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Comparison of Open Pool Fire Test according to Season

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1. Introduction

To obtain design approval, the metal cask classified as Type B transport cask need to be able to withstand a temperature of 800 °C for a period of 30 min. Therefore, an open-pool fire test was conducted. It was performed in the presence of the relevant authorities needed for the design approval of the metal cask. It can be carried out in summer or winter depending on various circumstances such as the fabrication method of the test model and the conditions of the institution wherein the test was conducted. Accordingly, an open-pool fire test for design approval was conducted in early summer. The objective of this study is to compare the effect of the flame temperature in the open-pool-fire-test conducted in early summer with that in the test conducted in winter by Bang et al.

2. Fire Test

2.1 Description of the Test Model

The test model was fabricated with the same shape and specifications as those used for the model in the fire test conducted in winter by Bang et al. The test models were one-sixth of the length of a real metal cask; thus, their resistance to thermal conditions could potentially be more severe. Fig. 1 shows the configuration of the test model. The test models had an outer diameter and axial length of 2,384 and 850 mm, respectively. Insulators were installed at both ends of the test models to prevent the high-temperature heat from entering the flame in the axial direction.

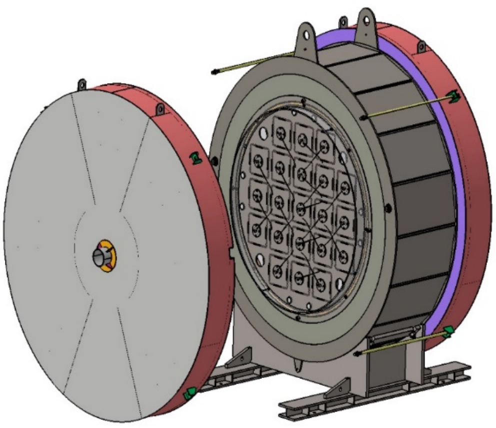

Fig. 1. Schematic of the test model

2.2 Open Pool Fire Tests

As mentioned previously, the open-pool fire test can be carried out in winter and summer depending on various circumstances such as the fabrication of the test model and the conditions of the institution. The open-pool fire test for design approval was performed in the early summer. Since the test generated a large amount of smoke and soot, it was difficult to perform it because of strict environmental regulations. Thus, a smokeless fire testing method was used; the open-pool fire tests were carried out in a smokeless fire test facility with dimensions of 3.5 (W) × 4.0 (L) × 3.0 m (H). In the open-pool fire tests, the test models were exposed for at least 30 min to fully engulfed flames with an average flame temperature of at least 800 °C. After the test was completed, the test model was allowed to cool naturally. In the fire tests, as shown in Fig. 4, a total of 21 thermocouples were installed around the test model to measure the flame temperature of the fire test facility; 9 at the upper part and 6 at the middle and lower parts.

2.3 Results and Discussion

Table 1 lists the average ambient temperature before ignition, the average flame temperature during the open-pool fire test, and the average ambient temperature during the cooling period after the test. In the test, the environmental temperature in the fire test facility before ignition was approximately 25 °C, the average flame temperature during the open-pool fire test was 851 °C, and the average ambient temperature during the cooling period after the open-pool fire test was 21 °C.

Comparing the flame temperatures measured in fire tests, the average flame temperature measured in the fire test conducted in early summer was as high as the difference in the ambient temperature measured in the tests conducted in winter and early summer.

Table 1. Average flame temperature during fire test

Winter			Early Summer		
Before Ignition	Fire	Natural Cooling	Before Ignition	Fire	Natural Cooling
5 °C	834 °C	3 °C	25 °C	851 °C	21 °C

Table 2 lists the maximum and average temperatures measured in the test model during the open-pool fire tests conducted in winter and early summer. Figure 2 shows the temperature profile during the test conducted in early summer. From Table 2, both the maximum and average temperatures of the test model measured in the open-pool fire test conducted in early summer were higher than those in winter.

In the open-pool fire test conducted in early summer, the initial temperature of the basket before the open-pool fire test was 22 °C. The maximum temperature was 57 °C after the fire was extinguished and 20.4 h had passed. Accordingly, the temperature rise in the basket during the open-pool fire test was 35 °C. Therefore, the temperature rise of the spent nuclear fuel rod was expected to be within this range. The results of the open-pool fire tests revealed that the thermal integrity of the metal cask could be maintained at 800 °C for 30 min.

In the open-pool fire test conducted in winter, when the ambient temperature was low, it took a considerable amount of time for the fire to ignite, and it took approximately 3 min for the flame to engulf the model. However, in the test conducted in early summer, when the ambient temperature was relatively high, the time it took to ignite the fire was not as long as it was in winter, and it took approximately 2 min for the flame to engulf the model. This is because the flash point of the kerosene used as a fire source in the open-pool fire test was 38 °C or higher.

Table 2. Temperature of the test model measured in winter and early summer

Temp(°C) / Location	Winter		Early Summer	
	Max.	Aver.	Max.	Aver.
Basket	33	29	58	55
Canister	40	37	64	60
Body	103	60	141	92
NS-4-FR	183	125	151	121
Surface	897	545	957	717

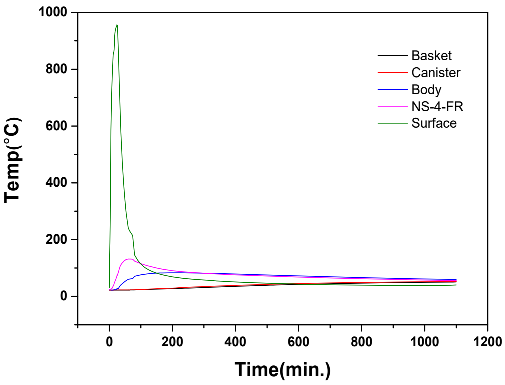

Fig. 2. Temperature history during the open-pool fire test (Early summer)

During open pool fire test, the test model received energy via convection and radiation heat transfer from the flame. Therefore, the heat input for the test model can be calculated as follows [1]:

$$q = hT_F + \sigma \propto \varepsilon F T_F^{\ 4} \quad (1)$$

where h is the convective heat transfer coefficient (10 $W \cdot m^{-2} \cdot °K^{-1}$), T_F is the flame temperature (°K), σ is the Stefan-Boltzmann constant ($W \cdot m^{-2} \cdot °K^{-4}$), α is the package absorptivity (0.8), ε is the flame emissivity, and F is the view factor for a fire that completely engulfs the model.

In the open-pool fire tests conducted in winter and early summer, the test models were estimated to have received 47 and 51 kW/m2 of heat from the flame, respectively. Therefore, the temperature of the test model was higher in the test performed in early summer than it was in the one in winter.

In the test conducted in early summer, it took longer for the high-temperature flame to transfer inside than it did for the flame in the test conducted in winter. This is because the temperature of the test model was higher because of the higher ambient temperature in early summer than it was in winter, and the thermal resistance was slightly greater. In addition, in the test conducted in early summer, it was estimated that the test model received more heat from the flame and took slightly longer to transfer heat to the inside. Accordingly, a more conservative test result could be obtained if the open-pool fire test was carried out in the summer when the ambient temperature was higher than it was in the winter. Therefore, it is more desirable to conduct open-pool fire tests in summer than in winter to evaluate the thermal integrity of a transport cask.

3. Conclusion

The main results are as follows.

i) The average flame temperature measured in the fire test conducted in early summer was as high as the difference in the ambient temperature measured in the fire tests conducted in winter and early summer.
ii) The test model received more heat from the flame in the open-pool fire test performed in early summer than it did from the one in winter. Therefore, both the maximum and average temperatures of the test model were high in the test conducted in the early summer.
iii) In the test conducted in early summer, it took longer for the high-temperature flame to transfer inside than it did for the test conducted in winter due to the higher temperature of the test model, resulting from the higher ambient temperature. Additionally, the overall testing period was longer.
iV) Performing the open-pool fire test in early summer rather than in winter could produce more conservative test results, owing to the high ambient temperature. Therefore, it is more desirable to conduct an open-pool fire test in summer than in winter to evaluate the thermal integrity of a cask.

REFERENCES

[1] Holman, J.P. Heat Transfer, International Student Edition, 5th Edition, 1985.