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ECC bypass Characteristics of a 4-EDG DVI system

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1. Introduction

The direct ECC (Emergency Core Cooling) bypass fraction is strongly dependent on the relative ECC injection angle because the suction zone of a broken cold leg has the characteristics of a strong ECC bypass (Kwon et al., 2002, 2006). The recently developed advanced PWR (Pressurized Water Reactor) such as USAPWR, EPR and APR+ have the 4-EDG (Emergency Diesel Generator) ECC system. For a single failure assumption during a LOCA condition, the two DVI nozzles are activated at both the broken cold leg and the opposite side of the broken cold leg. Therefore, the ECC water which is injected into the opposite side of the broken cold leg is well penetrated to the lower downcomer while the ECC water which is injected into the suction zone of the broken cold leg is bypassed all through the broken cold leg in the 2-EDG ECC system. However, the ECC water which is injected by the newly activated two DVI nozzles by the 4-EDG system is partially bypassed because the newly activated two DVI nozzles are located to the broken cold leg when compared to the opposite DVI nozzle of the broken cold leg in the 2-EDG ECC system. In this study, the effect of the EDG train change on the direct ECC bypass during a LBLOCA has been evaluated by a CFX simulation.

2. Analysis Model

2.1 Air-Water ECC Bypass Simulation

The numerical simulation model of the APR1400 for ECC bypass phenomena is performed using an air-water two fluid models of the CFX code. The 1/5-scale reactor vessel downcomer is modeled as a simplified cylinder annulus having 4 cold leg nozzles, 2 hot leg blunt bodies, and 4 DVI nozzles inside the downcomer annulus. The flow field is assumed a two phase mixing condition of air and water. The water level of downcomer was controlled as constant by a user control to prevent a swept out from the free surface. The injection velocity of DVI nozzle is 0.72 m/sec. The water temperature is 15 degrees, and the atmospheric pressure is applied for the system pressure. The DVI-2, which is located at the opposite side of the broken cold leg, was isolated to simulate the condition of no HPSI injection as a single failure assumption. The other three DVI nozzles are activated for a HPSI injection condition. The simulation conditions are summarized in Table 1.

Table 1 Calculation conditions

Description	Condition	
Cold leg Fluid	Air Injection (CL 1~3)	
Cole leg Temp.	15^{o}C	
Cold leg Velocity	15, and 18 m/sec, equally	
DVI	Water Temp	15^{o}C
	Injection	DVI-1,-3,and -4
	Velocity	0.72 m/sec
	single failure assumption	DVI-2 : no injection

2.2 CFX simulation

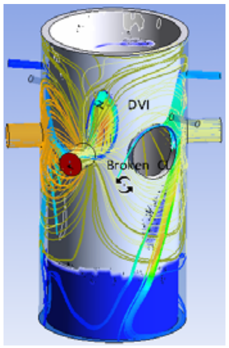
The bypass fraction is defined as equation (1). The entrained water into the break flow is calculated a total water fraction.

$$bypassfraction = \frac{m_{BrokenCL,Water}}{\sum_{DVI=1,3,4} m_{DVI,Water}} \tag{1}$$

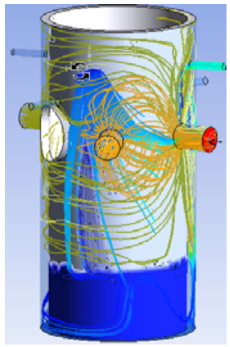
The governing equations are for the continuity, momentum, turbulent kinetic energy, and turbulent kinetic energy dissipation. The length scale of droplet is 4 mm for the air-water interaction. The uniform velocity distribution is applied at the inlet both the cold leg nozzles and the DVI nozzles. The turbulence intensity at the cold leg inlet is 5% applied. The number of hexagonal volumes in a mesh generation is 470,000.

3. Results

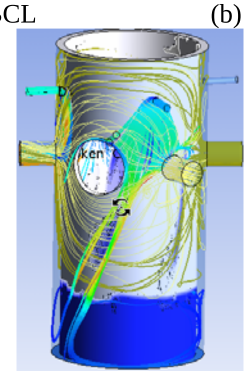
The overall flow shape of the ECC water and the air near the broken cold leg is shown in Fig. 1. The inlet air velocity of the cold leg is 18 m/sec. Fig.1(a) shows the flow pattern of the broken cold leg. The injected ECC water is bypassed out through the broken cold leg. The typical ECC water spreading film shape near the broken cold leg is formed at near the suction zone of the broken cold leg. All injected water by DVI-4 is bypassed out. The flow patterns of the DVI-1 and DVI-3 are shown in Fig. 1(b) and Fig.1(c). Fig. 1(c) shows that the ECC film is formed near the hot leg. Both the front zone and the behind the wake zone of the hot leg are a strong ECC penetration region. The water film spreading drops well to the lower downcomer. But, the film of the wake region of hot leg is disappeared because the water fraction is low near the broken cold leg.



(a) BCL



(b) DVI-2



(c) DVI-3

Fig. 1 CFX Simulation of Air-Water direct ECC bypass phenomena for $V_{coldleg,air\ velocity}$=18 m/s ; (a) flow pattern at broken cold leg (DVI-4), (b) at DVI-1, (c) at DVI-3.

The ECC bypass fraction of the CFX code simulation, as shown in Fig. 2, is generally over predicted when compared to the experimental result. However, the overall trend of the bypass fraction with a cold leg velocity is well coincided with the experimental results under the same flow condition for the 1/5-scaled down model.

The ECC bypass fraction of the three-DVI (DVI-1, DVI-3, and DVI-4) injection mode for the 4-EDG system is higher than that of the two-DVI (DVI-2 and DVI-4) injection mode for the 2-EDG system. The bypass fraction of the 3-DVI injection mode for the 4-EDG system is over 53% at the cold leg velocity of 18 m/sec while the bypass fraction of the current 2-EDG system is about 40% for the same flow condition. The direct ECC bypass fraction of the 4-EDG system has a high bypass trend when compared to the 2-EDG system. The DVI-2 nozzle makes these differences. In the 4-EDG system, the DVI-2 is isolated, and is replaced with DVI-1 and DVI-3. These two nozzles are more closed to the broken cold leg. Therefore, the suction force by a jet stream is increased to enhance the liquid entrainment in the downcomer.

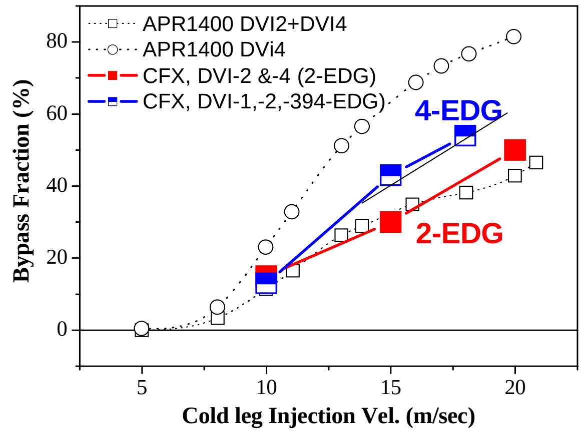


Fig. 2 Direct ECC bypass fraction

4. Conclusion

The CFD fine mesh simulation has been performed to evaluate the direct ECC bypass fraction when the HPSI water is injected by the 4 EDG system during a LBLOCA. The test results show that the total direct ECC bypass fraction of the 4-EDG system is higher than that of the current 2-EDG system. In the 2-EDG system, the ECC water injected by DVI-2 which is located the opposite side of the broken cold leg is all penetrated to the lower downcomer. However, the DVI-2 nozzle in the 4-EDG system should be assumed as an isolated nozzle for the single failure assumption. The other three DVI nozzles are closed to the broken cold leg when compare to that of the 2-EDG system. Therefore, the direct ECC bypass fraction is increased.

If the core power is increased, the cold leg steam flowrate is also increased by the increased decay power at the same time. Finally, the direct ECC bypass fraction is highly increased over the current simulation results.

REFERENCES

[1] T. S. Kwon, C. R. Choi, and C.-H. Song, 2003a, Three-dimensional analysis of flow characteristics on the reactor vessel downcomer during the late reflood phase of a postulated LBLOCA, Nuclear Engineering and Design (NED), Vol. 226, pp.255-265.

[2] T. S. Kwon, C.-H. Song, B. J. Yun, and H. K. Cho, 2003b, Effect of the Yaw Injection Angle on the ECC Bypass in Comparison with the Horizontal DVI, Nuclear Engineering and Design (NED), Vol. 225, pp.295-304.

[3] Tae-Soon Kwon, Chul-Hwa Song, and Won-Pil Baek, An Advanced Design Concept Of A Direct Vessel Injection, ICAPP, Reno, NV USA, June 4-8, 2006.