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Development of Model for Radionuclides Release Rate Calculation from A Transport Cask Submerged in the Deep Sea

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1. Introduction

Considering the domestic situation that all nuclear power plants are located along the coast, it is highly likely that intermediate storage facilities will also be located along the coast and maritime transportation is inevitable. 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. The maritime transportation risk assessment codes used in advanced nuclear power countries include MARINRAD, POSEIDON, and CRIEPI's Barrier Effect Model. In this study, as a step toward developing the maritime transportation risk assessment code considering the domestic situation, the barrier effect is implemented with more reasonable Computational Fluid Dynamics (CFD) techniques to evaluate the rate of radionuclide leakage and compare it with the CRIEPI model.

2. Methods and Results

Two models are developed using the sub-modeling technique: a full field model for the evaluation of fluid flow and heat exchange around a submerged cask, and a local field model for release rate calculation. They are compared with CRIEPI's Barrier Effect Model.

2.1 Barrier Effect

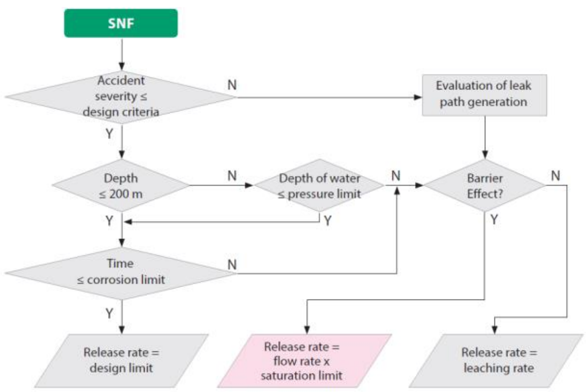

Fig. 1. Radioactive material ocean release scenario.

In MARINRAD, it was assumed that all the radioactive contents in the submerged cask leach out and were released to the ocean. CRIEPI's model considers that the leaching rate was suppressed if the flow path generated at the containment boundary was small. The leaching rate was kept constant equal if the concentration reaches the saturation limit. The effect was called as the barrier effect. The Spent Nuclear Fuel (SNF) cask had design criteria to maintain structural integrity in various accidents. Therefore, even if the flow path was created in the cask during an accident, it was likely that the size was tiny. CRIEPI's model simply calculates the release rate as the flow velocity formula due to buoyancy in a natural convection situation. In this study, the release rate was calculated using CFD for natural convection and forced convection.

2.2 An Outline

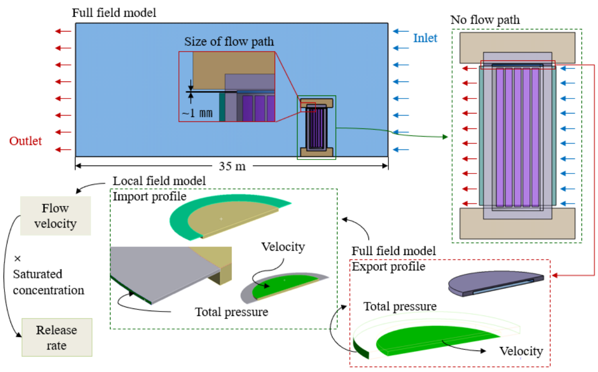

Fig. 2. Schematic diagram.

The final goal was to develop the maritime risk assessment code. In this study, the flow velocity was calculated using CFD to develop a model simulating the barrier effect. A reference transport cask with 21 fuel assemblies was considered. It was assumed the cask was submerged in the deep sea and the containment boundary was damaged in an accident, resulting in a flow path. The flow path to consider the barrier effect was very tiny compared to the size of the outer flow field, the simulation of flow through the breached containment boundary was computationally almost impractical. Thus, the sub-modeling technique was adopted. In the full field model, the breach in the containment boundary was not considered. The flow field and pressure distribution around the flow path was exported to the local field model and the flow rate was calculated.

2.3 Full Field Model

Among domestic SNF stored, PLUS7 occupied the largest portion of 20.7% as of 2019 [1]. Thus the PLUS7 was considered as the contents of the submerged transport cask. The fuel assemblies were simplified by the Porous model method proposed by the U.S. DoE [2]. The anisotropic effective thermal conductivity used was shown in Table I. In this study, fluent 2021 R2, a commercial code, was used. The viscous flow in the inner and outer boundary layers of the cask was calculated using the Grashof number and the Reynolds number. It was showed that the inside flow was transition flow and the outside flow was turbulent flow. Since the characteristics of turbulence were more dominant in the transition flow, the SST k-omega model, which was the turbulence model, was used. the thermal properties were shown in Fig. 4 [3]. A burn-up of 45 GWd/MTU and the cooling period of 10 years were assumed [4]. The temperature of the external seawater was 15 ℃, and the forced convection situation with the flow velocity of 0.1 m/s was assumed. Since the decay heat of one bundle of the nuclear fuel assembly was 800 W and 21 assemblies were loaded, the total decay heat was set to 16.8 kW. The analysis results were shown in Figure 5.

Table I: Anisotropic effective thermal conductivity

Temperature [℃]	Thermal conductivity [W/m-K]	
	X, Y axis	Z axis
104.85	0.4154	3.5515
211.85	0.5608	3.1984
321.85	0.7684	3.0115
432.85	1.0177	2.9492

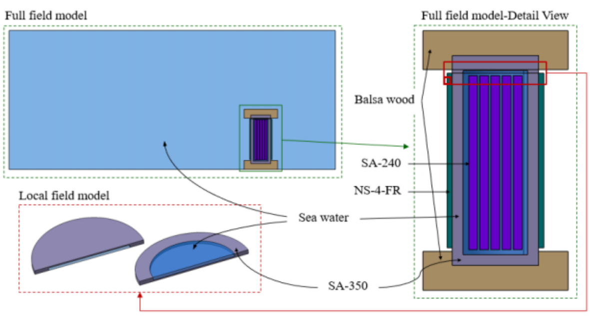

Fig. 4. Thermal properties.

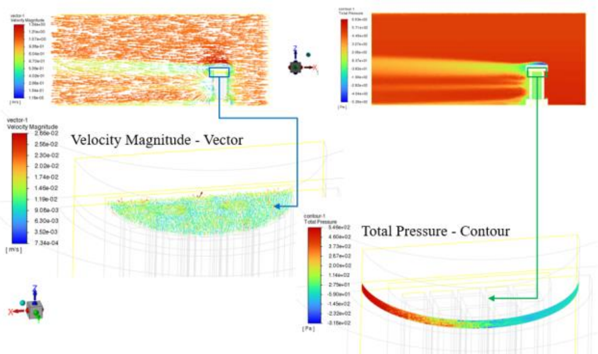

Fig. 5. Analysis result of full field model.

2.4 Local Field Model

The flow velocity and pressure profile of the full field model was imported to the local field model. In the model, the width flow path was assumed to be 10 mm. The viscous flow through the gap was calculated and confirmed to be the laminar flow. The analysis results were shown in Figure 6. It is confirmed that the forced convection flow was implemented through the flow path. The average release velocity was 0.34 m/s. Through Equation 1, the release rate of radionuclides can be calculated.

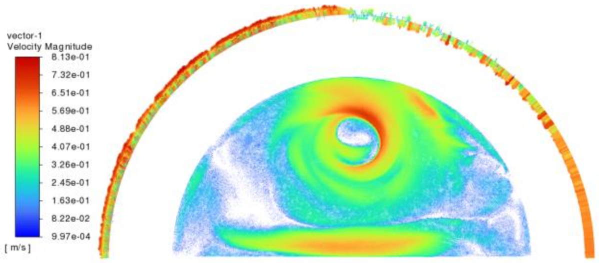

Fig. 6. Analysis result of local field model

$$R_o = \rho A v C_s \quad (1)$$

$(R_o: Release\ rate, \rho: Density, A: Area\ of\ flow\ path, v: velocity, C_s: Saturation\ Concentration\ in\ sea)$

3. Conclusions

To rationally calculate the release rate of radionuclides, the barrier effect was considered. CRIEPI's model was the only model that considers the barrier effect, but the flow velocity was calculated using the simple formula considering only buoyancy. In this study, CFD technique was used to calculate flow velocity from the breached cask. The fuels assemblies were simplified by the Porous method, and the flow rate was quantitatively calculated using the sub-modeling technique. In the future work, the flow rate prediction model will be constructed using the model developed in this work to account for the various environmental and cask design specific parameters.

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