Analysis on the Direct Vessel Injection Line Break Accident at APR+ Standard Design

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1. Introduction

APR+ (Advanced Power Reactor +) is the newest design variation of APR1400. The main characteristics of APR+, compared with APR1400, are passive safety systems and dedicated systems for severe accident mitigation. APR+ is under review for standard design certification. In this study, thermal hydraulic analysis on the Direct Vessel Injection (DVI) line break accident postulated in APR+ design was performed.

2. Analysis on APR+ DVI Line Break Accident

Among many other improved engineered safety features in APR+ standard design, Safety Injection System (SIS) should be one to be focused. The main concept of SIS design is to provide core cooling during the unlikely event of a Loss of Coolant Accident (LOCA). The purpose of SIS is to maintain core integrity by limiting fuel damages and the cladding metal-water reaction. SIS also can remove the energy generated in the core and can maintain the core subcriticality during the extended period of time following a LOCA.

By adopting the active and passive injection trains, reliability of SIS can be enhanced in terms of functional requirements. The active portion of the SIS consists of four mechanically separated trains, and a Safety Injection Pump (SIP) and associated valves consist of each train. Each SIP is provided with its own suction line from the In-containment Refueling Water Storage Tank (IRWST), and its own discharge line to a Direct Vessel Injection (DVI) nozzle on the reactor vessel. The passive portion consists of four Safety Injection Tanks (SIT).

The performance of such innovative engineered safety features during the progression of an accident should be verified. The main purpose of this study is to build DVI line break accident analysis model for MARS-KS, and the developed input deck for DVI line break accident at APR+ design can be utilized during that verification process.

2.1 Input Preparation for MARS-KS

As an analysis tool, MARS-KS was chosen. For the input preparation for the analysis, input files of APR1400 for MARS-KS were referred and modified into ones for APR+ by reflecting design changes. Basic node diagram was shown in figure.1. Node diagram of PAFS was shown in figure. 2.

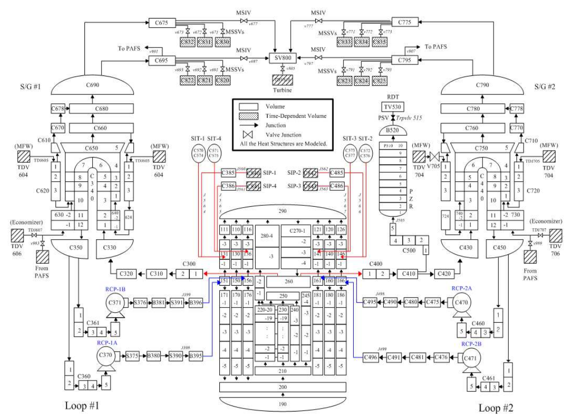

Figure. 1 Basic node diagram of APR+

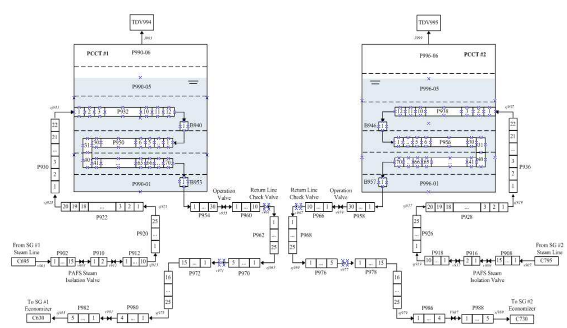

Figure. 2 Node diagram of APR+ PAFS

2.2 Assumptions and Initial Conditions

For the comparison of the results to those from the APR+ Standard Safety Analysis Report [1], all assumptions and initial conditions were set same as those in the reference [1]. Calculated operational parameters for the steady-states were compared in table 1.

Table 1. Steady-state parameter comparison

Plant Parameters	Reference Data	This Study
Core Power Level [MWt]	4376	4375.8
Moderator Temperature Coefficient [△ρ/℃]	0.0	0.0
SIT Gas Pressure [kg/cm^{2}A]	41.1	41.1
SI Pump Injection Delay Time [seconds]	40	40
Initial Core Flow Rate [kg/hr]	75.6×10^6	73.3×10^6
Initial RCS Pressure [kg/cm^{2}A]	158.2	158.2
Initial Reactor Vessel Inlet Temperature [℃]	291.7	290.6
Initial Reactor Vessel Outlet Temperature [℃]	327.6	325.3
Steam Generator Tube Plugging [%]	10	10
Low Pressurizer Pressure Reactor Trip Setpoint [kg/cm^{2}A]	123.5	123.5
SIAS Setpoint on Low Pressurizer Pressure [kg/cm^{2}A]	123.5	123.5

2.3 Accident Sequence Comparison

According to the reference [1], four break sizes of 372 cm^2, 186 cm^2, 93 cm^2, and 46.5 cm^2 were examined in this analysis. Inner vessel pressure changes during the accident were illustrated in Figure 3.

Based on the accident sequence in the reference [1], SIP operated at 51, 56, 65 and 93 seconds respectively, from the initiation of accident. In this study, SIP was operated at 60, 66, 82 and 127 seconds.

In the reference [1], SIT injection, except for 46.5 cm^2 size, was initiated at 224, 461 and 1342 seconds and SIT injection flow was formed at 267, 505 and 1255 seconds respectively in this study.

2.4 Behavioral Discrepancies

In the reference [1], loop seal clearing occurred at 22, 143, 328 and 704 seconds and in this study, loop seal clearing formed at 52, 218, 417 and 956 seconds. In Figure 3 and 4, inner vessel pressure and break flow rate behaviors were illustrated.

However, in reference [1], only peak cladding temperature (PCT) arose at 1,196 second in 93 cm^2 break size scenario, PCTs were occurred at the initiation of accident in all scenarios in this study. In the 372 cm^2 and 93 cm^2 break size scenarios, second PCTs were occurred at 175 and 402 second respectively. PCTs calculated were illustrated in Figure 5.

3. Conclusions

Comparisons of the major parameters which can represent the overall accident behavior during DVI line break accident, several discrepancies between this study and reference data were found and such discrepancies include actuation timing of SIPs and SITs, and also include parameter behaviors of break flow rate and PCT at the accident initiation.

These differences were mainly from the different thermal hydraulic models in simulation codes. The behavioral differences for break flow as well as peak cladding temperatures will be examined further as a next step for this study.

REFERENCES

[1] Korea Institute of Nuclear Safety, "Verification Safety Analysis for APR+ Design Characteristics", KINS/HR-1243, 2013.

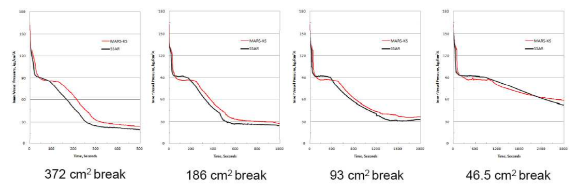

Figure. 3 Inner vessel pressure comparison

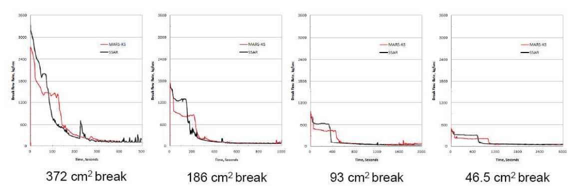

Figure. 4 Break flow rate comparison

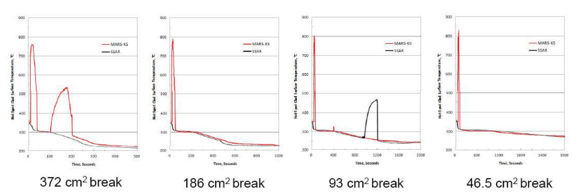

Figure. 5 Clad surface temperature comparison