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The Development for Advanced Direct Vessel Injection in APR+

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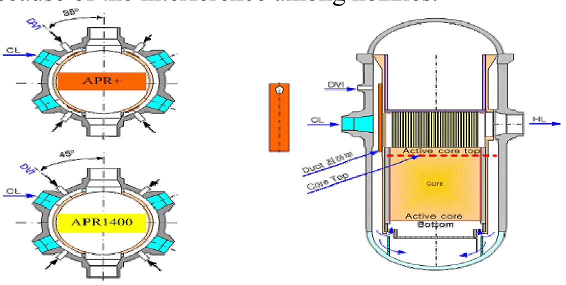
1. Introduction

A national plan to improve the safety and economy of the Advanced Power Reactor 1400(APR1400) was launched in 2007. The objective of this plan is to develop an Advanced Power Reactor Plus (APR+) which is a generation Ⅲ+ PWR in Korea. Several Advanced Design Features (ADFs) are introduced and are being developed in this APR+. One of these ADFs is a design improvement called Direct Vessel Injection (DVI+), which reduces the Emergency Core Cooling (ECC) bypass rate. After the feasibility study was completed in 2008 [1], various evaluations such as experiments, code analysis, and structural analysis for design applicability have been conducted. Results of these evaluations will be utilized in finalizing the basic design of DVI+.

2. The basic design for DVI+

2.1 The optimum location of DVI Nozzles

To reduce the bypass rate of ECC water, it is advantageous to move the DVI nozzles location close to the Hot Legs and to lower the DVI nozzles to about a half elevation of their current location in the APR1400. The location and opening size of nozzles on the Reactor Pressure Vessel (RPV) must meet the requirements that are presented in both the ASME Code, nb-3331 "General Requirements for Openings " and the NB-330.2(d)(2). So, the optimum location for the DVI nozzles was reviewed through those documents. As shown in Figure 1(a), the angle between the DVI nozzles and the Hot Legs was rearranged to 35^{o} (45^{o} in APR1400), within the acceptance range such as fillet edge. However, the elevation change was restricted because of the interference among nozzles.



(a) (b)

Figure 1. Basic arrangement and shape for DVI+

2.2 ECC Core Barrel Duct

The auxiliary structure, the ECC Core Barrel Duct (ECBD), was developed. As shown in Figure 1 (b), this, rectangular duct type, is vertically installed on the outer surface of the core barrel. The width and height of the ECBD are about 28 inches and 154 inches, respectively. Therefore, the ECBD is not included in the active core region. The short enough depth of about 3 inches prevents interference between the reactor core and the core barrel. Also, due to the deformation by thermal expansion, we are considering manufacturing the ECBD as three axial pieces. As mentioned above, the circumferential angle change contributes to the decrease of coolant jet force from the Cold Leg to the ECBD during normal operation.

3. DVI+ performance test and LOCA pre-analysis

The performance of the ECBD was evaluated by experiment. Also, Preliminary analysis for LOCA (Loss Of Coolant Accident) was conducted using safety analysis computer code.

According to the basic design of DVI+ (i.e ECBD and circumferential angle change), a Test facility having 1/5 scale was designed and is being constructed by KAERI(the Korea Atomic Energy Research Institute). SETs(Separate Effect Tests) such as axial flow distribution and pressure perturbation in downcomer by RCP (Reactor Coolant Pump) blade will be conducted using the test facility. First, an Air-Water test for ECC Bypass rate was conducted under the conditions of existence and nonexistence of ECBD. Major test conditions are as follows [2];

- ECC water temperature: ~ 15℃
- ECC water velocity: ~ 0.73 m/s
- Air velocity in Cold Legs: 5, 10, 15, 18 m/s
- Pressure: 1 atm.

Figure 2 shows two kinds of ECC water injection arrangements for the test. We considered the adaption of 4- Emergency Diesel Generator (4-EDG). So, those are the worst injection arrangements for a cold leg break accident according to 4-EDG.

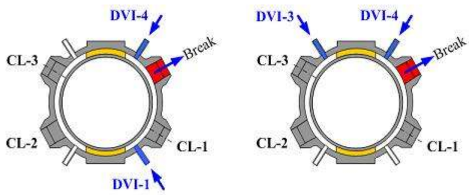


Figure 2. ECC water injection conditions for test

Figure 3 shows the test results for the performance of the ECBD. As shown in Figure 3, DVI-1 & 4 is higher than DVI-3 & 4 for ECC Bypass rate. This may explain why ECC water penetration appears more effective than bypass water because of the wake zone near the hot leg exits between DVI-4 and DVI-3. So, DVI-1 & 4 must be an injection arrangement that induces the highest ECC bypass rate.

When air velocity at cold leg is 18 m/sec on condition of DVI-1 & 4 injection arrangement, ECC Bypass rate in case of the test with ECBD is about 18%. This is much lower for the test without ECBD, in which the ECC Bypass rate is about 68%. Therefore, these results show that the attachment of ECBD will quite improve the injection performance of ECC water.

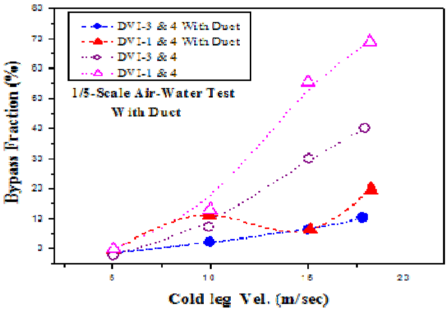
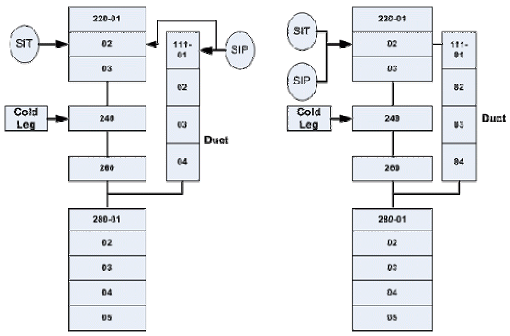


Figure 3. ECC Bypass rate evaluation for ECBD

Also, preliminary analysis for LOCA was conducted using RELAP5/MOD3.3 computer code; ECBD nodding was decided on through a sensitivity evaluation. First, after modeling ECBD equal to its design shape, as shown in Figure 4 (b), we simulated that RELAP code could automatically decide a flowrate flowing into both ECBD and downcomer. In such a case, RELAP code could not appropriately predict a flow being formed inside the ECBD. On the other hand, as shown in Figure 4 (a), after deciding on a flowrate flowing into the ECBD in advance, we were able to confirm a stable flow being formed inside the ECBD by using it as a boundary condition.

Preliminary LOCA analysis using nodding (a) showed that PCT(Peak Cladding Temperature) is quenched more rapidly than it is in the case without ECBD due to the penetration of more ECC water [3]. Specific analysis will be soon conducted using local experimental data.

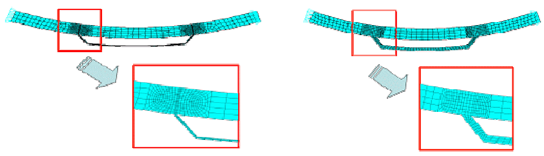


(a) (b)

Figure 4. ECBD nodding for sensitivity evaluation

4. Structural analysis for ECBD and CSB

Structural analysis using ANSYS computer code to evaluate static and dynamic loads is being conducted due to the attachment of ECBD on the CSB(Core Support Barrel). Now, the evaluation of static analysis and dynamic characteristics analysis as a part of dynamic analysis has been completed. Figure 5 shows analysis models, used for evaluation, having 5 mm and 20 mm thickness. As shown in Table 1, the side and axial stress of ECBD for hydraulic loads during normal and accident conditions were evaluated using the models shown in Figure 5.



(a) 5mm thickness (b) 20mm thickness

Figure 5. Stress Analysis Model for ECBD

In case of the side stress, thickness 5mm is six times the Pm stress and thirteen times the Pm+Pb stress more than the thickness 20mm. So, these values exceed the allowable stress presented from the ASME code [4]. On the other hand, the thickness 20 mm showed low stress values for both normal and accident conditions. However, because the allowable stress in Table 1 includes dynamic stress, final evaluation will be realized by adding stress obtained from dynamic analysis. Thermal stress that meets the allowable value was evaluated. Margins for the allowable stress were 57% for thickness of 5mm and 38% for thickness of 20mm.

Dynamic characteristics of ECBD and CSB with ECBD were also evaluated because of the flow vibration by RCP. Eigen-frequency and mode shape for both structures were deduced. As a result, the pulsation load by RCP and the attachment of ECBD had a weak influence on dynamic characteristics [5].

Table 1. Side and axial stress by static load (unit; psi)

Mode		Stress (Normal)		Allowable Stress (Normal)	Stress (Faulted)		Allowable Stress (Faulted)
		Side	Axial		Side	Axial	
5 mm	Pm	18,730	5.7	14,760	38,021	100	35,424
	Pm+Pb	78,670	9.8	22,140	159,700	172	53,136
20 mm	Pm	2,901	5.5	14,760	5,889	97	35,424
	Pm+Pb	6,014	6.9	22,140	12,208	121	53,136

- Pm : general primary membrane stress
- Pb : primary bending stress

5. Conclusions & Further Study

Interference between Reactor Vessel Internals (RVI) and ECBD, and a method of manufacture of ECBD are reviewed. After the analysis of dynamic load, two kinds of SETs, LOCA specific analysis, etc., have been done, the final decision about the applicability of ECBD will be taken.

REFERENCES

[1] "The Feasibility Study Report on Development of The Core Technologies for APR+", KHNP, S07NJ06-K-TR-001, 2008.7
[2] T. S. Kwon, et. al., "An advanced DVI for ECC direct bypass mitigation," NED, Vol. 239, 2009
[3] "Preliminary LOCA Analysis Report for DVI+ Using Licensing Safety Analysis computer Code", KHNP, S07NJ06-F-TR-001, 2009.7
[4] ASME Code Section III, Subsection NG
[5] "Preliminary Review Report for NSSS D&D suitability of DVI+", KHNP, S07NJ06-N-TR-004, 2009.7