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Effect of Core Asymmetry for the Analysis of DNBR Using Multi-scale codes

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1. Introduction

In recent studies, it was suggested that the BEPU approach could be extended to Non-LOCA cases as well. The structure of the suggested Best Estimate plus Statistical Uncertainty Analysis Method (BESUAM) shares a similar structure with most of the BEPU approaches. The approach claims that it is a modification from the deterministic bounding method. [1]

KINS (Korea Institute of Nuclear Safety) has been developing a Non-LOCA regulatory audit methodology, which consisted of advantages from both conservative method and BEPU approach. [2] The locked rotor transient was the representative asymmetric event resulted from the PIRT assessment. For this reason, KINS analyzed system behavior using the MARS-KS code to externally provide system results with boundary conditions for both computational fluid dynamic and CTF sub-channel analysis code. Mass flow distributions, which could flow into 241 assembly channels in the lower plenum at the core, were also analyzed using CFD. These CFD results were used to modify the mixing ratio of the MARS-KS and also used to provide CTF with boundary conditions to precisely assess the DNBR in the hottest channel.

2. Core flow of Locked Rotor transient by MARS-KS

System behaviors of the locked rotor transient were analysed using the MARS-KS system code to provide essential information such as mass flow rate, fluid temperature and pressure in the coldlegs with computational fluid dynamics to obtain the asymmetric flow distribution in the core inlet region.

Figure 1 represents the relative total mass flow rate between the calculation and FSAR results in the locked rotor transient. The results of FSAR were identified as more conservative than regulatory calculation using MASRS-KS in terms of total mass flow rate into core inlet which was significantly affected to DNBR assessment.

When a single RCP rotor seizure accident occurs, a reverse flow can occur in the clearance of the RCP rotor due to the initial high pressure inside the reactor because of the coastdown of the intact RCPs. The safety analysis report for the APR1400 reactor conservatively considers the flow rate to the reactor core without such a reverse flow phenomenon. Hence, the present study conducted the CFD simulations in the case applying the calculated results of the locked rotor accident analysis using the MARS-KS code and the case assuming a conservative flow rate at each cold leg without any reverse flow. [2]

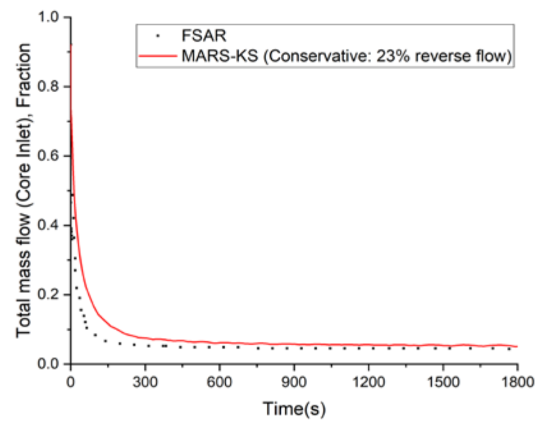

Fig. 1 Total mass flow rate (Fraction)

3. Asymmetric distribution of core flow by CFD

In this CFD study, a porous model for fuel assemblies and the upper plenum is applied to efficiently conduct the analysis on the flow field from the cold legs to the core inlet, which is predicted to have almost no effect on the flow at the lower plenum of the reactor. The unsteady Reynolds-Averaged Navier-Stokes (RANS) equations were used, which were solved using ANSYS-CFX code. The standard k-ε model was applied in consideration of the turbulence.

An important safety variable for accidents in which a single RCP rotor seizes is a departure from nucleate boiling ratio (DNBR), which is used as one of the acceptance criteria in terms of nuclear fuel integrity. The minimum DNBR is known to have occurred between 1 and 4 s after the accident. In this study, CFD transient simulations were conducted on the reactor internal flow up to 5 s after the RCP rotor seizure, and the flow rate distribution was evaluated at the core inlet.

Figure 2 shows a comparison of CFD in terms of core asymmetry. The total mass flow rate in FSAR was more conservative than that of MARS-KS. However, the deviation of the flow rate toward the core inlet could be more significant than the FSAR assumption when reverse flow into the affected RCP considered.

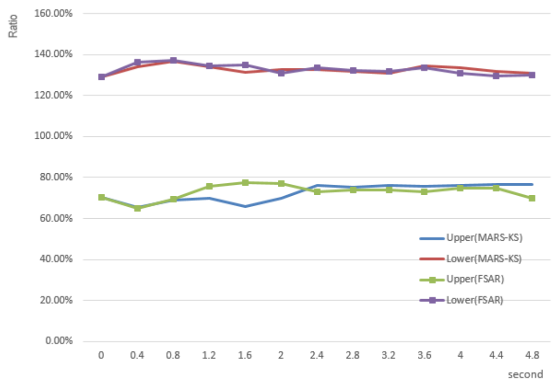

Fig. 2 Comparison of core asymmetry

4. Comparative Analysis for the effect of DNBR between MARS-KS and CTF

Figure 3 illustrates the results of MARS-KS calculated DNBR considering deviation of core flow rate based on the results of CFD. Its results did not show the variation of MDNBR substantially during locked rotor transient.

This result could be due to the fact that the 3-dimensional effect did not affect the system significantly or the limitation in the 1-dimensional code.

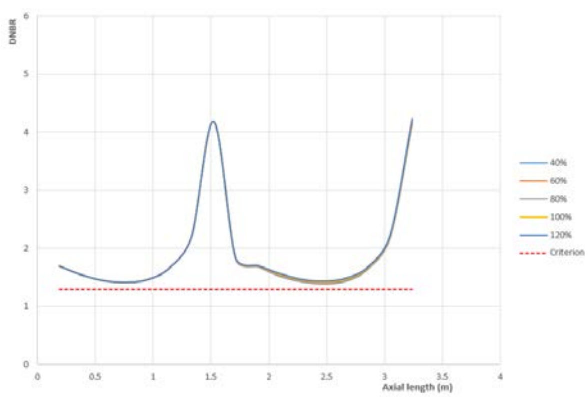

Figure 3 The DNBR results of MARS-KS

Subchannel analysis has performed by using CTF in order to evaluate the minimum DNBR in an assembly considering core flow asymmetry derived from the results of CFD.

Figure 4 shows the minimum DNBR results in the whole subchannels according to the core flow range of 65 ~ 120%. This result showed a large deviation of DNBR on the amount of core flow. Critical heat flux in the forced convective boiling has been affected by several parameters such as not only mass flow rate, temperature, pressure and geometry but also surface roughness and heating method. Among the several affective parameters, the mass flow rate into core assemblies has been considering the most important factor in assessing the DNBR. As can be seen, critical heat flux has a tendency to increase according to mass flow rate increases.

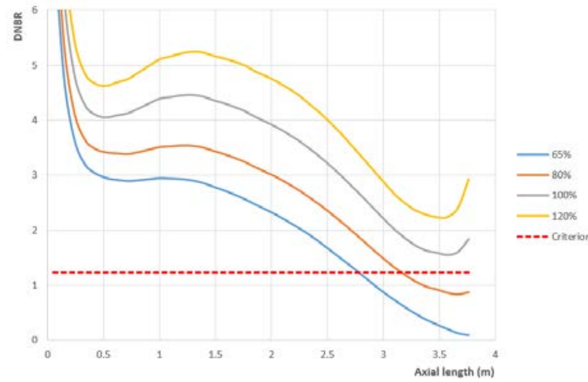

Figure 4 The DNBR results of CTF

4. Discussion

This study performed to investigate the effect of core asymmetry in the locked rotor transient considered a representative asymmetric accident based on the PIRT results using multi-scaled codes; MARS-KS, CFD and CTF. MARS-KS did not show the effect of core asymmetry on the DNBR, however CTF presented an insight that DNBR could be affected by core asymmetry.

5. Conclusions

This study presented the multi-scale results of core asymmetric effect on the analysis of DNBR. A combination code system that used MARS-KS, CFD and CTF successfully operated to assess the MDNBR in the condition of core flow asymmetry.

Acknowledgements

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