Validation of CFD Thermal Model for Dry Cask Simulator

Taehyeon Kim*, Yongdeog Kim, and Sunghwan Chung

KHNP-CRI, 70, 1312beon-gil, Yuseong-daero Yuseong-gu, Daejeon, Republic of Korea

*taehyeon.kim@khnp.co.kr

1. Introduction

The Electric Power Research Institute(EPRI) of USA is coordinating the Extended Storage Collaborating Program(ESCP) to evaluate aging effects for extended storage of spent nuclear fuel(SNF). ESCP consideration engages in functions important to safety that storage facilities must maintain including thermal performance. Recently, a storage cask demands for higher heat loads and high-burnup fuel become the norm, possible margins are decreased to the point that expected peak cladding temperatures(PCT) are very close to the permissible limits. Several type of casks showed almost no-margin in PCT without verification and validation(V&V) and uncertainty quantification. The computational fluid dynamics(CFD) code was continually used in thermal hydraulic analyses of casks to reduce analytical uncertainty[1]. Therefore, V&V must be performed to assess accuracy and reliability in CFD. In this research, CFD calculations are carried out to validate for CFD models and approximations with experimental results of the EPRI dry cask simulator(DCS).

2. Validation of Thermal Model

2.1 Test Apparatus

The DCS system designed to produce temperature data sets under well-controlled boundary-conditions with a various heat loads, internal gas pressure and surrounding situations[2]. Fig. 1 shows the general design overview. The DCS system has two ducting shells that were used to emulate conditions for vertical dry storage systems with canister. Canister pressure vessel are located in inner shell that includes basket structure and Incoloy-clad test 9x9 fuel assembly of prototypic boiled water reactor. Axial and radial temperature profiles are measured for a various range of heat loads and helium pressure in pressure vessel. Ambient air is drawn into inlet ducts at lower side of the DCS, flows upward along the heated outer wall of the pressure vessel and discharged outlet openings arear in the outer shell at the upper side of the DCS. Inlet velocity is measured by hot wire anemometer to calculate mass flow rate of air.

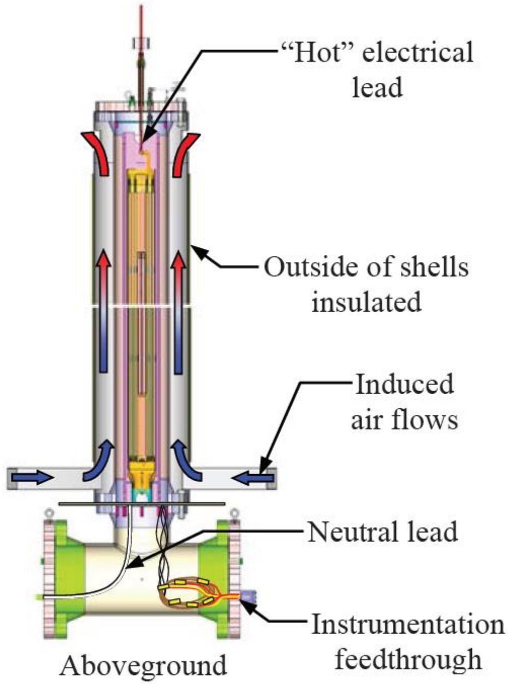

Fig. 1. The plan view of dry cask simulator.

2.2 CFD thermal analysis model

The CFD thermal model focus on the calculation for fuel cladding, inner helium gas, and air cooling temperatures. A 3D analytical geometry using a $1/8^{th}$ symmetry, as shown in Fig. 2 was used to evaluate temperatures. Boundary conditions were used to simulate experimental conditions for the DCS. The laminar model was used in the inner helium gas flow, and realizable k-epsilon model was used in the external air flow with full buoyancy effects. The surface to surface model with view factor was used for radiation heat transfer. The second order upwind scheme was used for momentum, turbulence, energy and radiation heat transfer. The velocity-pressure coupling method is SIMPLE.

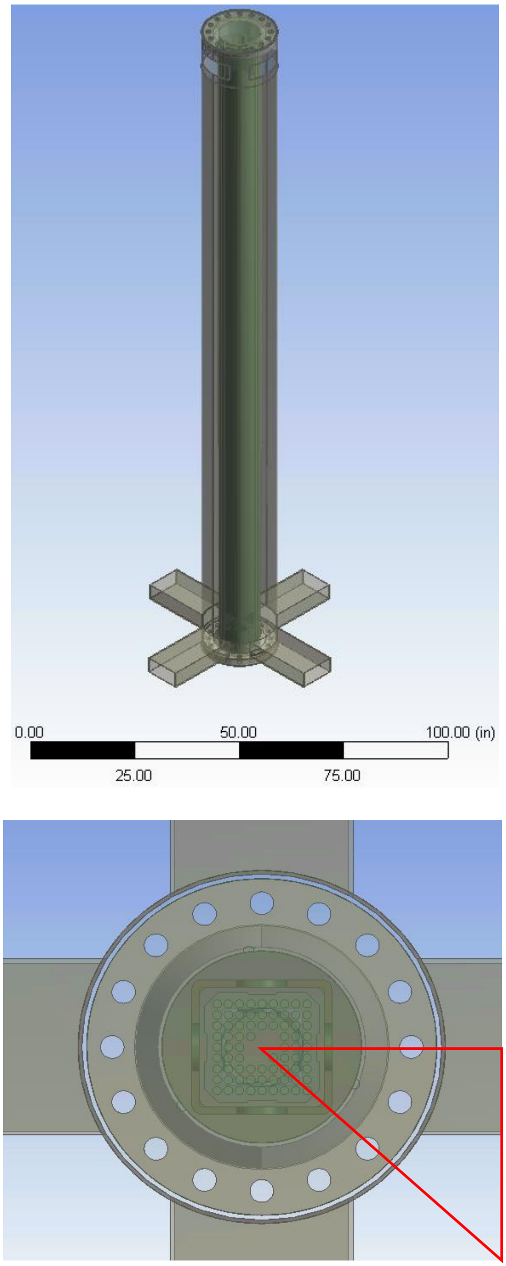

Fig. 2. The CFD analysis geometry of dry cask simulator.

Thermal Property of fluids and solids materials are presented in the DSC handbook[2] and material inventory of CFD code[3]. Ideal gas conditions are used helium and air densities.

3. Results and Discussion

Fig. 3 show temperature contour at middle plane that located in the height of 3.023 m. Fuels temperature higher than basket and helium region except near fuel region. Fig. 4 shows the steady state transverse temperature profile at middle plane. This figure shows the location and value of the temperature for each region of the test apparatus and CFD results. Maximum temperature different is 5.8K at the vessel structure and minimum is 0.5K at the basket structure. The results show good agreement between the experimental results and the CFD calculations for the DCS.

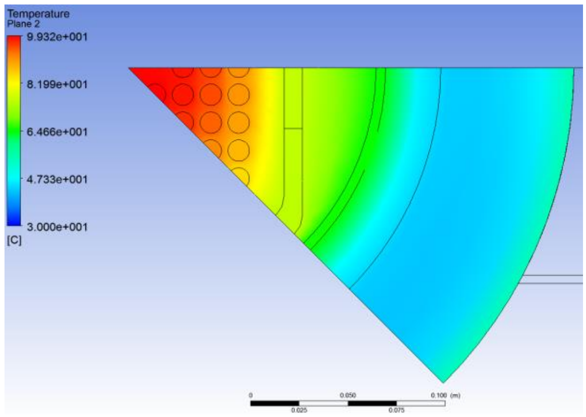

Fig. 3. The temperature contour of measured location (z=3.023).

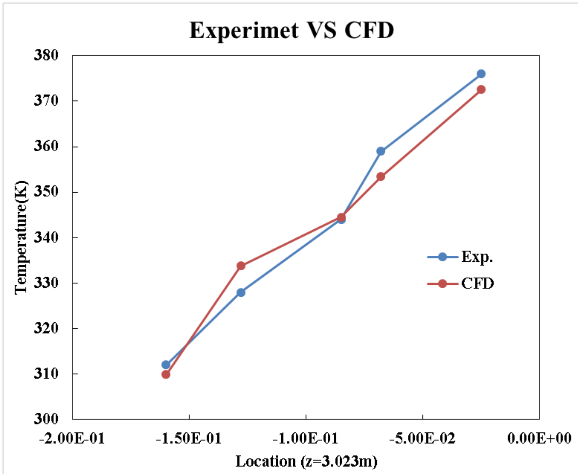

Fig. 4. Steady state temperature as a function of location.

REFERENCES

[1] A. ZIGH and J. SOLIS, "Computations Fluid Dynamics Best Practice Guidelines for Dry Cask Application," Nuclear Regulatory Commission, NUREG-2152, (2013).

[2] E.R. Lindgren and S.G. Durbin, "Materials and dimensional reference handbook of the boiling water reactor dry cask simulator", Sandia National Laboratories (2017).

[3] Fluent 17.2. ANSYS Fluent Theory Guide 17.0, ANSYS Inc, USA (2016).