Transactions of the Korean Nuclear Society Autumn Meeting
Yeosu, Korea, October 25-26, 2018

Development of Prediction Models for Spent Nuclear Fuel Storage Cask Monitoring

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■ Introduction (1)

- **SNF Dry Storage Casks**
  - Over 1500 casks installed in US
  - Delay in establishing permanent disposal facilities
  - Extension of licensed storage terms
  - Issues of aging management and monitoring arise
  - Confinement 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 from a breach of a welded canister due to aging degradation

※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.

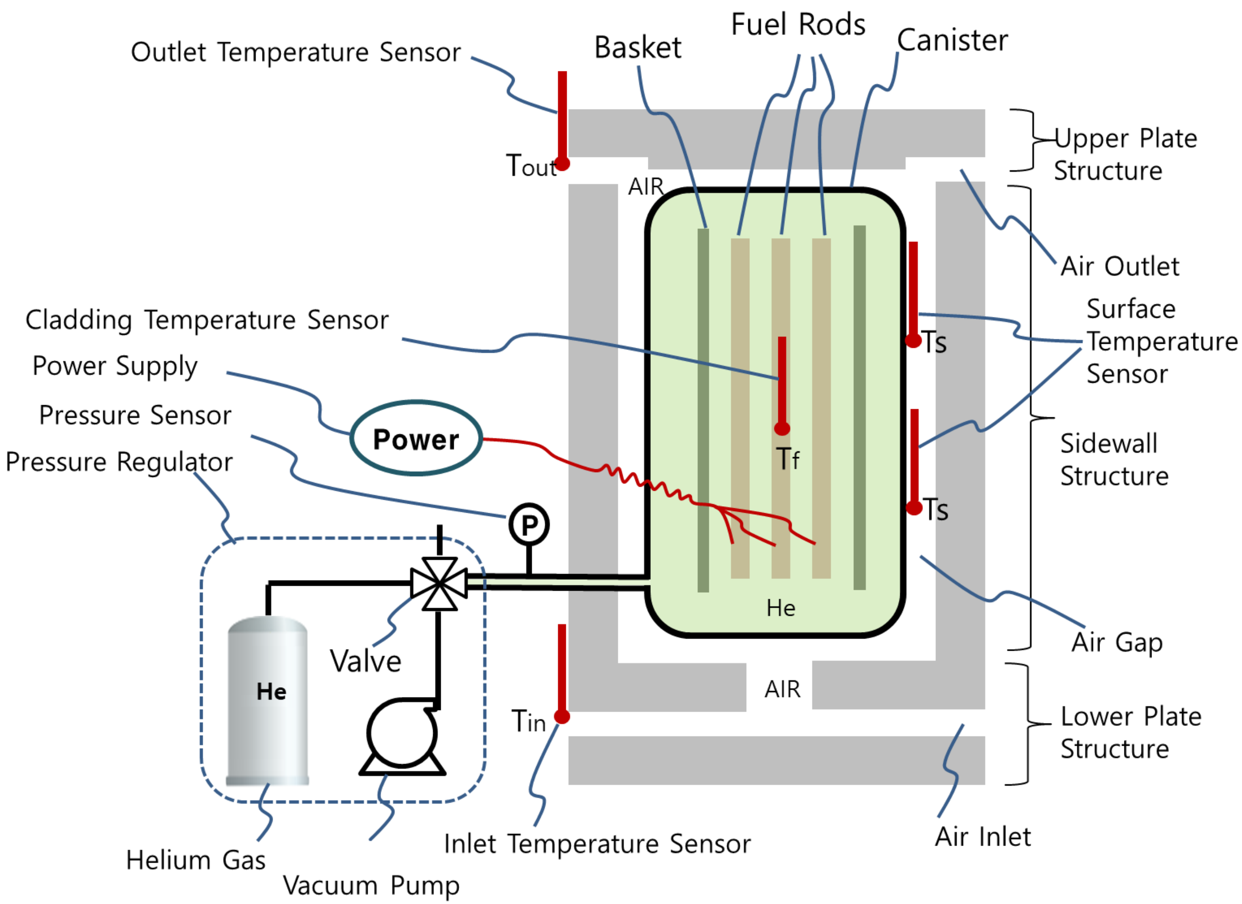
■ Introduction (2)

- **Focus of the Present Study**

  - **Feasibility of monitoring methods based on CST**
  - **Experimental studies on thermo-fluidic performance of dry storage cask**
  - **Artificial neural network model development for predicting:**
    - **canister internal pressure**
    - **peak cladding temperature**
  - **Experimental confirm of applicability of the prediction models**

■ Test Apparatus (1)

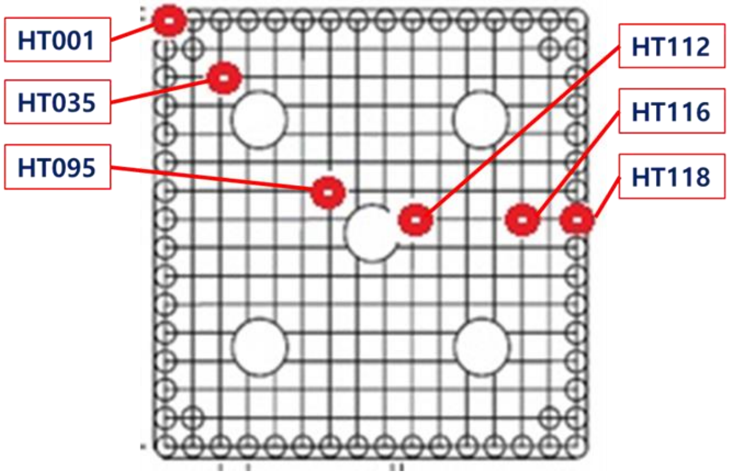
● Description of test apparatus



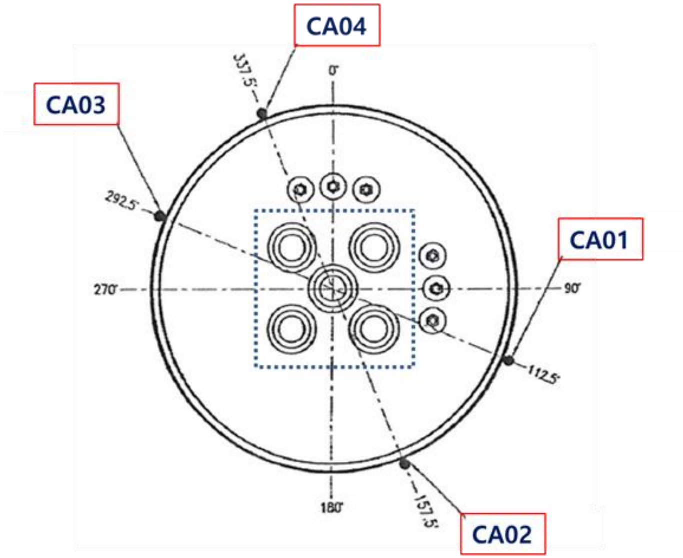
- Scaled-down with 1/3 height of reference design
- Single 16x16 fuel assembly
- Fill gas: helium
- Natural convection of helium in the canister
- Upward air flow in annular gap
- Temperature sensors:
  - fuel rod cladding
  - air inlet and outlet
  - cannister surface
- Pressure sensor

■ Test Apparatus (2)

- **Configuration of test apparatus**



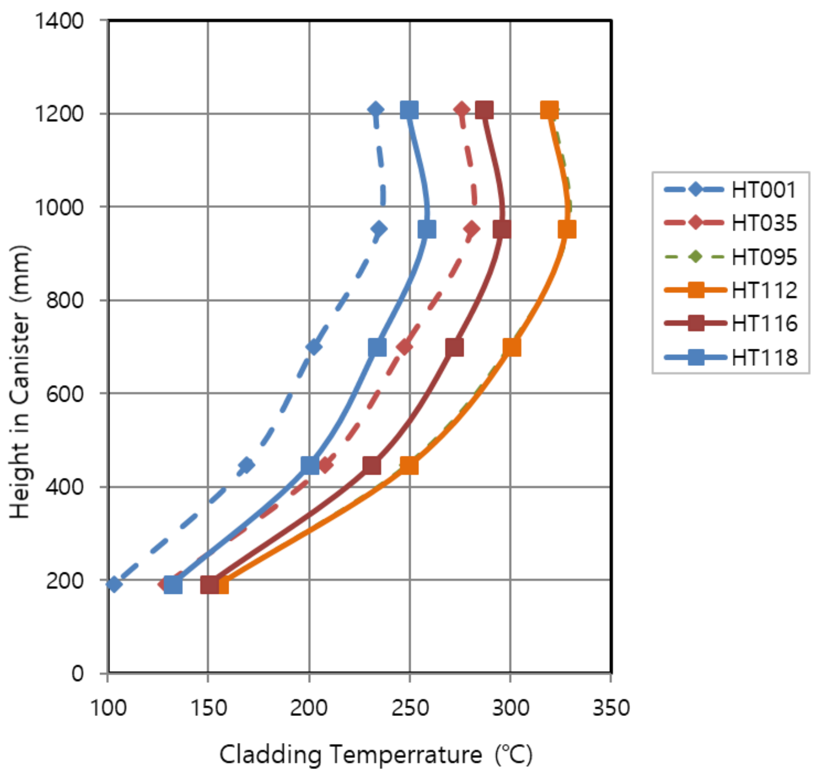
Temperature Measurement Positions in Fuel Assembly



CST Measurement Positions on the Canister

■ Test Results (1)

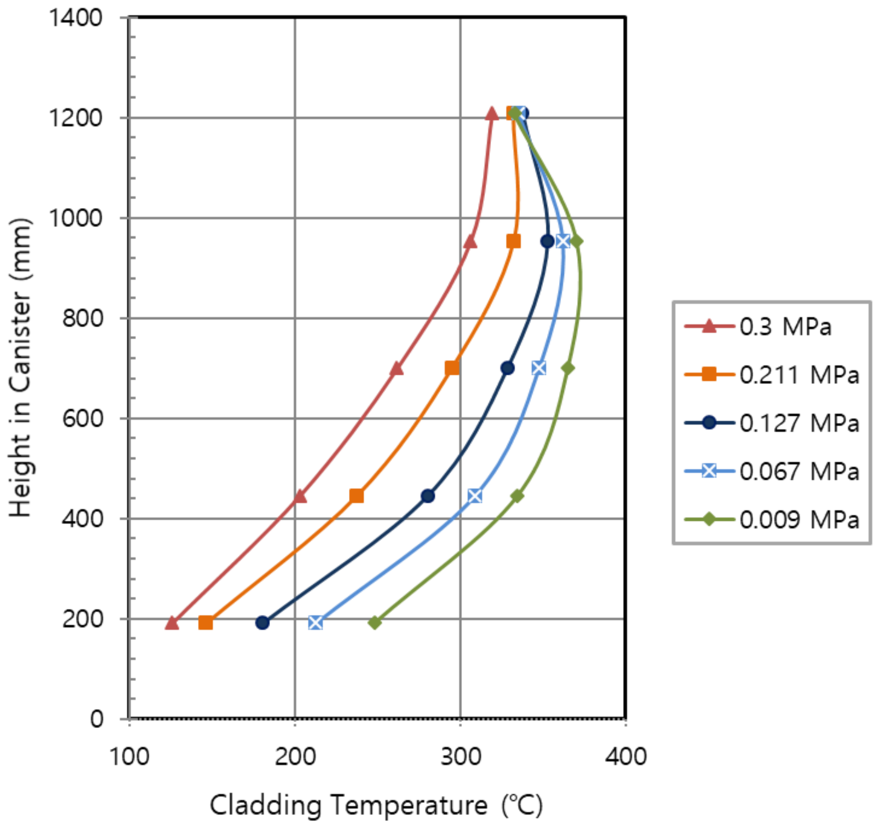
- **Experimental Range**
  - **PCT: 300℃ ~ 400℃**
  - **Ambient air temperature: 21℃ ~ 34℃**
  - **Helium pressure: 0.35 MPa ~ 0.01 MPa**
  - **Electric power: 1.60 kW, 1.72 kW**



Exemplary Cladding Temperature Profiles of the Fuel Rods (1.6kW, 0.155 MPa)

■ Test Results (2)

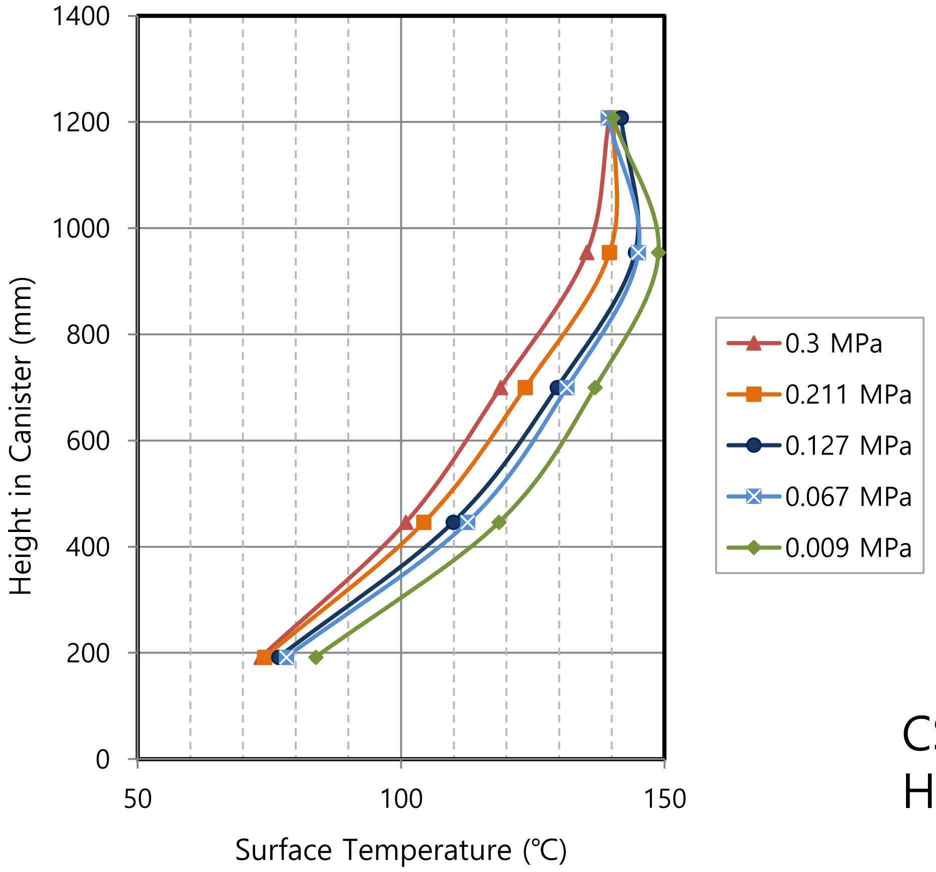
● PCT Measurement Results



Cladding Temperature Variation as a Function of Helium Pressure(HT095, 1.72kW)

■ Test Results (3)

● CST Measurement Results

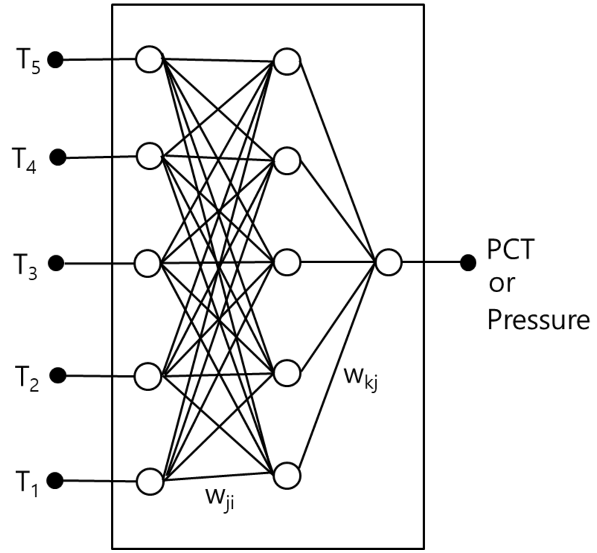


CST Variation as a Function of Helium Pressure.

■ Development of Neural Network Prediction Models (1)

- **Rationales**
  - **To keep the maximum fuel cladding temperature within the design limit during the extended long-term operation of dry storage casks**
  - **To take precautionary actions when helium leak is suspected**

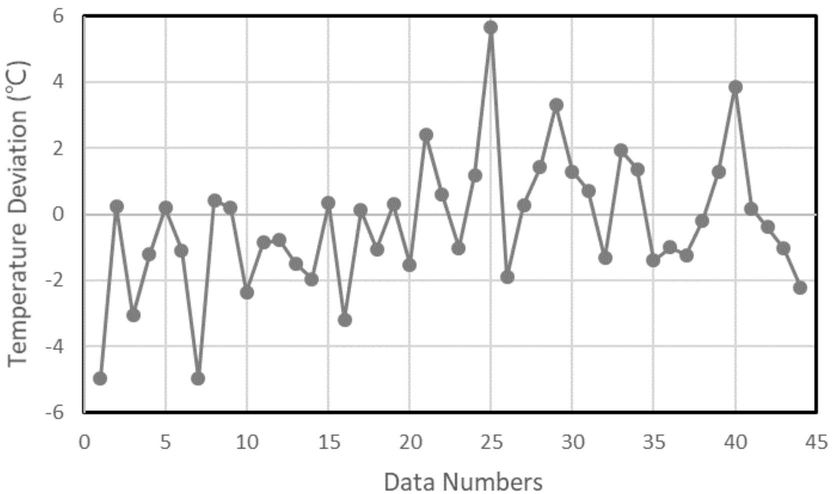
- **Description of Neural Network Models**
  - **3-layered artificial neural network using the delta rule with the backpropagation algorithm**
  - **Temperature slopes derived from CSTs were augmented as functional-link inputs to improve prediction performance**

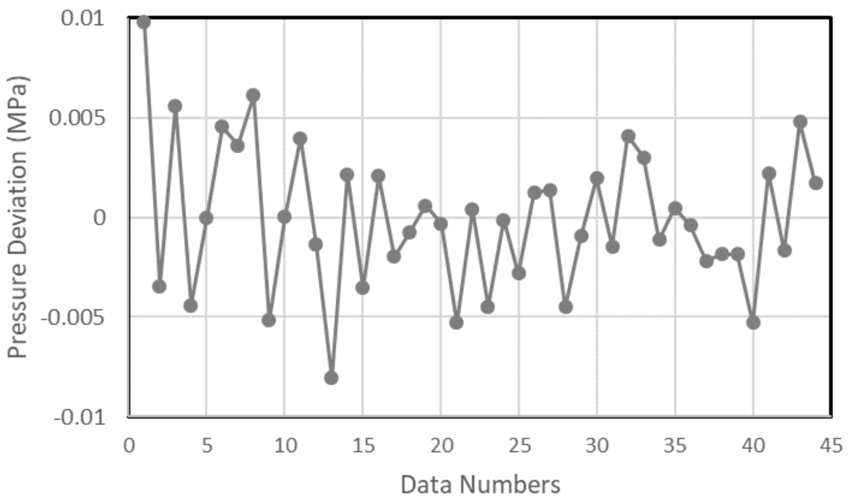


■ Development of Neural Network Prediction Models (2)

● Training Results of Neural Network Models

- **Training database for neural network models was built from 11 steady-state test points**



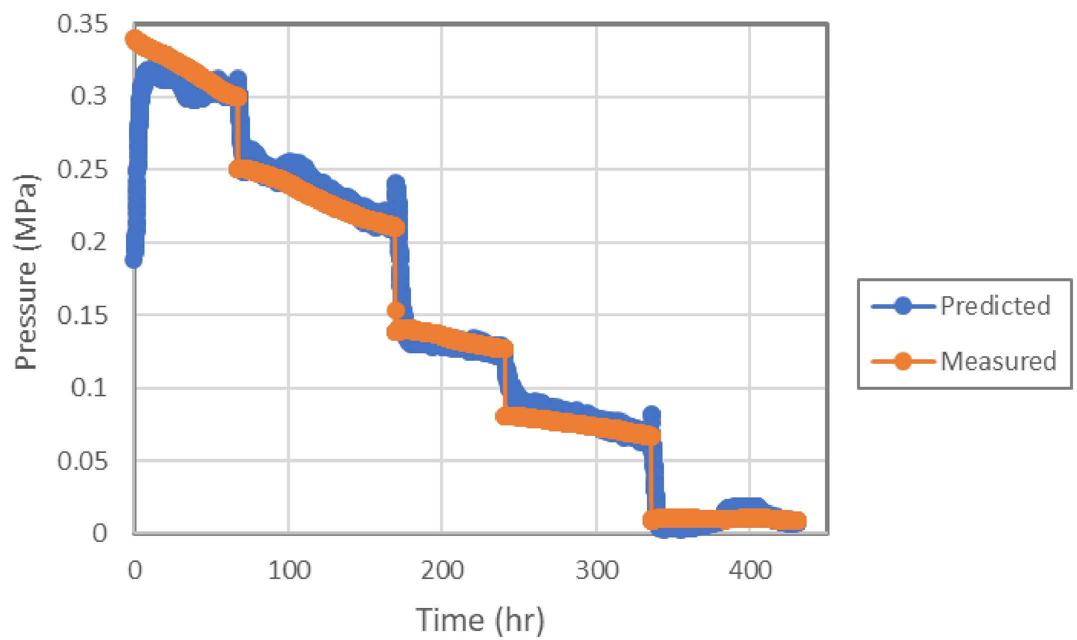


- Training Results of PCT Prediction
  - σ = 2.0℃
  - δ-max < 6℃

- Training Results of Pressure Prediction
  - σ = 0.0035 MPa
  - δ-max < 0.01 MPa

■ Results of Monitoring Application (1)

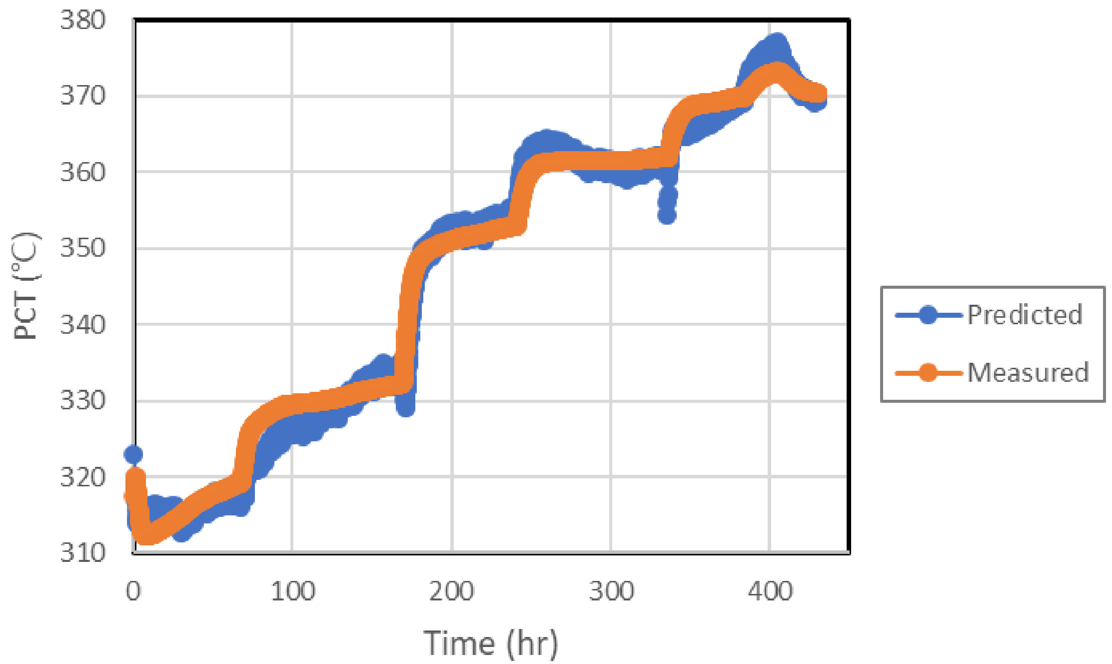
- **Application Test of Prediction Models**
  - **Prediction models were applied to the actual test data for verification as a means of monitoring method for dry storage casks**
  - **18 days long test with internal pressure variation from around 0.35 MPa to 0.01 MPa**
  - **Pressure variation presents transients caused by abrupt pressure drops and quasi-steady states between the transients**



Monitoring results of canister internal pressure.

■ Results of Monitoring Application (2)

- **Application Test of Prediction Models**
  - **The prediction results were relatively excellent for both pressure and PCT when the thermo-fluidic state becomes stabilized after transients.**
  - **The monitoring model could easily alarm any transient occurrence due to rapid helium gas leak when abnormal peaks or drops are observed.**



Monitoring results of peak cladding temperature

■ Conclusions

- Test apparatus was constructed to investigate thermal behaviors of the vertical dry storage casks.
- Results of tests have shown the thermo-fluidic characteristics of dry storage casks and were used to build database.
- Artificial neural network prediction models were developed using the axially aligned canister surface temperatures as input parameters.
- The prediction results of the developed models have been found to be excellent for stabilized thermo-fluidic states.
- Thermo-fluidic transients caused by rapid pressure loss could be easily alarmed from anomaly indication of the prediction models.
- Therefore, the neural network models can be used for predicting the canister internal pressure and the PCT based on the canister surface temperatures without any pressure gauge installation and appear promising for long-term confinement monitoring of dry storage casks.

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