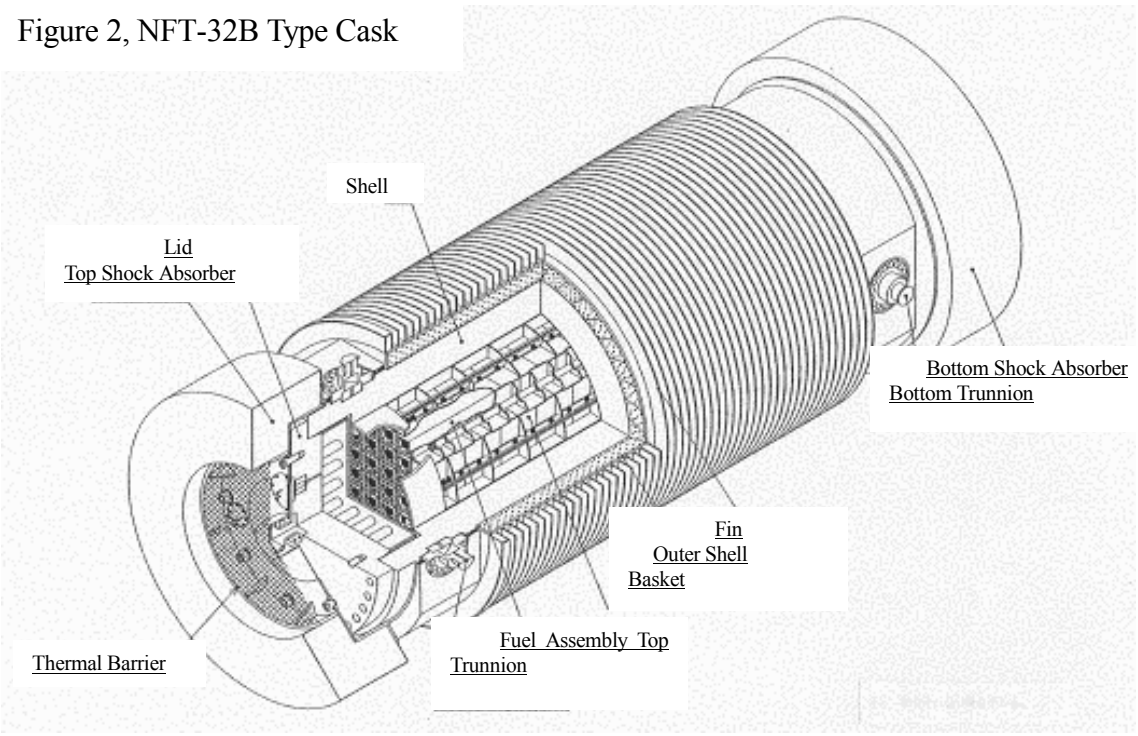


Figure 2, NFT-32B Type Cask



METHOD

Drop Accident

Regulatory Drop Test/Analysis

The methods of the regulatory 9 m drop test and the computer analysis by FEM (LS-DYNA3D) of the NFT-14P cask are as reported in the last PATRAM '98 [1].

Realistic Drop Accident Test/Analysis

In order to assume a realistic drop accident in this study, various drop/impact accident scenarios along the real transport route of high burn-up spent fuel from the power stations to the reprocessing plant at the Rokkasho-mura were investigated. The result is shown in Table 1. Of these scenarios, mechanical impact due to collision of transport vehicle is dominated by mechanical impact due to drop accidents during the cask loading onto a ship at port. This is because the running speed of the transport vehicle is low and the vehicle absorbs some of the mechanical impact due to the collision. Next, computer analyses using LS-DYNA3D for the drop accidents scenarios during the NFT-32B cask loading were carried out and the results were also shown in Table 2. Those scenarios are as shown in Figure 3:

a. Cask drop onto the deck of a ship
b. Cask drop onto the tank top of a ship hold
c. Cask drop onto the side of a ship
d. Cask drop onto a mooring pillar for a ship
e. Cask drop onto a loading wharf of a ship port.

Of these scenarios, the scenario "e. Cask drop onto a loading wharf of a ship port" was selected as the most severe accident. The drop height is 7.8m and the drop target is made of reinforced concrete.

Table 2 Various Scenarios of Drop/Impact Accident of Spent Fuel Shipping Cask and the Resultant Stress and Strain Generated in the Cask by Computer Analysis

Scenario		Height Impact Speed, etc.	Max. Stress (MPa)	Max. Plastic Strain	Remarks
Cask drop during loading at a ship port	a. Onto the deck of a ship	••	••	••	The impact energy is smaller than those for the scenarios b. and d.
	b. Onto the tank top of a ship hold	15 m	63	0	The trunnions are cut off. The transport frame and the tank top absorb the impact energy, partially.
	c. Onto the side of a ship	5.7 m	24	0	The side of the ship absorbs the impact energy, partially.
	d. Onto a mooring pillar for a ship	7.2 m	270	0.9 %	The trunnions are cut off. The transport frame, impact limiters and the mooring pillar absorb the impact energy, partially.
	e. Drop onto a loading wharf	7.8 m	290	1.4 %	The trunnions are cut off. The transport frame and impact limiters absorb the impact energy, partially.
Collision/ Overturn of vehicle	f. Collision with wall	25 km/h	••	••	The impact energies are smaller than those for the scenarios a. to e.
	g. Collision with vehicle	25 km/h	••	••	
	h. Overturn on a load shoulder	Angle of 30 degrees	••	••	

••Not calculated

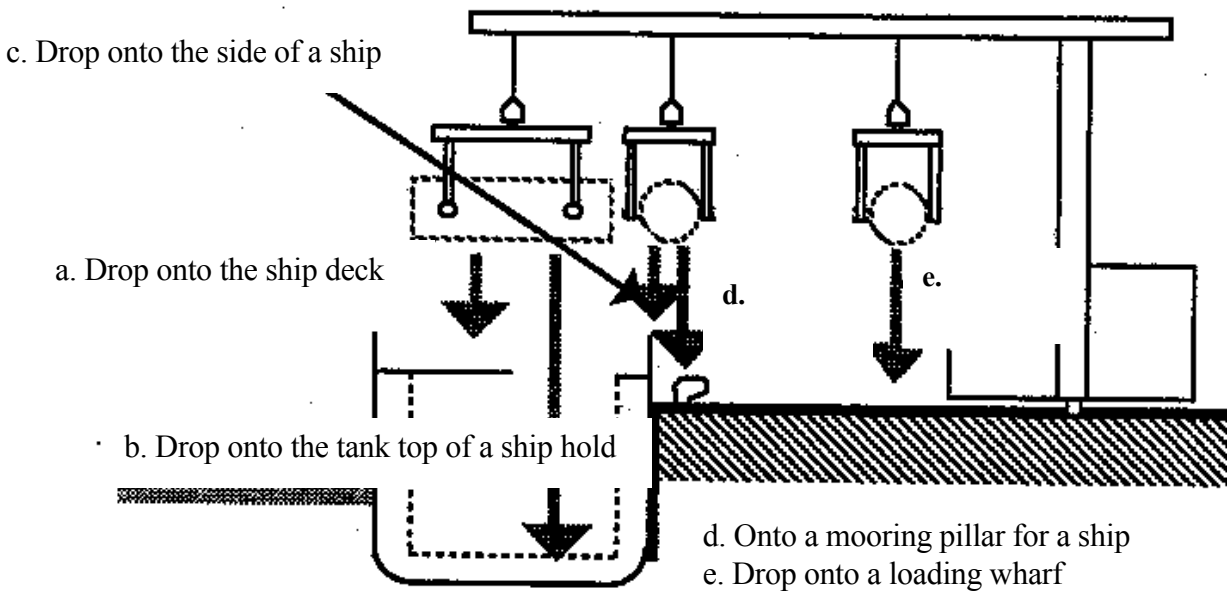


Figure 3, Options of Scenarios for Realistic Drop/Impact Accidents of Spent Fuel Shipping

A drop test simulating the accident scenario "e. Cask drop onto a loading wharf of a ship port" was carried out using the NFT-32B type cask with its transport frame. The test was simulated by the computer analysis using LS-DYNA3D and the analysis was verified by the test. Then, the verified analysis method was used to analyze an accidental drop of the NFT-14P type cask onto a loading wharf of a ship port. The result was compared with a result of the analysis of the regulatory drop (9-m) test of the NFT-14P type cask.

Fire Accident

Regulatory Thermal Test/Analysis

The methods of the thermal test and the computer analysis by FEM (ABAQUS) of the NFT-14P cask are as reported in the last PATRAM '98 [2].

Realistic Fire Accident Analysis

The most severe fire accident during land transport of spent fuel shipping cask in Japan was considered to be one with gasoline fire due to a collision of the cask trailer with a tank truck of gasoline, as shown in Table 3.

Table 3 Assumption of Realistic Fire Accident Condition during Land Transport of Spent Fuel

Item	Assumed Value	Remarks
Fuel Materials	Gasoline	-
Leakage Qty.	4 kl	Max. Qty. in a Partition of Tank Truck
Leakage Shape	Circle	-
Leakage Area	7 m in diameter	Width of 2 lanes of traffic roadway
Oil Thickness	10.4 cm in thickness	Calculated
Height of Fire	10.5 • (1.5 times the diameter)	From the past test result [8], [9]
Burning Speed	4 mm/min.	From the past test result [8], [9]
Fire Duration	26 min.	Calculated

The area of gasoline leakage was assumed to be 7 m in diameter so as to match with the width of 2 lanes of normal traffic roadway. The height of fire and burning speed of gasoline were assumed from the results of combustion test of gasoline in the literature [8], [9].

With these conditions of combustion, thermal conditions engulfing the real spent fuel shipping cask were assumed from the results of the fire test (JP-4 fuel pool fire for 122 min.) of a spent fuel shipping cask (68tonne, 3.96m in length, 1.5m in diameter) carried out by Sandia National Laboratory [10] and by a computer simulation using ABAQUS code carried out in this study. The emissibity of cask outer surface was assumed to be 0.8 from measurements and analysis considering the effect of soot covering the surface of a carbon steel plate by experiment of oil combustion.

The assumptions are summarized as follows:

- Emissibity of fire : 0.9
- Emissibity of the cask external surface : 0.8
- Temperature distribution of fire : Measurements of the fire test of a cask by Sandia national Laboratory (700 to 925 degree in Celsius after 26 min.)
- Heat Transfer Coefficient (average) : 10.5W/m^2K
- Distribution of Heat Transfer Coefficient : Heat Transfer Coefficient of Forced Convection Around Horizontal Cylinder [11], Uniform in the axial direction

RESULTS

Drop Accident

Regulatory Drop Test/Analysis

As the results of the regulatory 9 m drop test of the NFT-14P cask, the soundness of the cask was maintained, and the verification result of the computer analysis by LS-DYNA3D are as reported in the last PATRAM '98 [1].

Realistic Drop Accident Test/Analysis

A drop test of the NFT-32B cask specimen (the weight of the spent fuel was simulated, but the heat generation was not.) onto a loading wharf of a ship port was carried out as shown in Figure 4. As the result of the test, the trunions of the cask were cut off (Figure 5). The external surface of the cask body was partly deformed. There was neither deformation nor damage to the internal surface of the cask body and the fuel basket. The upper and lower mechanical impact limiters were deformed as much as 26/22 mm and 11/2 mm (the inner side/the outer side), respectively. The containment of the cask was maintained after the drop test, and the leak rate was maintained as required.

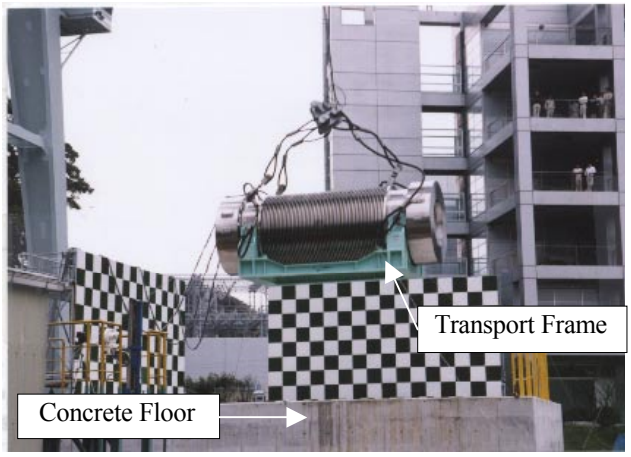


Figure 4, Test of NFT-32B Cask Specimen Simulating a Realistic Drop Accident at a Loading Wharf of a Ship Port (The cask on the transport frame is dropping from a height of 7.8 m onto a concrete floor.)

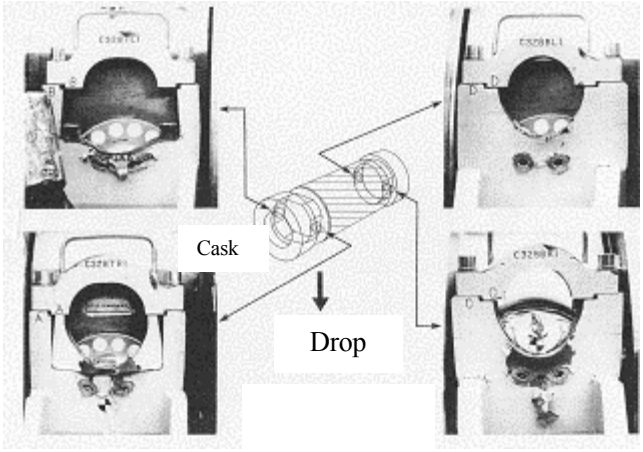


Figure 5, The trunnions Cut off as a Result of the Test Simulating a Realistic Drop Accident at a Loading Wharf of a Ship Port

Figure 6 shows the result of analysis of the status of deformation after the regulatory drop test and after the realistic drop accident at a loading wharf of a ship port. The cask deformation after the regulatory drop test is uniform and relatively small at the bottom part of the cask. On the other hand, the cask deformation as the result of the realistic drop accident is local (at points of impact between the transport frame and the cask) and the trunnions are cut off. Figure 7 shows the time history of stress generated during the drop. Figure 7 shows calculated results of time history of stress generated at the lower part of the cask body during the horizontal drop of NFT-14P type cask. The stress generated at the regulatory drop test is larger than that at the realistic drop accident. The maximum stresses are within the design limit and the soundness of the cask is maintained in both cases.

It is further found that the severity of the regulatory drop test dominates that of the realistic drop accident at the loading wharf at a ship port.

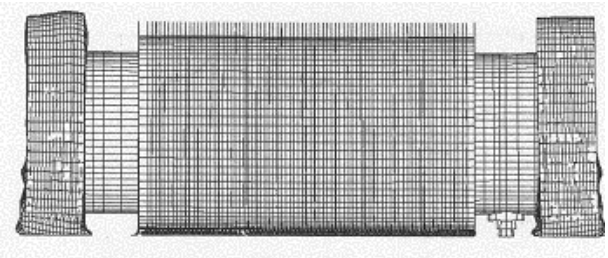


Figure 6-1, Result of Analysis of NFT-14P Cask Deformation Due to the Regulatory Drop Test

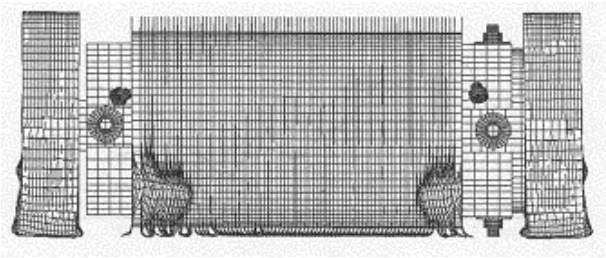


Figure 6-2, Result of Analysis of NFT-14P Cask Deformation Due to the Realistic Drop Accident at a Loading Wharf of a Ship Port

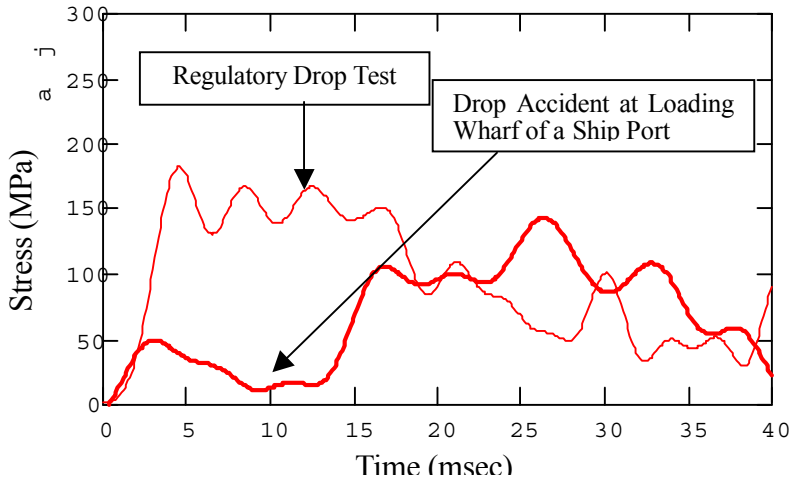


Figure 7, Calculated Results of Time History of Stress Generated at the Lower Part of the Cask Body during the Horizontal Drop of NFT-14P Type Cask

Fire Accident

Analyses of the regulatory thermal test and the realistic fire accident of the NFT-14P type cask were carried out. In the analyses, effect (deformation of surface fins, etc.) of the preceding drop test/accident was neglected. The effect of drop test/accident will decrease the thermal input to the cask body at the thermal test/fire accident. Neglecting the effect will be a conservative assumption.

Table 3 shows the results of analyses on the maximum temperature. Figure 8 shows the time history of temperature change at the cask component. In either case, the maximum temperatures were less than the design limit and the soundness of the cask will be maintained.

Table 3 Comparison of Calculated Results of the Maximum Temperature at the Major Positions of the NFT-14P Type Cask

Position	Calculation for Regulatory Furnace Thermal Test		Calculation for Realistic Fire Accident		Remarks
	Max Temp. (Degree in Celsius)	Time to reach	Max Temp.	Time to reach	
Cask Inner Surface (*1)	194 C	6.5 hr	190 C	6.4 hr	-
Lead in the Shell (*1)	188 C	4.7 hr	185 C	2.1 hr	Melting point : 327 C
O-ring of the Lid (*1)	199 C	0.8 hr	189 C	0.8 hr	Max Service Temp. : 300 C

(*1) : The upward direction in the horizontal attitude of the cask

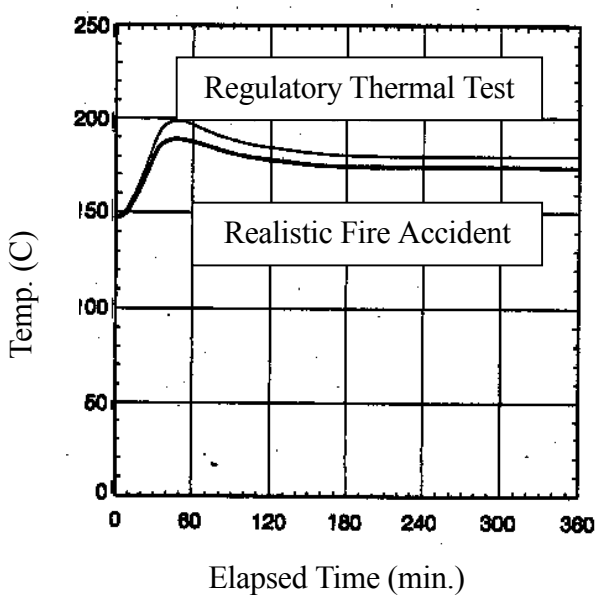


Figure 8, Calculated Result on Time History of Temperature Change at the O-ring of the Lid of NFT-14P Type Cask

The maximum temperatures at the major positions of the cask under the regulatory thermal test are larger than those under the realistic fire accident.
From these results, it was shown that the severity of the regulatory thermal test dominates that of the realistic fire accident.

CONCLUSION

It was ascertained that the high burn-up spent fuel cask NFT-14P was found sound under the regulatory drop and fire tests and realistically severe accident in Japan. Furthermore, it was recognized that the regulatory drop and fire test dominate realistically severe accidents in Japan.

ACKNOWLEDGEMENT

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