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Fire Test Plan for Spent Nuclear Fuel Transportation Package Using a Scaled-Down Model

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1. Introduction

Safe transport regulation [1] requires that type B packages must be designed to withstand the fire accident condition without a release of radioactive material. This paper presents the fire test plan for CANDU spent fuel transportation cask. The transportation cask can accommodate six fuel baskets loaded with 60 spent fuel bundles. The weight of the cask is approximately 70 tons. Thermal testing using a full scale model of large capacity cask is expensive. Slice models are usually used for the thermal testing of the PWR spent fuel casks with large length-to-diameter ratio. The CANDU spent fuel cask has a cuboid shape. In this study, thermal testing using a scaled-down model is proposed. The purpose of this study is to confirm the effectiveness of fire testing using a scaled-down model.

2. Thermal Analysis Modeling

2.1 Calculation of fire duration for scaled-down model

Regulatory thermal test corresponds to an engulfing fire at 800 ℃ for 30 minutes. Fire durations for the scaled-down models are calculated by the following equations [2].

$$Q_P = A_{SP}\sigma F \frac{T_F{}^4}{M_P} t_R \text{........................ (1)}$$

$$t_S = \frac{Q_P\, M_S}{A_{SS}\, \sigma\, F\, T_F{}^4} \text{ .... (2)}$$

Where,

Q_P: Heat input for prototype cask [J/kg]
A_{SS}: Surface area of scaled-down model [㎡]
σ : Stefan-Boltzmann constant [5.67x $10^{-8}\, W/m^2\, K^4$]
F : View factor for a fully engulfing fire
T_F : Flame temperature [K]
M_P: Mass of the prototype cask [kg]
t_R : Regulatory fire duration [s]
t_S : Fire duration of scaled-down model [s]

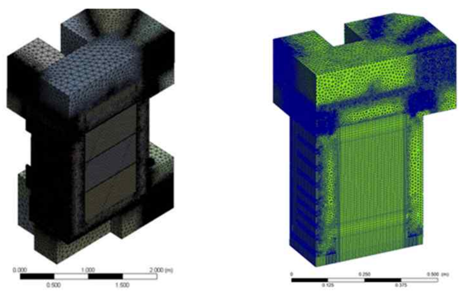
The heat input into the prototype package is calculated as 202,400 J/kg from the Eq. (1). The fire durations of the half-scale and quarter-scale models are calculated to be 15 and 7.5 minutes, respectively.

2.2 Analysis model for transportation cask

Thermal analysis of the transportation cask was performed using the ANSYS Fluent. Fig. 1(a) shows the thermal analysis model. The analysis model consists of about 20 million meshes. The decay heat from the half-scale model is reduced by 1/4 to conserve the cask surface temperature. Total decay heats of the prototype, the half-scale and quarter-scale models are 2,268 W, 567 W and 142 W, respectively. Thermal analyses were conducted for normal and fire accident conditions. The ambient temperature is considered as 38 ℃ with solar insolation and decay heat from the spent fuel for normal condition. The flame temperature is considered as 800 ℃ for 30 minutes for the prototype cask. Fire durations are considered as 15 minutes and 7.5 minutes for the half-scale and quarter-scale models.

2.3 Analysis model for preliminary model

Thermal test and analysis were performed for the quarter-scale preliminary model to verify the thermal performance of the cask. In the preliminary model, a lumped mass was considered in place of the fuel basket, and the bottom of the cask was assumed to be an adiabatic condition excluding the lower shock absorber. Fig. 1(b) shows the thermal analysis for the preliminary model.



(a) Real cask (a) Preliminary model

Fig. 1. Thermal analysis model

3. Results and discussion

3.1 Thermal analysis for transportation cask

Fig. 2 shows the temperature contours of the prototype cask. Tables 1 Table and 2 show the maximum temperatures of the main parts under normal and fire conditions for the prototype cask and half-scale model. The temperature at the cask surface is conserved between the prototype cask and the half-scale model in the normal condition. The temperature difference between the inner and outer walls is reduced to about 1/2 in the half-scale model. Fig. 3 shows the temperature differences between the normal and accident conditions. The temperature differences are similar for the prototype and scaled-down models. Therefore, the overall temperature distributions of the prototype cask could be predicted using the half-scale model.

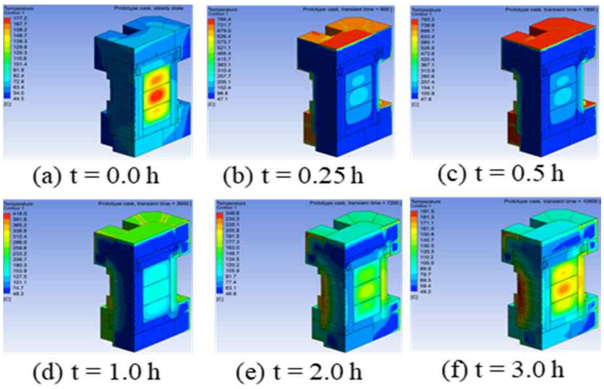


Fig. 2. Temperature contours for prototype cask

Table 1. Thermal analysis results for prototype cask

Location	Maximum temperatures (°C)							ΔT
	Normal	Fire phase		Post fire (t > 0.5 h)				
		0.25	0.5	0.6	0.75	1.0	2.0	
Fuel bundle	177	177	177	177	177	177	177	0
Fuel basket	151	151	151	151	151	151	152	0
Inner shell	71	118	195	212	210	198	176	92
Lid(O-ring)	65	80	129	147	157	155	143	361
Lid carrier	66	278	427	391	351	293	175	511
Carrier housing	65	476	576	479	399	317	187	141
Outer shell	66	353	493	435	380	330	240	667

Table 2. Thermal analysis results for half-scale model

Location	Maximum temperatures (°C)							ΔT
	Normal	Fire phase		Post fire (t>15Min.)				
		7.5	15.0	17.5	22.5	45	90	
Fuel bundle	128	128	128	128	128	128	129	0
Fuel basket	113	113	113	113	113	119	128	6
Inner shell	67	135	213	234	212	185	160	99
Lid(O-ring)	65	99	151	163	164	157	143	329
Lid carrier	65	270	394	368	308	201	158	458
Carrier housing	65	134	523	442	346	209	159	167
Outer shell	65	329	475	430	368	265	179	605

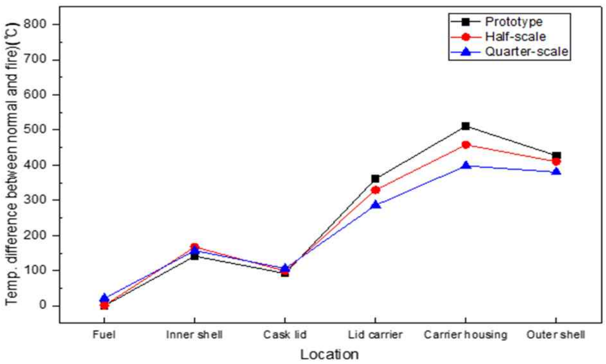


Fig. 3. Temperature differences between normal and fire conditions

3.2 Thermal analysis and verification for preliminary model

Fire test and analysis were conducted using a quarter-scale preliminary model. The initial temperature was assumed to be 20 °C for all parts of the cask. The test model was exposed at 800 °C for 7.5 minutes. Fig. 4 shows the temperature contours for the preliminary model. Table 3 shows the comparison of thermal test and analysis results. The analysis temperatures showed a slightly higher than the test temperatures.

The maximum temperature of the lid O-ring was lower than the allowable value [3]. Therefore, the reliability and conservatism of the thermal analysis results were proved.

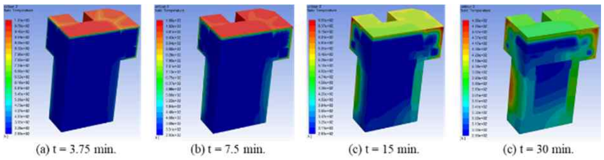


Fig. 4. Temperature contours for preliminary model

Table 3. Thermal test and analysis results for preliminary model

	Max. temp (°C)		Allowable (°C)
	Test	Analysis	
Lid O-ring	62	93	320
Outer shell	325	349	538
Flame	812	800	-

4. Conclusion

The thermal analyses were carried out for the prototype and scaled-down models. It was possible to predict the overall temperature distributions of the prototype cask by using the scaled-down models. Fire test and analysis were conducted using a quarter-scale preliminary model. The reliability and conservatism of the thermal analysis results were proved. Therefore, the effectiveness of the fire testing using a scaled-down model was confirmed. The results of this study can be used for the thermal testing of the cask using a scaled-down model.

ACKNOWLEDGMENTS

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