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An Experimental Investigation of the Correlation between Lid Displacement and Release Rate of Transport Cask

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1. Introduction

Considering the domestic situation where all nuclear power plants are located on seaside, the interim storage site of spent nuclear fuel is also likely to be located on coastal site. Maritime transportation is inevitable and the its risk assessment is very important for safety [1-2]. Technology development is necessary to assess the effect of transportation accidents and establish the regulatory framework to assess, mitigate, and prevent maritime transportation accidents causing serious radiological consequences. Previous studies show that the release rate of radionuclides contained in a submerged transport cask is significantly affected by the area of flow path generated at the breached containment boundary. CRIEPI investigated the effect of cask containment on the release rate of radioactive contents into the ocean and proposed a procedure to calculate the release rate considering the so-called barrier effect. However, the contribution of O-ring on the release rate was not considered in the work.
In this study, test and analysis is performed to determine the equivalent flow path gap considering the influence of O-rings. To evaluate the release rate as a function of lid displacement, a small containment vessel is engineered and a metal O-ring of the Helicoflex HN type is installed, which is the most commonly used one in transport and storage casks. The lid of containment vessel is displaced in vertical and horizontal direction and the release rate of the vessel was quantified using the helium leak test and the pressure drop test. Through this work, the relationship between the vertical opening displacement and horizontal sliding displacement of the cask lid and the actual flow path area created is established. This will be implemented in the CFD model for flow rate calculation from a submerged transport cask in the deep sea.

2. Test model design methods and result

2.1. Evaluation of leak path generation.

According to precedent research, the rate of radionuclide escape from a flooded containment is strongly influenced by the flow area of the containment boundary. As the containment boundary is expected to be very small even if a loss of containment flow is generated due to severe accident conditions, it is reasonable to consider the effect of delayed release, such as the barrier effect model. However, before considering the barrier effect, it is necessary to evaluate the release area and release rate according to the accident severity through the evaluation of leak path generation.

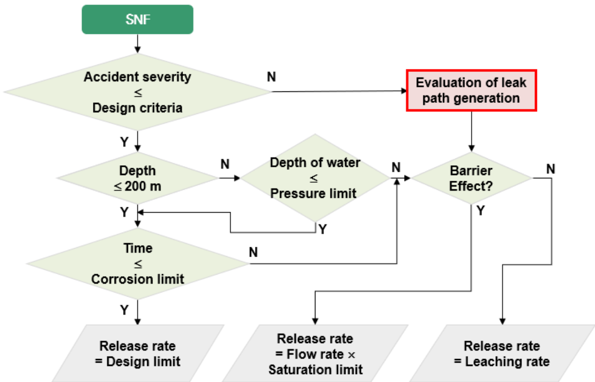
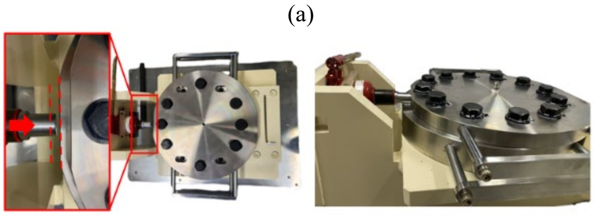


Fig. 1 Radioactive material ocean release scenario

2.2. Test model design

Assuming that damage to the containment boundary occurs in the vertical and sliding directions, the small containment vessels are designed to apply lid displacement in the vertical and sliding directions.
Vertical opening small containment vessel (A-type) use bolts and spacers to apply the targeted displacement. The slide-opening small containment vessel (B-type) is designed together with a piece of equipment to apply the sliding displacement to the lid, as shown in Fig. 2 (b).

(a)



(b)

Fig. 2 (a) Vertical opening small containment cask (A-type) (b) Slide-opening small containment cask (B-type)

2.3. Test method

From the helium leak test and the pressure drop test, the release rate can be derived from Eq. (1).

(1) $Q = \frac{\Delta P \cdot V}{t}$

According to Amesz's research, when an applied displacement is applied to a small containment cask, instead of a uniformly sized gap as shown in Fig. 3, a number of small tubes are formed, which are represented by capillaries. Depending on the diameter and pressure of the capillary, the nature of the flow through the capillary is categorized into viscous and molecular flow [3]. The gap size in this study is in the range of viscous flow, and we can use Poiseuille's law, which is used in the case of viscous flow.

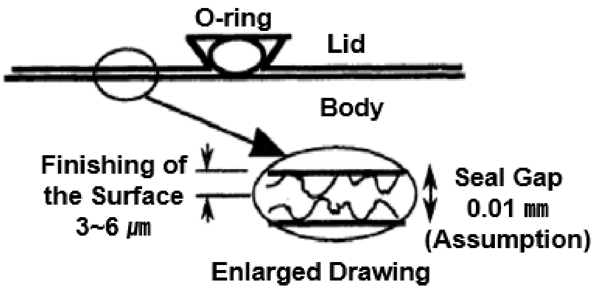


Fig. 3 Capillaries in containment cask gaps [3].

By evaluating the pressure drop test and the helium leak test at different hold pressures, pressures and release late in Eq. 2 can be obtained, and the average diameter of the capillary can be found.

(2) $D = 31 \cdot \eta_g \cdot \frac{P_A Q_{gB} - P_B Q_{gA}}{P_B^2 Q_{gA} - P_B^2 Q_{gB}} \cdot \mu$

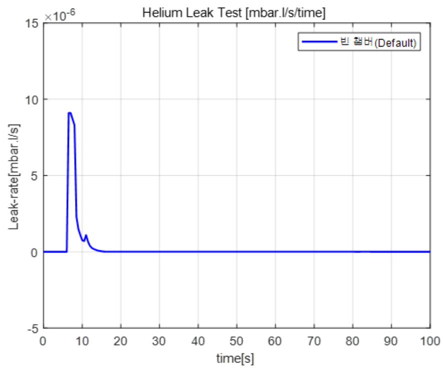
Substituting average diameter of the capillary from Eq. 2 into Poiseuille's law, Eq. 3, we can finally derive the amount of fluid flowing through the capillary per unit time.

(3) $Q_g = \frac{\pi}{256} \times 10^{-8} \times \frac{D^4}{L} \times \frac{p_1^2 - p_2^2}{\eta_g}$

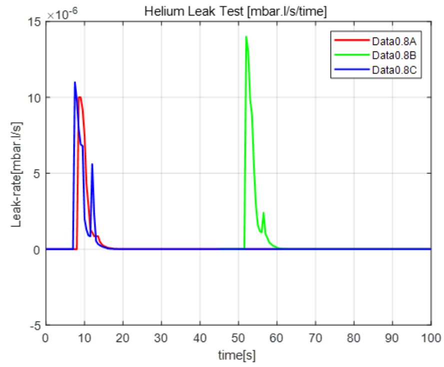
Through this work, the relationship between the vertical opening displacement and horizontal sliding displacement of the cask lid and the actual flow path area created is established. Furthermore, once this relationship is established, it can be applied to CFD and analyzed computationally for appropriate range of gap width.

2.4. Test result

Fig. 4 (a) is the result of the test after inserting a small containment cask with no internal pressure (Default), and Fig. 4 (b) is the result of the helium leak test at internal pressures of 0.5, 1.0, and 1.5 MPa with a gap of 0.8 mm. Compared to the default value, there is no release when the gap is 0.8 mm. The reason for testing with different pressures is to use Equation 2. Further testing at different gap lengths and pressures will be plan conducted to evaluate the release rate.



(a)



(b)

Fig. 4 (a) the result of the helium leak test at small containment cask with no internal pressure, (b) the result of the helium leak test at internal pressures of 0.5, 1.0, and 1.5 MPa with a gap of 0.8 mm.

3. Conclusion

Using Helicoflex HN type metal O-rings, which are most commonly used in spent nuclear fuel containment, a small cask model was designed considering the design and test conditions of the O-rings. Using the small cask model, the release rate is derived through helium leak test and pressure drop test. Based on the results of the helium leak test and pressure drop test, the relationship between the accident severity and the actual release area is quantified. For small release rates, the capillary mean diameter equation, Poiseuille's law, etc. can be used to derive the flow rate. Furthermore, it will be possible to combine testing and CFD model of the release area.

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