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

Thermal analysis of HISTORM-100 dry storage cask with heterogeneous WH14X14 fuel assembly using COMSOL MULTIPHYSICS program

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1. Introduction

The saturation of the PWR power plant wet storage pool in South Korea is expected to start in 2024. For this reason, dry storage systems have been selected as a means of intermediate storage and cask will be used as a dry storage means. Cask must meet safety standards in four areas: thermal, criticality, radiation shielding, and structure. In this study, thermal analysis of HISTORM-100 concrete cask containing WH14X14 fuel was performed. The conventional thermal evaluation was performed by describing the nuclear fuel assembly inside the canister as a hexahedron homogeneous fuel assembly. There are limitations in thermal analysis using homogeneous fuel assemblies. The first limitation is that it is impossible to obtain the temperature distribution of individual fuel rods. The second limitation is that uncertainty increases when using arbitrary values such as Permeability and Porosity. The final limitation is that individual properties cannot be assigned to each fuel rods. Therefore, in this study, thermal evaluation of dry storage cask using heterogeneous fuel assembly condition was performed.

2. Procedure and Result

In this study, thermal analysis of the HISTORM-100 dry storage cask containing WH14X14 heterogeneous fuel assemblies was performed using the COMSOL MULTIPHYSICS 5.4 program. Geometry, Material Property, and Boundary condition settings were referenced from HOLTEC INTERNATIONAL's Final Safety Analysis Report (FSAR).

2.1 Geometry and mesh setting

The specification of HISTORM-100 CASK, MPC-24(Multi Purpose Canister-24), WH14X14 is referred to the content of FSAR of HOLTEC INTERNATIONAL. In the HISTORM-100 cask geometry, a small flow channel inside the air path was not depicted. In the MPC-24, the basket was modeled by simplifying the structure to reduce the calculation capacity and shorten the calculation time. The WH14X14 nuclear fuel assemblies were depicted only with the fuel rods except for the spacer grid, top nozzle, and bottom nozzle. Geometry is composed of 4,021,868 meshes in total. 3,720,174 meshes are composed of Tetrahedral, and 301,694 meshes are composed of boundary layer. The average quality of the mesh is 0.3707. Geometry and mesh are shown in Fig.1 below.

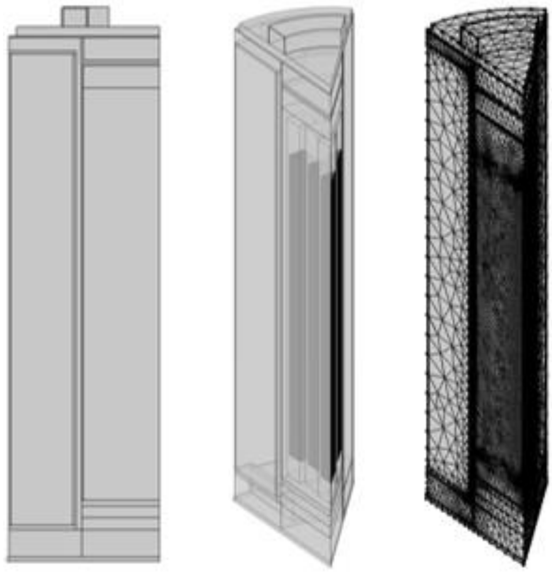

Fig.1. Geometry and mesh of HISTORM-100 cask with WH14X14 heterogeneous fuel assembly

2.2 Boundary conditions

45,000MWD burn-up, five-year wet-cooled nuclear fuel conditions were used, resulting in a heat load of 1,130W per assembly. Several functions are used to reduce the calculation capacity and to shorten the calculation time. Geometry is composed of 1/8 size and symmetry function is applied to reduce the total calculation capacity. Thin layer function was used to describe the cladding of the fuel rods and the basket. Heat flux function was applied to the outer surface of the cask to describe cooling by natural convection. Surface to surface radiation function was used to describe radiative heat transfer between the canister surface and the inner surface of the cask. Surface to ambient radiation function was used to describe the radiative heat transfer of the outer surface of the cask and the external insolation value was referenced to 10CFR71. The Insolation value of 10CFR71 is shown in Table I below.

Table I: Insolation data of 10CFR71

Form and location of surface	Total insolation for a 12-hour period(g cal/cm^2)
Flat surfaces transported horizontally;	
Base	None
Other surfaces	800
Flat surfaces not transported horizontally	200
Curved surfaces	400

The flow analysis of the cask describes the helium flow inside the canister and the air flow outside the canister. Turbulence condition was applied to the Helium cavity, and low Reynolds number condition was applied to the boundary layer. In this study, the upper gap of the canister is assumed to be conduction heat transfer. Laminar flow condition was applied to the air path.

2.3 Computing result

The calculation took about three days to complete, and 130GB of memory was used in the calculation. The difference between the FSAR results and the COMSOL MULTIPHYSICS program results is about 10℃, and the PCT(Peak Cladding Temperature) difference is about 1.92%. The temperature comparison results of the fuel rod, basket, MPC shell, cask inner shell, concrete and cask outer shell are shown in Fig.2 below. The temperature profile based on the 45° cut plane is shown in Fig.3 below. 2D temperature profile of PCT region, 2D temperature profile of 45 ° cutting plane are shown in Fig.6, and 3D analysis temperature profile result is shown Fig.7.

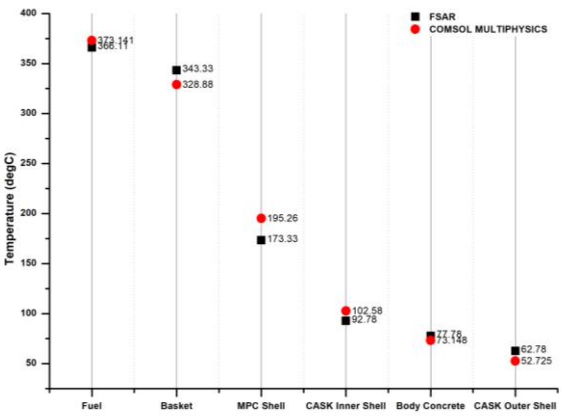

Fig.2. Comparison of FSAR and COMSOL MULTIPHYSICS results

As shown in Fig. 2 above, the temperature difference between the FSAR and COMSOL MULTIPHYSICS is about 10℃ in the Fuel, Basket, Cask inner shell, Body concrete, and Cask outer shell. In MPC Shell, the temperature difference is about 22℃. The reason for the difference seems to be that the laminar analysis was applied to the air flow path by ignoring the flow description above the canister.

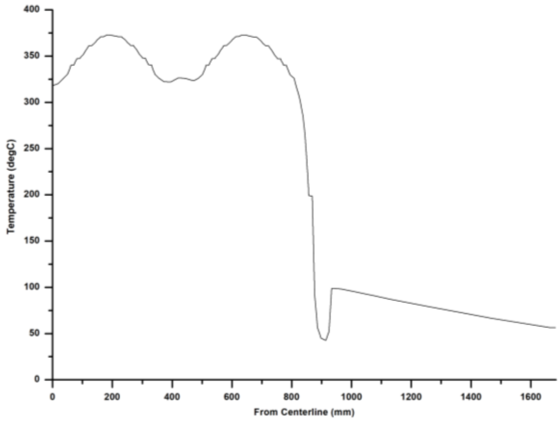

Fig.3. Temperature profile based on the 45° cut plane

Fig.3 shows the temperature profile from the centerline to the cask outer shell. The temperature profile was confirmed based on the z coordinate at which PCT appeared. The temperature was increased by nuclear fuel at about 200mm and 650mm from the centerline. The temperature drops sharply by the air flow path at about 900mm from the centerline.

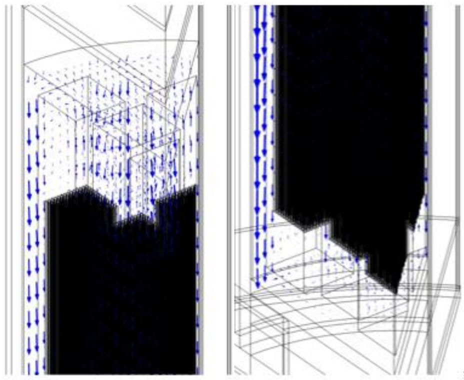

Fig.4. Helium flow distribution inside the canister

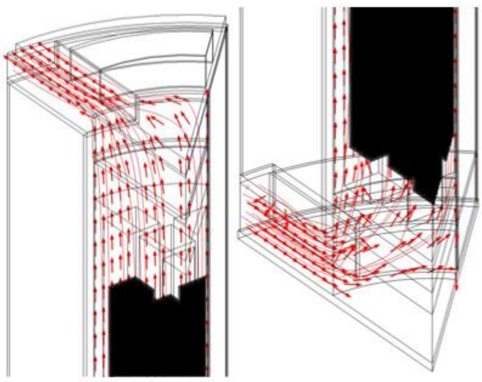

Fig.5. Air flow distribution inside the cask

Figure 4 and Figure 5 show the flow distribution inside the HISTORM-100 cask. The basket inside the canister was set to act as a virtual wall by describing only the boundary and then applying the interior wall function. Both air and helium were set to generate pressure difference and density difference flow by applying the compressible fluid setting and the include gravity function. The flow of Helium shows a rising flow in the area where the fuel is loaded, and a downward flow occurs from the top of the canister to the inner wall of the canister. The flow of air moves to the upper outlet as heat is applied to the air entering through the lower inlet.

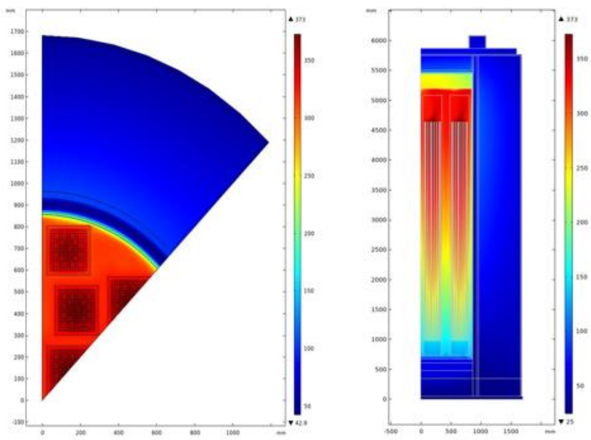

Fig.6. 2D temperature profile of PCT height cutting plane and 2D temperature profile of 45° cutting plane

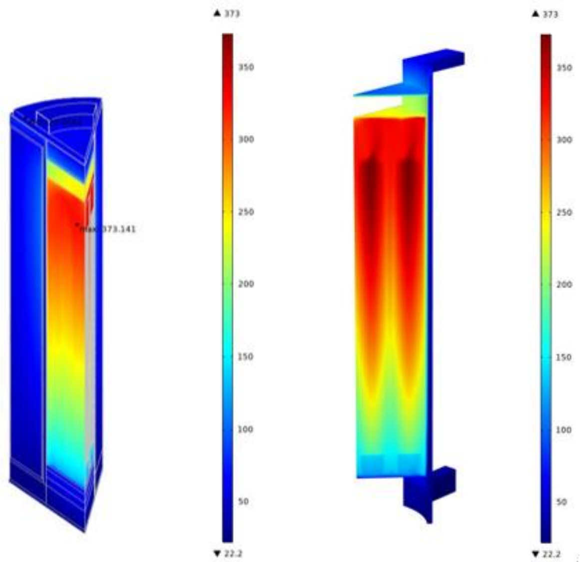

Fig.7. 3D temperature profile of HISTORM-100 cask with WH14X14 heterogeneous fuel assemblies

3. Conclusion

The PCT difference between the HISTORM-100 cask thermal evaluation with homogeneous fuel assemblies and the heterogeneous fuel assemblies using the COMSOL MULTIPHYSICS program was about 1.92%. This study will be used as a basis for further research such as sensitivity analysis and thermal evaluation using the properties of degraded fuel rods

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