Heat and Thermal Stress Analysis of Cask for Transporting Ir-192 and I-131

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1. Introduction

Recently, the nuclear energy has been widely applied in various fields. So the use of radioactive materials is increasing. Accordingly, the study of radioactive material transport is in progress actively in various fields[1]. The transport carrying the radioactive material is required strict safety standards. So domestic and international regulations of radioactive material is strict[2-4].

In this study, the thermal stress of the cask by decay heat of radioactive materials is analyzed using finite element analysis. The analyzed result is used in to evaluate the safety for transport by reference to domestic and international transport regulations.

2. Methods and Results

This study carried out the heat and thermal stress analysis using ANSYS^{TM} v15.0.

The conditions to apply to heat and thermal stress analysis was applied by reference to domestic and international regulation for the radioactive material transport. The analysis model and the process of the heat analysis are as follows.

2.1 FEM(finite element method) model

The cask to transport radioactive material is composed of the shield area, the capsule area and plug area. Specifically, the shield area is an area of the shielding function using tungsten and lead, the capsule area is made up of the suspension area and the area to hold the capsule. Plug area is a structure which can insert or remove the capsule, and is made of tungsten and lead to shield as in a shield area.

Fig. 1 shows the schematic of the radioactive material transport. Fig. 1 (a) shows the full model, Fig. 1 (b) shows the quarter model. In this study, the quarter model is used to analysis to save the time. Fig. 1 (c) shows the detailed schematic of the cask. The vessel is made of the stainless steel, the shield material is made of the lead and tungsten. Capsule is made of the aluminum to reduce the temperature increase by the decay heat of radioactive material.

The spring is installed in the original suspension area, but in this study, the spring does not have a significant affect on the thermal analysis. So the spring is excluded

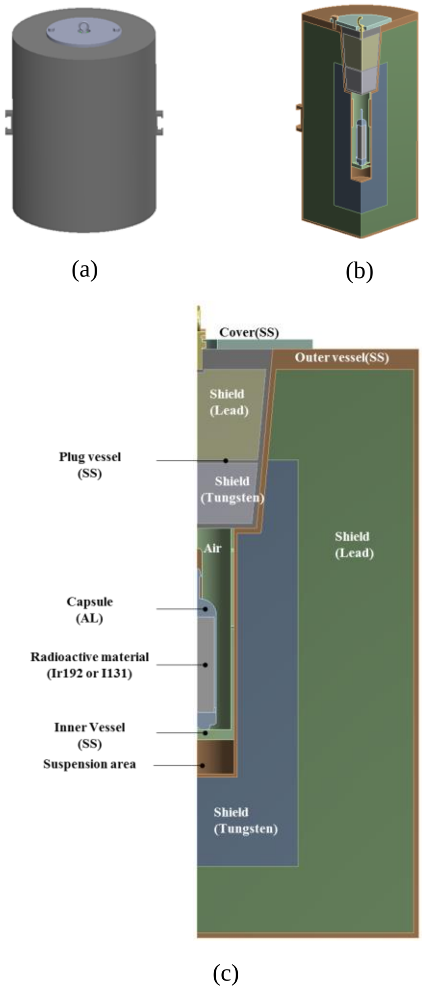


Fig. 1. The radioactive material transport: (a) full model, (b) quarter model and (c) schematic configuration

2.2 Regulation of the radioactive material transport

The domestic and international regulation for transport are examined in order to evaluate the safety of the transport. Because our cask to transport is classified as type B transport, we organize the transport regulations associated with the type B[2]. The transport regulations are consist of the various safety test about the fall, penetrating, watering and so on, but this study only considers the regulations related heat and thermal stress and practical use.

Accordingly to the regulations related heat, the maximum temperature of accessible surface should not exceed 85 ℃ in the absence of insolation under the ambient condition, and should not exceed 50 ℃, unless the package is transported under exclusive use. So if the maximum temperature of accessible surface is more than 50 ℃, it should be installed barriers or screens to protect persons.

Table. I shows the insolation conditions according to the surface shape of the cask. The insolation of the horizontal flat surfaces is 800 W/m^2, the insolation of the vertical flat surface is 200 W/m^2, and the insolation of all other surfaces is 400 W/m^2.

Table. II shows the regulations related thermal stress analysis[5-6]. The design stress intensity value should be the lowest value in the one-third of the specified minimum tensile strength and two-third of the specified minimum yield strength at room temperature. The symbol of the design stress intensity is 'S_m'. The regulations specify that the thermal stress should be less than 3*S_m.

In this study, we consider the thermal stress on the vessel. The material of the vessel is stainless steel, so the S_m of the stainless steel is 137.9 MPa.

Table I: Insolation condition according to the shape of surface

case	Form and location of surface	Insolation For 12 h per day (W/m^2)
1	Flat surfaces transported horizontally (downward facing)	0
2	Flat surfaces transported horizontally (upward facing)	800
3	Surfaces transported vertically	200
4	Other downward facing(not horizontal) surfaces	200
5	All other surfaces	400

Table II: Criteria for establishing design stress intensity values

	Tensile Strength	Yield Strength
S_m	$\frac{1}{3}S_T$	$\frac{2}{3}S_Y$

2.3 Analysis conditions

The safety of the cask to transport heated by decay of radioactive material is evaluated using the heat and thermal stress analysis

Table III shows the analysis conditions applied to heat and thermal stress analysis. The decay heat of the Ir192 8,000 Ci is about 46.16 W, the decay heat of the I131 100 Ci is about 0.336 W. The TCC(Thermal contact conductance) is considered because the cask for transporting the radioactive materials consist of various materials and composite structures. The TCC of contact boundary between the Al and SS is 2,288 $W/m^2 \cdot K$, the TCC of contact boundary between the SS and SS is 4,859 $W/m^2 \cdot K$, the TCC of the other boundary is set to 2,321 $W/m^2 \cdot K$[7-10].

The convective heat transfer coefficient is 5 $W/m^2 \cdot K$. The emissivity of the Al is about 0.3, the emissivity of the SS is about 0.35. The room temperature is set to 38 ℃.

The thermal stress analysis is conducted by using the result of the temperature distribution of the heat analysis using the above conditions, and that includes the conditions with and without insolation.

Table III: Boundary conditions for thermal analysis

Property	Value
Decay heat · Ir192 8,000 Ci · I131 100 Ci	 46.16 W 0.336 W
Thermal contact conductance · Capsule(AL) - Suspension(SS) · Vessel(SS) - Suspension(SS) · Vessel(SS) - Plug vessel(SS) · Vessel(SS) - Shield(W) · Plug vessel(SS) - Shield(W) · Plug vessel(SS) - Shield(Pb) · Shield(W) - Shield(Pb)	 2,288 $W/m^2 \cdot K$ 4,859 $W/m^2 \cdot K$ 4,859 $W/m^2 \cdot K$ 2,321 $W/m^2 \cdot K$ 2,321 $W/m^2 \cdot K$ 2,321 $W/m^2 \cdot K$ 2,321 $W/m^2 \cdot K$
Convection coefficient	5 $W/m^2 \cdot K$
Emissivity · Capsule(AL oxidized) · Suspension(SS oxidized) · Outer surface(SS oxidized)	 0.3 0.35 0.35
Room temperature	38 ℃

2.4 Heat transfer and Thermal stress analysis

Fig. 2 shows the result of the heat analysis according to the insolation conditions and radioactive materials. Fig. 2 (a) shows the temperature distribution and total heat flux of the cask heated by decay heat of the Ir192 under the insolation condition. Fig. 2 (b) shows the temperature distribution and total heat flux of the cask heated by decay heat of the I131 under the insolation condition. Fig. 2 (c) shows the temperature distribution and total heat flux of the cask heated by decay heat of the Ir192 without the insolation condition, Fig. 2 (d) shows the temperature distribution and total heat flux of the cask heated by decay heat of the Ir192 without the insolation condition. Commonly it can be seen that the highest temperature distribution shown in the capsule contained the radioactive material, it can be seen that the temperature of the outer structure is lower than inner structure. The vectors of the total heat flux show that the heat flows well to the outside. Because the heat flows well to the outside, the maximum temperature in each conditions are distributed below the melting point of the materials used in the cask for transporting radioactive materials.

Table. IV shows the results of the heat analysis and the regulations about the temperature. The maximum temperature of the accessible surface under insolation condition for Ir192 is about 131 ℃, in the case of I131 is about 126 ℃. The maximum temperature of the accessible surface without insolation condition for Ir192 is about 42 ℃, in the case of I131 is about 38 ℃. There are no r about the insolation condition in the regulation for transporting the radioactive material, so the evaluating temperature distribution of insolation condition should be determined under the condition without insolation, thus the cask is required the protection for persons because the maximum temperature of the accessible surface is more than 50 ℃. Next, when there is no insolation condition, it was confirmed that the maximum temperature of the accessible surface is lower than 50 ℃, so it is well suited to the requirements of the regulation[2].

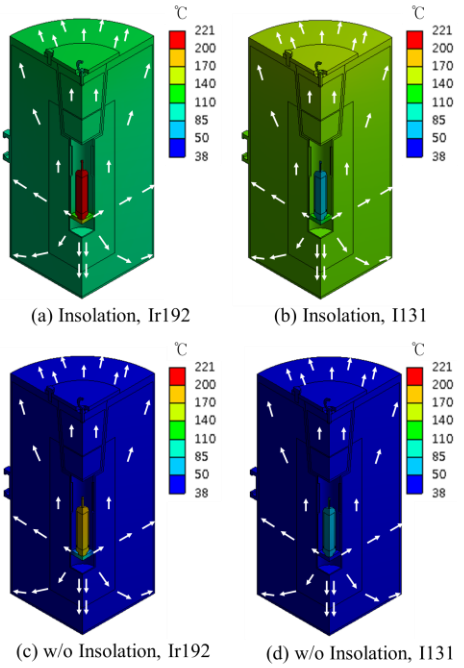


Fig. 2. Temperature distribution and total heat flux of the radioactive material transport according to the radioactive material and insolation: (a) Ir192 with insolation, (b) I131 with insolation, (c) Ir192 w/o insolation and (d) I131 w/o insolation

Table IV: Comparison of the temperature of the accessible surface at the FE analysis results and regulation according to the insolation and radioactive materials

Insolation	Radioactive material	Temperature of the accessible surface	Regulation
Yes	Ir192	131 ℃	-
Yes	I131	126 ℃	-
No	Ir192	42 ℃	85 ℃
No	I131	38 ℃	85 ℃

Fig. 3 shows the results of the thermal stress analysis for the Ir192. Fig. 3 (a) shows the thermal stress distribution. Fig. 3 (b) shows the results of the SCL(Stress Classification Line) of in the presence of the maximum stress intensity, it could confirm that the Secondary stress is lower than $3*S_m$.

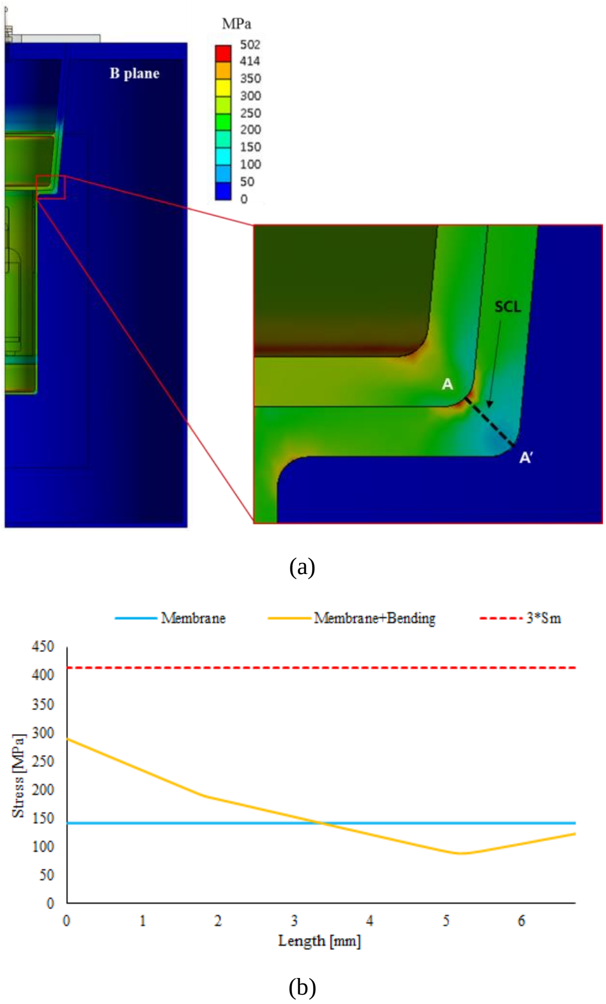
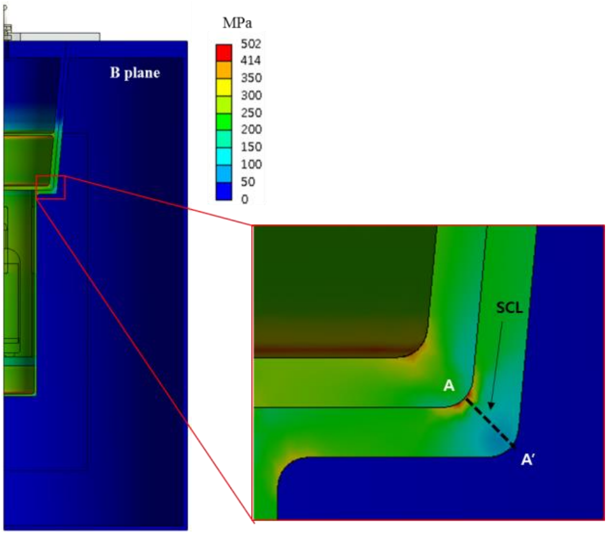
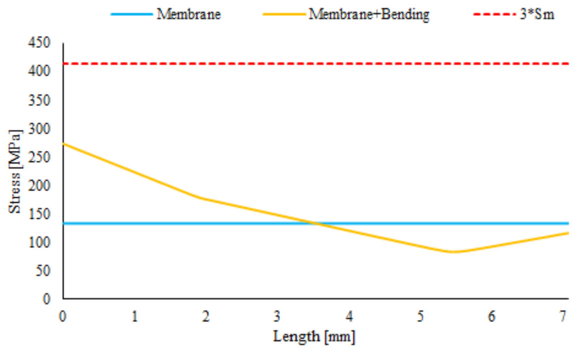


Fig. 3. Results of the thermal stress for the Ir192: (a) Thermal stress distribution and (b) SCL result of the line(A-A')

Fig. 4 shows the results of the thermal stress analysis for the I131. Fig. 4 (a) shows the thermal stress distribution. Fig. 3 (b) shows the results of the SCL of in the presence of the maximum stress intensity, it could confirm that the Secondary stress is lower than $3*S_m$.



(a)



(b)

Fig. 4. Results of the thermal stress for the I131: (a) Thermal stress distribution and (b) SCL result of the line(A-A')

Table. V shows the results of the thermal stress analysis according to the insolation condition. The results of the thermal stress under insolation condition equates to the results of Fig. 3 and Fig. 4. The results of the thermal stress under condition without insolation only summarize in the Table. V. Regardless of the insolation condition, the results of the thermal stress analysis is lower than the value of the regulations for transporting the radioactive material. As a result, the decay heat of radioactive material does not have a significant affect on the deformation of cask, so it means that the cask has been designed safely.

Table V: Comparison of the Secondary stress at the FE analysis results and regulation according to the insolation and radioactive materials

Insolation	Radioactive material	Analysis (MPa)	Regulation (MPa)
Yes	Ir192	289	< 413.7 ($3S_m$)
Yes	I131	273	
No	Ir192	62	
No	I131	44	

3. Conclusions

Heat and thermal stress analysis of the cask for transporting radioactive materials are carried out using the finite element analysis program. The safety of the cask is evaluated by reference to the domestic and international transport regulations. As a result, it has been verified that the developed cask for transporting Ir-192 and I-131 is safe

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