Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 23-24, 2019

Leak Detection Method for Integrity Monitoring of Spent Nuclear Fuel Dry Storage Casks

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NSE TECHNOLOGY

Contents

1. Introduction (1)

- **SNF Dry Storage Casks**
  - Operated at NPPs over more than 30 years
  - Delays in establishing permanent disposal facilities
  - Extended storage terms
  - Issues of aging management arise
  - Integrity monitoring becomes important

- **Related Studies**
  - Canister surface temperature (CST) measurements for detecting helium gas leak from canister
  - CST as a means to detect helium leakage of a welded canister

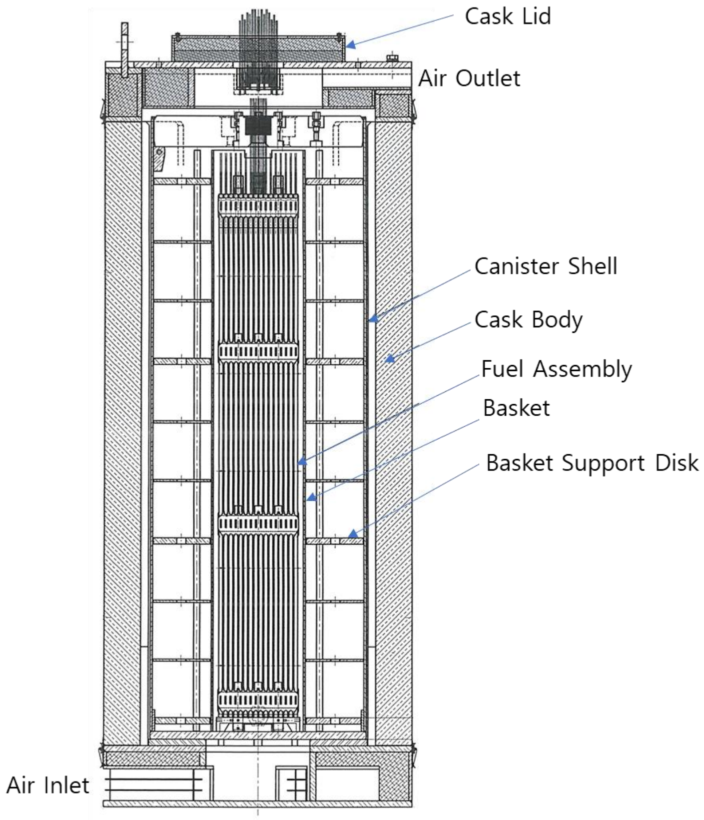
※1. Hirofumi Takeda, et. al, Development of the Detecting Method of Helium Gas Leak from Canister, Nuclear Engineering and Design, Vol. 238, pp.1220-1226, 2008.
※2. Jie Li and Yung Y. Liu, Thermal Modeling of a Vertical Dry Storage Cask for Used Nuclear Fuel, Nuclear Engineering and Design, Vol. 301, pp.74-88, 2016.

Focus of the Present Study

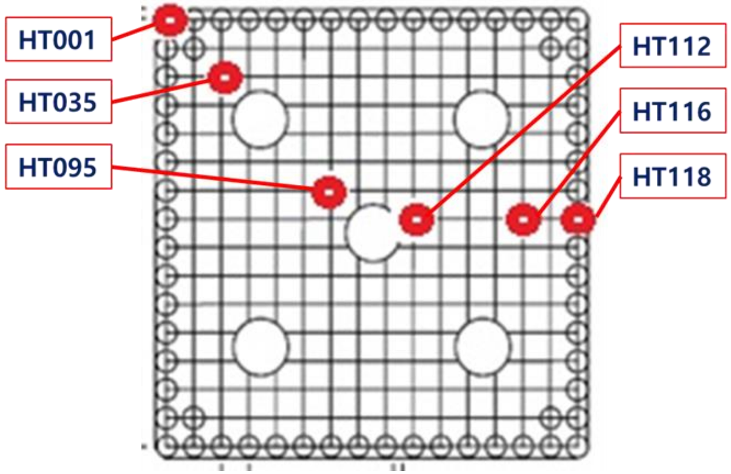
- Leak detection method based on CST is proposed for integrity monitoring of SNF dry storage casks
- Artificial neural network models are used for predicting :
  - canister internal pressure
  - peak cladding temperature
- Prediction method is validated through a pressure variation test

Test Rig (1)

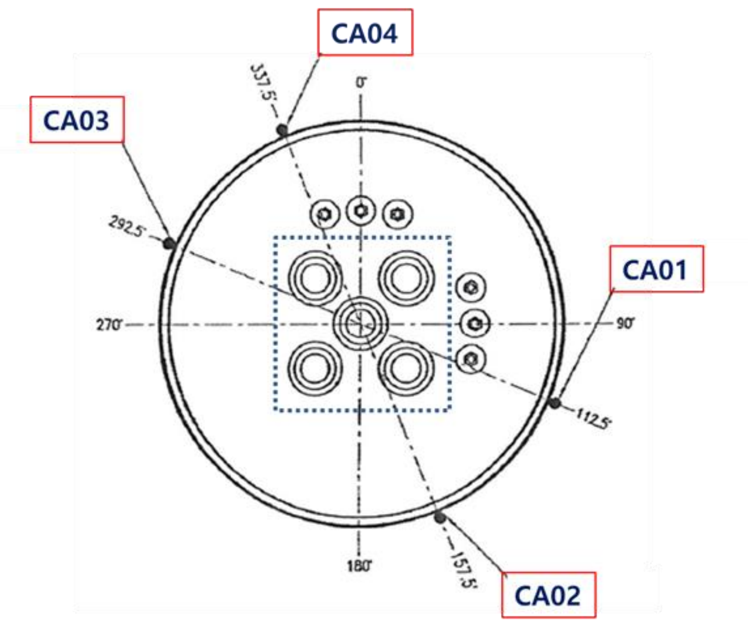
- To investigate thermal behaviors of the vertical dry storage cask
- To analyze relationships among the internal pressure, PCT, and CSTs
- To validate the prediction models



- **Test Rig (2)**
  - **Scaled-down with 1/3 height with a single CE Type fuel assembly**
  - **Fuel temperature sensors are attached at five axial levels of the active fuel length (10%, 30%, 50%, 70%, and 90%)**

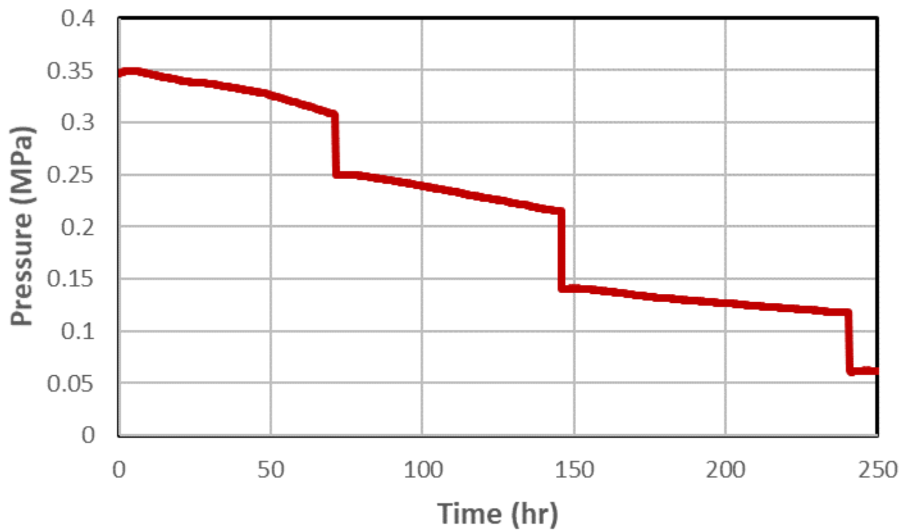


<Sensor-attached rods in the fuel assembly>

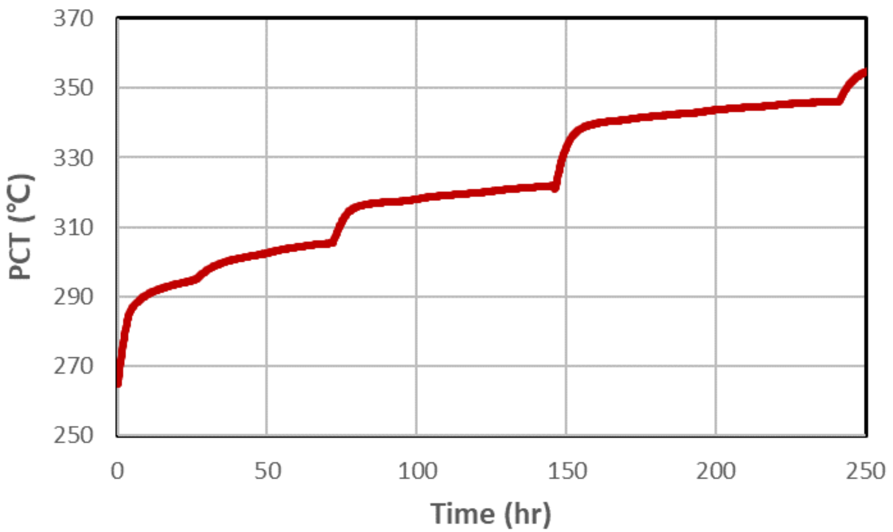


<CST measurement positions on the canister>

- **Pressure Variation Test**
  - To simulate helium leak in the test rig
  - Assembly power of 1.7 kW
  - Ambient air temperature : ~ 16 ℃

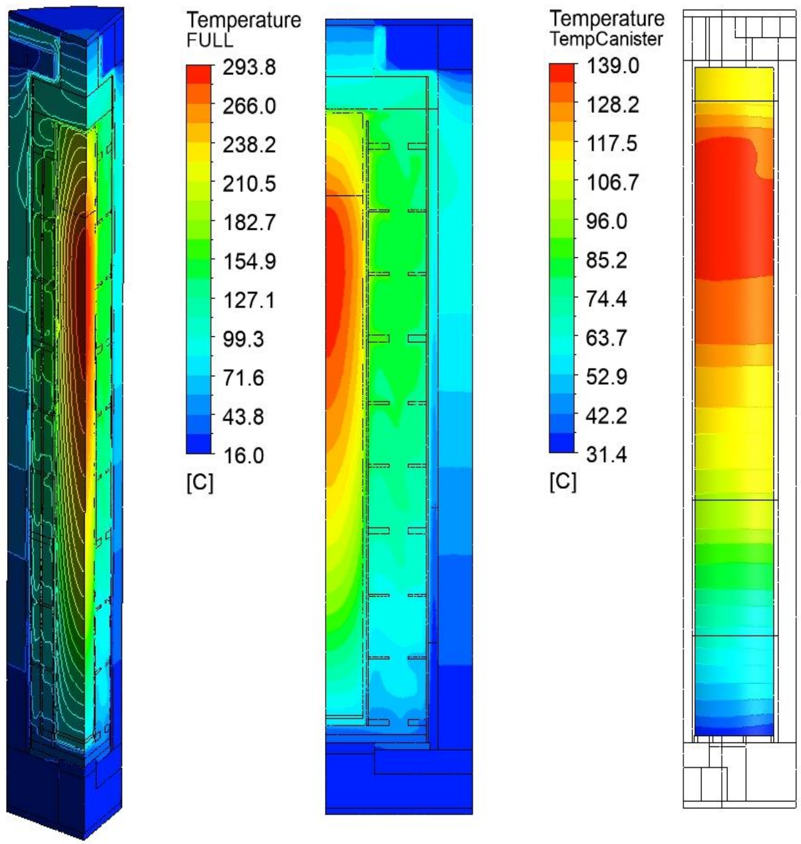


<Pressure variation during the test>



<Measured PCT during the test>

- **Thermal Analysis of the Test**
  - **Steady-state FLUENT results of 1/8 symmetry 3D model**



(a) Temperature distribution at 0.308 MPa

(b) Temperature on the symmetry boundary

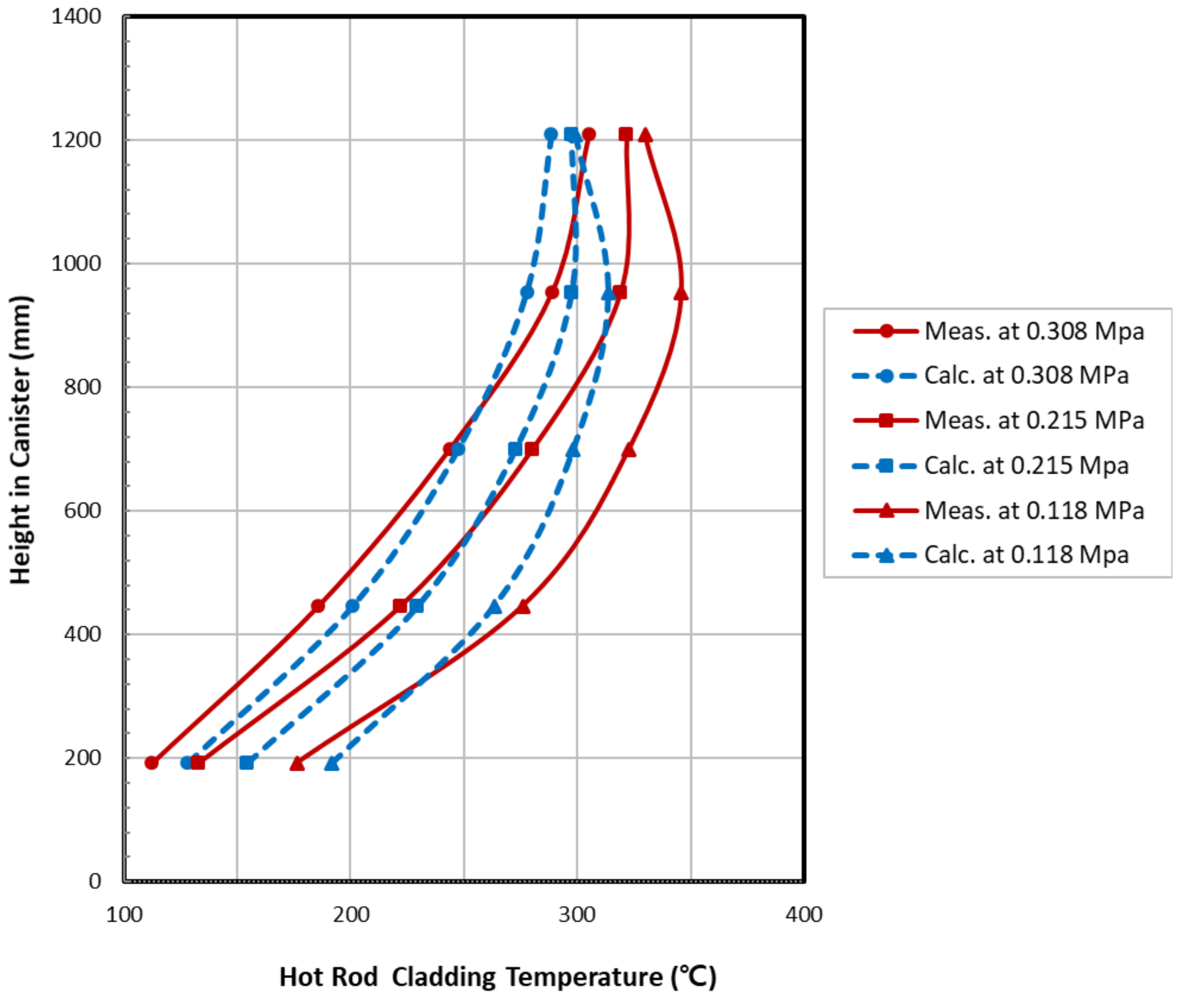
(c) Temperature on the canister shell surface

2. Pressure Variation Test and CFD Analyses (5)

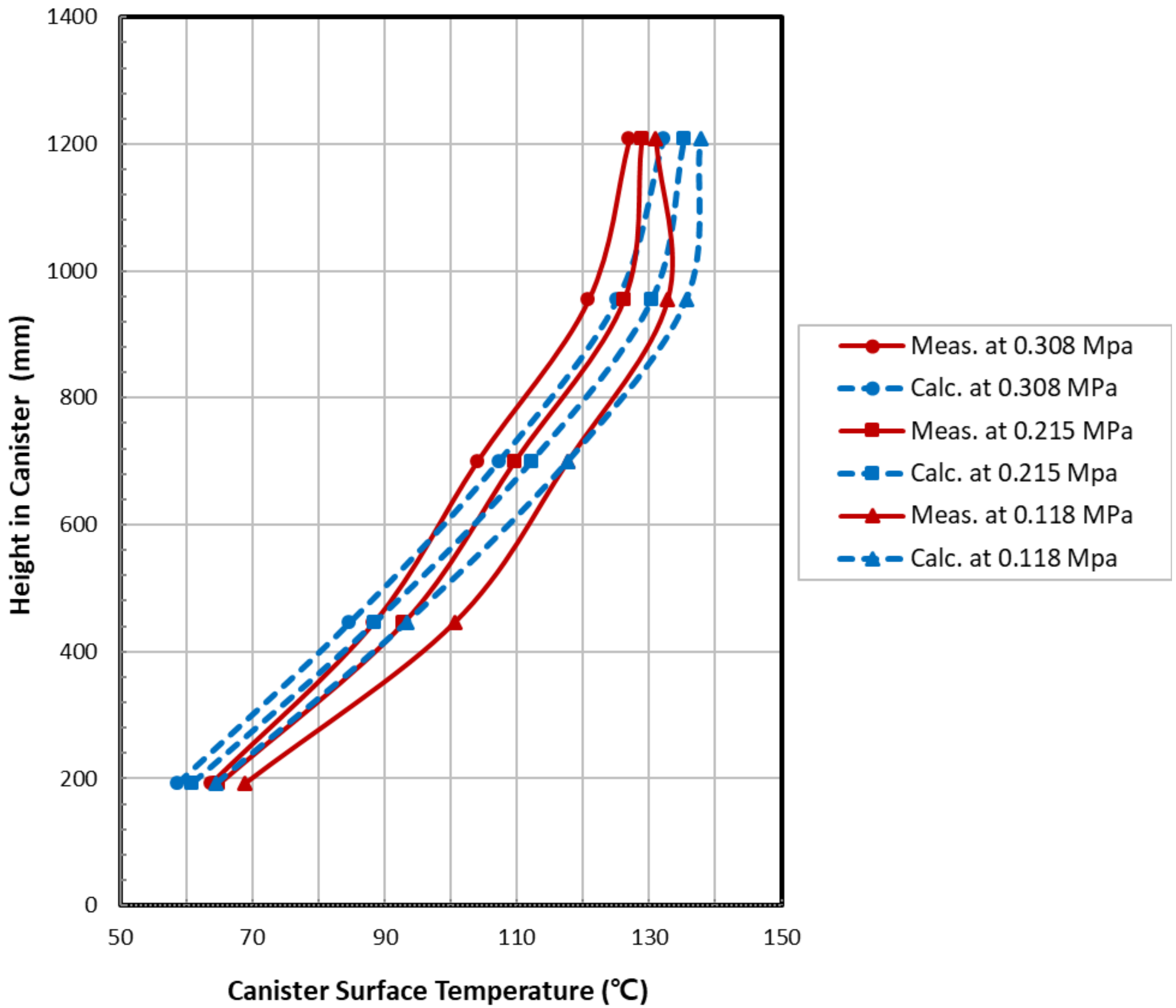
CFD Options for Thermal Analysis

- The viscous model : Realizable k-ε model with standard wall function option.
- Thermal radiation : discrete ordinates model with 5x5 divisions.
- The pressure-velocity coupling scheme : 'coupled' algorithm.
- He density property : Ideal-gas law
  - for driving force for natural convection flow
- Fuel assembly : modeled by a porous media
  - separate FLUENT calculations
  - Transverse effective thermal conductivity
  - Flow resistance

- **Hot Rod Temperature Results compared with Measurements**



- **Surface Temperature Results compared with Measurements**



2. Pressure Variation Test and CFD Analyses (8)

Summary of Analysis Results

- As the helium pressure decreases,
  - Heat conduction and convection become less active
  - Fuel and canister surface temperatures increase
  - Peak temperature tends to move towards the central zone
- FLUENT model underestimates the cladding temperature while overestimates the canister surface temperature
- Prediction performance deteriorates as the canister pressure is lowered
- Thermal behavioral trends over canister pressure are predictable to some degree

Database for Neural Network Training

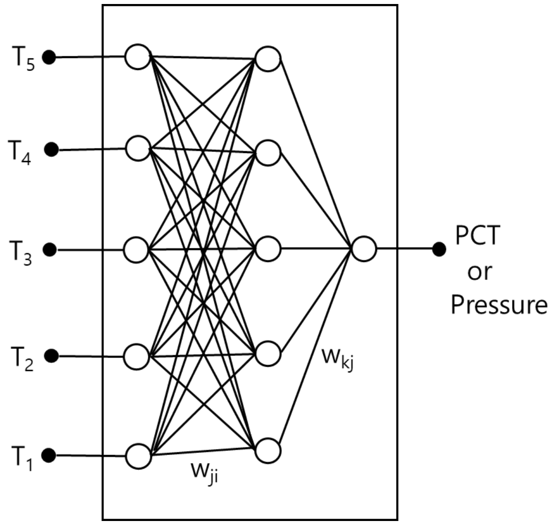
- 84 calculation cases
  - 7 pressures (0 ~ 0.46 MPa)
  - 3 assembly powers (1.6 ~ 1.84 kW)
  - 4 ambient temperatures (10 ~ 35 ℃)

Neural Network Prediction Model

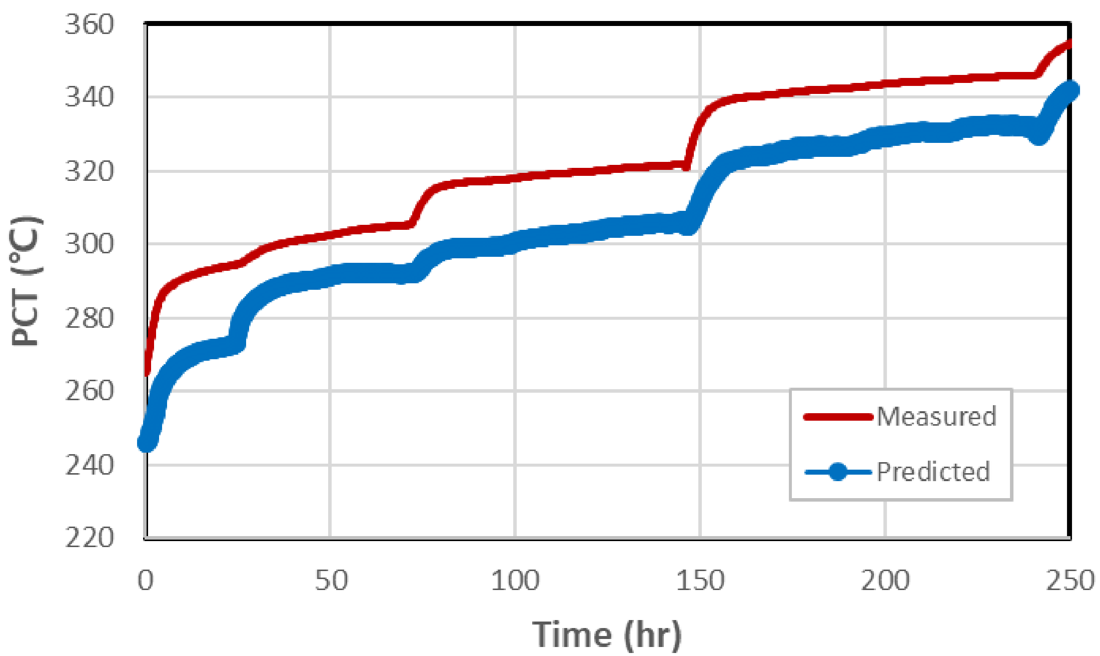
- Delta rule with the backpropagation algorithm
- Separate prediction engines for PCT and pressure
- Additional secondary inputs of temperature slopes

$$\Delta w_{ij} = -\eta \frac{\partial E}{\partial w_{ij}}$$

$$E = \frac{1}{2}\sum_{p}\sum_{k}\left(t_{pk} - o_{pk}\right)^2$$

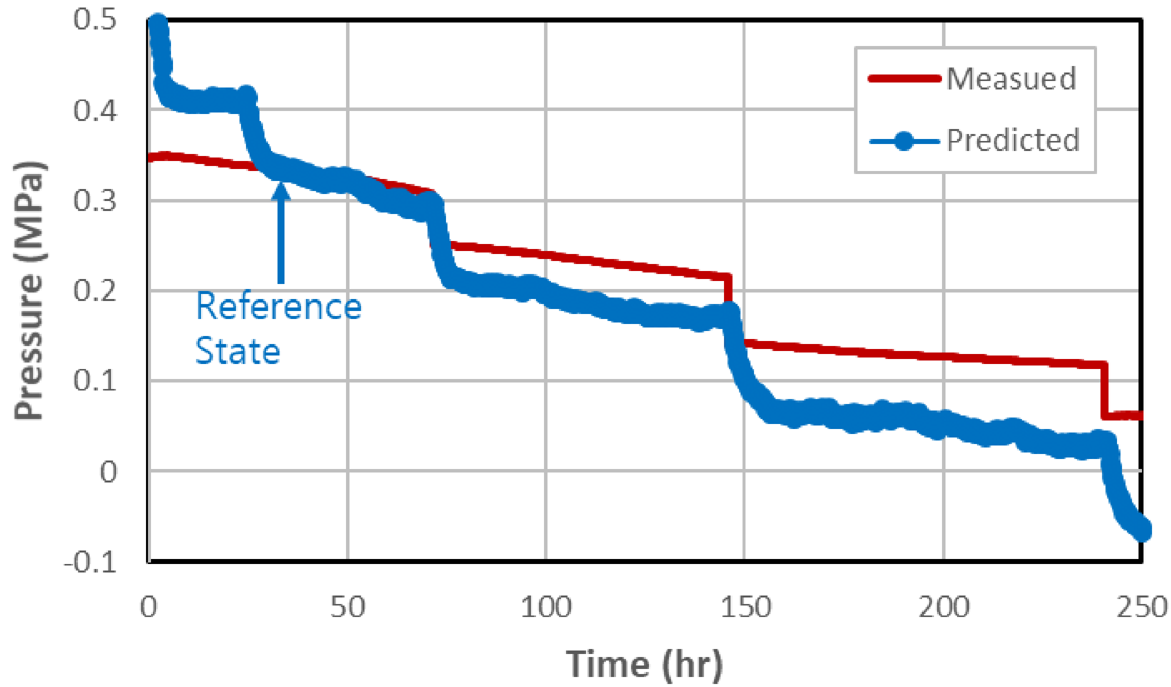


- **Predicted PCT Results Compared with Measurements**



<Monitoring results of peak cladding temperature>

- **Predicted Canister Pressure Compared with Measurements**



<Monitoring results of canister pressure>

Assessment of Monitoring Results

- The primary goal of the integrity monitoring is not to obtain the PCT and the pressure with a high degree of accuracy, but to detect any leakage occurrence in the canister resulting from confinement degradation.
- It is important to detect any changes in the PCT and the canister pressure from the reference values.
- Initial He pressure is assumed known according to the relevant work procedure.
- In the test, a stabilized state was obtained after 33 hours of initial transient.
- For improved prediction, input temperature signals were compensated by the deviations obtained at the reference state.
- After initial dead band period, the prediction engine can perceive even a very slow loss of pressure as well as a sudden drop of pressure.
- He leak is detectable by a pressure decrease accompanied with PCT increase.
- When the pressure and the PCT changes exceed specified limit values, the system should raise an alarm for maintenance actions.

5. Conclusions

Concluding Remarks

- A leak detection method has been developed for integrity monitoring of dry storage casks.
- The method employs a prediction engine comprising of neural network models for predicting PCT and canister pressure.
- The prediction engine uses only canister surface temperatures as input for prediction without need of sensors installed through canister wall.
- Database for training neural networks was generated by CFD calculations.
- The prediction engine has been applied to a pressure variation test for validation.
- The test results showed that helium leak in the cask is detectable by monitored pressure and PCT changes with the proposed method.

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