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Evaluation of the In-vessel Downstream Effects for the APR1400 Design and License

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1. Introduction

During the emergency core cooling system (ECCS) operation following a postulated loss-of-coolant accident (LOCA), a portion of the particulates, fibrous and chemical debris may be ingested into the reactor coolant system (RCS) in the APR1400. This debris could deposit on fuel assemblies and thereby affect long-term core cooling (LTCC) while circulating coolant from the containment sump.

To address this safety issue, KHNP prepared the test report [1] and the evaluation report [2], and submitted them to the United States Nuclear Regulatory Commission (U.S.NRC) and the Korea Institute of Nuclear Safety (KINS), respectively. These reports include the licensing issues as follows; the effect of a flow channel gap change, the effect of debris settling, the accuracy of the GF630 flow meter, the effect of bubbles impinging on the bottom nozzle, and the bypass fiber amount.

In this paper, the valuation results of the in-vessel downstream effects for the APR1400 were described. In addition, the effect of a flow channel gap change and the bypass fiber amount were evaluated.

2. Evaluation Method and Results

2.1 In-vessel Downstream Effects of the APR1400

The in-vessel downstream effect tests for the APR1400 were described in Ref. 3. In this study, various ranges of debris amount were applied up to 100 g of fiber, 6,300 g of particulate and 300 g of chemical debris.

In this study, hot-leg break and cold-leg break conditions were simulated. The available driving head is 44.8 kPa at hot-leg break condition, and 15.1 kPa at cold-leg break condition. The testing represents that the p:f ratio of 1:1 produces the highest pressure drop for a constant fiber loading at hot-leg break condition. The presence of chemical debris causes an additional increase in the overall pressure drop. But, after some amount of chemical debris, subsequent chemical debris addition does not play a role to increase pressure drop.

In the hot-leg break conditions tests, all the cases showed lower pressure drop than the acceptance criteria and the highest pressure drop was 20.78 kPa. In the cold-leg break conditions tests, the highest pressure drop was 3.6 kPa across the full fuel assembly.

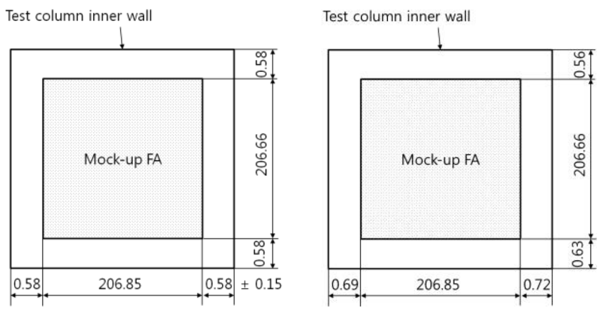
Therefore, all the tests satisfied the acceptance criteria to ensure ECC flow through the fuel assembly region of the APR1400.

2.2 Effect of a Flow Channel Gap Change

This section describes the impact of a flow channel gap on the validity of testing that has already been conducted to address in-vessel downstream effects of the APR1400.

To simulate the arrangement of fuel assemblies (FAs) in the core, the gap between the mock-up fuel assembly and the test column was set to 1/2 of the distance between the fuel assemblies. However, the manufacturing tolerance in the gaps between the test column and the bottom nozzle resulted in some discrepancies compared to the design value.

This section presents the test result of the most limiting condition with a re-manufactured test column, which meets the nominal value of the FA pitch and its tolerance (0.58 mm ± 0.15 mm), as shown in Fig. 1.



(a) Design condition (b) Re-manufactured condition
Fig. 1. Comparison of gaps between mock-up fuel assembly and test column (Unit: mm)

2.2.1 Test Conditions

The sensitivity test was performed under the condition of a hot-leg break which gave the most limiting results. The test parameters are provided in Table 1. This test was designed to be conducted with 15 grams of particulate and 15 grams of fiber (for a particulate to fiber ratio of 1:1).

2.2.2 Test Results

The pressure drop behavior in the sensitivity test is shown in Fig. 2, and it is similar to that of the previous test. The test procedures were also similar to those of the previous test, except for the time interval between the final fiber addition and the first chemical addition. In the sensitivity test, the system was allowed to stabilize for 250 minutes instead of 125 minutes.

The maximum pressure drop recorded for the test was 19.73 kPa under the re-manufactured condition.

Table I: Test parameters

Parameter	Value
Temperature	22℃ ± 1℃ (between 21 and 23℃)
Flow Rates	77.6 lpm ± 3.8 lpm
Coolant Volume	1,810 liters
Fiber	15 g
Particulate Debris	15 g
AlOOH Chemical Product	768 g (70 liters of 11 g/L AlOOH surrogate)

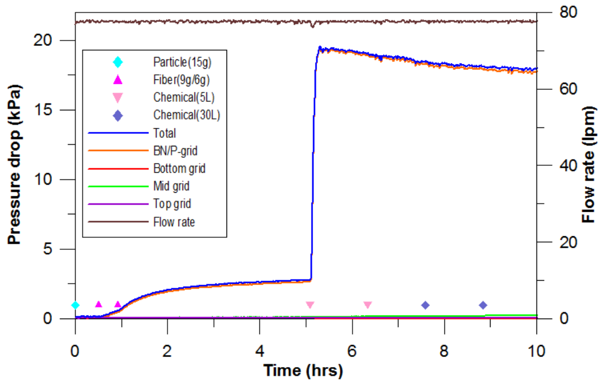


Fig. 2. Pressure drops at P/F = 1

2.3 Calculation of the Bypass Fiber Amount

To establish the quantity of fibrous debris that could potentially penetrate the strainer, prototype test was performed [6]. The test was performed with only fibrous debris as adding particulates may reduce the amount of bypass debris due to clogging at the strainer. Additionally, the most conservative approach with bypass test is to assume all sump strainers are active running at the maximum flow rates since it stands to reason that more mass flow rate and more perforated plates causes more bypass. Table 2 lists the amount of fiber fines added and the amount of bypass fiber after each fiber addition [6].

Table II: Summary of fiber bypass

Fiber addition	Fiber added (g)	Bypass fiber amount (g)
First	37.2	1.213
Second	37.2	1.194
Third	74.4	2.057
Fourth	74.4	1.153
Fifth	74.4	0.851

To determine the plant strainer bypass debris, the cumulative quantity of bypass debris from the prototype test was scaled by a ratio of the plant strainer to the prototype strainer (955/1.22 = 782.8). The cumulative bypass quantities for debris loads are presented in Table 3. The total bypass debris is the sum of the bypass debris for all active strainers as presented in Table 4.

The amount of fibrous debris into the core are determined by the four safety injection pumps (SIPs) : 3.994kg×4=15.98kg

The SIP bypass amount during SIP+CSP operation : 15.58kg×1,235gpm/6,660gpm=2.89kg

However, a bigger value is used for conservative calculation.

Therefore, the amount of bypass fiber per FA in the APR1400 : 15.98kg/241FA=0.0663kg/FA=66.3 g/FA

Table III: Cumulative prototype bypass debris

Fiber added(g)	Bypassed fiber weight(g)	Bypass rate(%)
37.2	1.213	3.26
74.4	2.406	3.23
148.8	4.463	3.00
132.2	5.616	2.52
297.6	6.467	2.17

Table IV: APR1400 bypass debris quantities

Pump	Flow rate (gpm)	Plant strainer debris load$^{1)}$(kg)	Prototype strainer debris load$^{2)}$(g)	Prototype bypass debris(g)	Bypassed fiber mass (kg)
SIP+ CSP	6,660	718.0	917.2	19.9$^{3)}$	15.58
SIP+ CSP	6,660	718.0	917.2	19.9$^{3)}$	15.58
SIP	1,235	133.1	170.1	5.1$^{4)}$	3.994
SIP	1,235	133.1	170.1	5.1$^{4)}$	3.994
Total	15,790	1,702.2			39.15

1) Proportion based on the flow rate: 1,702.2kg×6,660gpm/15,790gpm=718.0kg
2) Scaling by the surface area: 718kg×1.22m^2/955m^2=0.9172kg
3) As the bypass rate decreases depending on increase of the fiber addition, applying the test result of 297.6 g in the Table 3: 917.2g×2.17%=19.9g
4) Apply the test result of 148.8g in the Table 3: 170.1g×3%=5.1g

3. Conclusions

In-vessel downstream effect tests with a mock-up PLUS7 fuel assembly were performed to confirm that the head losses caused by debris meet the available driving head following a LOCA. All the test results showed lower pressure drops than the available head limits. Therefore, a sufficient driving force is available to maintain an adequate flow rate, and the LTCC capability is adequately maintained in the APR1400.

A sensitivity test was conducted to assess the effect of a change in the gap size between the mock-up fuel assembly and the test column. The maximum pressure drop recorded for the test was 19.73 kPa under the re-manufactured condition. This value is larger by 1.6% than the previous test result (19.4 kPa) under the same conditions. As such, changing the gap of the flow path between the mock-up fuel assembly and the test column from the previous manufactured conditions to the re-manufactured conditions is expected to result in a slight increase in the differential pressure. However, this is a negligible amount compared to the test uncertainty value of 25%. Therefore, the results of test that have already been conducted are valid because there is a plenty of margin under the limiting condition of hot-leg break.

Although the amount of calculated bypass fiber increased to 67.3 g/FA, conservatism was ensured by using 100g of fiber for the in-vessel downstream effect tests of the APR1400.

REFERENCES

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