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Effect of Emergency Core Cooling Barrel Duct on Core Inlet Flow Distribution of APR1000

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1. Introduction

The application of Emergency Core cooling Barrel Duct (ECBD) on APR1000 design has been considered for safety enhancement to reduce the safety injection flow escaping from downward passages to the cold leg bypassing the core in case of a loss of coolant accident (LOCA). Since the application of ECBD may induce changes in the flow distribution at the core inlet of the reactor, which is a key data for assessing the core thermal margin, the effect of installing the ECBD and its configurations on the flow distribution at the core inlet should be analyzed. In this study, a numerical calculation using a commercial computational fluid dynamics (CFD) software was conducted on the APR1000 reactor to analyze the effect of ECBD and its configurations.

2. Analysis Methodology

A commercial CFD software based on finite volume method, was used to obtain the core inlet flow distribution based on steady Reynolds-Averaged Navier-Stokes (RANS) analysis.

2.1. Numerical analysis model

The three-dimensional modeled fluid domain of APR1000 for CFD analysis was created using Spaceclaim 2021. Fluid analysis domains with/without ECBD installed were created as shown in Fig. 1. Fluid domains for three different installation angles and lengths of ECBD were created as shown in Fig. 2. The ECBD installation angles were calculated from the center of the reactor outlet and the ECBD lengths were calculated from the center of the reactor inlet.

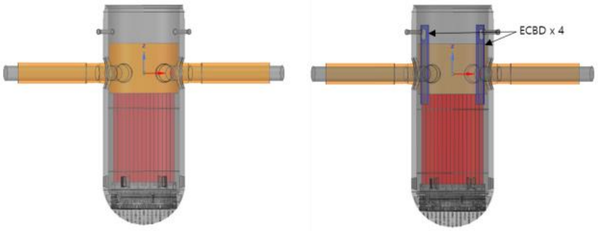
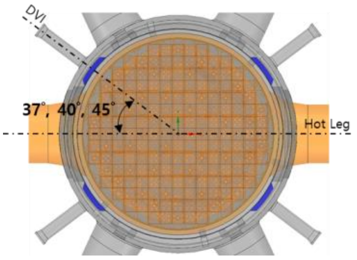
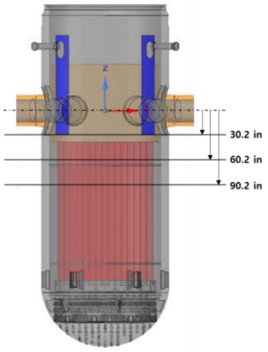


Fig. 1. CFD analysis domains for APR1000 reactor model with/without ECBD installation.



(a) ECBD installation angles



(b) ECBD lengths

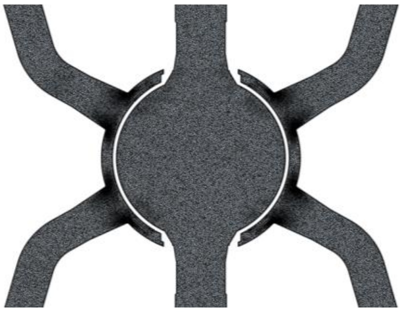
Fig. 2. CFD analysis domains for APR1000 reactor model for different ECBD installation angles and lengths.

The turbulence model was determined to be k-ε standard through the turbulence model sensitivity analysis. Near-wall grids were created with an assumption y+ of 100 since the k-ε standard model is reliable when the y+ value is located in the logarithmic region.

2.2. Grid and boundary conditions

The size of the first grid in contact with the wall surface was calculated, and grid sensitivity analysis was performed through GCI uncertainty evaluation [1] to determine the size and number of grids. The grid model is shown in Fig. 3. The grid information is described in Table 1.

(a) Grid systems for whole domain



(b) Grid systems for upper plenum section

Fig. 3. Grid systems for APR1000 reactor model.

Table 1. Grid information

Base size (mm)	Number of layers	Near-wall thickness (mm)	Layer thickness (mm)	Number of meshes
30.00	17	0.067	9.3	113,620,107

The boundary conditions for the analysis are shown in Fig. 4. The mass flow inlet condition was applied to the reactor inlet. The porous model was adopted to calculate pressure drops through the core region by using the pre-calculated axial and lateral loss coefficients.

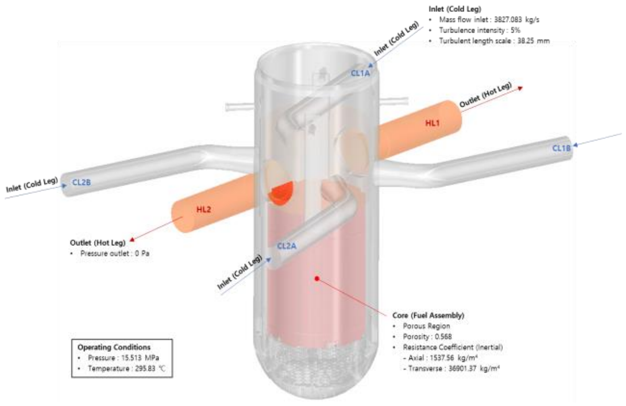


Fig. 4. Boundary conditions for CFD analysis.

3. Analysis results

Figures 5 to 7 show the core inlet flow distribution according to the presence of the ECBD, its installation angles and lengths. The differences in the mean absolute deviation of the overall core inlet flow distribution due to the presence of the ECBD, installation angles, and lengths were 1.03%, 0.25% to 0.84%, and 0% to 0.25%, respectively, which were almost identical. Especially when comparing the flow distribution within the 1.96σ (standard deviation) range, they were found to be almost identical regardless of the analysis cases, ranging from 0.82 to 1.18. Therefore, the change in core inlet flow distribution due to the presence and shape effects of the ECBD can be regarded negligible.

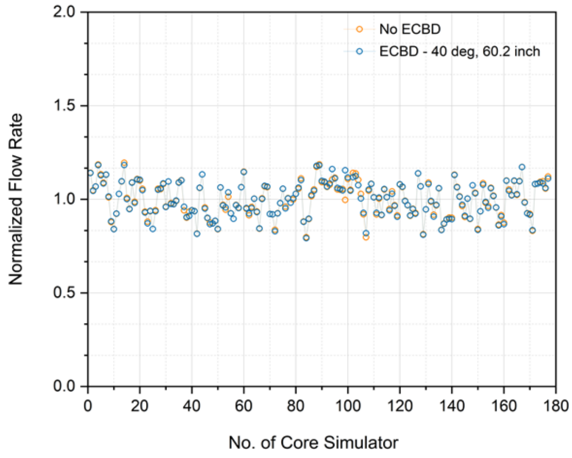


Fig. 5. Core inlet distribution of APR1000 reactor with/without ECBD installed.

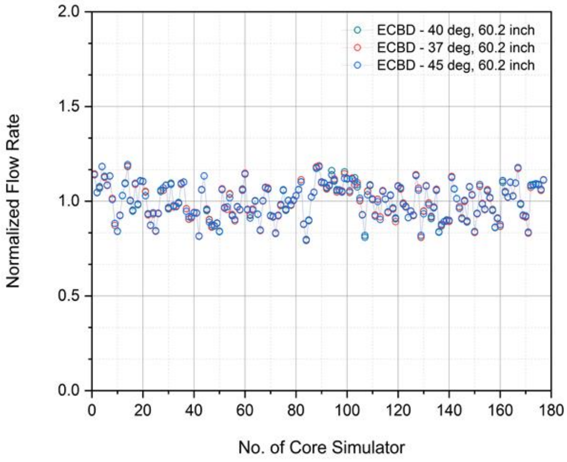


Fig. 6. Core inlet distribution of APR1000 reactor for different ECBD installation angles.

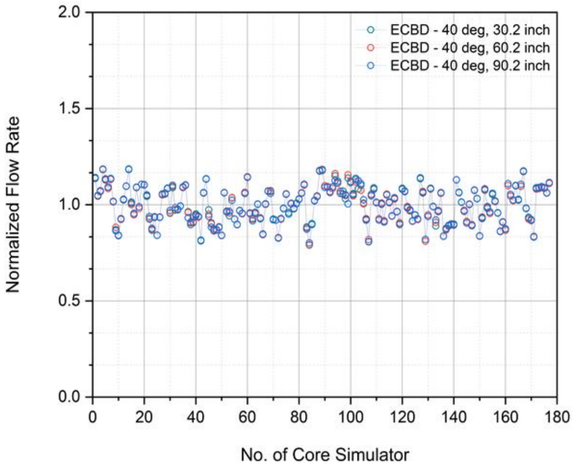


Fig. 7. Core inlet distribution of APR1000 reactor for different ECBD lengths.

4. Conclusion

The shape effect of the ECBD on the core inlet flow distribution of the APR1000 reactor was numerically studied. CFD analysis was performed based on the presence of the ECBD, installation angle, and installation length, of which results were statistically analyzed, concluding that the change in core inlet flow distribution was negligible. This study showed that the ECBD that has little impact on the core inlet flow distribution is applicable to APR1000 with an advantage of reducing the safety injection flow bypassing the core.

ACKNOWLEDGEMENT

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REFERENCES

[1] ASME, Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer, ASME V&V 20-2009 (Reaffirmed 2016), The American Soc. Mech. Eng., 2009.