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Analysis on the Steam Generator Tube Rupture Accident at APR+ Standard Design

Huichang Yang [a*], Youngho Lee [a], Kap Kim [b], Young Suk Bang [b], Sang Jin Cho [b]
[a]*TÜV Rheinland Korea Ltd., Goro-dong 197-28, Guro-go, Seoul 152-719*
[b]*Korea Institute of Nuclear Safety, 62 Gwahak-ro, Yuseong-gu, Daejeon 305-338*
[*]*Corresponding author: huichang.yang@kor.tuv.com*

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 application of standard design certification and the review for this is ongoing by regulator. As a part of design certificate review, thermal hydraulic analysis on the Steam Generator Tube Rupture (SGTR) accident postulated in APR+ design was performed.

2. Analysis on APR+ SGTR

Among many other improved engineered safety features in APR+ standard design, Passive Auxiliary Feedwater System (PAFS) should be one to be focused. The main concept of PAFS design is the continuous provision of feedwater to steam generators to maintain the secondary side cooling capability during the mitigation of accident sequence, by utilizing the natural condensation of released steam from steam generator in Passive Condensate Cooling Tank (PCCT). During the supply of feedwater, no active components such as conventional motor-driven or turbine-driven pumps and modulating valves which require the electricity as a driving power source. This passive feature of PAFS enhanced the reliability of secondary side cooling function and this enables the stable natural circulation to cool the core during the accident sequences.

Another benefit of the PAFS implementation, the dependency on the feedwater sources can be eliminated in virtue of the recirculation and condensation process adopted in PAFS design.

Nevertheless, the concept of PAFS was not implemented in actual plant design till now and this means that the verification of the PAFS performance is required. As a part of the verification during the review phase, SGTR was selected as a reference case in which the performance of PAFS plays an important role.

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 deviations. Basic node diagram was shown in fig.1. Node diagram of PAFS was shown in fig. 2.

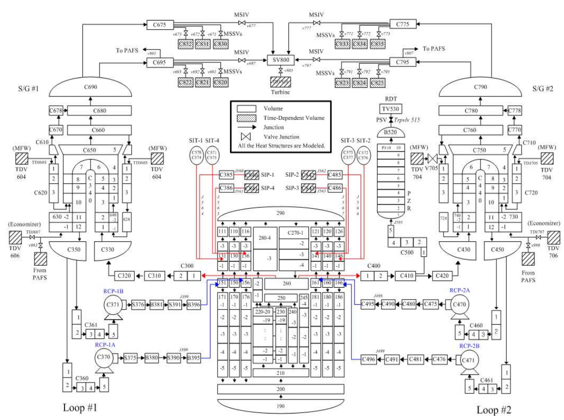

Fig. 1 Basic node diagram of APR+

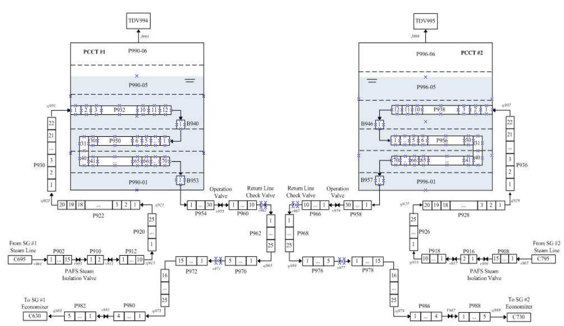

Fig. 2 Node diagram of APR+ PAFS

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	SSAR	This Study
Initial Core Power Level [MWt]	4375.8	4375.8
Initial Core Inlet Coolant Temperature [℃]	296.11	294.67
Initial Pressurizer Pressure [kg/cm^{2}A]	163.46	158.20
Initial Core Mass Flow Rate, 10^6 [kg/hr]	71.83	73.30
One Pin Integrated Radial Peaking Factor, with Uncertainty	1.8829	1.0
Moderator Temperature Coefficient [10^{-4} $\Delta\rho$/℃]	0.0	0.0
Doppler Coefficient	Least Negative	0.0
CEA Worth at Trip [% $\Delta\rho$]	-8.0	N/A

2.3 Accident Sequence Comparison

Based on the accident sequence in the reference [1], safety injection initiated at 418 second from the initiation of accident. In this study, SI was initiated at 494 second. In the reference [1], PAFS initiated its injection of feedwater at 1,080 second and in this study, PAFS injection flow formed at 974 second. Among other discrepancies, these two points showed biggest deviation.

2.4 Behavioral Discrepancies

In the reference [1], RCS pressure peaked to 17 MPa and RCS temperature peaked to 605K. In this study, the pressure and temperature peaks were 16 MPa and 596K. In fig. 3 and 4, RCS pressure and temperature behaviors were illustrated.

Pressure in steam generators are controlled by the cycling operation of Main Steam Safety Valves (MSSVs). In MARS-KS calculations, the frequencies of MSSV cycling are much shorter than those in the reference [1]. As a result, the volume of released steam through MSSVs was evaluated larger in MARS-KS calculation than SSAR. This was illustrated in fig. 5 in terms of pressure in steam generators.

3. Conclusions

Comparison the major parameters which can represent the overall behavior during SGTR accident, showed that there exist several discrepancies between this study and SSAR such as RCS pressure and temperature at the accident initiation, volume of steam released through MSSVs, and the flow injected via PAFS. These differences were mainly from the different thermal hydraulic models in simulation codes. Especially for the flow via PAFS, the condensation model in MARS-KS should be assessed for the future application.

REFERENCES

[1] Korea Institute of Nuclear Safety, Design basis Accident Assessment for the Safety Evaluation of APR+ Passive Auxiliary Feedwater System, KINS/HR-1068, 2011.
[2] Korea Hydro and Nuclear Power Co. Ltd., APR+ Standard Safety Analysis Report, Chapter 15, 2012.

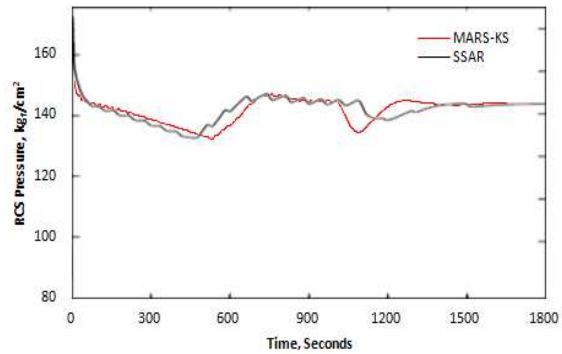

Fig. 3 RCS pressure comparison

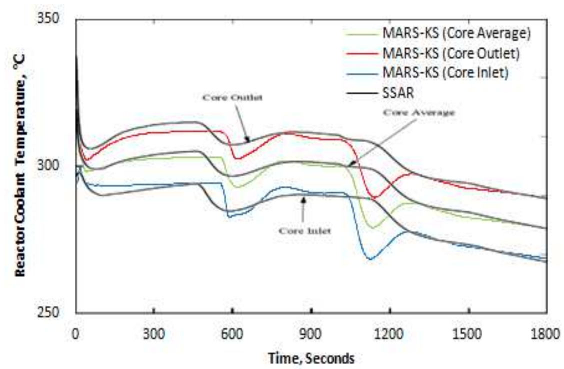

Fig. 4 RCS temperature comparison

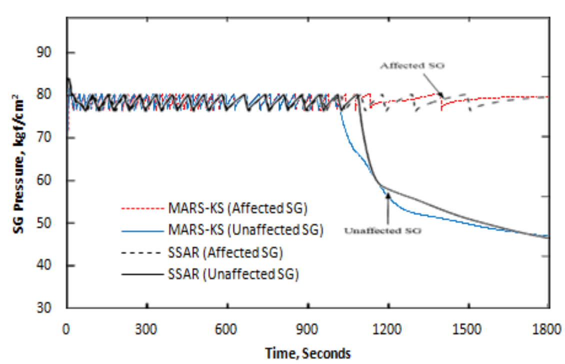

Fig. 5 Steam generator pressure comparison