Influence of ECCS Core Barrel Duct on Reflood Behavior Predicted by MARS Code

Young Seok Bang [a*], Gong Hee Lee [a], Sweng Woong Woo[a], Min Jeong Hwang [b], S. K. Sim [b]
[a]*Korea Institute of Nuclear Safety, 64 Kwahak-ro, Yuseong, Daejeon, 305-338, Korea*
[b]*Environment & Energy Technology, Inc., 100 Sinseong-dong, Yuseong-gu, Daejeon 305-804, Korea*
[*]*Corresponding author: k164bys@kins.re.kr*

1. Introduction

A device, ECBD (Emergency Core Cooling System Core Barrel Duct), has been proposed at APR+ Standard Design [1], which was to provide a direct flow path from the elevation of Direct Vessel Injection (DVI) nozzle to the one of active core within the reactor vessel downcomer. It's main function is to reduce the amount of the bypassed ECCS water especially during the reflood phase of large break loss-of-coolant accident (LBLOCA). Since the ECBD design was based on the DVI of APR1400 which was approved through licensing process [2], the impact of ECBD needs to be assessed in comparison with APR1400 DVI and also the case without ECBD. The present study is to discuss the influence of ECBD on the thermal-hydraulic behavior during the reflood phase of LBLOCA using the MARS-KS code and the related modeling consistent with the one previously developed [3].

2. Code and Modeling

A methodology based on MARS-KS code [3] and plant model was applied consistently with the one for APR1400 [4]. Since the reactor power was increased by 1.06 times and the sizes of the major components including reactor vessel, Steam Generator (SG), Reactor Coolant System (RCS) were changed from the APR1400, all the changes were incorporated into the input, while the basic modeling scheme such as number of volume and flow path configuration for the specific part was unchanged.

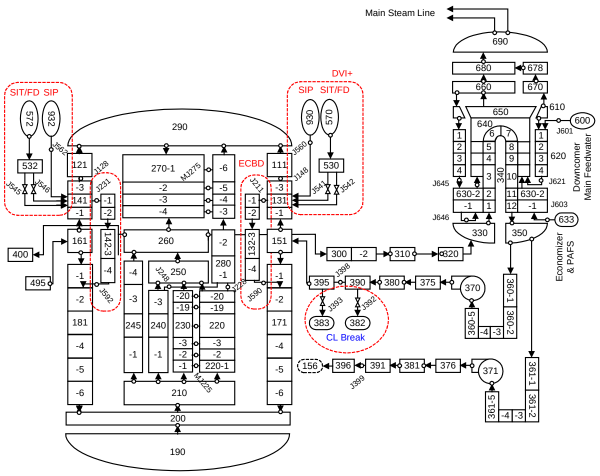

Fig. 1 MARS-KS modeling of APR+ LBLOCA

Figure 1 shows a MARS modeling of the reactor vessel and one RCS loop of APR+ including ECCS, SG, and break part. The Passive Auxiliary Feedwater System (PAFS) of APR+ was also modeled although it was not activated during the LBLOCA. Four ECBD were individually modeled by 'pipe' component embedded within the downcomer volumes, which have junctions to represent the openings at inlet and outlet. An appropriate K-factor was assigned for each junction based on the engineering handbook. It enables to simulate the process that ECCS water injected from the Safety Injection Tanks (SIT) and Safety Injection Pumps (SIP) comes to the downcomer volumes, divides into two parts (inside and outside ECBD), and combines at the outlet volumes of downcomer. The SIT having Fluidic Device (FD) was modeled with 'accum' component of MARS code and two valves switched-over by the water level of the tank. The K-factors for the valves were obtained by the derivation from the actual plant test data [5].

Double-ended cold leg guillotine break which was the most limiting accident in SAR was calculated. According to the N+2 design concept for APR+, two units among four Emergency Diesel Generators (EDG) were assumed to fail, thus, the worst set of two operable SIP was determined as two SIP connected to the DVI lines close to the broken cold leg.

Initial condition of LBLOCA was selected based on 100% nominal core power, core flow (19,861.1kg/sec) and pressurizer pressure (15.514 MPa), which was comparable with the Safety Analysis Report (SAR) [1]. The minimum SIP flow curve and the conservative containment pressure from the SAR were applied. Other boundary condition such as the reactor trip, Reactor Coolant Pumps trip, ECCS signal and the associated delay time was also considered as the same as SAR.

3. Result and Discussion

Using the methodology explained above, a steady state and the subsequent transient calculation were conducted. Also the case without ECBD was calculated.

Since APR1400 and APR+ have the same size of cold leg, the break flow behavior for both cases was identical during the choked flow regime. For the unchoked regime, break flow behavior can be different due to the differences in flow resistance to the break, in

ECCS flow rates at a given pressure, and in characteristics of ECC bypass. Fig. 2 shows a comparison of break flow. A little higher break flow was found after SIT starting and at the time of high-to-low flow switchover in the case without ECBD.

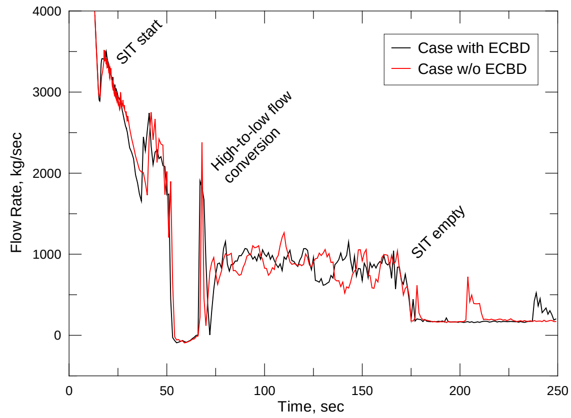

Fig. 2. Comparison of break flow

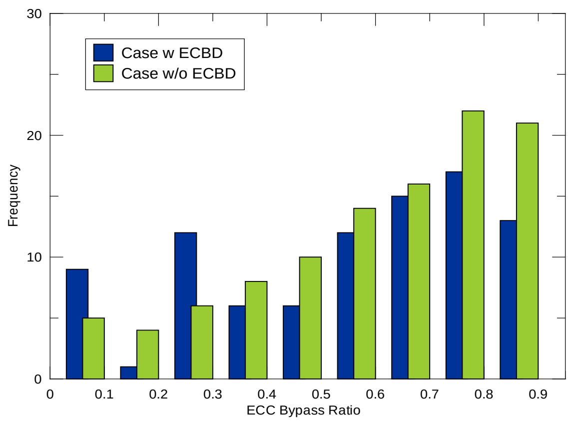

Fig. 3. Comparison of Histogram of ECCS Bypass Ratio

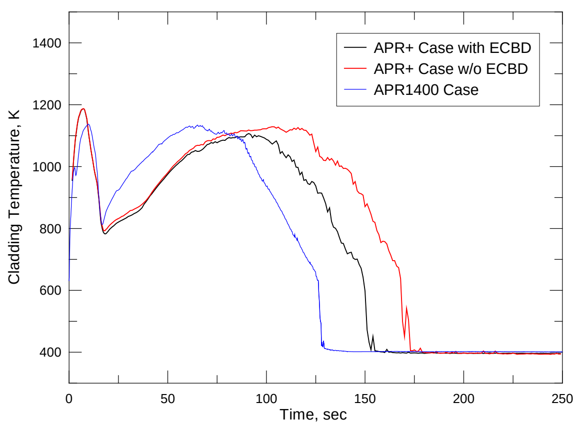

Fig. 4. Comparison of cladding temperature.

Fig. 3 shows a comparison of histogram of ECCS bypass ratio. The ratio is defined as a portion of instantaneous mass flow rate not entering the core inlet over the total ECCS flow rate. The calculation showed a significant oscillation of the ratio, thus, a representation of the ratio in frequency basis was attempted for better evaluation of the ECBD impact. The histograms were generated from the data until 250 seconds. As shown in the figure, a higher frequency was found at the high bypass ratio region for the non-ECBD case, which may imply the reduction of ECCS bypass by the ECBD. Thus, it may be true that the ECBD has an effect to reduce ECCS bypass during the reflood phase if the code can predict well the ECBD related phenomena.

Fig. 4 shows a comparison of the fuel cladding temperatures for both cases. Also APR1400 case [5] was compared. The thermal response during blowdown phase was almost identical for both cases, while a little higher Peak Cladding Temperature (PCT) and a delayed quenching during reflood phase are predicted in the case without ECBD. It may be due to lower ECCS bypass by the ECBD. Compared to APR1400 result, the reflood PCT of APR+ was a little lower and the quenching time was a little later. The reasons for the PCT difference may be ECBD effect. The later quenching may due to the increased size of the reactor vessel of APR+.

3. Conclusions

Influence of ECBD adopted in APR+ Standard Design on LBLOCA reflood behavior was discussed based on the MARS-KS code prediction. The ECBD was modeled as close as to its physical configuration. The prediction result shows a reduction of ECCS bypass due to ECBD but not significant impact on PCT during reflood phase. Aside from the PCT impact, further code assessment is needed using the applicable experiment simulating a LBLOCA with ECBD to confirm the expected ECBD related phenomena and to get an information of the uncertainty of the phenomena.

REFERENCES

[1] KHNP, Standard Safety Analysis Report APR Plus, 2011..
[2] KHNP and KNF, Topical Report for the LBLOCA Best-Estimate Evaluation Methodology of the APR1400 Type Nuclear Power Plants, TR-KHNP-0018 (Rev.1), Approved Version, 2010. 8.
[3] KAERI, MARS Code Manual, KAERI/TR-3042/2005, Daejeon, Korea (2005).
[4] Y. S. Bang, et al., Differences in LBLOCA Thermal-hydraulic Response Between 1D and 3D Calculations, Transactions of the Korean Nuclear Society Autumn Meeting Gyeongju, Korea, October 25-26, 2012.
[5] Y. S. Bang, et al, Modeling of Safety Injection Tank with Fluidic Device and Its Effect on LBLOCA Calculation, Paper No. KF098, Proceedings of ICAPP 2013 Jeju Island, Korea, April 14-18, 2013.

.