Impact of k-factor at the Entrance from Downcomer to Broken Cold Leg on ECC Bypass

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1. Introduction

Emergency Core Coolant (ECC) Bypass is an important phenomena occurred at the reactor vessel downcomer and to the broken cold leg following a Large Break Loss-of-Coolant Accident (LBLOCA). The ECC Bypass has been regarded as a combined phenomenon with the several two-phase flow phenomena in a complex manner. It includes interfacial drag between steam generated from the core and ECC water in the downcomer, Counter Current Flow Limitation (CCFL), hot wall effect, etc. [1] A best estimate system thermal-hydraulic code to predict the LBLOCA should have capability on those items. Generally, it has been reported that some of the system codes such as TRACE, RELAP5, and MARS have such a capability and that conservative result of ECC Bypass may be obtained based on the code validation using the test data from Upper Plenum Test Facility (UPTF) [2]. However, it is still not known where and why the conservatisms come from. Therefore, the specific parameters relevant to the quantification of uncertainty of ECC Bypass prediction have not been identified.

The present study is to discuss the effect of hydraulic resistance (k-factor) from the downcomer to the broken cold leg (BCL) on ECC Bypass. MARS-KS 1.4 code was used. To obtain the k-factor at the point, computational fluid dynamics (CFD) analysis was conducted. The result of CFD analysis was implemented into the plant model for MARS calculation.

2. Scope

The ECC Bypass can be considered dependent on

(1) Thermal-hydraulics within downcomer, i.e, CCFL, interfacial drag, wall friction, hot wall effect, etc.
(2) Flow restriction at the flow path from downcomer to break, i.e, choking flow, k-factor, etc.
(3) Amount of steam flow generated from the core and ECC flow per system pressure

Besides those items, several parameters and models may be involved, however, those three categories were assumed to be primarily important in this study.

Among them, the first category, the downcomer thermal-hydraulic phenomena should be considered in a separate method and will be discussed in different study. Regarding the third category, amount of steam flow was already considered as a source of uncertainty in the present method [3]. The ECCS flow was also considered because it is a function of system pressure which can be predicted with uncertainty of break flow. Accordingly, the present study is focused on the second category, actually k-factor along the flow path.

3. CFD analysis

3.1. K-factor distribution

A CFD analysis was conducted to determine the k-factors from the intact cold legs, through the downcomer annulus, cold leg nozzle, and to the break with the APR1400 reactor vessel geometry and the typical condition of reflood phase of LBLOCA [4]. ANSYS CFX-18 was used in the computation. Fig. 1 shows the calculated stream line pattern of the domain.

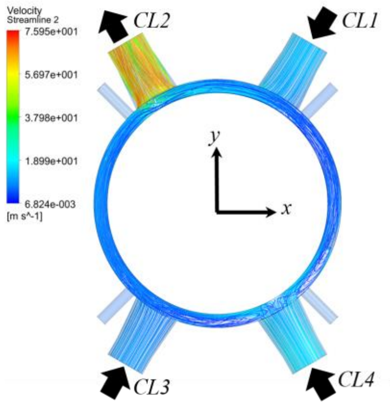

Fig. 1. Streamlines and Velocity magnitude

Fig. 2 shows k-factor distribution along the streamlines in a cumulative manner.

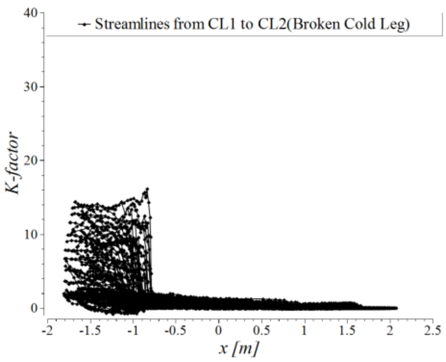

Fig. 2. K-factor along streamlines from cold leg 1 to cold leg 2

As shown in the figure, a sudden increase of the cumulative k-factor was found at x range of -0.7~-1.0, i.e, the cold leg nozzle to the break, which indicated the k-factor at the point is important role to the pressure drop and flow rate.

3.2. K-factor under two-phase condition

The second CFD analysis was conducted to determine the k-factor under the two-phase condition at the cold leg nozzle point to the break [5]. Fig. 3 shows the solution domain, composed of a portion of downcomer and the broken cold leg.

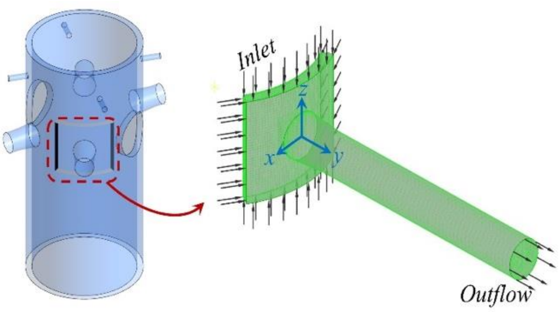

Fig. 3. Computational domain and grid system-

At the inlet, a homogeneous air-water flow with 10 m/sec was assigned and the void fraction range was 0 to 1. Fig. 4 shows the calculated k-factors for the assigned void fractions.

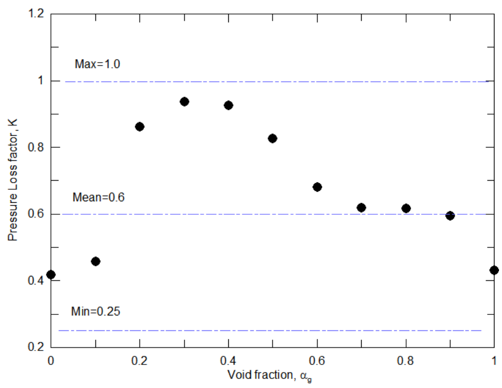

Fig. 4. Calculated k-factor at nozzle and uncertainty range

The calculated k-factor was within the range 0.4 ~0.95. To determine the maximum, mean and the minimum k-factor, two-times of the standard deviation of the data was assumed.

4. System code analysis

4.1. Modeling scheme

A double ended guillotine break at cold leg of Advanced Power Reactors of 1400 (APR1400) was calculated using MARS-KS 1.4 code. Fig. 5 shows a nodalization of the plant for LBLOCA calculation. At the break junction, Henry Fauske critical flow model was applied with the discharge coefficient, C_D=1.0 and the non-equilibrium constant of 0.14 and the core decay heat was assumed by ANS73 model. The fuel was assumed at a burn-down state of 30,000 MWD/MTU. The degraded thermal conductivities of the fuel pellet and the oxidized cladding were applied.

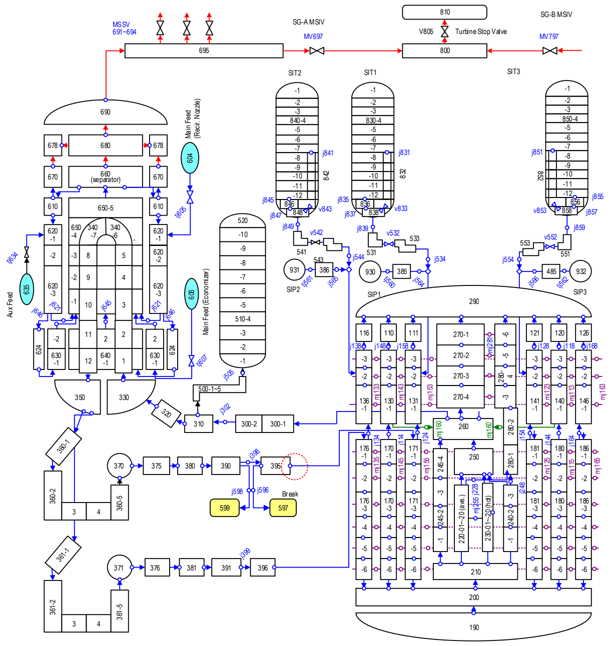

Fig. 5. MARS-KS nodalization for LBLOCA of APR1400

The k-factor predicted by the CFD analysis was applied to the junction from the downcomer to the broken loop cold leg using the scheme of variable k-factor driven by control variable in MARS code as shown in Fig. 4. The k-factor was set to activate when the break flow is changed from choking to non-choking condition.

4.2. Results and discussion

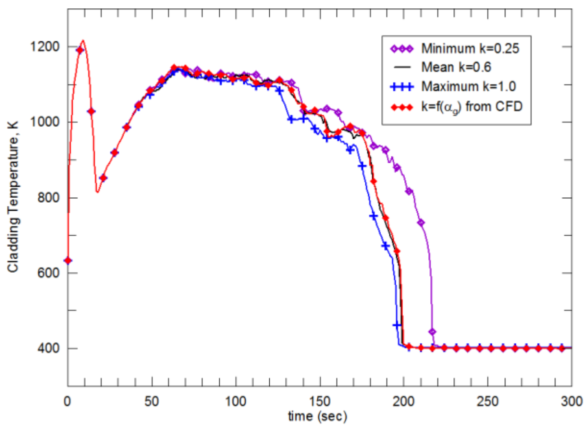

Fig. 6. Comparison of cladding temperatures

Fig. 6 shows a comparison of cladding temperature for the cases explained above. An identical behavior was found before 40 sec. After that time, the cladding thermal responses were similar but with slightly different timing due to the different k-factor. The impact by the k-factor on peak clad temperature (PCT) during reflood phase was less than 10K and the impact of core quenching time was 20 sec.

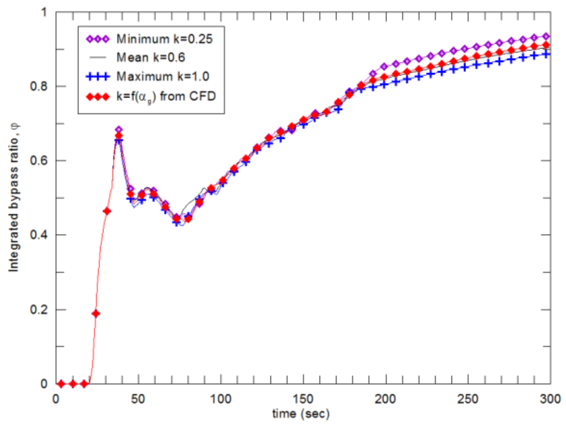

Fig. 6. Comparison of bypass ratio

Fig, 7 shows a comparison of bypass fraction of ECCS to break in a integrated manner. This parameter was derived from the calculation result as follows:

$$\varphi = \int_{t_{ECCS}}^{t} \dot{m}_{ECC-Break}\, dt \Big/ \int_{t_{ECCS}}^{t} \dot{m}_{ECC}\, dt \qquad (1)$$

Where, *m* denotes mass flow rate and subscripts *ECC* and *ECC-Break* mean one from ECCS and one discharged out of break among the one from ECCS. To capture this quantity, boron was added to the ECCS and counted at the break junction.

The calculated values shows an almost identical trend. It reached 0.7 when Safety Injection Tanks (SIT) started to inject and 0.8 when the SIT injection terminated. After that time, the bypass ratio was increased in higher level for the low k-factor case than the high k-factor case. However, the core cooling was not influenced by the magnitude of the k-factor.

The current result indicated the k-factor at the BCL entrance has not significant impact on ECC Bypass, i.e, reflood PCT and quenching time, for the proposed range of k-factor. It may simplify the process for evaluation of uncertainty of ECC Bypass by excluding the subjected k-factor from the candidate parameters. However, the validity of this finding should be further confirmed through the calculation of the applicable Integral Effect Tests (IET) such as tests in Loss Of Fluid Test (LOFT) using the present k-factor model.

5. Summary and conclusion

The effect of hydraulic resistance (k-factor) from the downcomer to the broken cold leg on ECC Bypass was discussed. MARS-KS 1.4 code was used to calculate the LBLOCA of APR1400. To obtain the k-factor at the entrance of BCL under two-phase condition, computational fluid dynamics (CFD) analysis was conducted and its result was implemented into the plant model for MARS calculation. The followings can be concluded:

(1) The k-factor is significantly increased at the entrance from the downcomer to broken cold leg.
(2) The k-factor with the inlet void fraction can be derived from the CFD analysis.
(3) The calculated impact of k-factor on bypass ratio, PCT, and quenching time during reflood phase is insignificant for the proposed range. This finding needs to be confirmed by IET calculation.

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