THERMAL TESTS OF A TRANSPORT/STORAGE CASK IN BURIED CONDITIONS

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INTRODUCTION

Thermal tests for a hypothetical accident which simulated accidents caused by building collapse in case of an earthquake were conducted using a full-scale dry type transport and storage cask (total heat load : 23kW). The objectives of these tests were to clarify the heat transfer features of the buried cask under such accidents and the time limit for maintaining the thermal integrity of the cask. Moreover, thermal analyses of the test cask under the buried conditions were carried out on basis of experimental results to establish methodology for the thermal analysis.

CHARACTERISTICS OF TEST CASK

CASK BODY

The test cask is a MSF-IV type cask configured to hold 21 PWR spent fuel assemblies after 5 years of cooling (total heat generation rate 23 kW). The bird's eye view of the cask is shown in Fig. 1. The body of this cask is of three-layer construction as SUS-Lead-SUS. And there is a layer of polyester resin as neutron shielding and cooling fins made of copper welded between the outer shell and the cask body. Moreover, the lid has a double structure to maintain the efficiency of the containment system over long-term storage.

CONTENTS

To simulate the decay heat of 21 spent fuel assemblies after 5 years of cooling, one simulated spent fuel assembly with an equivalent shape and generating heat was housed in the center of the basket. 20 simulated objects with the equivalent generating heat and thermal capacity were housed in other tubes in the basket (for taking into account of thermal behaviors of the test cask under burial conditions)

REQUIREMENTS FOR THERMAL INTEGRITY

Three criteria for evaluation of the thermal integrity of the test cask under burial conditions were selected as follows.

- Temperatures of the lead used for a gamma shielding of the cask (melting point : 327 ℃)
- Metal O-ring temperatures at seal portion of the cask (short term usage for around one month : 250 ℃)
- Fuel cladding temperatures used for evaluation of the integrity of spent fuel assemblies.

(short term usage : a little over 500℃)

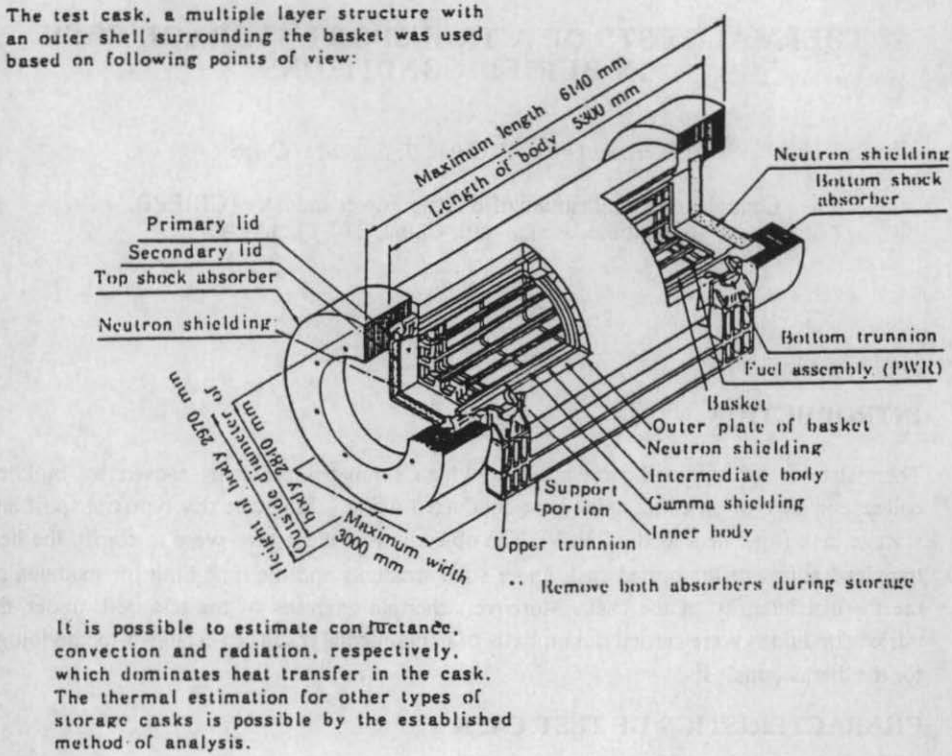

Fig. 1 The bird 's eye view of the test cask

TEST METHOD

TEST CASES

Storage casks can be buried if building collapse is caused by an earthquake, and if roof slabs of it drop onto the casks or walls of it fall down over the casks.
Four cases of the thermal tests (both in vertical and horizontal orientations)were carried out on basis of such estimation for burial accidents.

COMPLETE BURIED CASE (CASE Ⅰ)

This hypothetical condition for burial storage casks is supposed not to occur in actual accidents, but corresponds to the most severe thermal condition which occurs if the whole body of the storage cask is buried by debris (refer to Table 1).
To simulate this test condition, the whole surface of the test cask was covered with adiabatic materials to verify the thermal integrity of the test cask conservatively.
Moreover, it becomes to be possible that the verification of the thermal test analysis model is performed by using the present test skill which simplifies the modeling of the test analysis.

PARTLY BURIED CASES (CASE Ⅱ～Ⅳ)

These test conditions correspond to those of storage casks which are partially (bottom portion etc.) buried in debris or covered with walls. Three cases of thermal tests shown in Table 1 were carried out to take into account of the cooling effect of the ventilation air (depending on flow rate) for the test cask surrounded by reflecting boards . The schematic views of test conditions are shown in Fig.2 and Fig.3 as representative examples.

TEST PROCEDURES

① After the test cask was placed in a heat transfer hood (width 7 m × length 10 m × height 8 m) at an ambient temperature of 38 ℃, the wind speed at the inlet of the hood was set at 0.4(m/sec).

② After the cavity of the cask was evacuated, helium gas prescribed in the design was charged in the cavity, and the pressure in the cavity was adjusted to become the equivalent value of the design pressure.

③ The cask containing the simulated spent fuel assembly and 20 simulated heating objects heated at 23 kW which was equivalent to the heat generation of the decay heat at 21 PWR type spent fuel assemblies, the cask was heated and the temperature of the cask was raised until it reached to the steady state(initial condition).

④ After the temperature of the cask reached to the steady, the cask was continuously heated at the same heat output. However, the outer boundary conditions of the cask was changed as shown in Table 1, and the temperature at each portion of the cask, etc. were measured (totaled about 500 points). In test case Ⅱ through Ⅳ required to chose flow rate of ventilation air as test parameters, tests were continuously carried out after the outer boundary conditions had been only changed.

Table 1 Test Cases in Burial Accidents

Test Case	Posture	Supposed Burial Condition	Remarks
I	In horizontal orientation	The inflow of the heat removal ventilation air is completely stopped	The whole surface at the cask was covered with the adiabatic materials
Ⅱ	In horizontal orientation	The heat removal of the cask is partly restricted	The cask surface is surrounded with metal frames connected with the metal wire-nets which are covered with sheets of heat-resisting boards with required thickness(inflow of the ventilation air chosen as parameters)
Ⅲ	In vertical orientation	The ventilation air dose not flow onto the lower part of the cask surface	The cask surface except the lower part of it is surrounded with reflecting boards with surfaces covered with the aluminum-vaporized resin films (emissivity : 0.05) and the lower part of the cask surface is surrounded with the sheets of new reflecting boards with required thickness in order to restrict the inflow of the ventilation air (inflow of the ventilation air chosen as parameters)
Ⅳ	In vertical orientation	The upper part of the cask is covered with debris.	The cask surface except the lower part of it is surrounded with reflecting boards with surfaces covered with the aluminum-vapored resin films (emissivity : 0.05), and the lid portion of the cask and the upper part of reflecting board covered with adiabatic materials.

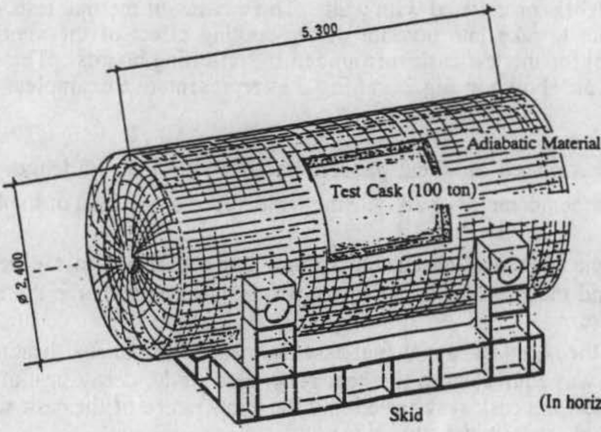

Fig. 2 Schematic view of test condition in case I

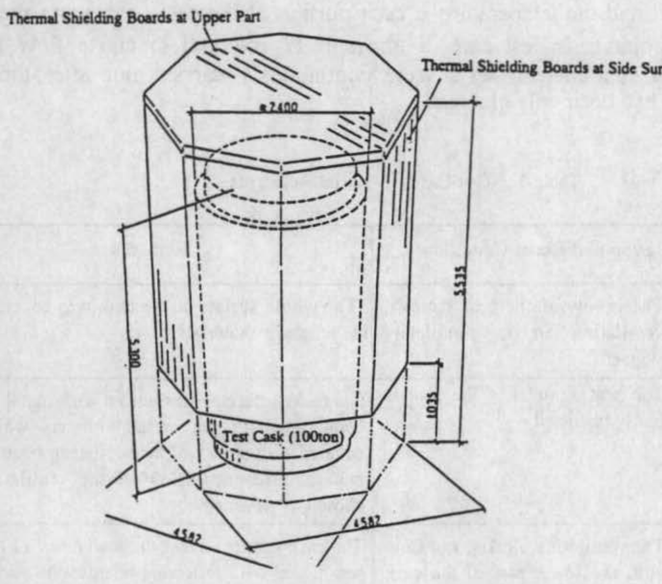

Fig.3 Schematic view of test condition in case IV

TEST RESULTS

COMPLETELY BURIED CASE (CASE I)

The results of test case I (the whole surface of the test cask covered with adiabatic materials) were are shown in the following.

THERMAL BEHAVIORS OF TEST CASK

The test data of case I obtained by the following test procedures shown as follows, because a part of the polyester resin as neutron shielding material bad begun to melt and blow out.

The test procedures of ① through ③ were the same as those described in the above paragraph. After 7 days from the start of the test, a part of the resin had began to melt and blow out. Therefore, the heating of the simulated spent fuel assembly etc. was interrupted in order to check the electric heaters of those. the test was restarted in one and half an hours, and moreover the thermal behaviors of the cask body were observed for 2 days.

MAXIMUM TEMPERATURES AT STRUCTURAL MEMBERS FOR EVALUATING INTEGRITY, ETC.

Temperature history at structural members of the cask used for evaluating the thermal integrity is shown in Fig.4. Maximum temperature and the increment of temperature from steady state are shown in Table 2. Judging from these results, it was confirmed that the maximum temperature at each structural members of the cask used for evaluating the thermal integrity was respectively below the allowable value at the elapsed time after the whole surface of the cask was covered with adiabatic materials and the cask was set under the hypothetical burial accident for 7 days, and that these measured temperatures had sufficient safety margin.

Moreover, the measured temperatures at the simulated spent fuel assembly and the metal O-ring of the cask did not almost include the disturbance data except those influenced on the interruption of the test, and were considered to be reliable data. However, it was observed that the temperature at around 180 ℃ and higher than its value of the lead included the disturbance data supposed to be caused by the electric noise.

The increment of the cavity pressure in the cask during the test was lower than 0.04 MPa and considered to be very small.

Table 2 Maximum Temperature at Important Structural Members of Test Cask (℃ : Case I)

Measured Elements	Maximum Temperature	Temperature Increment from Initial Steady State	Allowable Temperature
Center of Simulated Fuel Assembly	342*	68	a little over 500
Lead	230	82	327
Primary Lid	176	67	250**
Secondary Lid	159	74	250**

* : The test was interrupted after 7 days before reaching to the maximum temperature. The analytical result shows the maximum temperature will be 425℃ in about 2 months

** : Temperature of the metal O-ring for short term usage.

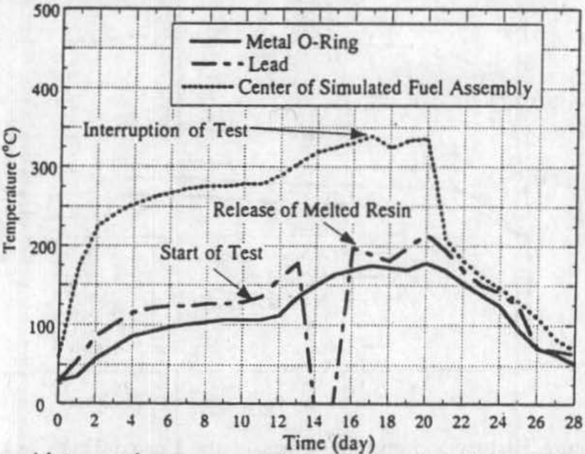

Fig.4 Temperature history at important portion of test cask under burial accidents (case I)

CONTAINMENT OF CASK

The tests were performed by leaving each containment system of the primary lid and the secondary lid in a vacuum state before and after the test in order to confirm the integrity of the containment system of the cask. The leakage rate at the containment system of the primary lid after the test was 2.3×10^{-6} (atm.cc/sec) and below the allowable value (1.0×10^{-3} atm.cc/sec). Therefore the integrity of the containment system of the cask was maintained because the efficiency of the containment system of the primary lid was kept.

PARTLY BURIED CASES(CASE Ⅱ～Ⅳ)

The test results of the case Ⅱ through Ⅳ(taking into account of in flow of the heat removal ventilation air) are as follows.

BOUNDARY CONDITIONS SURROUNDING CASK

The inflow of the heat removal ventilation air onto the cask surface was chosen as test parameters in case Ⅱ through Ⅳ and the temperature at the inlet of the heat transfer hood was altered to be 20 ℃ in order to take into account of the safety margin for the resin during the test.

CHARACTERISTICS OF TEMPERATURE AT THE REPRESENTATIVE PARTS

The temperature histories at simulated fuel assembly, lead portion and the metal O-ring which are very important to evaluate the thermal integrity of the test cask were shown in Fig.5.

It was confirmed that temperatures at the center of the simulated fuel assembly, the lead portion and the metal O-ring respectively converged to another constant values of those and reached to a new steady state. Therefore it was considered that the temperature rise of the cask continued in about 10 days after the hypothetical storage building collapse caused by an earth quake even if the ambient fresh air flowed to the vicinity of the burial cask a little. And it was shown that the most severe test condition for the cask was in case that the upper part of the reflecting boards used for surrounding the cask was covered with similar adiabatic objects (loss of the heat removal air) in horizontal and vertical orientation.

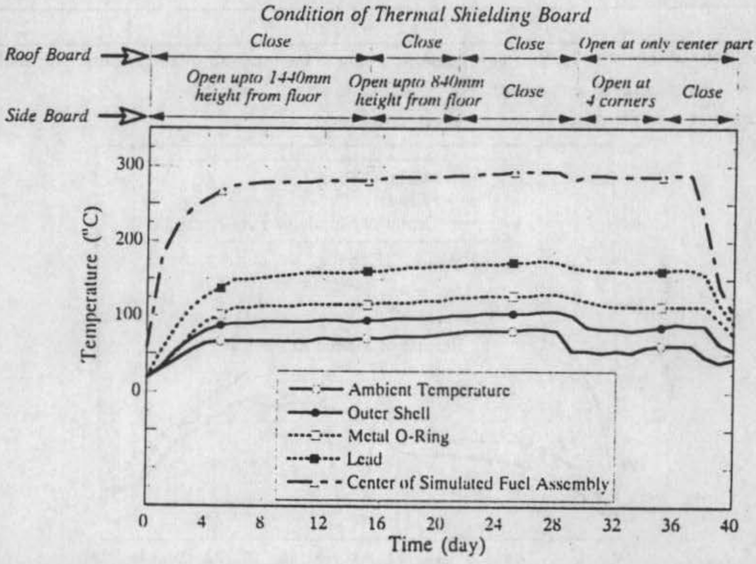

Fig.5 Temperature History at Important Parts of the Buried Test Cask under Burial Accidents(Case Ⅱ)

MAXIMUM TEMPERATURES AT PARTS FOR EVALUATION OF INTEGRITY

Maximum temperatures and temperature rises from the steady state of the cask used for evacuating the thermal integrity (the simulated fuel assembly, the lead portion and the metal O-ring portion), which were measured under the most severe condition in test case Ⅱ through Ⅳ, are shown in Table 3.

Judging from these results, it was confirmed that the maximum temperature at each portion of the cask used for evaluating the thermal integrity was respectively below the allowable value at the time when the temperature of the cask reached to the newly steady state, and that these measured temperatures had sufficient safety margin.

Table 3 Maximum Temperature at Important Portion of Test Cask (℃ : Case Ⅱ through Ⅳ)

Elements Measured \ Item / Test case	Maximum Temperature			Temperature Increment from Intial Steady State			Allowable Temperature
	Ⅱ	Ⅲ	Ⅳ	Ⅱ	Ⅲ	Ⅳ	
Center of Simulated Fuel Assembly	320	335	349	55	53	67	a little over 500
Lead	201	208	226	70	55	72	327
Primary Lid	156	171	207	48	54	100	250
Secondary Lid	136	147	190	47	54	97	250

CONTAINMENT OF THE CASK

Tests were performed by leaving a containment system in a vacuum state before and after the tests in case Ⅱ through Ⅳ, and the integrity of the containment system of the cask was confirmed.

THERMAL ANALYSIS OF A BURIED CASK

OUTLINE OF ANALYSIS

It was at first confirmed that the methodology for the thermal analysis under the normal storage condition was able to be applied to the evaluating for the thermal integrity of the cask under the burial accidents. The analytical result of the test case Ⅰ (the whole body of the cask is buried by debris) is shown in the following as a representative example. Unsteady heat transfer analyses (axis-symmetric model) were carried out to estimate the time when the temperature of the cask reached a new steady state, moreover, to calculate the maximum temperatures of the cask body including contents (the fuel cladding, etc.) and to evaluate the thermal integrity of the cask.

ANALYTICAL RESULTS

The measured temperature at the inner surface of the inner shell which was scarcely disturbed by the electric noise, was compared with the analytical result obtained by the unsteady heat transfer analysis. And the fairly good agreement between the analytical result and test result for the whole history of the temperature was obtained during the test. Therefore, it was confirmed that the methodology for the thermal analysis of the cask under the normal storage condition was able to be applied to evaluation for the thermal integrity of the cask under the burial accidents (refer to Fig.6).

Unsteady heat transfer analysis using the aforementioned axis-symmetric model was carried out to estimate the time when the temperature of the cask reached a new steady state and to calculate the maximum temperatures at each portion of the cask in case that the resin had not melted nor blowed out.

The temperature history of the primary lid is shown in Fig.7. From this figure it has been concluded as follows.

The temperature at each part of the cask reach a new steady state in about 2 months.

The maximum temperature of the lead part is about 240 ℃, which is within the limit.

The maximum temperature at seal portion of the primary lid is little under 250 ℃, and thermal integrity of the cask can be maintained if the buried cask was returned to the normal state as before in around one month.

Moreover, a two-dimensional slice model was used to analyze the maximum temperature at the fuel cladding. It was confirmed that the maximum temperature at fuel cladding is about 425 ℃ under a buried accident and below the allowable value.

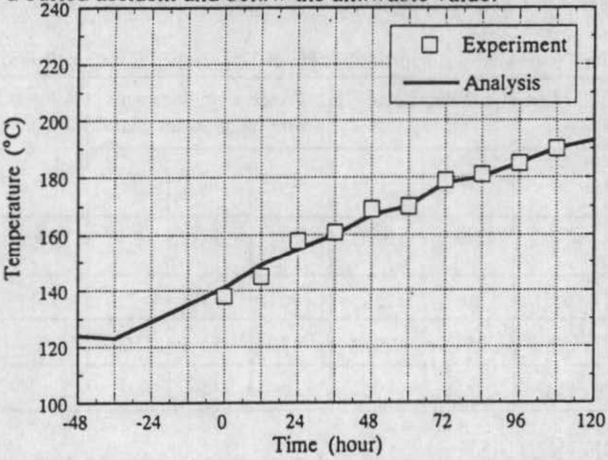

Fig.6 Temperature history of inner surface of inner shell in burial accidents

(Case I : 2-dimentional slice model)

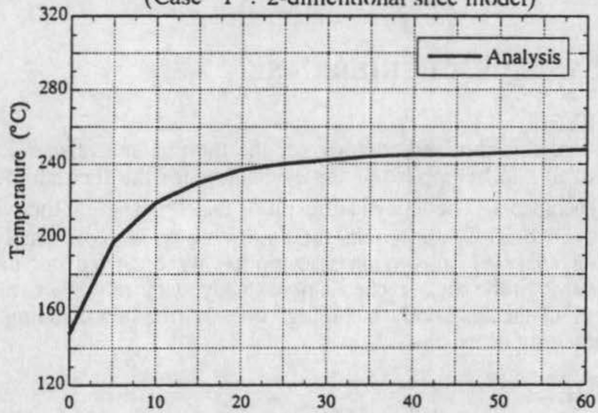

Fig.7 Temperature history of the primary lid seal

(In case that neutron shieldting material had not melted but blowed out)

CONCLUSION

Thermal tests of a buried transport/storage cask caused by building collapse were conducted. The heat transfer features of the buried cask under such accidents and a time for maintaining the thermal integrity of the cask were obatined. Moreover, maximum allowable burial time of a completely buried cask by debris is about one month taking into account of the thermal integrity of the parimary lid seal.

SESSION 7.4

New Regulations