Safety Evaluation for IHTS Integrity due to the Steam Generator Sodium-Water Reaction Event in the PGSFR

Sang-Jun Ahn[a*], Kwi Lim Lee, Kwi-Seok Ha, Seung Won Lee, Taekyeong Jeong
SFR Reactor Design Division, Korea Atomic Energy Research Institute(KAERI)
Daedeok-daero 989-111, Yuseong, Daejeon, 305-353, Republic of Korea
[*]Corresponding author: enginasj@kaeri.re.kr

1. Introduction

Korea Atomic Energy Research Institute(KAERI) has been developing the Prototype Generation IV Sodium Cooled Fast Reactor(PGSFR). As a rector coolant, a sodium is used to transfer the heat from the core to the turbine. A sodium has a chemical characteristics to rigorously react the water or steam and produce the high pressure waves and high temperature reaction heat. It has an excellent characteristics as a reactor coolant. But, there is an event to be considered in the sodium cooled fast reactor design. The Sodium-Water Reaction (SWR) event can be occurred by the water or steam leaks due to the break of the steam generator tubes. The propagated high pressure waves threathen the structural integrity of the affected Intermediate Heat Transport System (IHTS) and steam generator. If the IHTS pipes are failed, the sodium of the IHTS can be released to the containment building. In this paper, the integrity of the IHTS and SG by the SWR event are evaluated using the SWAAM-II[1] code.

2. Analysis methods

The sodium-water reaction event can be occurred in the part of manufacturing defect and improper welding of the SG tubes. Depending on the degree of the water or steam leakage, this event is classified as AOO, DBA Class I and II.[2] The most severe DAB event is defined as a break of simultaneous five SG tubes in PGSFR. Generated pressure point of view, it must be evaluated to the structural integrity to the items which represent an affected SG, IHTS and components including the IHTS EM pump, expansion tank and related pipes. Each item must be satisfied with a designed pressure.

When a water or steam of the SG tubes is released to the outside, high pressure waves and reaction heat due to the instantaneously expansion of the hydrogen bubble gas is generated and propagated through the IHTS pipes. The generated high pressure waves are most influential variable to threaten the structural integrity.

In PGSFR, the Sodium Water Advanced Analysis Method(SWAAM-II) code which was developed in the ANL is used for calculating the propagated pressures to the each position of the IHTS. It is capable of modeling the sodium-water reaction, growth and expansion of the hydrogen gas bubble, propagation through the loops.

Fig. 1 presents the overall configuration of one IHTS loop in PGSFR. It is composed of the one SG, two IHXs, one hot leg pipe, one cold leg pipe, one expansion tank, two rupture disks and one IHTS EM pump. The red and blue lines present a hot leg and cold leg with 22.0 inch outer diameter, respectively. The part of the two rupture disks, one expansion tank and the Sodium Dump Tanks (SDT) are out of the figure.

Fig. 2 presents the nodalization for the SWAAM-II input. [3] The pipes of 77 and junctions of 76 are used for modeling the sodium of the closed loop type IHTS. As a SWRPRS, one rupture disk with a reverse buckling type and one SDT as a pair are connected with the pipe of the hot leg and cold leg, respectively. An expansion tank filled with argon inert gas is connected with the hot leg to control and maintain the design pressure of the IHTS sodium. The numbers inside the hollowed circle represent the junction number to connect the pipes to each other. The blue and red lined rectangles boxes represent the major interested positions such as the SG inlet and outlet, expansion tank, IHX inlet, outlet and IHX active tubes. In the right side of the figure, the vertically arranged pipes and junctions represent the sodium side of the SG shell and the corresponded level positions of the SG tube filled with water and steam. The SG tube side is composed of 40 nodes and 41 junctions. As the boundary conditions, the values of 17.2 MPa, 230 ºC for the inlet and 16.7 MPa, 512 ºC for the outlet are applied to time dependent volumes 1 and 2, respectively.

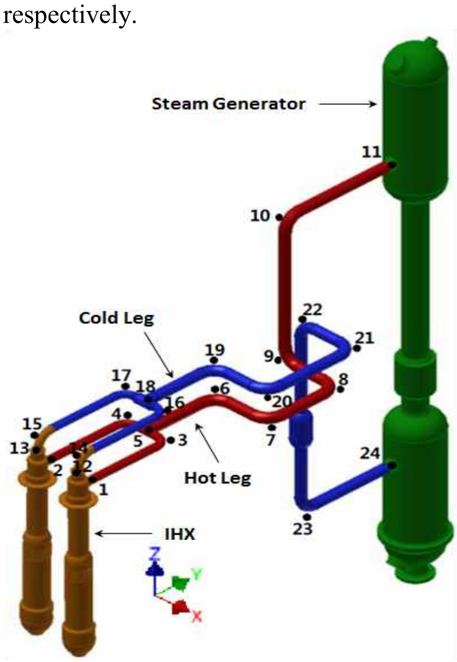

Fig. 1 The configuration of the one IHTS loop in PGSFR

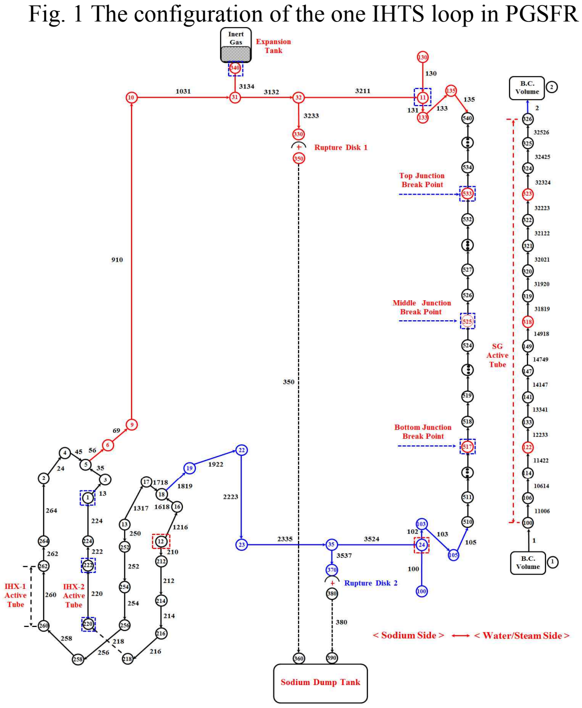

Fig. 2 The Nodalization for SWAAM-II code

2.1 Assumption & Calculation

Prior to evaluate the integrity in the components, the variables such as node length, calculation time step, the uncertainty of the rupture disk and pressure distribution to the axial direction of the SG must be determined by a sensitivity analysis. [4]

The maximum node number is limited to the 80 in SWAAM-II. Fig. 3 presents the result to the sensitivity analysis for the rupture disk burst time as to the node length. Comparing with an original node length, the new applied node length is shown the stable distribution for the rupture disk burst time to the SG axial positions.

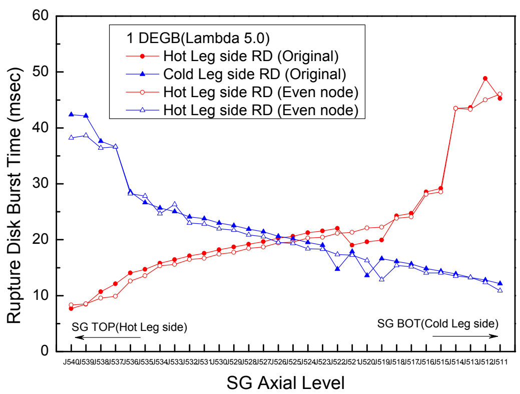

Fig. 3 The sensitive analysis to the node length

Fig. 4 presents the generated peak pressures to the SG axial direction in the case of the simultaneous five SG tube break. In case the event occurs in the bottom of the SG, the highest pressure is generated. This result is analyzed to be due to the large amount of the subcooled water leakage comparing with the top of the SG.

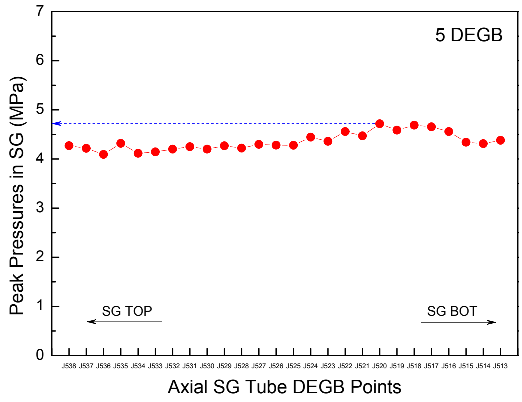

Fig. 4 The Peak pressures to the axial direction of the SG

Fig. 5 present the result of the sensitivity analysis for the uncertainty of the rupture disk which is designed to the ± 10.0% of the design burst pressure 1.0 MPa. From the result, the peak pressures at the components in the IHTS are generated in the case of the burst pressure 1.1 MPa of the rupture disk.

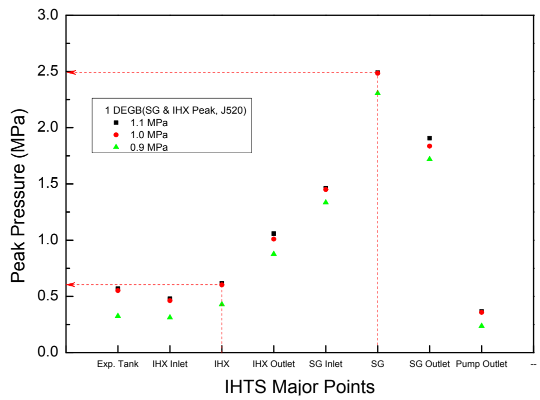

Fig. 5 The uncertainty analysis to the rupture disk uncertainty

2.2 Results

To the maximum pressure point of view, the most conservative conditions are determined by a sensitivity analysis for major variables. Fig. 6 presents the pressure behavior in the affected SG due to the five SG tubes simultaneous break event. The peak pressure is 4.72 MPa at 26.3 msec and then gradually decreased due to the burst of the rupture disks. The peak pressure is less than the design pressure 5.0 MPa to the SG.

Fig. 7 presents the pressure behavior in the affected IHX active tubes due to the five SG tubes simultaneous break event. The peak pressure is 0.96 MPa at 83.3 msec. Comparing with the initial peak pressure in SG, the pressure reached to the IHX is reduced as much as it passes through the expansion tank, IHTS EM pump and connected pipes. The maximum pressure is less than the design pressure 2.5 MPa to the IHX active tubes.

Fig. 8 presents the calculated maximum pressures in the major components of the IHTS. The lowest pressure is generated at the outlet of the pump due to the pressure drop in the pump. The maximum pressures are within the design pressure 2.5 MPa to the IHTS loop.

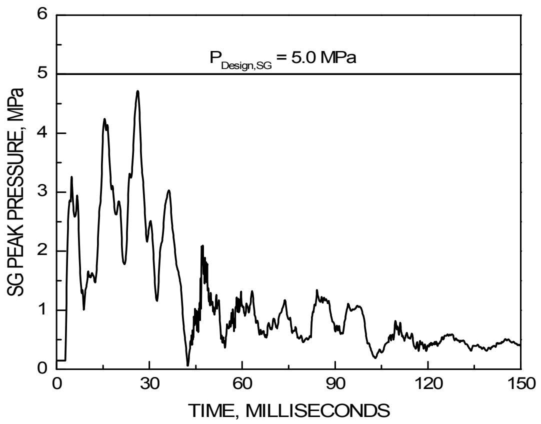

Fig. 6 The pressure behavior in the affected SG (5 DEGB)

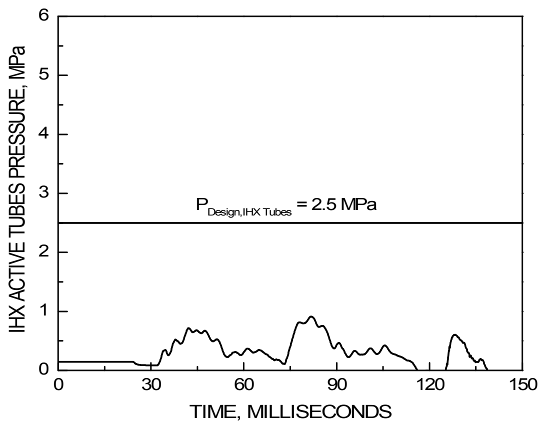

Fig. 7 The pressure behavior in the IHX tubes (5 DEGB)

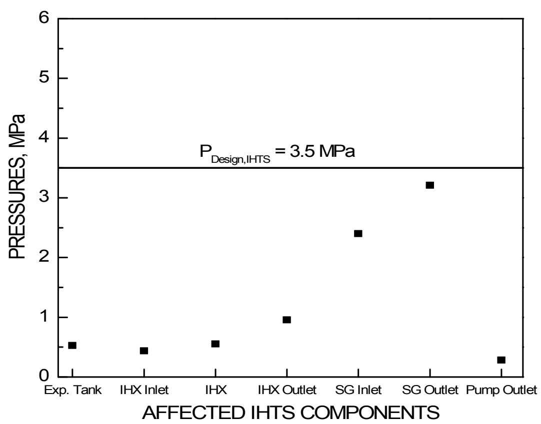

Fig. 8 The maximum pressures in major positions (5 DEGB)

3. Conclusions

To the peak pressure point of view, it is performed to evaluate the integrity of the major components due to the SWR event in the SG.

The generated peak pressures due to the five SG tubes simultaneous break event are within the range of the design pressure for the SG, IHX and IHTS including the related pipes.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government MSIP. (No. 2012M2A8A2025634)

REFERENCES

[1] Y. W. Shin and C. K. Youngdahl, "User's Manual for the Sodium-Water Reaction Analysis Computer Code SWAAM-II,"ANL-83-75-1983, 1983

[2] Lee, K.L., "Analysis report for design bases events in PGSFR," SFR-900-DS-486-001, 2015

[3] Han, I.S., "Mechanical input data for safety analysis in 2015," SFR-IOC-MS-15-003, 2015

[4] Ahn, S.J., "Analysis report for Sodium-Water Reaction Event in PGSFR," SFR-300-DS-475-002, 2015