Thermal Test and Analysis for Transporting Vitrified High-Level Radioactive Wastes

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INTRODUCTION

The vitrified high-level radioactive waste generated from the first-extraction process will be returned from the U.K.and France to Japan according to the contracts with BNFL and COGEMA for reprocessing spent fuels.
The simulated canisters of vitrified waste and shipping casks for them were designed and fabricated and subjected to the tests under the normal and accident conditions prescribed in the Japanese domestic transport regulations for radioactive materials to confirm that the technical standards are satisfied and to ensure safe transport of these vitrified wastes.

The thermal tests of the cask (left unattended at an ambient temperature of 38℃ for a period of one week) are reported in this paper.
This study was executed in 1991 as a part of the safety demonstration tests for transport casks of radioactive wastes under the sponsorship of the Science and Technology Agency.

CHARACTERISTICS OF THE TEST CASKS

A bird's eye view of the test cask is shown in Figure 1. This transport cask consists of baskets made of aluminum alloy to hold the canisters of vitrified wastes, an outer shell and a cask body made of carbon steel, and silicone rubber as a neutron shield.
Instead of the real canisters of vitrified high-level radioactive wastes, 10 canisters of simulated vitrified wastes without radionuclides and 18 canisters of alumina-cement were housed in the cavity as contents.

ENVIRONMENT THERMAL TEST

Sumary of the test

This test is executed to assure the radiation performance of a transport cask under the normal condition of being "left unattended at an ambient temperature of 38℃ for a period of one week" prescribed in IAEA regulations and the Japanese domestic transport regulations for a BM type package. The tests are performed before and after a side free drop test from a 30 cm height, and both results are compared. This test is performed in consideration of the damage of the basket segments caused by the free drop test. Moreover, a containment test is also executed to assure the safety of the seal of the cask.

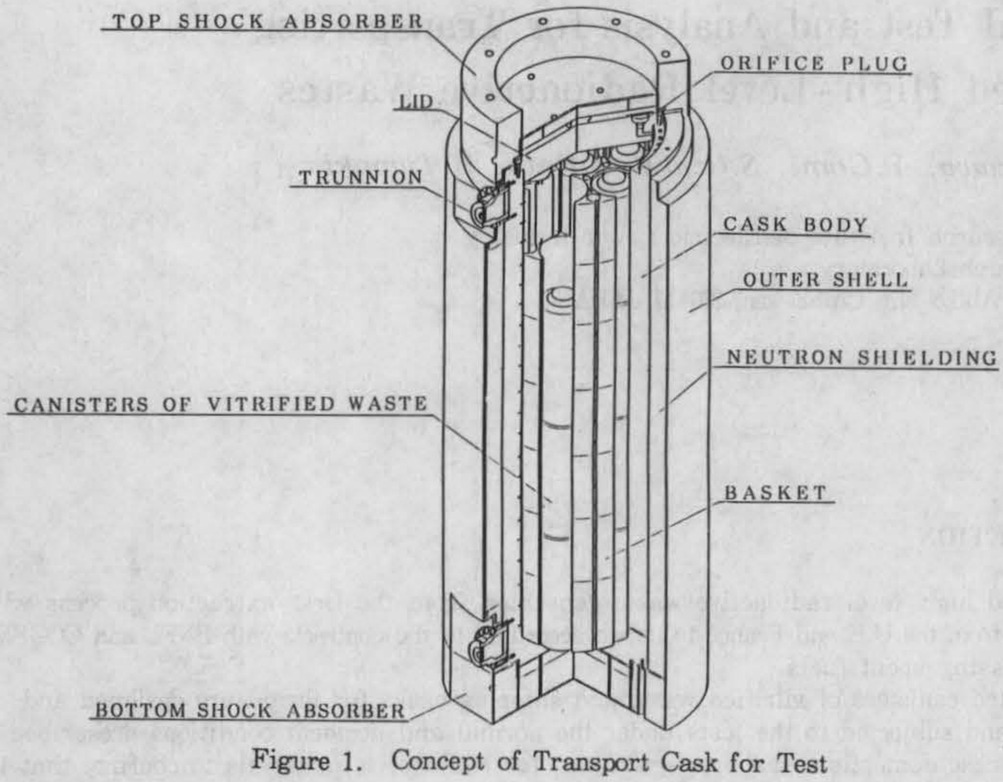

Figure 1. Concept of Transport Cask for Test

Test conditions

The test conditions are as follows

(1) Environment temperature
The test cask was left unattended in the thermal test equipment at an ambient temperature of 38 ℃.

(2) Simulation of the decay heat
In this test generating heaters were utilized to supply the quantity of heat as much as those of the 28 canisters of the vitrified wastes (total 41 kW). Because the heater wires were presumed to be cut due to the impact force during the free drop test, at least 7 pieces of the heaters were axially embedded in each canister of the vitrified wastes. For this reason, the total heat flux at the center cross section of the cask was increased at least 10 % according to the extra heat generation from the heater wires.

(3) 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.

(4) Duration of the test
About 10 days were required to raise the cask temperature and the cask was kept in a steady state for at least 7 days before and after the side free drop test from a 30 cm height.

Measured subjects

The measured subjects in this test were as follows

(1) Temperature: cask body, baskets, canister of the vitrified waste, ambient in the test hood.

(2) Generating heat: heater in the vitrified wastes

(3) Wind speed: neighboring the outer shell and the thermal test equipment

Results of the test

(1) The outline of the thermal test
The temperature history of the cask after the side drop test from a 30 cm height is shown in Figure 2. It was shown that the steady state was achieved about 10 days after the start of raising the temperature and a test condition with an ambient temperature was kept at 38℃.

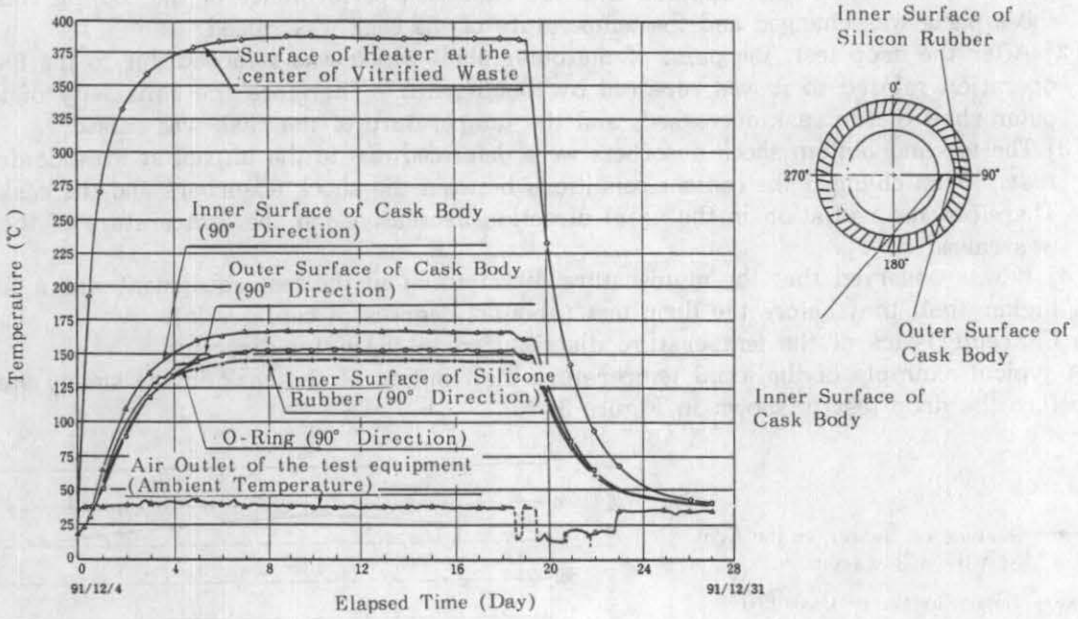

Figure 2. History of Temperature at each part of Transport Cask (After Side Drop Test from 30 cm Height)

(2) Maximum temperature at each part of the cask
The maximum temperature at each part of the cask in the steady state before and after the side drop test from a 30 cm height is shown in Table 1. From this table the following is shown.

Table 1. Result of Thermal Test for High-Level Vitrified Transport Cask (Temperature:℃)

Measured Elements	Maximum Temperature		
	Before Drop Test	After Drop Test	Allowable Value
Outer Shell	136	141	
Inner Surface of Silicone Rubber	150	155	200
Outer Surface of Cask Body	158	163	
Inner Surface of Cask Body	169	174	
O-Ring	162	166	200
Inner Surface of Basket Segment	233	239	
Surface of Canister	306	312	
Center of Canister	388	390	500
Surface of Top Shock Absorber	57	59	85
Surface of Trunnion	82	85	85
Protection Wire Net	59	57	85

[1] The temperature at each part of the cask was lower than the allowable values before and after the drop test.

[2] The temperature at each part of the cask after the drop test was about 5 degrees higher than those before the drop test (including the contents).

Moreover the following are supposed as the causes of the forementioned second result.

[1] The under part of the transport cask was deformed due to the impact at the side drop test. Therefore it was supposed that the radiation performance of the cooling fins at those parts was changed and the temperature of the cask was raised.

[2] After the drop test, the paint of the outer shell which was removed due to the handling operation related to it was repaired by touch paint. Therefore the emissivity of the outer shell of the cask decreased, and the temperature of the cask was raised.

[3] The top and bottom shock absorbers were deformed due to the impact at the side drop test. This changed the contact conditions between the shock absorbers and the cask body. Therefore the radiation in the axial direction decreased and the temperature of the cask was raised.

[4] It was observed that the temperature distribution in the test equipment was a little higher than that before the drop test (about 2 degrees of centigrade).

(3) Characteristics of the temperature distribution in the axial direction

A typical example of the axial temperature distribution of the cask in the steady state before the drop test is shown in Figure 3.

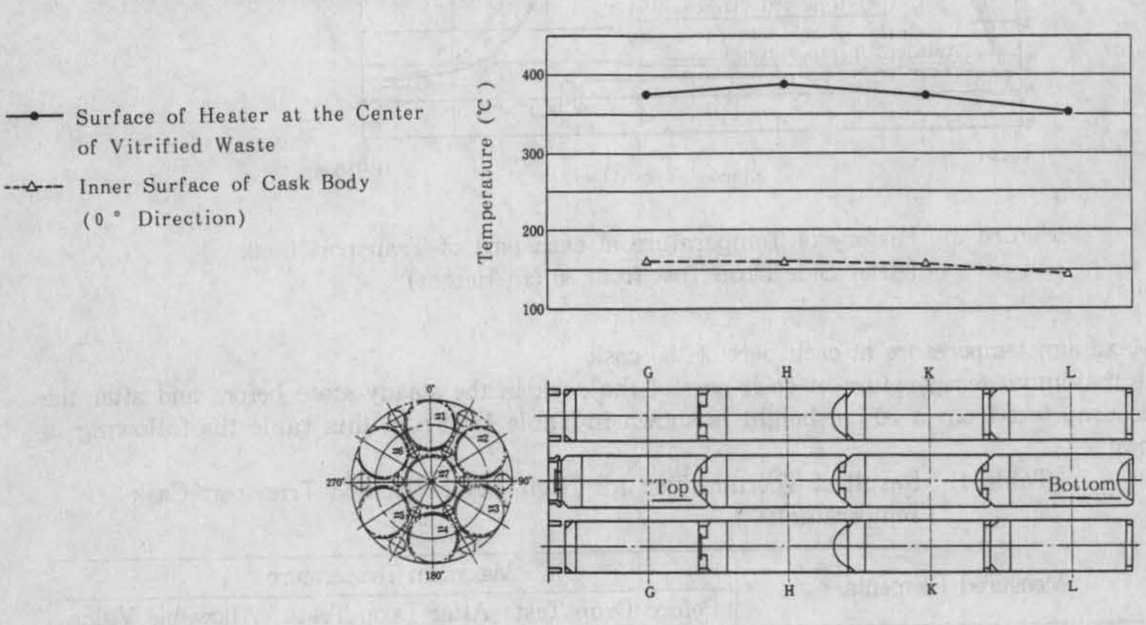

Figure 3. Temperature Distribution in Axial Direction of Transport Cask (Before Side Drop Test from 30 cm Height)

In this figure temperature at the lid was observed to be higher than that at the bottom. The following are supposed as the causes of those results.

[1] According to the heat radiation from the heater wire embedded in the vitrified waste, the averaged generating heat increased at the top portion of the cask.

[2] According to the loss of the cross section caused by the attachments of the measuring equipments, the heat capacity of the upper portion of the cask decreased.

[3] The terminal box was set in the portion stated in the forementioned subject [2]. The surface of the electronic wires in it was covered with cloth to keep the electronic isolations. Therefore the neighbor of the terminal box was supposed to be almost insulated, and the heat radiation from the upper portion of the cask was supposed to

decrease. The temperatures at the lid portion and the inner surface of the cask body of this transport cask compared with those of other 50 ton and 100 ton casks are shown in Table 2. It was shown that the test conditions of this test were severe for this transport cask.

Table 2. Comparison of Maximum Temperature for Various Casks
(Before Side Drop Test From 30 cm Height: ℃)

Cask Type	Backfill	Measured Elements	
		O-Ring	Inner Surface of Cask Body
Vitrified Wastes Cask	Air	162	169
100 ton Dry-type Cask	Helium	106	148
	Nitrogen	113	159
100 ton Wet-type	Water	139	148

(4) Thermal gap in the baskets

The structure of baskets contained in this transport cask is shown in Figure 4. Separate type basket segments (made of aluminium alloy) are bolt fixed by clamp bars to the locating keys at the inner wall. Therefore the heat resistance exists in this portion. But it is difficult to specify the magnitude of the heat resistance by using conventional methods because of the structural complexity. Therefore the reference of the experimental results is indispensable to establish the thermal analysis model.

Figure 5 shows the steady state temperature distribution of the inner surface and the basket in the circumferential direction before and after the side drop test from 30 cm height. It was shown that the thermal gap before and after the test was changed little and the difference of the temperature between the inner surface and the baskets was about 23℃ in both cases.

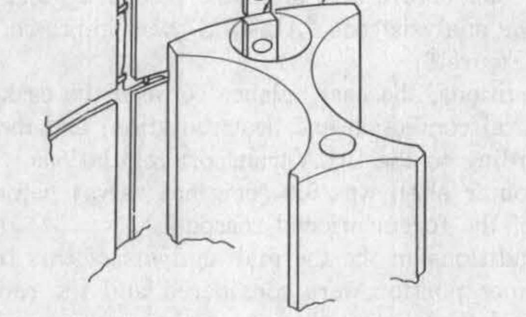

Figure 4. Illustration of Basket

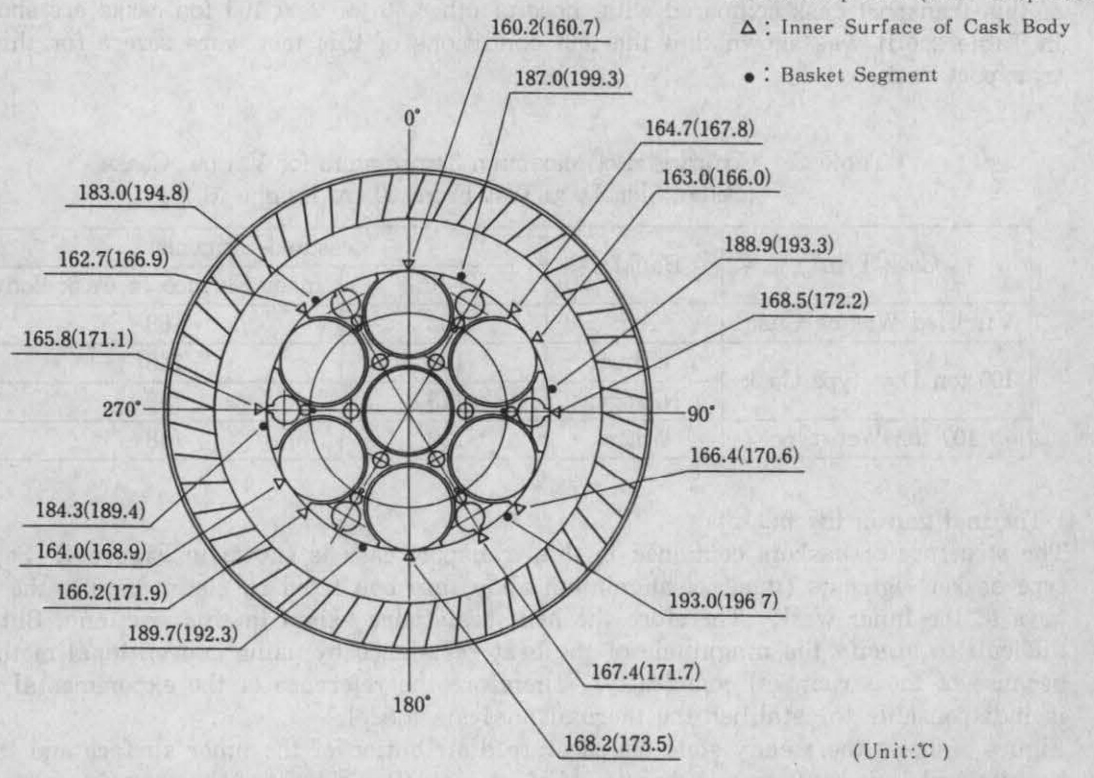

Figure 5. Thermal Gap Between Basket and Inner Surface of Cask Body

(5) Existence of the damage of the vitrified wastes and the baskets
Since the temperature of the vitrified waste and the baskets changed little before and after the side drop test from 30 cm height, it is supposed that no damage happened to the contents of the cask by the impact force at the test.

THERMAL ANALYSIS

Method of analysis

The thermal analysis was executed by using a 2-dimensional slice model to verify the steady state of the transport cask before and after the free drop test. The general purpose Finite Element Method nonlinear analysis code "ABAQUS" was improved and utilized in this analysis. The model is shown in Figure 6.
For outer boundary conditions, the heat balance between the cask and the atmosphere (38℃) was assumed to be natural convection and heat radiation, and the ambient emissivity was assumed to be 1.0 according to the IAEA transport regulations.
The emissivity of the outer shell was 0.9 (original valve) before the drop test and 0.85 after the drop test because of the forementioned reasons.
For inner boundary conditions in the thermal analysis of this transport cask, the heat conductivities of the inner portion were considered and the radiations, the conductivity of the backfill gas(air), and the contact thermal resistance were also taken into account when necessary. Moreover, temperature dependencies on the thermal properties (heat conductivity, etc.) of materials were considered in this analysis.

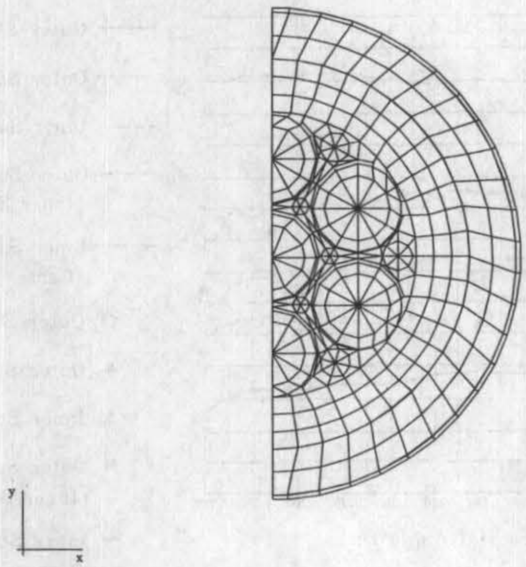

Figure 6. Finite Element Mesh
(for 2-Dimensional Heat Transfer Analysis Model)

Results of analysis

The comparisons between the test and analysis before and after the free drop test are shown in Figure 7 and Figure 8. The good agreement is observable in the cask temperature distributions. Therefore, by using this established thermal analysis model, the temperature distribution of the cask, which contains the real high level vitrified wastes will be calculated, and the thermal safety margin of this transport cask will be discussed.

CONCLUSION

As a part of the safety demonstration tests for transport casks of high level radioactive vitrified wastes, the thermal tests of the cask (left unattended at an ambient tempereture of 38℃ for a period of one week) were executed before and after the side free drop test (from height of 30 cm). This condition was set according to the prospect of the damage of contents (baskets, etc.) by the impact force at the drop test. It was shown that the cask temperatures at the representative parts, such as the vitrified wastes, the containment system, and the protection wire net, were lower than allowable values. From the result of measured temperatures it was considered that no damages and no large deformations could happen to the contents in this drop test. Thermal analysis was also done to establish the analysis model.

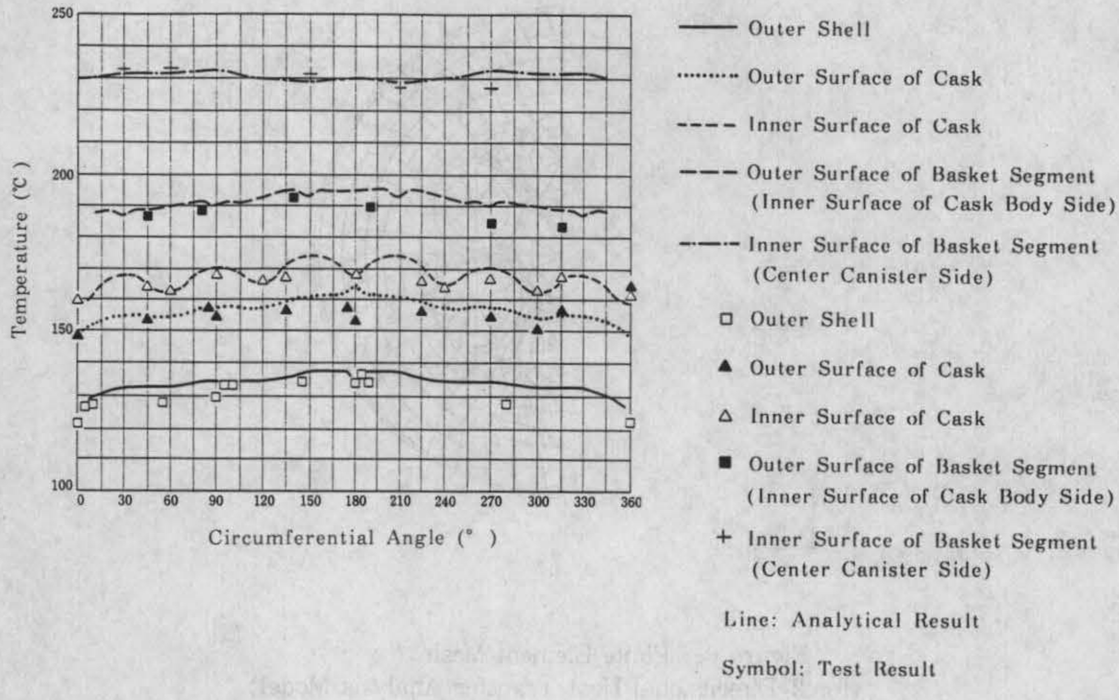

Figure 7. Comparison between Analytical Result and Test Result (before Side Drop Test from 30 cm Height)

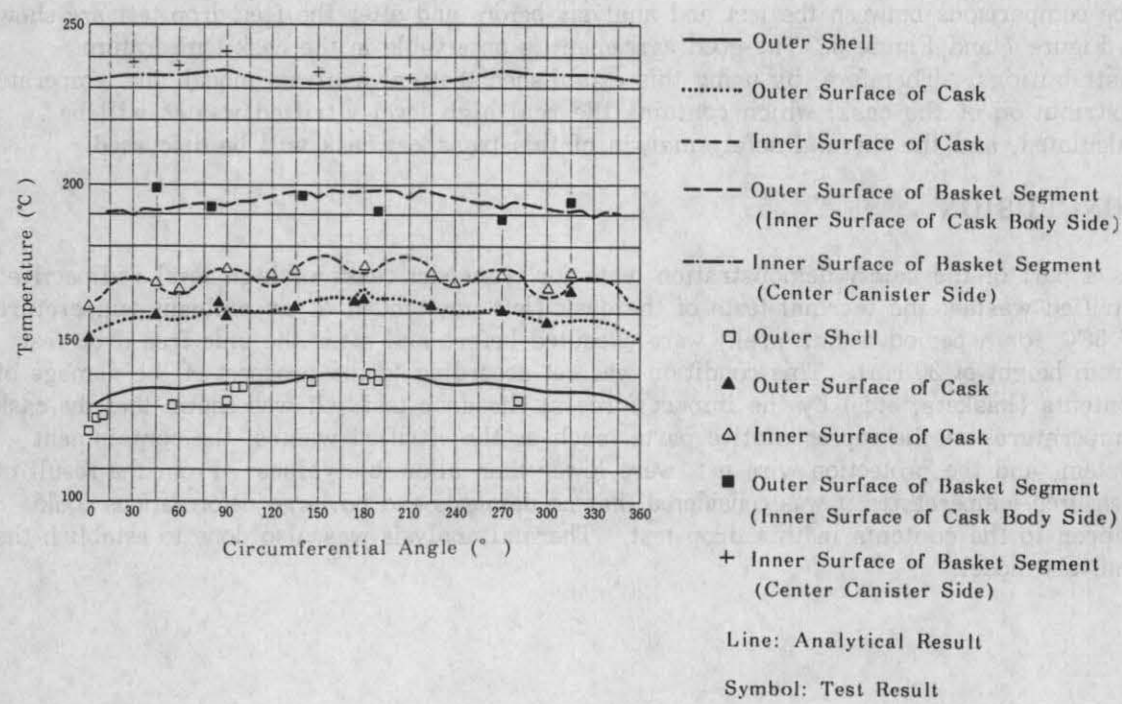

Figure 8. Comparison between Analytical Result and Test Result (after Side Drop Test from 30 cm Height)