Heat Transfer Tests by Slice Model of High Performance Spent Fuel Shipping Cask

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Introduction

In consideration of high burn-up plan for LWR fuel and future transportation of spent fuel to the Rokkasho reprocessing plant, the High Performance Spent Fuel Shipping Cask (HP-CASK) has been developed to transport more contents(number of fuel assemblies) than the existing casks. During the development work, heat transfer tests by slice model simulating the body of the HP-CASK were performed. In this paper, the heat transfer tests are reported.

General Description

The HP-CASK has multi-layer structure which consists of steel or lead as gamma shield and resin as neutron shield.

In addition, internal fins are embedded in the resin in order to improve heat transfer characteristics.

In order to investigate primarily the radial heat transfer performance across the internal fins, the heat transfer tests were performed using the slice model of the HP-CASK. The model is 2479 mm in diameter and 700 mm in length. Both ends are covered with heat insulators to prevent the axial heat transfer.

The tests were carried out at 30 kW, 50 kW and 70 kW heat power which were assumed for the HP-CASKs.

Radial, circumferential, and axial(for evaluating heat loss from both ends) temperature distributions and ambient temperature were measured at thermal equilibrium conditions.

From the results of the tests, the following were clarified.

(1) The total heat transfer ability of a multi-layer structure satisfied the design value

(2) To evaluate the accurate temperature of each place, it is necessary to take account of modeling of welded parts of the internal fins, etc.

The established analysis method and modeling were found justifiable and will be applicable to the detailed design of the HP-CASK.

Purpose of Test

The HP-CASK has a multi-layer structure which consists of steel or lead as gamma shield and resin as neutron shield. In addition, internal fins are embedded in the resin in order to improve heat transfer characteristics. The heat transfer test was performed to verify the heat transfer performance of the body of the HP-CASK.

Description of Test

Simulating the heat power of an actual cask as test parameters, the heat transfer test was carried out for the three cases of heat power corresponding to 30 kW, 50 kW, and 70 kW.

Test Flow

As shown in the test flow indicated in Fig. 1, the test, using the heat power as parameters, was successively carried out in order of the tests each corresponding to 30 kW, 50 kW, and 70 kW heat power.
The 30 kW value represents the heat power of the contents of large size BWR type HP-CASK and the 50 kW value represents the heat power of the contents of large size PWR type HP-CASK. The test of the 70 kW value was performed to estimate the limits of heat performance of the HP-CASK.

Temperature Measurement

Sheath CA thermocouples for temperature measurement were fixed at positions where the following items could be verified in the heat transfer test and temperatures were measured every 30 minutes.
Temperatures at the tip of the fin, locations between the fins, and the surface of the outer shell were measured as much as possible under steady state by using a surface thermometer :
(1)Radial temperature distribution, (2)Circumferential temperature distribution, (3)Axial temperature distribution, (4)Thermal resistance of the welded part of the internal fins, and (5)Ambient temperature.

Description of the Specimen

As shown in Fig. 2 and Photo. 1 and 2, the specimen was a slice model of the central part of a large size PWR HP-CASK(lead-steel-resin type) which would be thermally most severe. The model has an outer diameter of 2479 mm and an axial length of 700 mm. Heat power simulation was provided by an electric heater fixed on the inner surface of the model. The interior of the model was filled with heat insulator to prevent occurrence of natural convection. Furthermore, in order to minimize heat loss in the axial direction, both ends of the model were covered with heat insulator.

Results of Test

The heat transfer test was performed with history shown in Fig. 3. Radial temperature distributions measured at the center section of the slice model under steady condition are shown in Fig. 4(heat power : 30 kW), Fig. 5(heat power : 50 kW) and Fig. 6(heat power : 70 kW).

Furthermore, an example of the axial temperature distributions measured(heat power : 30 kW) is shown in Fig. 7 and an example of the circumferential temperature distribution measured (heat power : 30 kW) is shown in Fig. 8.

Evaluation of the Results of the Test

From the radial temperature distributions shown in Fig. 4, 5, and 6, it is seen that, for each case, the temperature at the tip of the fin generally tends to be lower on the 180 degrees side and higher on the 0 degree side.

Regarding the temperature distribution from the outer shell to the inner shell, the temperature distribution in the direction of 180 degrees and that in the direction of 0 degree were about the same with each other in each case, showing no difference in the vertical direction of the specimen.

As shown by the axial temperature distribution of the outer surface in Fig. 7, the axial temperature distribution of the outer shell surface, excluding the end part of the model, shows a flat characteristic, allowing us to judge that the center portion of the model sufficiently simulates the heat transfer performance at the center section of an actual cask.

As shown by the circumferential temperature distribution in Fig. 8, the temperature of the tip of the fin is nearly constant from 180 degrees to 45 degrees, and tends to increase from 45 degrees to 0 degree. In contrast to this, the temperature of the outer shell is nearly constant for the range covering from 0 to 180 degrees.

Comparison with the Results of the Analysis

We analyzed the heat transfer test using the analysis code ABAQUS by the finite element method. As shown in Fig. 9, the analysis model covers 0 to 180 degrees in the circumferential direction and a half pitch of the fin in the axial direction. The concept adopted for heat transfer in the analysis is shown in Fig. 10.

When modeling the internal fins, a thermal resistance for which the thermal conductivity and weld shape of the welding material at the welded portion was taken into account was adopted as shown in Fig. 11. In using these analysis modelings, calculated value and measured value compared. This analysis method and the modeling are verified to give safety side results rather than measured results. So these modeling and analysis method can be applied to the detail design of the HP-CASK.

Summary

In consideration of high burn-up plan for LWR fuel, the HP-CASK has been designed to transport more contents than the existing casks. The high performance cask required a high heat transfer performance inside the cask body, because the strong intensity of the neutron source due to the contents required use of a thick resin shielding layer. This led to a design in which internal fins welded at both ends were provided in the resin layer to ensure heat transfer performance, which was verified by means of a slice model heat transfer test. It was shown, as a result, that the heat transfer performance in the cask body had a performance as originally designed.

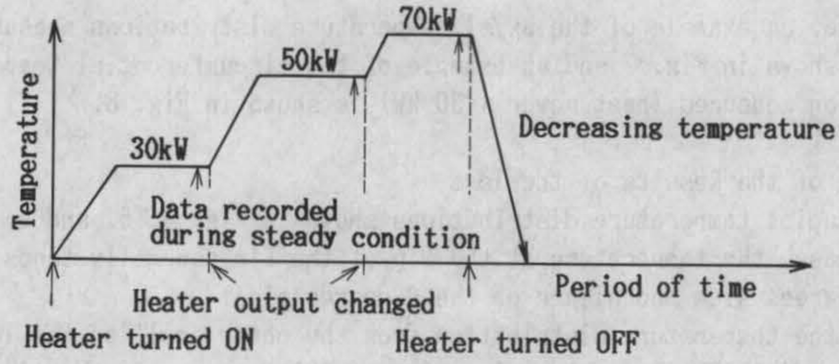

Fig. 1 Test Flow

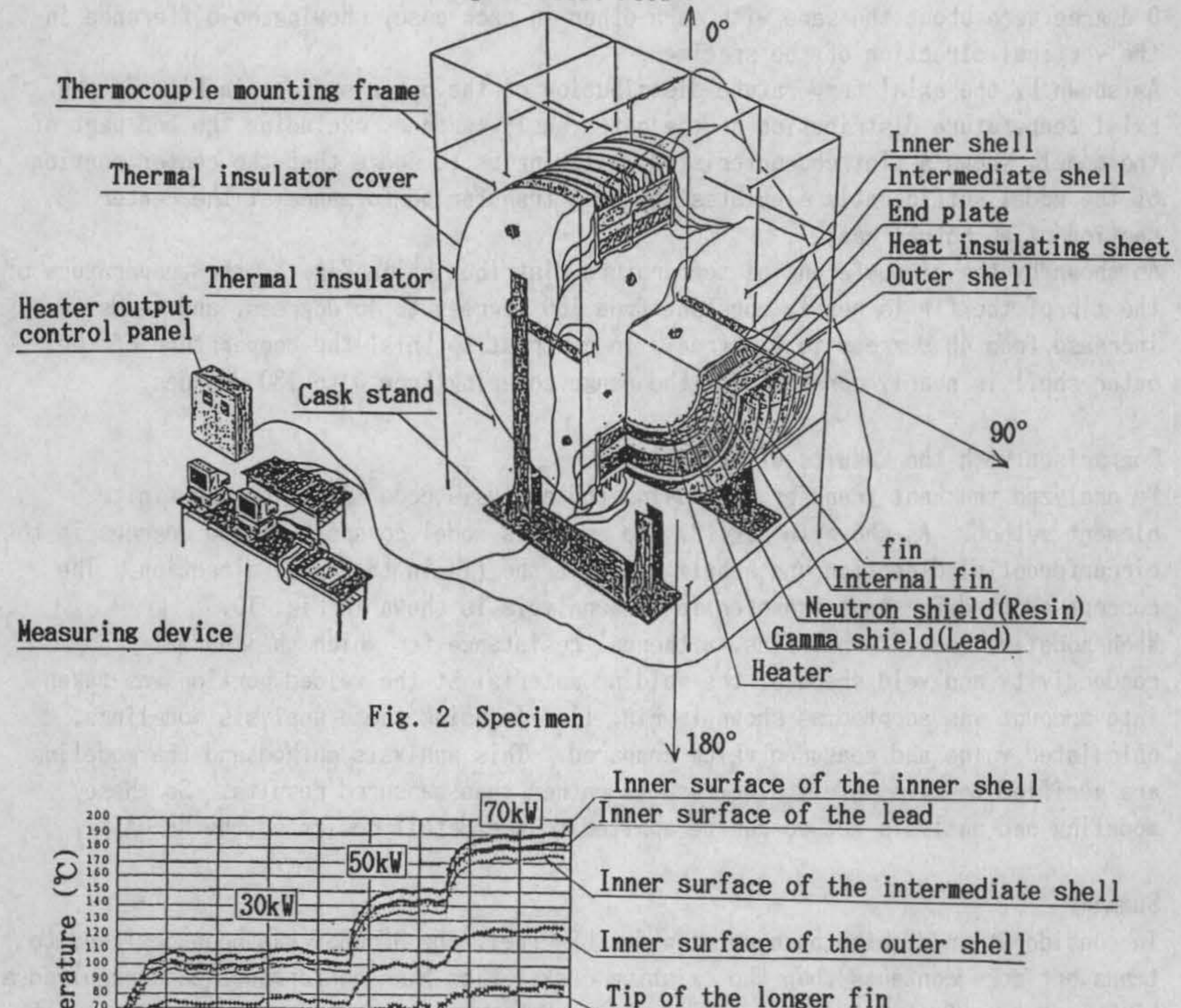

Fig. 2 Specimen

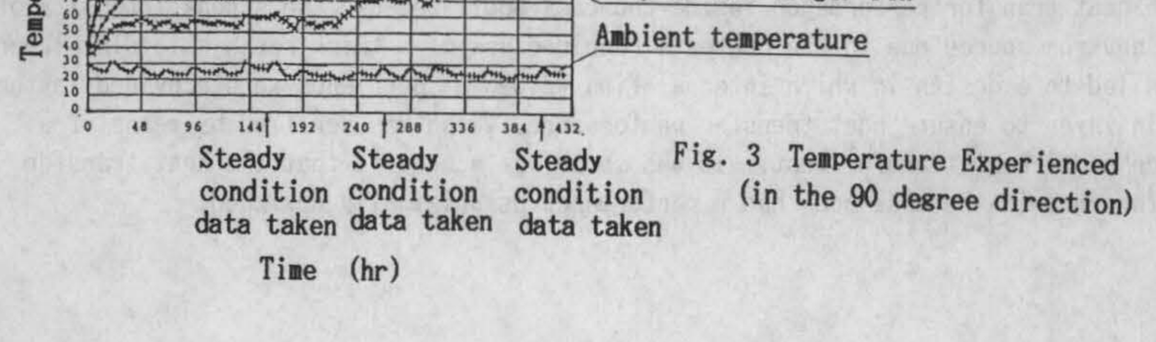

Fig. 3 Temperature Experienced
(in the 90 degree direction)

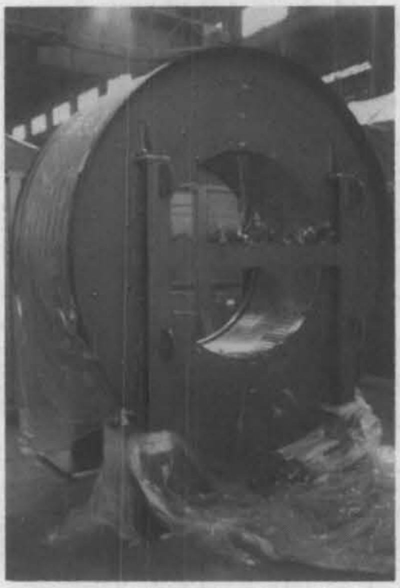

Photo. 1 Specimen (before the thermal insulator was built in)

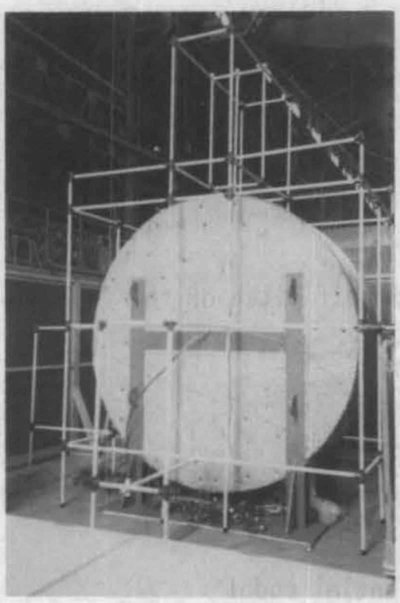

Photo. 2 Specimen

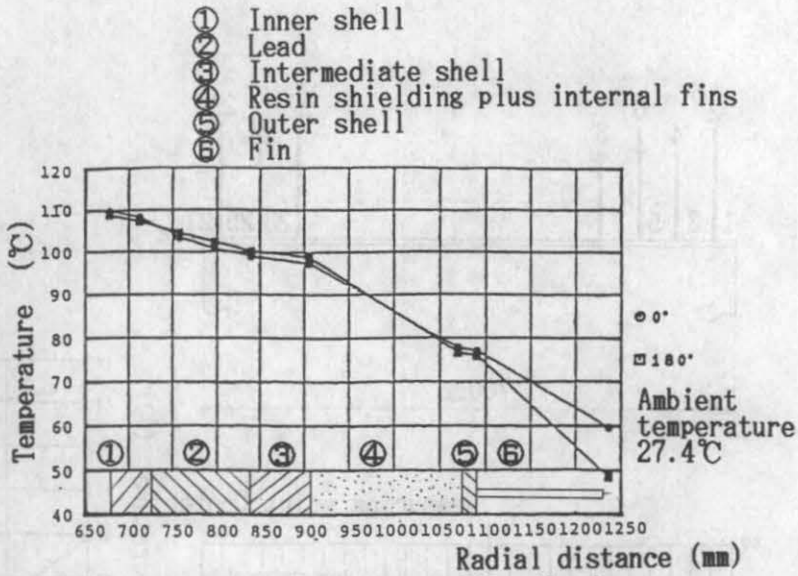

Fig. 4 Radial Temperature Distribution (heat power corresponding to 30 kW)

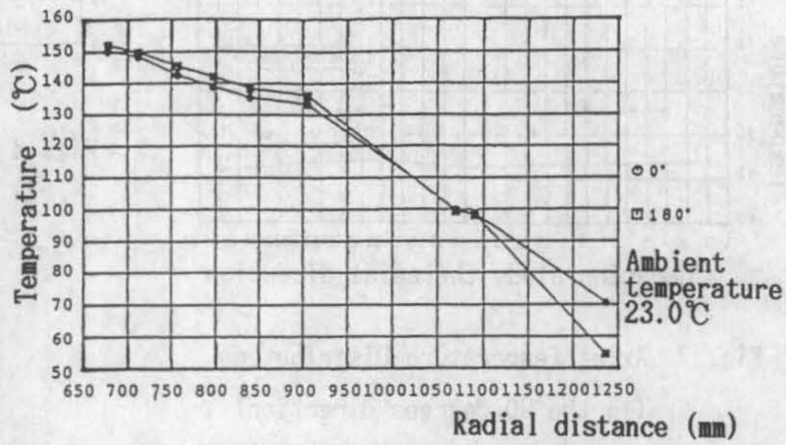

Fig. 5 Radial Temperature Distribution (heat power corresponding to 50 kW)

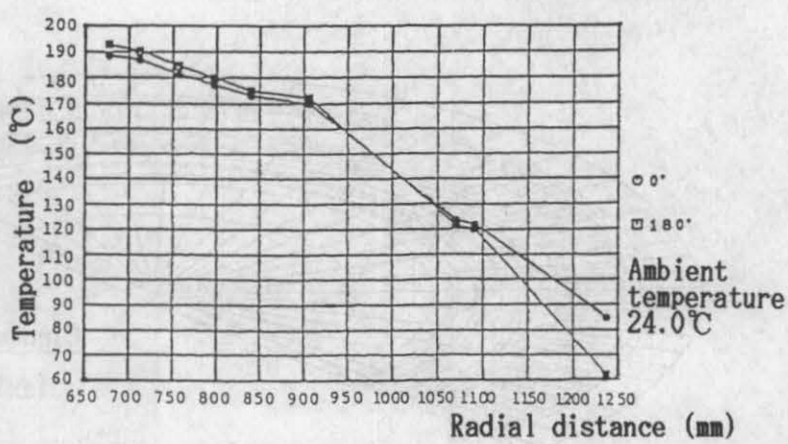

Fig. 6 Radial Temperature Distribution (heat power corresponding to 70 kW)

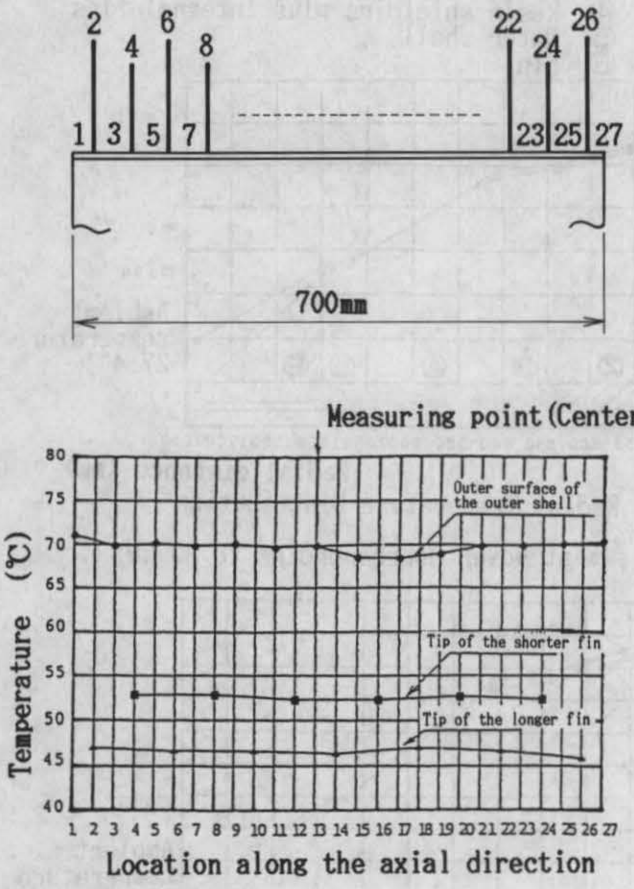

Fig. 7 Axial Temperature Distribution (in the 90 degrees direction)

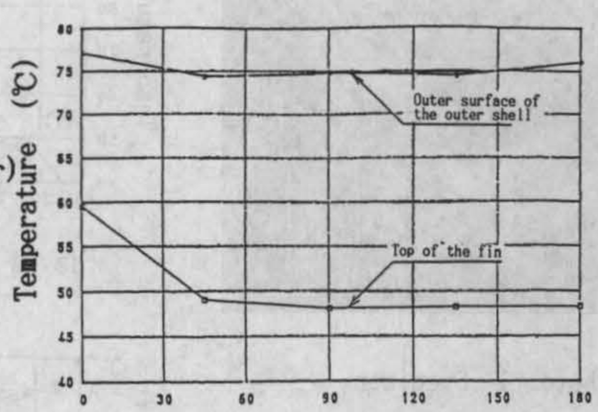

Fig. 8 Circumferential Temperature Distribution

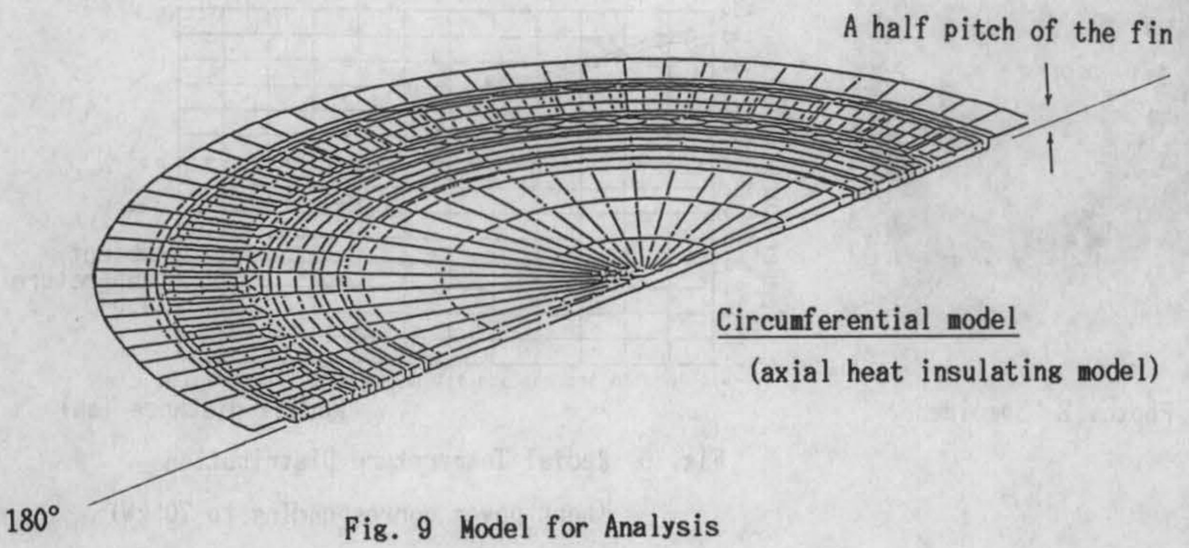

Fig. 9 Model for Analysis

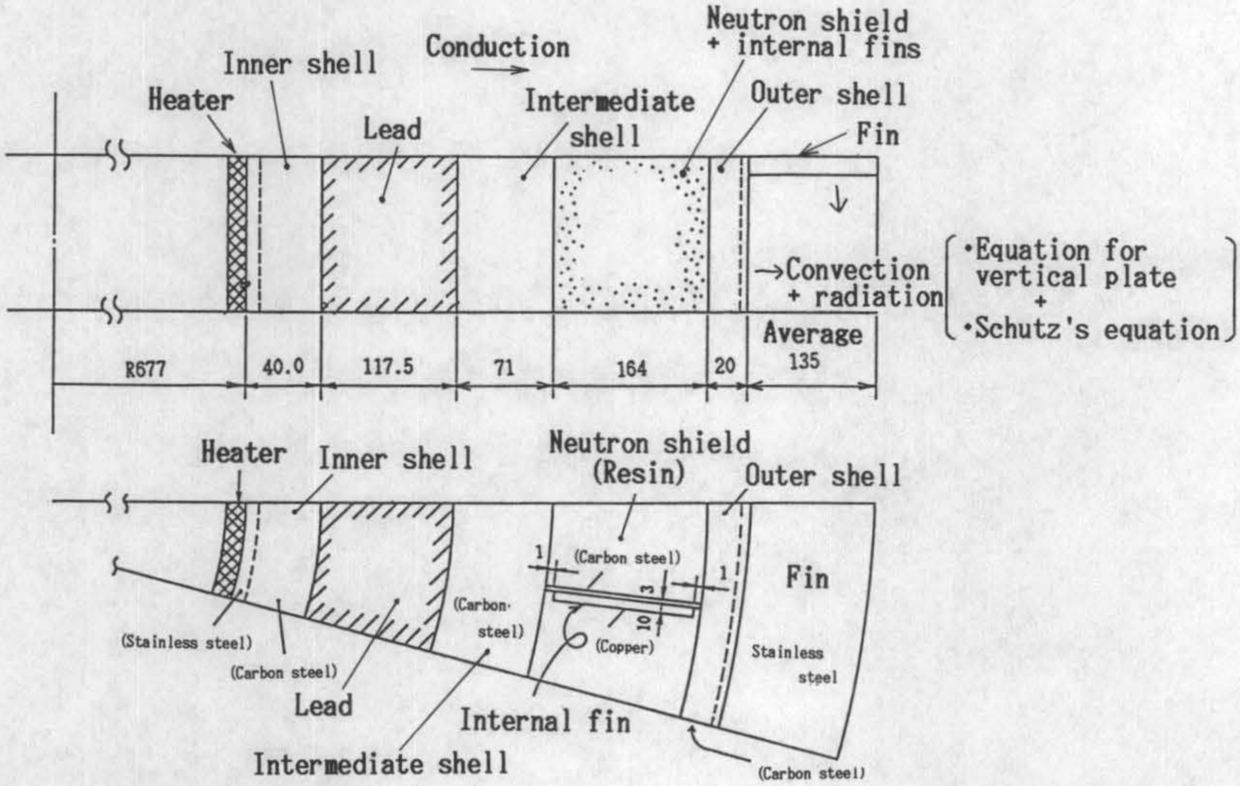

Fig. 10 Concept adopted for heat transfer in the analysis

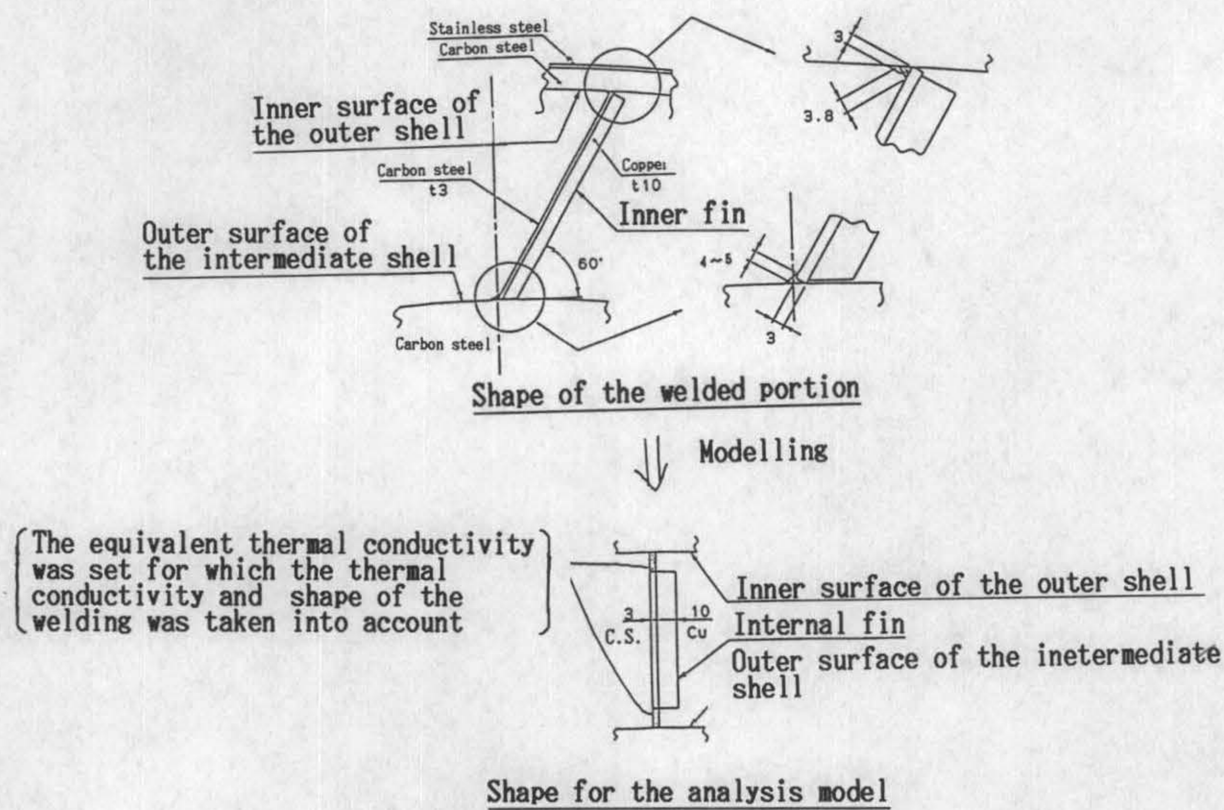

Fig. 11 Modelling of the welded portions of the internal fins

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