Scoping Analysis of Spent Fuel Storage Cask for Monitoring Application

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1. Introduction

Over the last 30 years at commercial light water reactor sites across the United States, more than 1500 spent nuclear fuel (SNF) dry storage casks have been installed with initial license terms of 20 years [1]. The need for extension of storage-term of SNF is increasing due to continued delays in establishing permanent disposal facilities in most countries that operate nuclear power plants. As the storage terms of SNF in the dry storage casks are extended, aging management and monitoring issues became progressively more important. One of the regulatory requirements for ensuring the safe operation of dry storage casks is the confinement monitoring [2].

It would be very beneficial if canister confinement can be monitored without any pressure sensor line penetration through the canister wall. Recently, methods based on surface temperature measurements have been proposed for detecting helium gas leak from canister [3].

In this study, we assess the feasibility of canister integrity monitoring by analyzing the dependence of canister surface temperature on the canister internal pressure of the SNF storage cask.

2. Methods of Analysis

An analysis model has been developed for a reference vertical type dry storage cask design having a metallic canister with separate concrete overpack that provides radiation shielding and physical protection. Cross-sectional view of the reference cask is shown in Fig.1 [4].
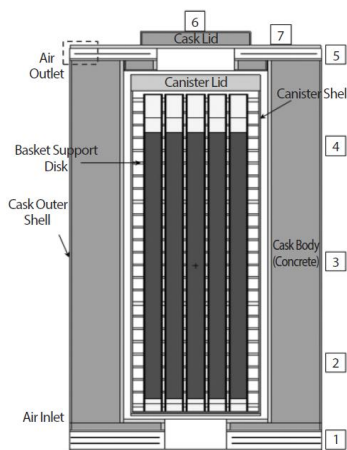
COBRA-SFS code [5] was used for the thermo-dynamic analysis of the canister and RELAP5 code [6] was used for the analysis of the air gap between the canister and the concrete over pack. Two code calculations were coupled using the air gap temperature distribution as boundary condition. Some modifications were made in the codes and auxiliary programs were developed for automation of the overall calculation process.

2.1 COBRA-SFS Input Model

COBRA-SFS input nodalization for the reference model is shown in Fig. 2. The input consists of 22 assemblies and 308 slabs having 36 equal-height axial nodes.

Of the 22 assemblies, 21 assemblies represent fuel assemblies and the remaining one assembly represents the downflow helium region in the periphery. Each fuel assembly is composed of 241 rods (fuel and guide tube rods) and 284 channels as shown in Fig. 3. The downflow assembly consists of 36 channels.
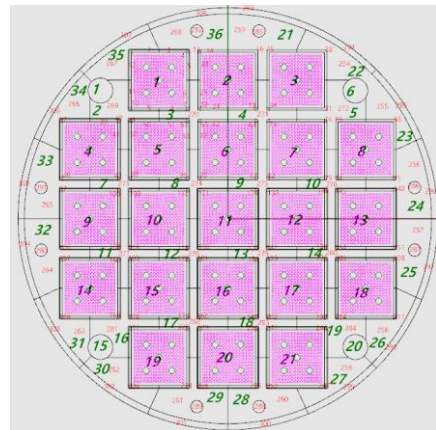

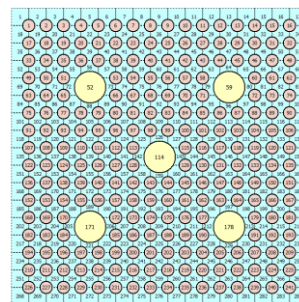
Fig. 2. COBRA-SFS input nodalization.

Fig. 3. COBRA-SFS fuel assembly nodes.

Fig. 1. Vertical cross-sectional view of the concrete cask [4].

Baskets enclosing the fuel assemblies, basket support disks, and canister shell are modeled using 308 slabs.

2.2 RELAP5 Input Model

RELAP5 input model consists of two pipe components, two branch components, and three heat structures as shown in Fig. 4. Here, HS150 and HS 250 represent the canister shell and the concrete overpack, respectively. HS500 models a virtual heat sink. P150 represents the air gap between the canister and the concrete overpack and P270 represents the ambient air outside the overpack. B120 and B180 are branch components and represent the air inlet and outlet paths.
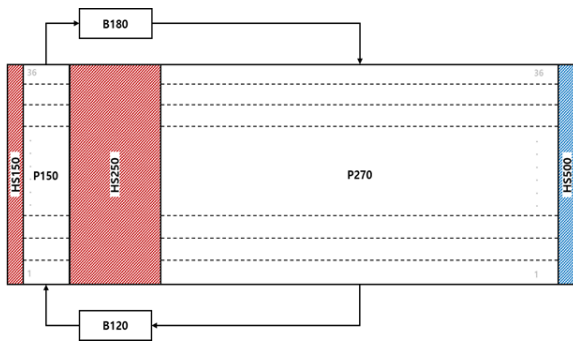

Fig. 4. RELAP5 Nodalization.

2.3 Correlation Development by Neural Network Model

To assess the feasibility of SFP storage cask integrity monitoring application, the correlation between the internal pressure of the canister and surface temperature profile needs to be investigated. The correlation is modeled by a neural network model using the generalized delta rule for feedforward net with backpropagation of error. Input variables of the correlation are canister surface temperature and ambient air temperature, and output variables are canister internal pressure.

3. Results of Analysis

3.1 Calculation Results of Canister Surface Temperature as Function of Helium Pressure

Calculations using the COBRA-SFS/RELAP5 codes were carried out with variation of helium pressure, fuel assembly power, and ambient air temperature.

Fig. 5 shows the canister surface temperature distribution as a function of active fuel height and helium pressure at the circumferential position of the canister shell where it is closest to the side faces of the fuel assemblies. The calculations were carried out for 800 W assembly power of and 20 ℃ ambient air temperature.

Fig. 5 shows that the peak canister surface temperature and the slope of the canister surface temperature decrease as the helium pressure increases. This result is well expectable because heat conduction and convection becomes more active when the helium pressure becomes higher.
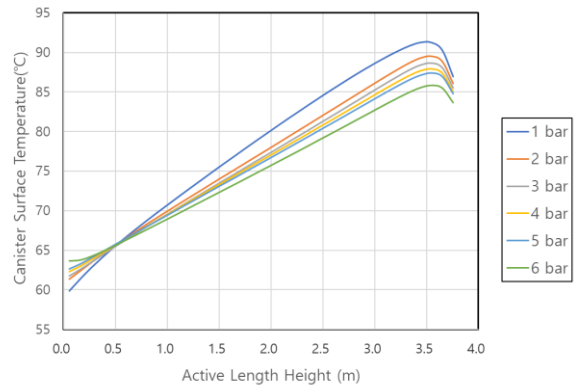

Fig. 5. Canister surface temperature distribution.

3.2 Prediction Results of Neural Network Correlation Model

A database was built for formulating a pressure prediction algorithm by neural network model. For the database, helium pressure range was varied from 1 to 6 bars. Fuel assembly power was varied from 600 to 1000 W and ambient air temperature was varied from 10 to 35 degrees Celsius. In total, 108 calculation cases were analyzed and used to train the neural network model.

Input variables of the correlation model were the canister surface temperatures at 5 axial positions of 10%, 30%, 50%, 70%, and 90% of the active fuel length and the ambient air temperature.

Fig. 6 shows the prediction results of the canister helium pressure. The prediction accuracy was 4.6% in terms of standard deviation of pressure prediction ratio.
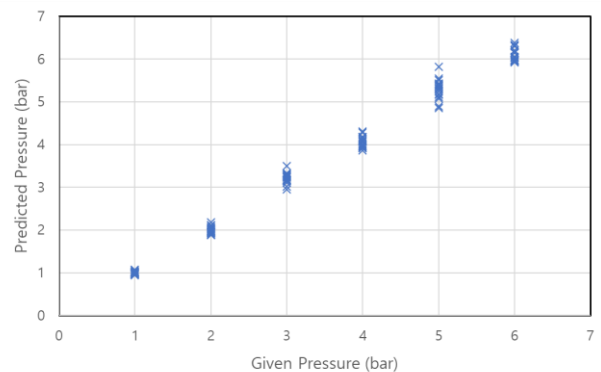

Fig. 6. Prediction results of helium pressure.

In addition to the pressure prediction above, the peak cladding temperature prediction was tried with a similar

model of neural network. Fig 7 shows the prediction results for the peak cladding temperature. The prediction accuracy was 1.1% in terms of standard deviation of peak cladding temperature prediction ratio. It is notable that the prediction accuracy is valid regardless of fuel power level and ambient air temperature.
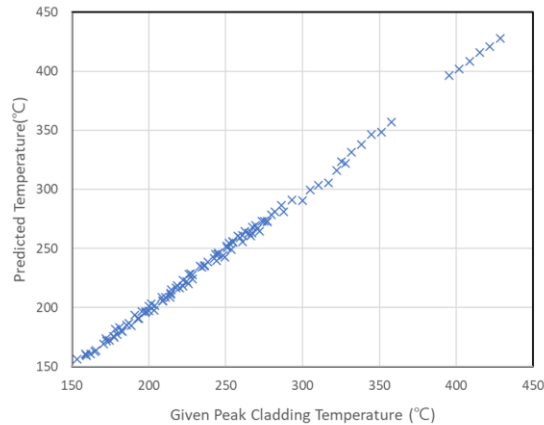

Fig. 7. Prediction results of peak cladding temperature.

4. Conclusions

A COBRA-SFS/RELAP5 code system has been established for the thermo-dynamic analysis of SNF dry storage casks having metallic canisters with separate concrete overpacks.

Analyses were carried out to investigate the canister surface temperature distribution dependence on the canister internal pressure. A neural network model was employed to predict the canister internal pressure based on the canister surface temperatures.

The preliminary results of this study show that canister integrity can be monitored by helium leak detection based on the canister surface temperature measurement eliminating the need for pressure sensor line penetration through the canister wall.

The analysis results also suggest that a similar prediction model may be applicable for predicting peak cladding temperature using the surface temperature measurements.

Detailed computational fluid dynamics analyses and supporting experiments are needed for more extensive verification of this study.

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ACKNOWLEDGMENTS