HEAT REMOVAL DESIGN FOR A MODULAR SHIELDING HOUSE FOR KEEPING SPENT FUEL TRANSPORTABLE STORAGE CASKS IN AN INTERIM STORAGE FACILITY

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ABSTRACT

OCL and NFT have developed the modular shielding house, which is one of forms for a storage building. In this study, the scale model testing and the thermo-fluid analysis considering both heat transfer and fluid flow have been performed in order to evaluate the heat removal performance of the modular shielding house precisely. As the result, the modular shielding house was confirmed to have the adequate heat removal ability and the heat removal evaluation method with a high degree of accuracy has been established for the modular shielding house. The following results are obtained from the thermal tests using the 1/4 scale model;

The air temperature in the shielding house model goes up uniformly in the vertical direction and the significant stagnant air portion is not observed.

The tests of total 7 cases were performed by changing parameters such as heat output, height of shielding house, area of air inlet and outlet. For all cases, measurement values of the exhaust air temperature were nearly agreed with calculation results using a air draft head calculation method used in stack design and it is concluded that this method can be applied for the heat removal design of the modular shielding house.

The four analysis models were created for the scale test model to evaluate the effects of pressure drop of louvers and thermal radiation and mesh size. The model which has fine mesh for air layer adjacent to cask surface was verified to be adequate by comparing with scale test results. The thermo-fluid analysis results performed for the actual shielding house show that our proposed modular shielding house has the effective heat removal performance.

INTRODUCTION

It is difficult to provide a spacious site for an interim storage facility in Japan. Therefore, transportable storage casks must be stored in a storage building which has sufficient shielding performance, because of the dose limit at the site boundary.

Though a storage building such as the modular house needs measures to prevent the radiation streaming, the measure results in a disturbance for the required heat removal performance. Accordingly, in order to optimize the design of the shielding house, it is indispensable to improve the precision of heat removal evaluation. The conception of our proposed modular shielding house is shown in Fig.1.

The testing using an actual size model is considered to be difficult from a viewpoint of cost and the enlargement of test equipment. On the other hand, the numerical thermo-fluid analysis has given reliable simulation results for heat transfer behavior of fluid recently. Therefore, the thermal tests using the simple scale test model were performed to establish and verify analysis modeling by compared with test results.
The heat removal performance of the actual shielding house was analyzed using the established analysis modeling.

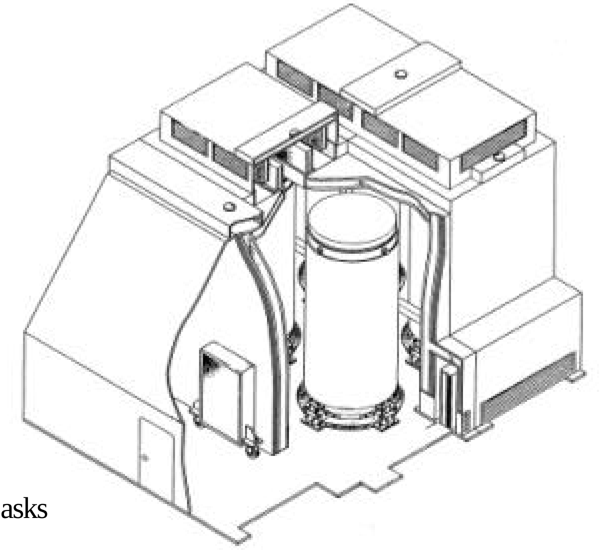


Fig.1 NEO-SSS Type Modular Shielding House
for Keeping Spent Fuel Transportable Storage Casks

SCALE MODEL TESTING

The test model used is shown in Fig.2. In order to simplify test model and equipment, one row of the modular shielding house is modeled and insulated walls are set for both sides. Two cask models constructed of cylindrical shells, where sheet heaters are attached inside, are used to simulate storage casks. The dimensions of test model are reduced to be 1/4 of actual one.

The temperatures of air inside test model, inlet air and wall of cask model are measured at typical points by using thermocouples. The air velocity inside test model and inlet air flow rate are measured by hot-wire anemometers. In order to recognize the air flow pattern, smoke flow was observed. The tests of total 7 cases were performed by changing test parameters such as heater output, height of test model roof, area of air inlet and outlet louver. The observed air flow pattern inside test model are illustrated in Fig.3.

The test results are summarized as follows;

1) The inlet air flows horizontally along the floor and reaches into the central of test model. Subsequently, the strong upward flow is formed along the surface of cask model and narrowed toward the center above the top of cask model. The significant air flow is not observed in a large part of the space inside test model, except for the base area and boundary layer adjacent to cask model surface.
2) The air temperature in the test model goes up uniformly in the vertical direction and the variation in air temperature of crosscut surface is within 2°C except for the boundary layer adjacent to cask model surface and neighborhood of the base.
3) When the test parameters such as heater output, height of shielding house are changed, the outlet air temperature and cask surface temperature are varied accordingly. However, the air flow pattern is not changed and a significant stagnant air portion is not observed.

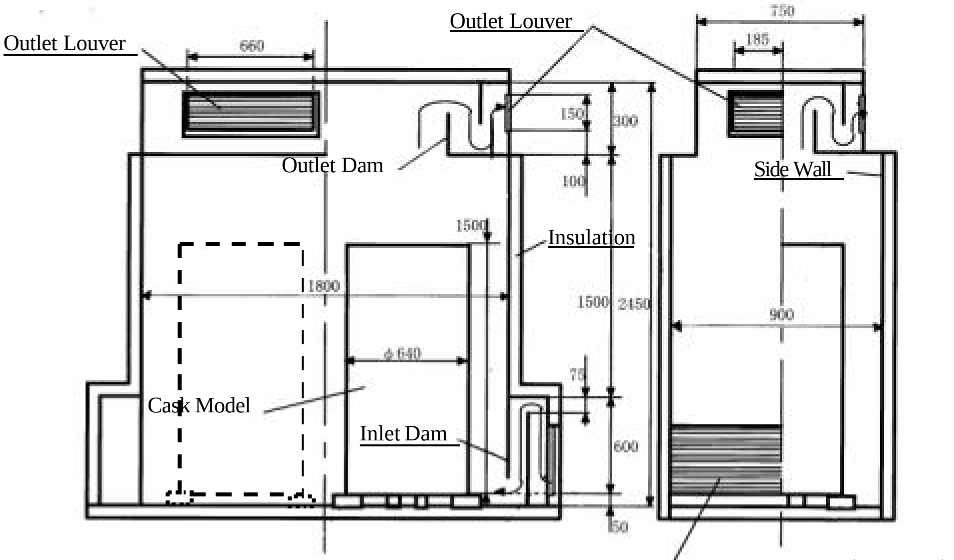


Fig.2 1/4 Scale Test Model

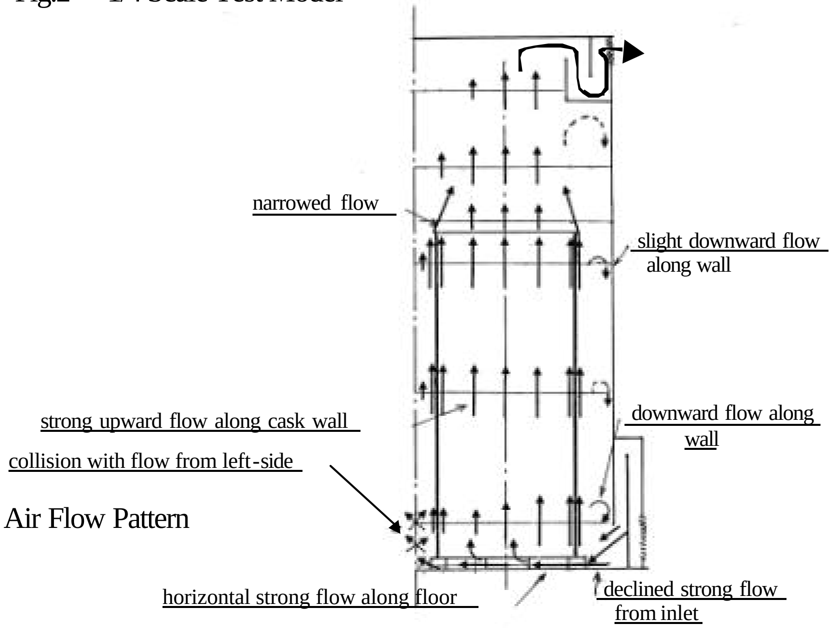


Fig.3 Observed Air Flow Pattern

COMPARISON WITH AIR DRAFT CALCULATION METHOD

In a air draft head calculation method used for calculating the exhaust gas temperature in the stack design, the air draft head, Z is expressed as the difference in static head between outside and inside air as follows;

$$Z = \rho_a \cdot H \cdot g - \int_0^H \rho(T) \cdot g \cdot dz \qquad (1)$$

And, the balanced pressure drop due to air flow, Zr is determined by the following equation.

$$Zr = \Delta p + \frac{1}{2}\rho_g \cdot v_o^2 \qquad (2)$$

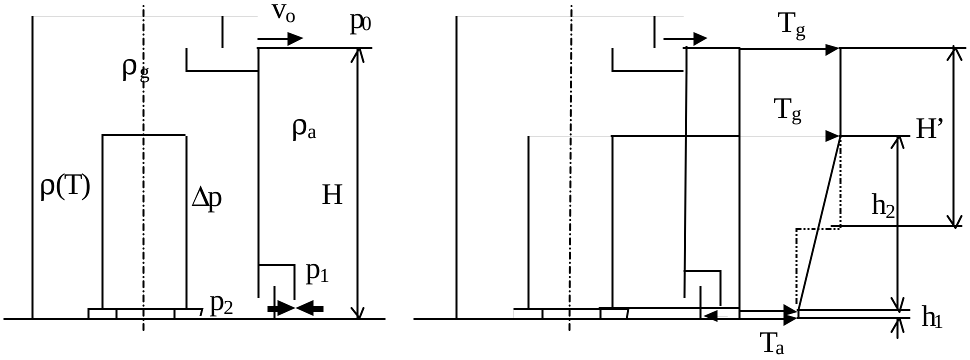
where, ρ_a : density of outside air

H : height of outlet
g : acceleration of gravity
$\rho(T)$: density of inside air
T : temperature of inside air
Δp: pressure drop
ρ_g: density of outlet air
v_o : velocity of outlet air

The air temperature in the test model goes up linearly in the vertical direction. Therefore, the air draft head, Z is assumed to be modified as follows;

$$Z \quad (\rho_a \quad \rho_g) \quad H' \quad g \tag{1'}$$

where, H' : effective height of draft head = $H-(h_2/2+h_1)$



(a) Pressure Balance (b) Air Temperature

Fig.4 Air Draft Head Calculation Model

Table 1 shows the comparison of calculated values of temperature difference with test results. For all test cases, measurement values are nearly agreed with calculation results and it is concluded that this method can be applied for the heat removal design of the modular shielding house.

Table 1 Comparison between Test Results and Air Draft Head Calculation Results

Test Case No.	Test Parameter	Heater Output /Cask (kW)	Temp. Difference between Inlet and Outlet Air(°C)		Calculated Pressure Drop(Pa)
			Test	Calculation	
1	Fundamental	1.50	40	40	2.2
2	Heater Output Reduced	0.75	25	25	1.4
3	Inlet Louver Area Opened	1.47	35	35	2.0
4	Outlet Louver Area Opened	1.49	39	37	2.1
5	Inlet Dam Area Reduced	1.48	39	40	2.2
6	Outlet Dam Area Reduced	1.46	40	40	2.2
7	Roof Height Reduced	1.52	48	47	1.7

ESTABLISHMENT OF ANALYSIS MODELING

The air flow in the shielding house is considered basically to be a natural convection flow along vertical plate and transited to a turbulent flow. Therefore, a turbulence model is required to simulate thermal and flow behavior of air inside the shielding house. In this study, we used the standard k-ε model as a turbulence model and Boussinesq approximation modeling which is considered the buoyancy term into the momentum conservation equation for incompressible fluid. And, the analysis was performed using the three-dimensional thermo-fluid analysis system "SCRYU" which can treat both heat transfer and fluid flow.

The following four analysis models were created for scale test model to evaluate the effects of pressure drop of louvers and thermal radiation and mesh size.

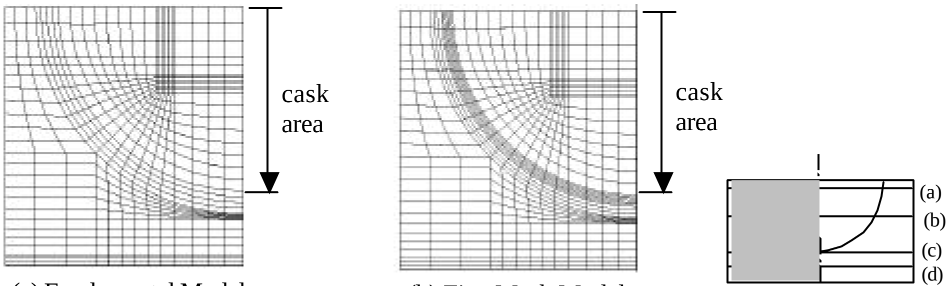
1) Fundamental model (Pressure drop of louvers and thermal radiation to side walls are included.)
2) Model neglecting pressure drop of louvers
3) Model neglecting thermal radiation
4) Fine mesh model (Fundamental model was modified so as to have fine mesh for air layer adjacent to cask surface, as shown in Fig.5.)

The analysis results are summarized in Table 2. The obtained air velocity vector and air temperature distributions are shown in Figs 6 and 7. The following conclusions are derived from these analysis results by comparing with test results.

1) The pressure drop of louvers effects largely on the calculated value of air flow rate and outlet air temperature and is required to be evaluated exactly.
2) The fine mesh model is found to evaluate the air flow rate and outlet air temperature more precisely than fundamental model, as shown on Table 2.
3) The analysis results of fundamental and fine mesh models are agreed with test results, as shown in Figs. 6 and 7. The flow pattern of inside air shown in Fig. 6 is very similar to the observed test result shown in Fig. 3.
4) A significant stagnant air portion is not existed and the inside air temperature goes up uniformly in the vertical direction, as well as the test results.
5) All analysis models can not simulate the surface temperature distribution of cask model and a finer mesh than the fine mesh model is considered to be required for air layer adjacent to cask surface. However, the object of this study is to evaluate the outlet air temperature and air flow behavior in the shielding house and it is concluded from the comparison with test results that the fine mesh model is adequate for the heat removal evaluation of the shielding house.

Table 2 Comparison between Test Results and Analysis Results

Item		Inlet Air Flow Rate(m^3/s)	Outlet Air Temp.(°C)	Surface Temp. at Middle of Cask (°C)
Test Result		0.015	54	93
Analysis Result	Fundamental Model	0.0163	52	118
	Model Neglecting Pressure Drop of Louvers	0.0207	45	111
	Model Neglecting Thermal Radiation	0.0153	53	131
	Fine Mesh Model	0.0154	53	77



(a) Fundamental Model (b) Fine Mesh Model

Fig.5 Mesh of Fundamental Model and Fine Mesh Model

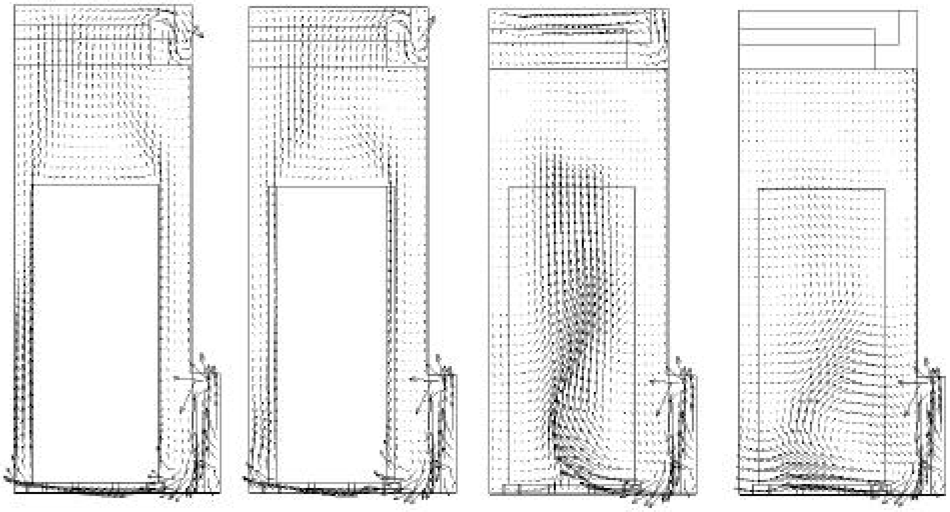


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Fig.6 Analysis Result of Air Velocity Vector (Fundamental Model)

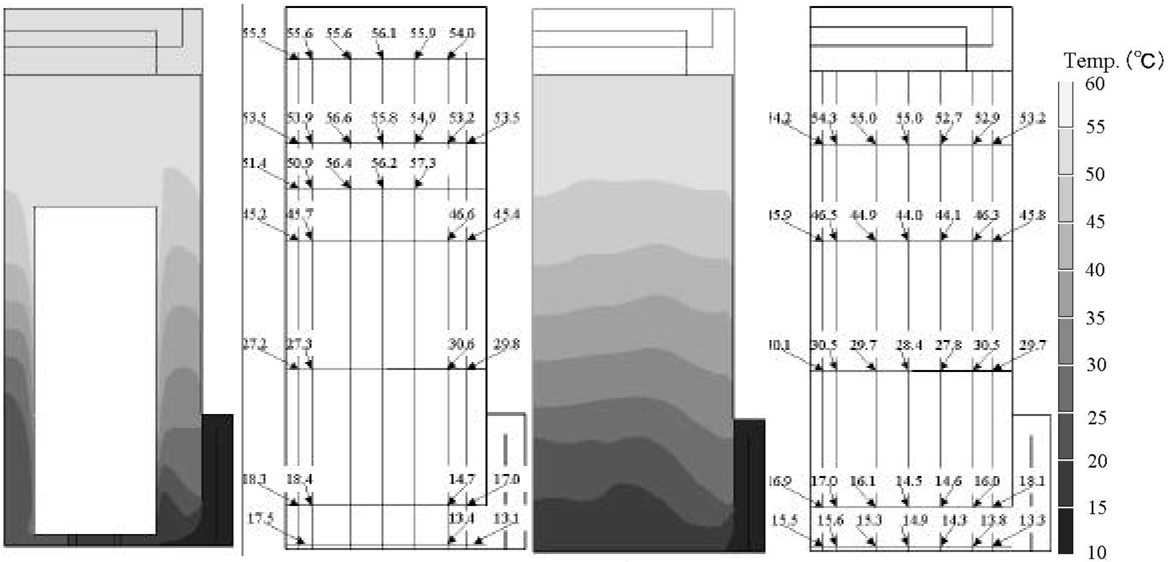

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Fig.7 Comparison of Air Temperature Distribution (Fundamental Model)

ANALYSIS RESULT OF ACTUAL SHIELDING HOUSE

The thermo-fluid analysis was performed using the fine mesh model for the actual typical shielding house to evaluate the heat removal performance. The analysis conditions and results are presented in Table 3. The obtained air velocity vector and air temperature distributions are shown in Figs. 8 and 9.

Table 3 Analysis Conditions and Results for Typical NEO-SSS Type Shielding House

Item		Value
Condition	Heat Output	20 kW/Cask
	Inlet Air Temperature	33 °C
Result	Inlet Air Flow Rate	0.375 m^3/s
	Max. Air Velocity	1.1 m/s
	Outlet Air Temperature	57 °C

The calculated value of outlet air temperature is well with in the allowable design value of 60°C and Figs. 8 and 9 show that air flows smoothly inside the shielding house and there is no air space with locally raised temperature. Therefore, our proposed modular shielding house is verified to have the effective heat removal performance.

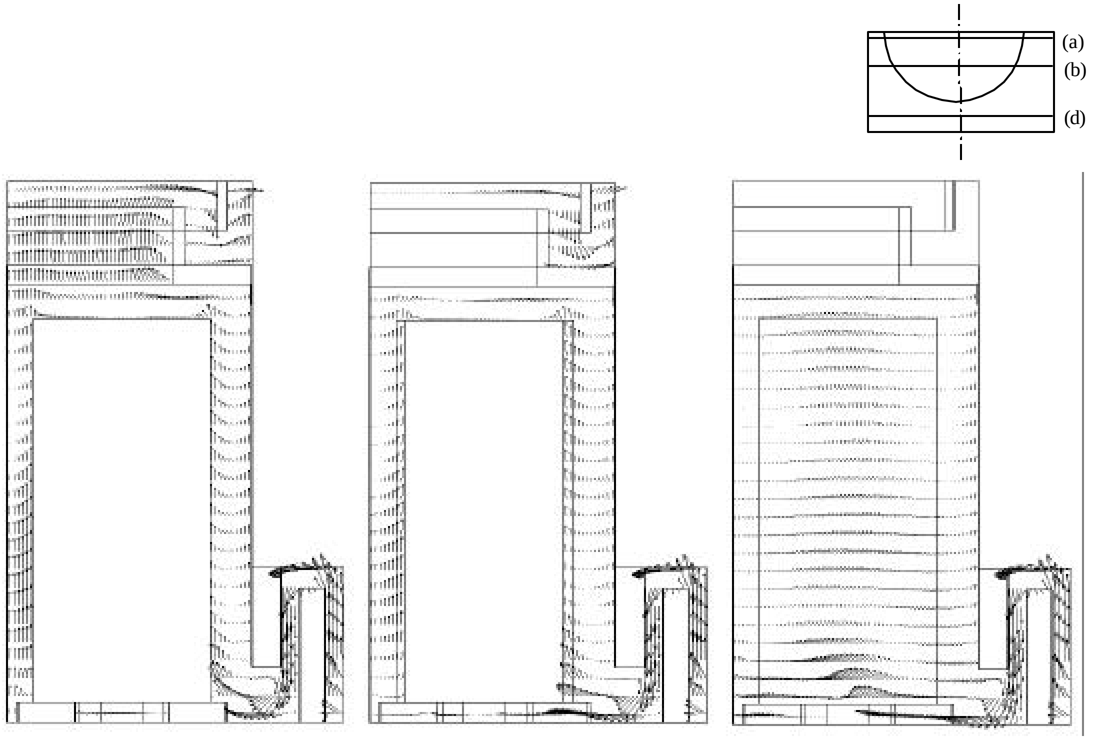

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Fig.8 Air Velocity Vector Distribution for Actual Shielding House

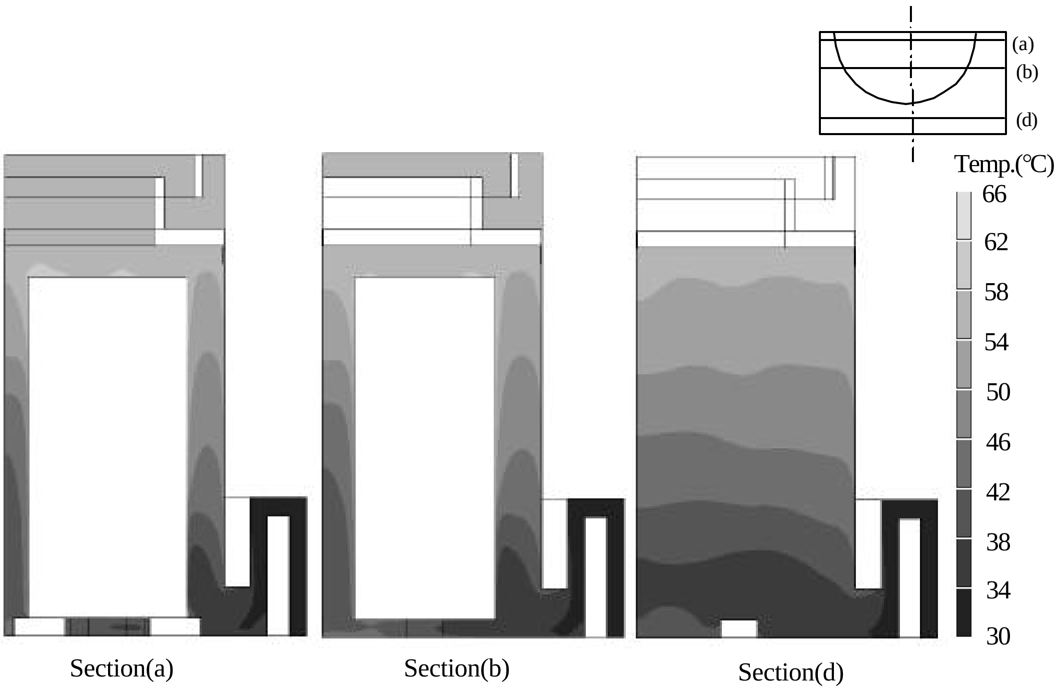

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Fig.9 Air Temperature Distribution for Actual Shielding House

CONCLUSION

In this study, the scale model testing and the thermo-fluid analysis considering was performed in order to evaluate the heat removal performance of the modular shielding house precisely.

The test results using the 1/4 scale model show that the air temperature in the shielding house model goes up uniformly and the significant stagnant air portion is not observed.
The analysis model which has fine mesh for air layer adjacent to cask surface was verified to be adequate by comparing with scale test results. The thermo-fluid analysis results performed for the actual shielding house show that our proposed modular shielding house has the effective heat removal performance.

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