Demonstration Test for Transporting Vitrified High-Level Radioactive Wastes: Thermal 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 regulations were carried out in the Central Research Institute of Electric Power Industry(CRIEPI). This paper describes the thermal test. This work was conducted under a contract from the Science and Technology of Japan.

TEST CASK

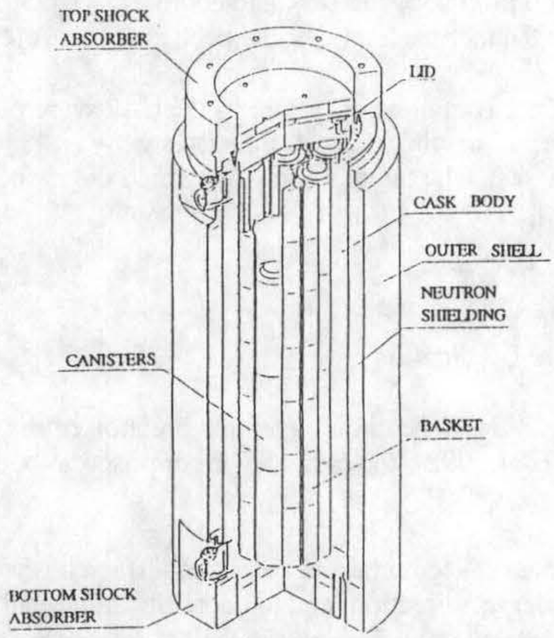
The test cask is designed as a Type B package and the design combines the specific structural features of both the COGEMA and the BNFL (planned) casks, which are used for shipping HLW from France and the U.K respectively. The specifications and external view of the cask used for the thermal test are shown in Figure 1. The thermal characteristics of the test cask are shown as follows:

Total Heat Generation

The package holds 28 canisters (4 x 7) of simulated vitrified wastes. Heat generation of each canister is about 1.46kW, so heat generation totaled to 41kW.

Cask Body (COGEMA type)

The specimen package consists of an outer shell (carbon steel), a neutron shielding layer and a body (carbon steel). Between the inner surface of the outer shell and the outer surface of the body, copper plates are welded, which serve as the main heat path. Welded points of the copper plates have heat resistance and are important in the safety evaluations.The structure also allows the outer shell and the copper plates to be partially deformed after the horizontal 9m drop test.



SPECIFICATIONS

Total Weigt : 115ton

Total Length : 6800mm

Diameter of Cask : 2400mm (including outer Cask)

Thickness of Cask Body : 254mm

Total Number of Canisters : 28

Quantity of Heat : 1.46 kW/canister

Figure 1 Concept and specifications of demonstration test cask

Basket (BNFL type)

The specimen package carries 21 vitrified residue containers in a support structure (basket) made up of 30 cast aluminum segments secured by a bolting system to the inner surface of the package body. Therefore, the heat resistance between the outer surface of the basket fixed on the inner surface of the body and the inner surface of the body is important for the safety evaluation, especially because it varies along the circumferential direction due to the impact force of the drop test. The heat resistance between the central canisters and the basket segments on the central side also important due to the partial contact.

Simulated Contents

28 simulated canisters of vitrified wastes were utilized in this test: 10 canisters possessed the same components and conductivities as COGEMA type vitrified wastes,and the other 18 consisted of alumina-cement which possessed the same quantity of generating heat and weight.

TEST METHOD

The cask containing the simulated canisters heated at a fixed output (decay heat : 41kW) had been horizontally. After the temperature of the cask reached a steady state, it had been promptly carried into an 800 ℃ furnace and held for 30 minutes, in accordance with the IAEA transport regulations. Moreover the cask had been placed at the same ambient temperature until the steady state was reached. The temperature of the simulated vitrified wastes, the baskets, the cask body, and the the seal part (O ring) etc. had been measured, and the thermal integrity was confirmed according to the maximum temperature of the cask. Temperature data (approximately 240 points for the cask and approximately 50 points for the ambient) which was utilized for the thermal analysis had been also measured.

The tests to confirm the integrity of the containment system of the cask were performed before and after the thermal test. Before the thermal test, this package was subjected to the 9m drop test and the 1m penetration test. The thermal test was carried out at the Yokosuka laboratory of CRIEPI.

TEST RESULTS

Characteristics of Initial Temperature Distribution

According to the temperature distribution in the circumferential direction of the cask body before the thermal test (Yamakawa et al.1992), the cask can be supposed to be in the state as follows:

- The heat resistance between the basket segments and the inner surface of the cask body tended to increase at the 30 and 90 degree direction, and to decrease at the 150 degree direction. The impact force in the horizontal 9m drop test caused to release the part of the bolts attached between the inner surface of the cask body and the basket segments.
- Therefore, the temperature of the cask body was the lowest at the 0 degree direction and the highest at approximately 180 degree direction as shown in Figure 2.
- The surface temperature of the cask body at the bottom part (from 150 to 180 degree direction) was 20℃ lower than that at 90 degree direction. The inner fins at these part were supposed to be deformed and damaged by the impact force in the horizontal 9m drop test.

Neutron Shielding during the Thermal Test

The thermal behavior of the neutron shielding during the thermal test was observed as follows:

- The combustible gas was spouted from the fusible plugs of the cask at 5 minutes after the cask carried into the test furnace and it combusted outside of the cask body.
- The combustion of the spouted gas was continued for about 40 minutes after the thermal test (800℃,30 minutes) was finished.

Temperature of the Furnace and the Cask Surroundings

The temperature in the furnace at the thermal test was shown in Figure 3. It reached 800℃ in 5 minutes after the test cask was carried into it. The temperature at the control point in the furnace had been held constantly in 800℃ for about 30 minutes, so the condition prescribed in the transport regulations for radioactive materials was satisfied. And the temperature surroundings of the cask was the highest at 180 degree direction shown in Figure 3. This suggested that the initial temperature of the neutron shielding was the highest in this direction and therefore a lot of the combustible gas was spouted from this portion.

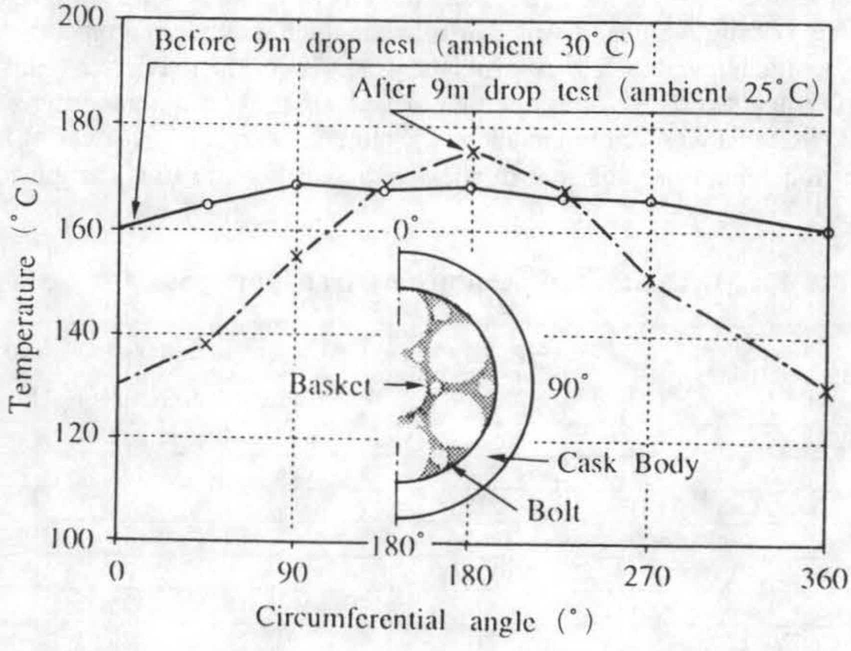


Figure 2 Distribution of temperature(inner surface of cask body)

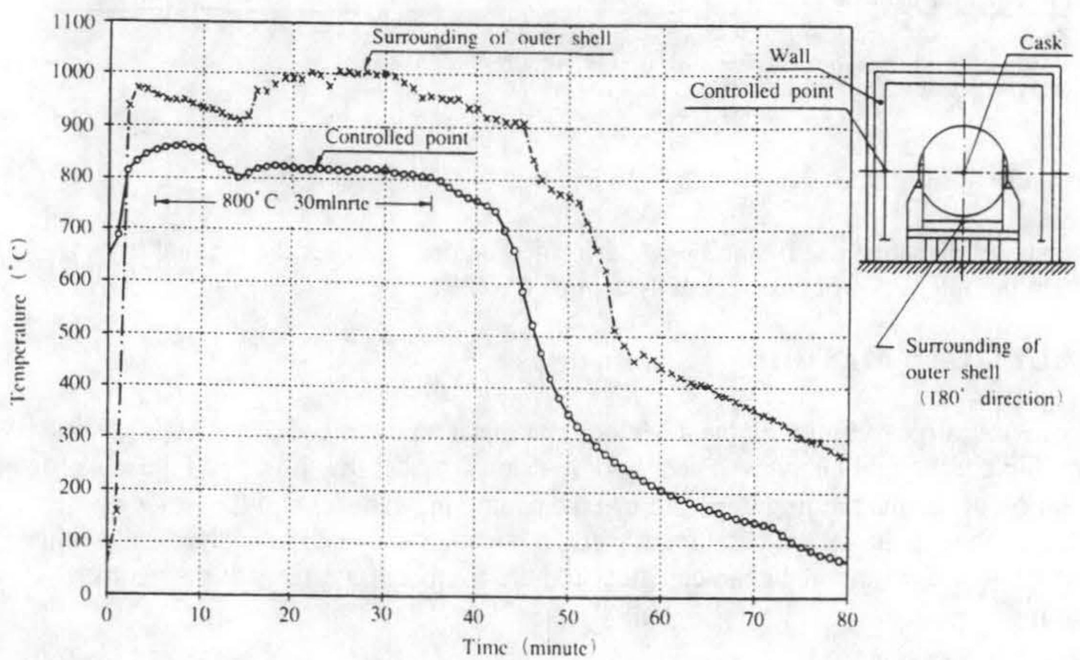


Figure 3 History of ambient temperature in the furnace

Maximum Temperature at the Representative Parts

The maximum temperatures (including the time reaching to the maximum and the increment from the initial temperature) at the representative parts of the cask were shown in Table 1 with the regulated design values. It was confirmed that the maximum temperatures of the cask were below the allowable values sufficiently. Moreover the maximum temperature of the seal part (O ring) which is very important to evaluate the thermal integrity is 178℃. It was confirmed that this was below the allowable temperature (300℃ for O ring) under the accident condition. Therefore,this type of package has sufficient safety margin for the fire accident.

Table 1 Maximum temperature of transport cask for test

Measured Elements	Maximum Temperature (℃)	Arrival time*	Increment of Temperature	Allowable Value **
Outer Shell	986	32	894	
Silicon Rubber	365	96	141	
Outer Surface of Cask Body	213	66	72	
Inner Surface of Cask Body	217	1104	42	
O-Ring	178	1239	30	300***
Inner Surface of Basket Segment	301	1104	30	
Surface of Canister	341	1294	20	
Center of Canister	406	2314	16	
Surface of Top Shock Absorber	994	6	970	
Surface of Trunnion	554	45	472	
Ambient of Furnace	1004	24	980	

* Elapsed time after the thermal test started.
** Allowable values here are valid in the accident condition
*** 300℃ is allowable in short range usage.

Characteristics of the Sealing of the Cask

The tests by pressure rise method was performed before and after the thermal test to confirm the integrity of containment system of the cask

ANALYTICAL METHOD

The general purpose Finite Element Method nonlinear analysis code "ABAQUS" was utilized in the thermal analysis. The two-dimensional model (as shown in Figure 4) for evaluation of the maximum temperature at the containing canister and the axis-symmetric model for the maximum temperature at the seal portion were used to analyze and evaluate the aforementioned thermal characteristics and the combustion effects of the neutron shielding.

For outer boundary conditions, the heat balance between the cask and the atmosphere was assumed to be natural convection and heat radiation, and the ambient emissivity was assumed to be 0.9 during the thermal test (in the test furnace) and 1.0 before and after the test according to the IAEA transport regulations.

The effect of the local temperature rising in the test furnace was considered by using the measured temperatures around the cask body. For inner boundary conditions in the thermal analysis of this transport cask, the heat conductivity of the inner portion was considered. The radiations, the conductivity of the backfill gas(air), and the thermal resistance due to contact between the outer surface of the basket and inner surface of the body were also taken into account.

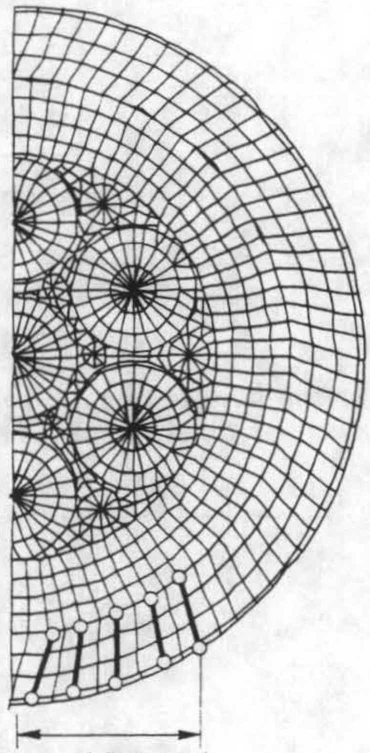


Figure 4 Finite element mesh(for 2-demensional model)

ANALYTICAL RESULTS

The history of the temperatures at the representative portion of the cask was shown in the Figure 5 and Figure 6. From these figures it has been concluded as follows:

- The thermal fins at approximately 180 degree directions are supposed to be damaged from results of both the analysis and the thermal test.
- Consideration the damage of the internal fins near 180 degree directions, (which means the decrease of the heat paths efficiency) and the release of attached bolts for the baskets, the fairly good agreement between the analysis and the test were obtained. The analysis results were shown to be slightly conservative.
- Therefore by using these analysis model, the thermal integrity of the transport cask including inner neutron shielding can be evaluated sufficiently in the fire accident.

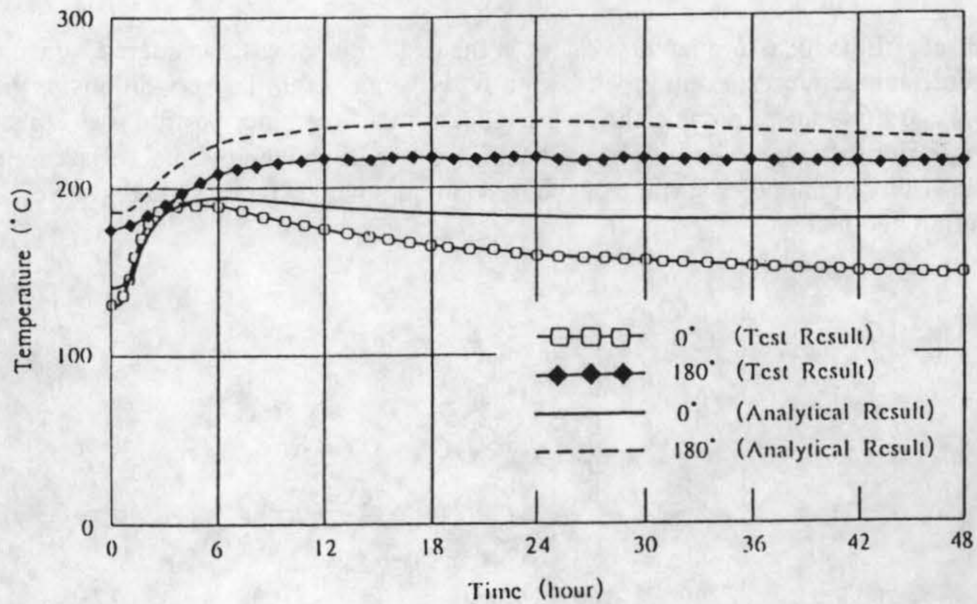


Figure 5 Comparison between analytical result and test result (temperature hisory at the inner surface of cask)

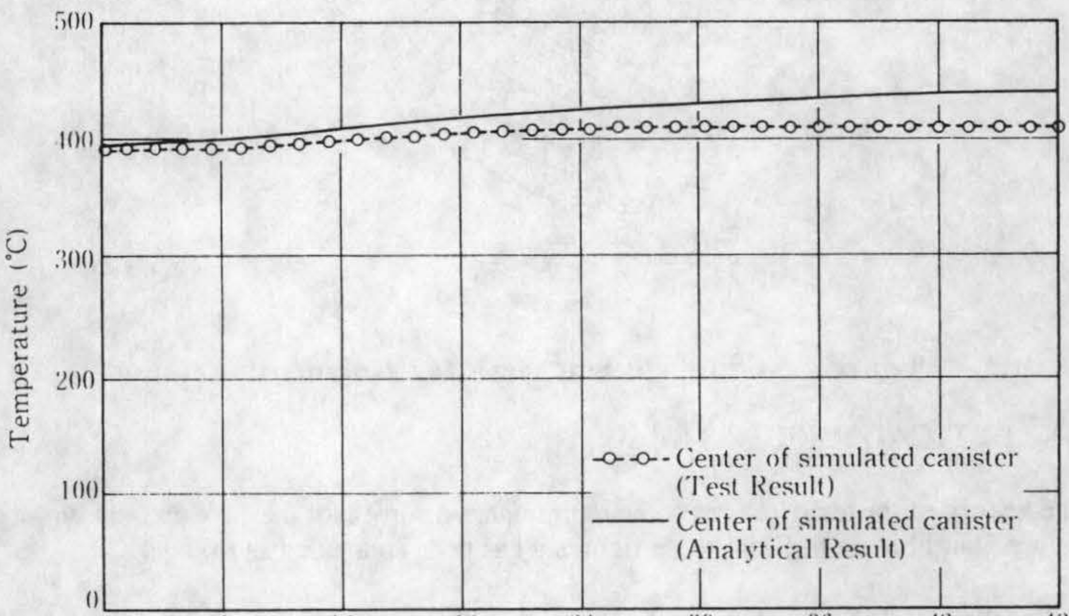


Figure 6 Comparison between analytical result and test result (temperature history at the center of simulated canister)

CONCLUSION

It was observed that both the maximum temperature during and after the thermal test (800 ℃, 30 minutes) are sufficiently below the regulated design values. And fairly good agreements between the analysis and the thermal test were obtained, and the methodology for the thermal analysis can be established, as shown in Figure 5 and Figure 6.

REFERENCE

Yamakawa, H., Gomi, Y., Ozaki, S., Kato, O. and Tamaki, H. ,"Thermal Test and Analysis for Transporting Vitrified High-Level Radioactive Wastes," , proc. of PATRAM '92 (1992).