Experimental Study on the Effect of a Metal Storage Cask and Openings on Flame Temperature in a Compartment Fire

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Compartment fire tests were performed using kerosene and Jet A-1 as fire sources to evaluate the relationship between flame temperature and opening size. The tests were performed for a fire caused by the release of kerosene owing to vehicle impact, and for a fire caused by the release of Jet-A-1 owing to airplane collision. The compartment fire tests were performed using a 1/3-scale model of a metal storage cask when the flame temperature was deemed to be the highest. We found the combustion time of Jet-A-1 to be shorter than that of kerosene, and consequently, the flame temperature of Jet-A-1 was measured to be higher than that of kerosene. When the opening was installed on the compartment roof, even though the area of the opening was small, the ventilation factor was large, resulting in a high flame temperature and long combustion. Therefore, the position of the opening is a crucial factor that affects the flame temperature. When the metal storage cask was stored in the compartment, the flame temperature decreased proportionally with the energy that the metal storage cask received from the flame.

Keywords: Compartment fire, Flame temperature, Opening, Metal storage cask

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1. Introduction

The management of spent nuclear fuel generated at nuclear power plants has become a major policy issue owing to continued delays in obtaining a safe and permanent disposal facility. Most nuclear power plants store their spent nuclear fuel in wet storage pools. However, after decades of use, most storage pools have reached their maximum capacity. For the nuclear industry, finding sufficient capacity for the storage of spent nuclear fuel is essential if nuclear power plants are to be allowed to continue operating.

In the USA, spent nuclear fuel assemblies are currently stored in various dry storage systems: metal casks, concrete casks, horizontal modules, and vaults. In the EU and Japan, spent nuclear fuel assemblies are mainly stored in metal casks. The USA has operated various dry storage systems in open air. The EU and Japan store metal casks within storage buildings. Korea is planning to construct interim storage facilities using a dry storage method to store spent nuclear fuel discharged from nuclear power plants.

Storage systems should be able to withstand accidents, such as a fire from the release of jet fuel after an airplane collision. Thus far, the evaluation of fire accidents has been mainly conducted under kerosene conditions. However, the regulatory requirement for a Type C package specifies that the package must be exposed to luminous flames from a pool fire of JP-4 or JP-5 aviation fuel for a period of at least 60 min [1–3]. In addition, the need for an evaluation under aviation fuel conditions has been elevated since the 9–11 terror attacks. Consequently, Greiner (Nevada University) and Lopez (Sandia National Laboratories: SNL) performed research on fire accidents using jet fuel [4, 5]. In Germany, Wenzel Brücher (Gesellschaft für Anlagen- und Reaktorsicherheit: GRS) and Bruno Thomauske (Bundesamt für Strahlenschutz: BfS) conducted a study of fire accidents that occurred after an aircraft had collided with interim storage facilities (STEAG and WTI type buildings) [6, 7]. If an interim storage facility is provided in Korea, there is a possibility that a method of storing storage cask in

buildings, such as Europe or Japan, will be selected. Therefore, it is necessary to evaluate the characteristics of the compartment fire and the fire characteristics when the storage cask in the building is stored.

In this paper, compartment fire tests were performed using kerosene and Jet-A-1 as fire sources under compartment conditions to evaluate the flame temperature according to the opening size in a fire from the release of kerosene as a result of vehicle impact, and a fire from the release of Jet-A-1 as a result of an airplane collision. For a metal storage cask stored in a compartment, the flame temperature was also evaluated over a prolonged period of time. It is expected that the results obtained in this study can be used as basic reference data for cask storage facilities in the future.

2. Compartment Fire test

The size of the compartment and test model was determined by the budget. In addition, the fire test generates a great deal of smoke and soot and is difficult to perform because of strict environmental regulations. Therefore, the fire test should be carried out in the Korean Fire Protection Association where the smoke and soot collection equipment is prepared.

2.1 Description of the Fire Test Facility

As shown in Fig. 1, the fire test facility was constructed as a compartment, 4 (W) × 4 (L) × 4 m (H) in size, using light concrete, 10 cm thick. Openings were made in the front and rear sides of the compartment. The size of each opening was designed to be controlled: from 40 (H) × 70 cm (W) to 50 (H) × 80 cm (W). On the roof, a 30 cm diameter hole was designed with the intention of creating a chimney effect.

All thermocouples used in these tests were of a Type K, sheathed in inconel tubing, ungrounded, and insulated using magnesium oxide. Fig. 2 shows the locations of the

Fig. 1. Fire test facility.

thermocouples installed in the compartment. A total of 63 thermocouples were installed at heights of 80, 200, and 320 cm above the inner floor of the compartment, to measure the flame temperature in it. Ten of the thermocouples were selected and calibrated at 100, 300, and 800℃. In addition, their uncertainty was found to be ±1.0℃ at a 95% confidence level.

2.2 Heat Transfer Mode and Measurement System

A fire in the compartment may progress in four phases, as shown in Fig. 3. In addition, a fire in a compartment is affected by the heat release rate, enclosure size, enclosure construction, and enclosure ventilation [8]. The heat transfer in a compartment fire occurs by convection and radiation from the enclosure, and conduction through the walls. Heat is generated by the fire source within the compartment and transferred from the combustion zone to the upper layer through convection and radiation. This heat is then transferred to the adjacent wall by radiation and conduction, and to the compartment lower layer by radiation. Furthermore, this heat is then transferred to the ambient atmosphere by convection through the openings.

The temperature data acquisition system used in the compartment fire test consisted of a thermocouple scanner, a signal conditioner, an A/D converter, and a PC. The signal, detected by the thermocouple scanner, was filtered
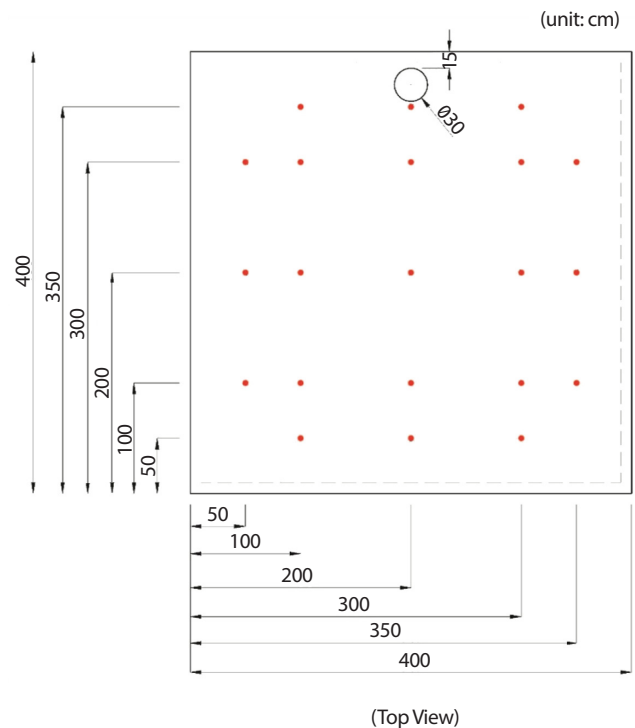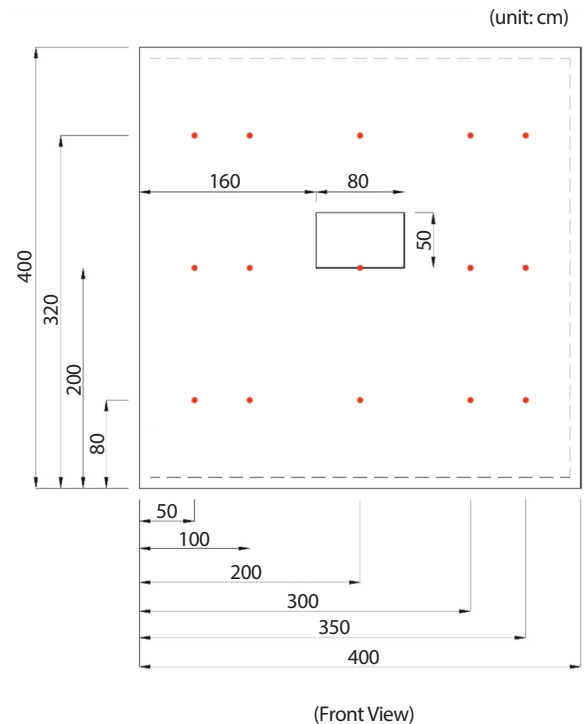

(Front View)

(Top View)

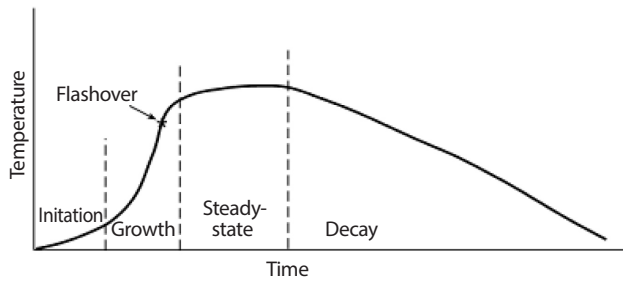Fig. 2. Location of thermocouple installed in the compartment.

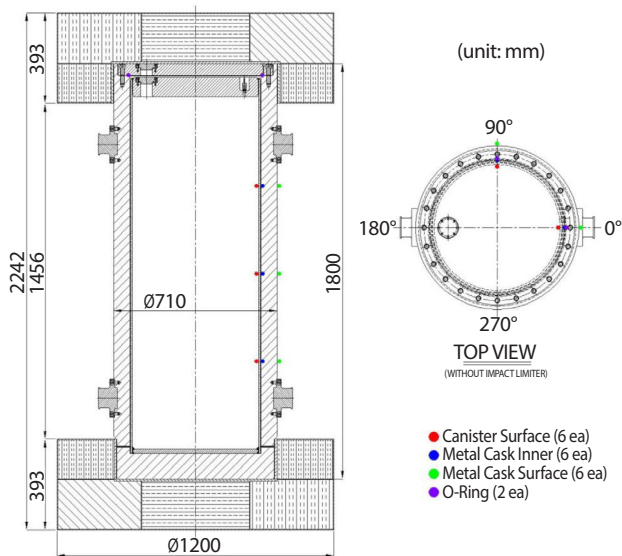Fig. 3. Phases of fire development in the compartment fire.

Fig. 4. Cross section of the fire test model.

and amplified through the signal conditioner, and converted from an analog signal to a digital signal through the A/D converter. This signal was then stored and analyzed using PC-based software.

2.3 Metal Storage Cask Test Model

The compartment fire test was performed using a 1/3 scale model of the metal storage cask. The body of metal storage cask was made of carbon steel. The lid was made of stainless steel and fixed to the cask body by stud bolts and cap nuts. The baskets containing the spent fuel assemblies were made of stainless steel. Fig. 4 shows the temperature

measurement points in the cross section of the metal storage cask test model. A total of 20 thermocouples were installed. These thermocouples were located on the containment seal, the exterior and interior surfaces of the cask body, and the canister surface.

2.4 Compartment Fire Test

Compartment fire tests were performed using kerosene and Jet-A-1 as fire sources under compartment conditions to evaluate the flame temperature according to the opening size. In addition, the compartment fire test was performed using a 1/3 scale model of the metal storage cask under test conditions in which the flame temperature was deemed to be the highest measured.

2.4.1 Compartment Fire Test using Kerosene

Compartment fire tests using kerosene as the fire source were carried out for three cases in accordance with the size of the opening. In the first case, the compartment fire test was performed by using 350 l of kerosene as the fire source in the compartment. The compartment consisted of one opening on the front and rear sides, respectively. The size of the both openings was 50 (H) × 80 cm (W). In the second case, the compartment consisted of one opening on the front and rear sides, and one roof opening. To increase the flame temperature, the size of the opening was 50 (H) × 80 cm (W) on both sides, with a 30 cm diameter hole on the roof. The compartment was then filled with 50 l of kerosene. In the third case, the compartment consisted of one opening on the front and rear sides, and one roof opening. The size of side openings was 40 (H) × 70 cm (W), with a 30 cm diameter hole on the roof. The compartment was then filled with 50 l of kerosene.

2.4.2 Compartment Fire Test using Aviation Fuel

The compartment fire tests were also performed using aviation fuel as a fire source under compartment conditions to evaluate the flame temperature according to the

Fig. 5. Compartment fire test.

Fig. 6. 1/3 scale model of the metal storage cask in the compartment.

opening size in a fire from the release of jet fuel involving an airplane collision. The compartment fire tests using aviation fuel as the fire source were carried out for three cases in accordance with the size of the opening. JP-4 fuel is difficult to obtain as it is used by the military. Jet-A-1, however, is easier than JP-4 to obtain, but only through the refueling team of the Korea Airport Service. Consequently, we used Jet-A-1 as the aviation fuel in the compartment fire test.

In the first case, the compartment fire test was performed by filling the compartment with 50 l of Jet-A-1 as the fire source. The compartment consisted of one opening on the front and rear sides, respectively. The size of the side openings was 50 (H) × 80 cm (W). In the second case, the compartment consisted of one opening on the front and

rear sides, and one opening on the roof. The size of the side openings was 50 (H) × 80 cm (W), with a 30 cm diameter hole on the roof. The compartment was then filled with 50 l of Jet-A-1. In the third case, the compartment consisted of one opening on the front and rear sides, and one opening on the roof. The size of the side openings was 40 (H) × 70 cm (W), with a 30 cm diameter hole on the roof. The compartment was then filled with 50 l of Jet-A-1.

2.5 Compartment Fire Test using 1/3 Scale Model of the Metal Cask

The compartment fire test was performed using a 1/3 scale model of the metal storage cask. Fig. 6 shows the 1/3 scale model of the metal storage cask installed in the compartment. The compartment consisted of one opening on the front and rear sides, and one opening on the roof. The size of the side openings was 50 (H) × 80 cm (W), with a 30 cm diameter hole on the roof. The compartment was then filled with 170 l of Jet-A-1.

3. Results and Discussion

Table 1 shows comparisons of the average engulfed flame temperature, engulfed flame time, and fuel consumption measured during the compartment fire tests.

In the case of the compartment fire test using kerosene: In the first case the compartment fire test was performed by filling the compartment with 350 l of kerosene as the fire source. This quantity of fuel burned in an open pool 4 × 3.5 m in size, for approximately 10 min. However, the engulfed flame time was more than 2 h in the compartment fire. In addition, the average engulfed flame temperature was 561℃ in the upper section of the compartment. The temperature measurement in the middle and lower sections failed as the temperature data acquisition system had a software problem. In the second case, the engulfed flame time was approximately 15 min. The average engulfed flame tempera-

Table 1. Engulfed flame temperature and time

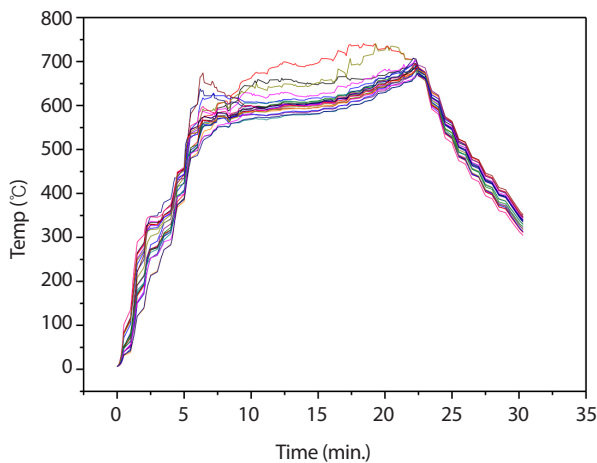|		Engulfed Flame Temp. (℃)			Engulfed Flame Time (min.)	Fuel (liter)
		Upper Part	Middle Part	Lower Part		
Kerosene	First case	561	-	-	120	350
	Second case	675	-	-	15	50
	Third case	611	-	-	23	50
Jet-A-1	First case	618	602	551	15	50
	Second case	692	677	616	12	50
	Third Case	646	623	568	17	50

Fig. 7. Flame temperature in during the first fire test (upper part).

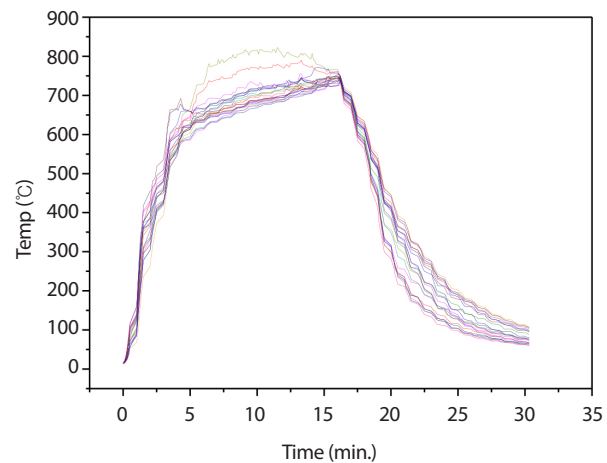
Fig. 8. Flame temperature in during the second fire test (upper part).

ture was 675℃ in the upper section of the compartment. In the third case, the engulfed flame time was approximately 23 min. The average engulfed flame temperature was 611℃ in the upper section of the compartment.

In the case of the compartment fire test using Jet-A-1: In the first case, the engulfed flame time was approximately 15 min. The average engulfed flame temperature was 618℃ in the upper section of the compartment, 602℃ in the middle section, and 551℃ in the lower section. In the second case, the engulfed flame time was approximately 12 min. The average engulfed flame temperature was 692℃ in the upper section of the compartment, 677℃ in the middle section, and 616℃ in the lower section. In the third case, the engulfed flame lasted for approximately 17 min. The av-

erage engulfed flame temperature was 646℃ in the upper section of the compartment, 623℃ in the middle section, and 568℃ in the lower section.

In the case of the compartment fire test using Jet-A-1, the maximum flame temperatures in the three case were 778℃, 851℃, and 779℃ in the vicinity of the opening, respectively. This was because the convective heat transfer increased as the air flowed into the opening. The temperature profiles of the flame in the first and second cases are shown in Figs. 7 and 8, respectively. As can be seen in these figures, the engulfed flame temperature continuously increased during the compartment fire tests. NUREG-1805 states that the temperature of the flame in the compartment fire increased gradually, and reached 1,260℃ after an

Table 2. Heat release rate and mass flow rate

		Heat release rate (kJ·s⁻¹)	Mass flow rate (kg·s⁻¹)	Effective Constant (k₀)	Combustion time (s)
		Heat release rate (kJ·s^{-1})	Mass flow rate (kg·s^{-1})	Effective Constant (k_0)	Combustion time (s)
Kerosene	First case	1,722	0.040	0.070	7200
	Second case	1,905	0.044	0.078	900
	Third case	1,283	0.030	0.084	1380
Jet-A-1	First case	1,920	0.044	0.078	900
	Second case	2,400	0.055	0.098	720
	Third Case	1,694	0.039	0.110	1020

elapsed time of 8 h [9].

In the compartment fire, a crucial factor influencing the flame temperature is the heat release rate. The heat release rate in the compartment fire can be calculated as follows [10]:

$$\dot{Q} = \begin{cases} \dot{m}_f\,\Delta h_c, & \text{Ø} < 1 \\ \dot{m}_{air}\,\Delta h_{air}, & \text{Ø} \geq 1 \end{cases} \tag{1}$$

$$\dot{m} = k_0 A_0 \sqrt{H_0} \tag{2}$$

$$\dot{m} = \rho L / t \tag{3}$$

where $\dot{Q}$ is the heat release rate (kW), $\dot{m}$ is the mass flow rate (kg·s⁻¹), Δh is the effective heat of combustion (kJ·kg⁻¹), Ø is the equivalence ratio, k_0 is the effective constant (kg/s. m^{5/2}), A_0 is the flow area (m²), H_0 is the height of the opening (m), ρ is the density of fuel (kg·m⁻³), L is the amount of fuel (m³), and t is the combustion time (s).

The effective heat of combustion of kerosene is 43,200 kJ·kg⁻¹ [9]. The effective heat of combustion of Jet-A-1 is 43,333 kJ·kg⁻¹, which was calculated based on the results of the quality assurance performance in accordance with the ASTM method by SK energy Co., Ltd [11].

Table 2 shows the heat release rate and mass flow rate calculated during the compartment fire tests. As can be seen in Table 2, the heat release rate and mass flow rate of Jet-A-1 were larger than those of kerosene. Consequently, the combustion time of Jet-A-1 was shorter than that of kerosene, and the flame temperature of Jet-A-1 was higher than

that of kerosene. The heat release rate and mass flow rate in the second case of the compartment fire test using Jet-A-1 were the largest at 2,400 kJ·s⁻¹ and 0.055 kg·s⁻¹, respectively. Therefore, we know that the flame temperature was highest when the size of the opening was large.

In the compartment fire, the mass flow rate depended on the ventilation factor, which in turn depended on the size, shape, and position of the opening. For a compartment with more than one opening, the ventilation factor can be calculated as follows:

$$A\sqrt{H} = \sum_i A_i \sqrt{H_i} \tag{4}$$

where A is the fuel surface area (m²) and H is the height of the opening (m).

For a compartment with a horizontal opening on the roof, the ventilation factor can be determined from the alignment chart in Fig. 9 [12].

Table 3 shows the ventilation factor according to the area and location of the opening. As can be seen in Table 3, the area of the opening in the second case was the largest. The ventilation factor was the largest in the second case, too. Therefore, we know that the flame temperature in the second case was the highest. If the first and third cases are compared, however, the area of the opening in the first case was larger than that of the third case, but the ventilation factor in the third case was larger than that of the first case. As can be seen in Table 1, the flame temperature in the third case

Table 3. Ventilation factor according to the area and location of the opening

	Opening Area (m^2)				Ventilation factor (m$^{5/2}$)			
	Front	Rear	Roof	Total	Front	Rear	Roof	Total
First case	0.4	0.4	-	0.8	0.283	0.283	-	0.566
Second case	0.4	0.4	0.07	0.87	0.283	0.283	0.396	0.962
Third Case	0.28	0.28	0.07	0.63	0.177	0.177	0.248	0.602

Table 4. Test results of compartment fire using the metal storage cask

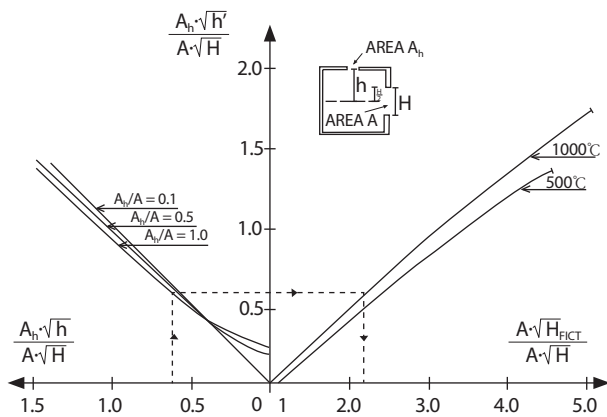| Temperature (℃)							Engulfed Flame Time (min.)	Fuel (liter)
Flame			Metal Cask		Canister Surface	O-ring		
Upper Part	Middle Part	Lower Part	Surface	Inside				
701	707	608	357	337	247	171	40	170

Fig. 9. Alignment chart for the calculation of the value of the modified ventilation factor [12].

was higher than that of the first case. When the opening was installed on the roof, even though the area of the opening was small, the ventilation factor was large, the temperature of the flame was high, and the burning time was significant. Therefore, we know that the position of the opening is a crucial factor influencing the flame temperature.

The compartment fire test was performed using a 1/3 scale model of the metal storage cask under the condition which the flame temperature was deemed to be the highest measured. The compartment fire test results obtained using the 1/3 scale model of the metal storage cask are summarized in Table 4. The engulfed flame time continued for approximately 40 min. The average engulfed flame temperature was measured to be 701℃ in the upper section of the compartment, 707℃ in the middle section, and 608℃ in the lower section. In the compartment fire tests conducted to evaluate the flame temperature in the compartment, the flame temperature in the upper section was the highest. However, another trend was exhibited in the compartment fire test performed using the 1/3 scale model of the metal storage cask. The flame temperature was the highest in the middle section. It is thought that the convective heat transfer increased because the 1/3 scale model was installed near the opening.

In the case of the compartment fire test using Jet-A-1: In the second case, the engulfed flame lasted for approximately 12 min. The average engulfed flame temperature was 692℃ in the upper section of the compartment, 677℃ in the middle section, and 616℃ in the lower section. However, in the case of the compartment fire test using a 1/3 scale model of the metal storage cask, the engulfed flame temperature for 12 min was observed to be 633℃ in the upper section of the compartment, 621℃ in the middle section, and 510℃ in the lower section.

In the compartment fire, heat was generated by the combustion of Jet-A-1 and transferred to the surface of the metal storage cask through convection and radiation. This heat was then transferred from the surface of the metal storage cask to the inner part of the metal storage cask through conduction. During a compartment fire, the metal storage cask receives energy via convection and radiation heat transfer from the flame. The heat input for the 1/3 scale model of the metal storage cask can be calculated as follows:

$$q = hAT_F + \sigma\varepsilon AFT_F^4 \qquad (5)$$

where h is the convective heat transfer coefficient (10 W·m^{-2}·°K^{-1}) [13], A is the surface area (m^2), T_F is the flame temperature (°K), σ is the Stefan-Boltzmann constant (W·m^{-2}·°K^{-4}), ε is the flame emissivity, and F is the view factor for a fully engulfing fire.

The 1/3 scale model of the metal storage cask was estimated to have received 105 kW of heat from the flame in the compartment fire. Therefore, it is thought that the flame temperature of the compartment decreased by as much as the energy that the metal cask received from the flame.

The regulations related to dry storage cask do not describe specific conditions related to fire accidents. However, in the NUREG-1536, Section 2, the following passage regarding fire accident conditions, states [14].

(3) Accident Conditions (c) "Fire: The fire conditions postulated in the SAR should provide an "envelope" for subsequent comparison with site-specific conditions. The NRC accepts the methods discussed in 10 CFR 71.73(c)(4)."

10CFR 71.73(c)(4) states that a Type B package for transportation of radioactive materials should be able to withstand a period of 30 min under a thermal condition of 800℃. However, the average flame temperature and fire duration in the compartment fire test using a 1/3 scale model of the metal cask were such that the average flame temperature was 672℃ and the fire duration was 40 min. Thus, we should be able to estimate the fire duration for a flame temperature of 800℃.

The fire duration for the full-scale cask is determined by comparing the full-scale metal storage cask regulatory heat input to the 1/3 scale model specific heat input. The specific heat input for the 1/3 scale model is calculated as follows:

$$Q_M = (hT_F + \sigma\varepsilon FT_F^4) A_M \frac{\tau_M}{M_M} \qquad (6)$$

where Q_M is the specific heat input per unit mass of the 1/3 scale model (J·kg^{-1}), A_M is the surface area of the scale model (m^2), τ_M is the compartment fire duration (s), and M_M (2,714 kg) is the mass of the 1/3 scale model.

The fire duration for the full-scale metal storage cask was calculated as 4,773 s (79.6 min) based on the following equation:

$$\tau_F = \frac{Q_M M_F}{A_F (hT_F + \sigma\varepsilon FT_F^4)} \qquad (7)$$

where, A_F is the surface area of the full-scale metal storage cask (m^2), and M_F (73,269 kg) is the mass of the full-scale metal storage cask.

The main concerns when conducting a fire test are the peak temperature of the cask body and the seal temperature at the containment boundary. In the compartment fire test, the maximum surface temperatures of the cask body and the canister were 357 and 247℃, respectively. The allowable temperature for short-term exposure, during which the structural strength of carbon steel remains constant, is 538℃ [15]. The maximum surface temperature of the cask body was lower than the permitted maximum temperature limit. The maximum temperatures of the containment seal, measured using the thermocouples installed on the lid along the depth of the seal, was 171℃. According to the temperature range presented in the Parker O-ring Handbook, it is recommended that fluorocarbon be kept below a temperature of 204℃ [16]. In the compartment fire test, the maximum temperature of the containment seal was lower than

that recommended by the manufacturer. The maximum temperatures of the cask body and the containment seal were lower than the permitted maximum temperature limits. Therefore, the thermal integrity of the components of the metal storage cask was considered to have been maintained.

4. Conclusions

Compartment fire tests were performed using kerosene and Jet-A-1 as fire sources under compartment conditions to evaluate the flame temperature in a fire from the release of kerosene due to vehicle impact, and a fire from the release of Jet-A-1 due to the collision of an airplane. The main results were as follows:

(i) The combustion time of Jet-A-1 was shorter than that of kerosene because the effective heat of combustion of Jet-A-1 was bigger than that of kerosene. Therefore, the flame temperature in Jet-A-1 was higher than that of kerosene.

(ii) As the opening and ventilation factor increased, the fuel consumption rate also increased. Therefore, when the size of the opening and ventilation factor were large, the flame temperature was high.

(iii) When the opening was installed on the roof, even though the area of the opening was small, the ventilation factor was large, the flame temperature was high, and the burning time was long. Therefore, the position of the opening is an important factor affecting the flame temperature.

(iv) When a metal storage cask was stored in a compartment, the flame temperature of the compartment decreased by as much as the energy the metal storage cask received from the flame.

Acknowledgements

REFERENCES

[1] Nuclear Safety and Security Commission, Regulations for the Safe Transport of Radioactive Material, NSSC Notice No. 2019-7 (2019).

[2] International Atomic Energy Agency, Regulations for Packaging and Transportation of Radioactive Material, IAEA Safety standard Series No. SSR-6 (2018).

[3] United States Nuclear Regulatory Commission, Packaging & Transportation of Radioactive Material, U.S. Code of Federal Regulations, Title 10, Part 71 (2005).

[4] M. Greiner, M. del Valle, C. Lopez, V. Figueroa, and E. Abu-Irshaid, "Thermal Measurements of a Rail-Cask-Size Pipe-Calorimeter in Jet Fuel Fires", Proc. of ASME 2009 Heat Transfer Summer Conference, HT2009-88520, 173-181, July 19-23, 2009, San Francisco.

[5] V.G. Figueroa, C. Lopez, and V.F. Nicolette, "Regulatory Fire Test Requirements for Plutonium Air Transport Packages: JP-4 or JP-5 vs. JP-8 Aviation Fuel", Proc. of the PATRAM 2010 Conference, October 3-8, 2010, London.

[6] W. Brücher, M. Röwekamp, and V. Kunze, "FDS3 Simulations of Indoor Hydrocarbon Fires Engulfing Radioactive Waste Packages", Proc. of the PATRAM 2004 Conference, September 20-24, 2004, Berlin.

[7] B. Thomauske, "Realization of the German concept for interim storage of spent nuclear fuel-current situation and prospects", Proc. of the Waste Management '03 Conference, February 23-27, 2003, Tucson, AZ.

[8] J.G. Quintiere, Principles of fire behavior, 2nd ed., 267-269, CRC Press, New York (2017).

[9] United States Nuclear Regulatory Commission, Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program, U.S. NRC Report, NUREG-1805 (2004).

[10] J.G. Quintiere, Fundamentals of Fire Phenomena, 339-355, Wiley, England (2006).

[11] J.S. Han, S.J. Kim, and Y. Kim, "Effect of droplet length on a burning constant rate of suspended

droplet", J. of the Korean Society of Propulsion Engineers, 6(1), 47-54 (2002).

[12] S.E. Magnuson and S. Thelandersson, Temperature-Time curves of Complete Process of Fire Development- Theoretical Study of Wood Fuels in Enclosed Spaces, Acta Politechnica Scandinavica, Ci 65, 34-38, Royal Swedish Academy of Engineering Sciences, Stockholm (1970).

[13] International Atomic Energy Agency, Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material, IAEA Safety Standards No. SSG-26 (2012).

[14] United States Nuclear Regulatory Commission, Standard Review Plan for Spent Fuel Dry Cask Storage Systems, U.S. NRC Report, NUREG-1536 (2010).

[15] American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Class 1 Components in Elevated Temperature Service, 1995 Code Case, Nuclear Components, ASME Code Case N-47-33 (1995).

[16] Parker Seal Company, Parker O-Ring Handbook, Catalog ORD 5700/US, 18 (2007).