Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 29-30, 2014

Thermal Analysis of Conceptual Multi-Purpose Dry Cask for Spent Nuclear Fuel

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1. Introduction

The storage for spent fuel pool starts to be full from 2016, so the solution for this problem is needed. One of solutions is to employ the Multi-Purpose Dry Cask (MPC). It can transport the nuclear spent fuel such as KN-12 and also can store long-term duration which is needed for fuel disposal. By using this multi-functional cask, we can minimize the cost for building another spent fuel pool. However, it must fulfill some criteria for criticality, radiation shielding, thermal evaluation and so on, and these criteria are categorized and regulated by 10CFR Part 71[1].

In this paper, the thermal analysis of conceptual MPC is illustrated by using the computational fluid dynamics (CFD) code, FLUENT[2]. Conduction, convection and radiation are all considered for normal condition and for hypothetical accident condition. After the conceptual model and its characteristic are explained, Boundary conditions and temperature criteria for simulation also introduced. The 2D cross-section model is analyzed considering the gap size effect and the 3D entire model is explained including mesh quality.

2. Conceptual model and characteristics

2.1. Conceptual model with material composition

Fig.1 is the schematic half model of MPC and assumed that it can transport and store 24 PWR fuel assemblies. Each fuel assembly is located in basketcell (stainless steel) and it is supported by other support components (stainless steel). Also, there exists a neutron absorber (B_4C) between the basketcell for prevent excessive neutron fission. Neutron shield material (Resin) is located on the surrounding of the cylindrical assembly bundle and it is covered by the carbon steel. The both end of top and bottom are covered impact limiter which is also carbon steel casing including wood.

2.2. Boundary conditions and temperature criteria

The heat source is only the decay heat from fuel assembly and its maximum value is assumed as 796.2W/assembly. Boundary conditions for each normal and hypothetical accident condition are needed. According to 10CFR Part 71[1], the ambient temperature is 38℃ with the insolation (400W/m^2) for normal condition. In case of hypothetical accident condition, 800 ℃ fire temperature for 30minutes without insolation and cooling in ambient temperature for 20hours are applied consecutively.

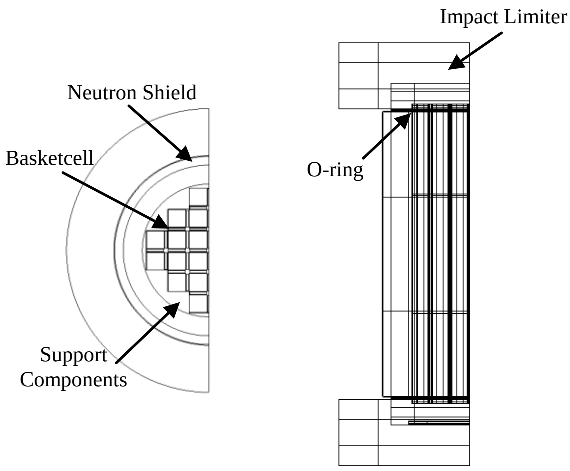

Fig. 1. Schematic MPC model: top view (left) and side view (right)

All components constructing the cask have to satisfy their allowable temperature. In case of fuel cladding, if the calculated temperature exceeds 400℃, the hybrids presented in irradiated fuel rods precipitate and reorient to an undesirable radial direction which gives negative effect for cladding stress perspective.

3. Results and discussion

3.1. 2D case results and temperature sensitivity test

For the computational efficiency, the cross-section of cask middle part was chosen, and this 2D design contains most components except impact limiter. In case of normal condition, the total temperature distribution was calculated like Fig.2 and as we see the results in Table.1, all the important component of the cask satisfied their own temperature criteria. Actually, the personal barrier is implemented for not exceeding the surface temperature[3], so changed boundary conditions were applied without additional geometry.

A little margin was shown in the neutron absorber region. In general, the cask is composed of many assemblies, so the gap size has to be considered. Therefore, I analyzed the effect of gap size on the temperature variation on the low margin part.

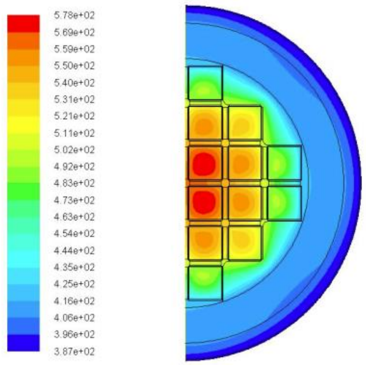

Fig. 2. Temperature distribution for 2D cross-section

Table. 1. Calculated maximum temperature of components

Components	T_{max} [℃]	T_{allow} [℃]
Surface	81.9	85
Cask body	154.1	371
Neutron shield	146.9	148
Neutron absorber	319.3	454
Fuel	331.0	400

Table. 2. The results gap size effect between assemblies

Components	T(℃)		
	Gap	No gap	T_{allow} [℃]
Neutron shield	146.9	147.9	148

I conducted the two cases; the first case has a general gap size between the cask components which is used in other Safety Analysis Report [4] and the other case is the compact assembled model which has no gap size for conservative condition. The results of Table.2 showed that the temperature variation of neutron shield was a little, but the magnitude of margin should be considered.

3.2. 3D case results and mesh quality

The other important components such as O-ring seal and bottom neutron shield cannot be implemented in 2D model, so 3D model simulation is needed to analyze those components with accurate data.

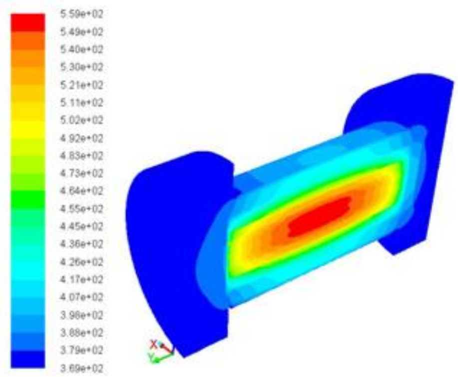

Fig. 3. Temperature distribution for MPC 3D model

Table. 3. Maximum temperature results for 3D model

Components	T_{max} [℃]	T_{allow} [℃]
Surface	81.9	85
Cask body	155.6	371
O-ring	134.5	250
Neutron shield	147.8	148
Neutron absorber	278.6	454
Fuel	285.7	400

The calculated temperature of all components including O-ring was lower than their own allowable temperature. The fuel region maximum temperature was lower than 2D case because of the additional axial conductivity effect. Fig.4 is the temperature variation for hypothetical accident condition (800℃ fire for 30minutes) and cooling condition (38℃ for 20hours). The accuracy of the value or the gradient of temperature was affected by the mesh quality such as ‘orthogonality’ or ‘aspect ratio’ and it should be optimized for accurate 3D MPC model calculation.

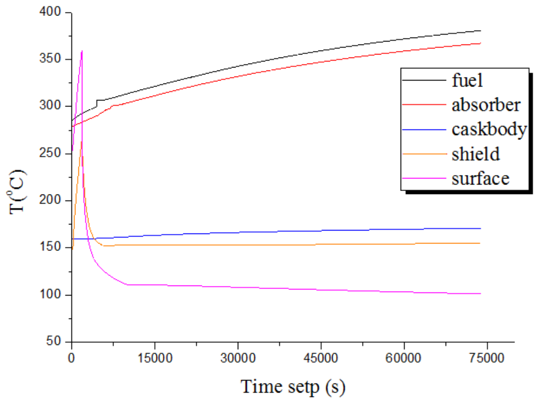

Fig. 4. Temperature variation for hypothetical accident condition

8. Conclusions

Thermal analysis for the 2D and 3D MPC model of MPC was performed with using FLUENT for normal and hypothetical accident conditions. All components satisfied the design criteria and the low margin at the specific components should be carefully considered. It was noted that the effect of gap size was insignificant to the thermal limit of the MPC design. For the 3D analysis, it was recognized that the mesh quality for the simulation including ‘orthogonality’ and ‘aspect ratio’ should be carefully maintain for the accurate analysis.

REFERENCES

[1] U.S. NRC, NRC Regulations (10CFR Part71-Packaging and Transportation of Radioactive Material.
[2] FLUENT 14.0 User’s Guide
[3] 원자력 안전위원회고시 제 2011-49 호, “방사성물질등의 포장 및 운반에 관한 규정”
[4] “HI-STAR Cask System Safety Analysis Report”, HI-951251, rev. 7, Holtec International, 2010.