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Safety Analysis of ATWS for OPR1000 with DPS using SPACE code

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1. Introduction

Anticipated Transient Without Scram (ATWS) is a multiple failure accident which occurs failure of the reactor trip during Anticipated Operational Occurrence (AOO). To reduce the risk of ATWS, the U.S. NRC issued code 10 CFR 50.62, and its amendments SECY-83-293. According to SECY-83-293, an ASME SERVICE Level C pressure of 22.06 MPa (3,200 psig) is an acceptable plant condition [1]. Additionally, the Peak Cladding Temperature (PCT) shall not exceed 1,477.59 K (2,200 °F). The major concern of the ATWS is the expected high pressure in the primary system, which can cause the failure of the primary system. An ATWS results in a rapid increase of RCS pressure and threaten the integrity of RCS. Therefore, the final ATWS Rule was approved by the U.S. NRC and the OPR1000 PWRs installed the Diverse Protection System (DPS). This system can automatically initiates a reactor trip signal on high pressurizer pressure to decrease the consequence or risk of an ATWS and provides an auxiliary feed-water actuation signal to assure the heat removal of steam generators. In this paper, the DPS performance was analyzed during an ATWS. For this study, the reference plant of OPR1000 was selected the Shin-Kori units 1 and 2 and SPACE code was used.

2. Description of Methods

Generally, Loss of Normal Feedwater (LONF) causes the most severe consequence during the ATWS. This event reduces capability of the secondary system to remove the heat generated in the reactor core. As heat removal from the primary side decreases, primary coolant temperature and pressure increase. Therefore, the LONF is considered as the initiating event in this paper, conservatively.

2.1 Nodalization

The nodding diagram for OPR1000 is shown in figure 1. The nodding model was developed based on the nominal conditions. The reactor core is modeled as one hot and average channel each with 20 axial volumes. Some models such as Pressurizer Safety Valve (PSV), Steam Bypass Control System (SBCS), and Safety Depressurization System (SDS) were added. The PSVs are needed to regulate the pressure rise in an ATWS transient. The pressurizer has 3 PSVs which opens at 2,500 psia. Since the PSVs normally operate in the ATWS transients, they can be grouped into one set in the SPACE model. The Turbine Bypass System (TBS) consists of 8 Turbine Bypass Valves (TBVs) which are controlled by Steam Bypass Control System (SBCS). SBCS is operated by the signal such as PZR pressure, secondary steam flow rate, and main steam header pressure.

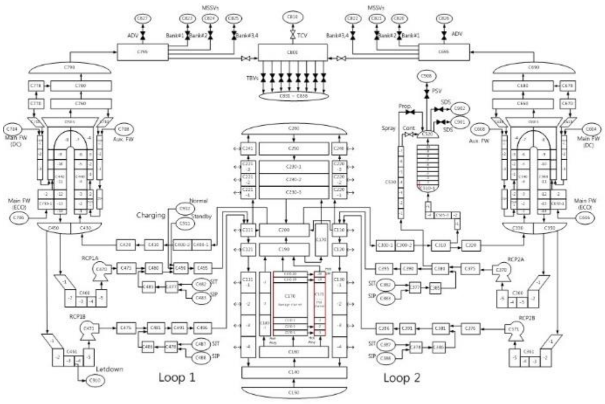

Fig. 1. SPACE nodalization for OPR1000 PWR.

2.2 Major set-points related to DPS

The DPS is a backup system that initiates if the RPS and ESFAS fail. The DPS automatically initiates the auxiliary feedwater system and reactor trip under conditions indicating an ATWS. Auxiliary feed water which is initiated by DPS assumes flowrate of 650 gpm. The design flow rate of AFW injection is from 500 gpm to 800 gpm so that the average value was applied. 22.6 seconds of injection delay time includes PCS delay and supply valve delay time. The major set-points related to DPS is described in table I.

Table I: DPS set-points for Analysis

Function	Set-point	Note
Aux. feedwater injection	SG WR 22.1%	22.6 s delay
		650 gpm / SG
Reactor trip	16.52 MPa	High PZR Pressure (HPP) signal

3. Analysis results

The sequence of events during ATWS is presented in table II. The PZR pressure during the ATWS is shown in figure 1. About 9.0 s after the accident begin, the PZR pressure increases and reaches set-point of PZR spray so that the PZR spray valve opened. The pressure maintains during 61.0 s because the turbine still operates and PZR spray also operates. However, the heat transfer of steam generator is rapidly decreased and the RCS pressure is rapidly increased. The PZR spray operates with maximum flow of 39.3 kg/s and PZR PSV is also opened. However, these actions are insufficient to reduce the pressure and PZR pressure reaches the set-point of reactor trip by DPS. So, the reactor trip occurs as shown in figure 2 and turbine trip also occurs by reactor trip. The PZR pressure peaks at 70.0 s and this pressure is about 17.1 MPa. The pressure is rapidly decreased due to reactor trip and PSV opening. After accident begin, SG collapsed level decreased as shown in figure 3 and the SG pressure is increased during 60.0 s. The SG level decreases and reaches WR 22.1% which is set-point of AFW injection by DPS. After 24.0 s of delay time, the AFW injection initiates and SG inventory slowly increases as shown in figure 6. As a results, the pressure and fuel cladding temperature not exceed acceptance criteria as shown in figure 1 and 7, respectively.

Table II: Sequence of ATWS

Events	Time (s)	Note
Proportional spray initiate	9.0	15.8 MPa
SG level reached 22.1 WR%	46.0	
HPP signal on	68.0	16.52 MPa
Reactor trip		By DPS
Turbine trip		By reactor trip
AFW injection initiate	69.0	
PZR PSV open	70.0	
Peak pressure occurs		17.09 MPa

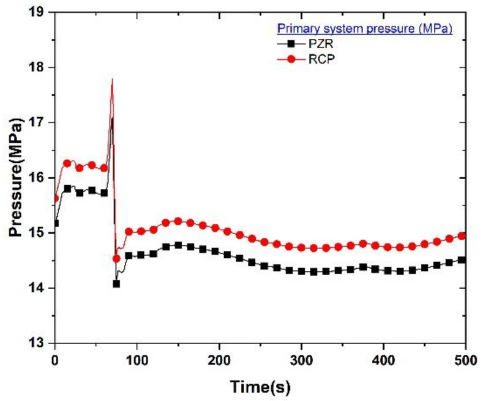

Fig. 1. PZR and RCP pressure during the ATWS.

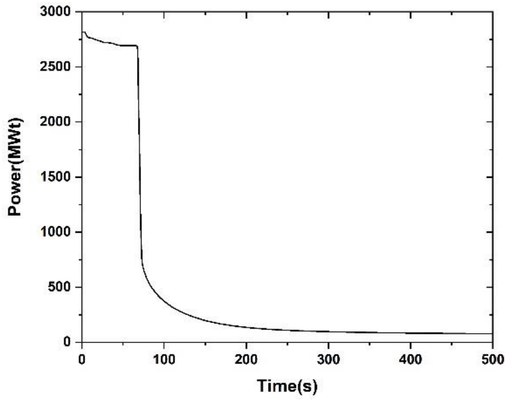

Fig. 2. Thermal power during the ATWS.

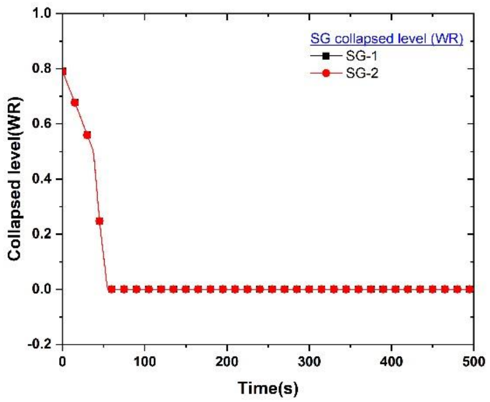

Fig. 3. SG level (WR) during ATWS.

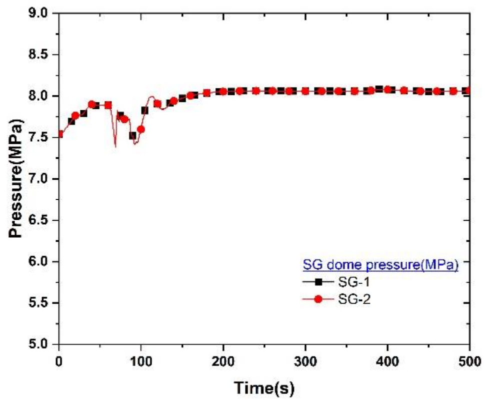

Fig. 4. SG pressure during the ATWS.

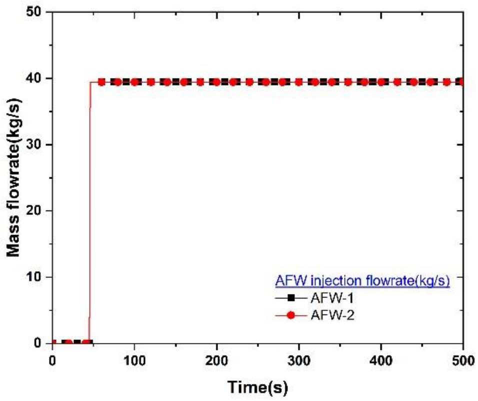

Fig. 5. AFW injection rate during ATWS.

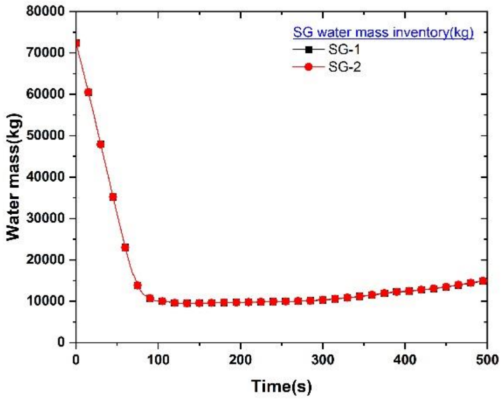

Fig. 6. SG water inventory

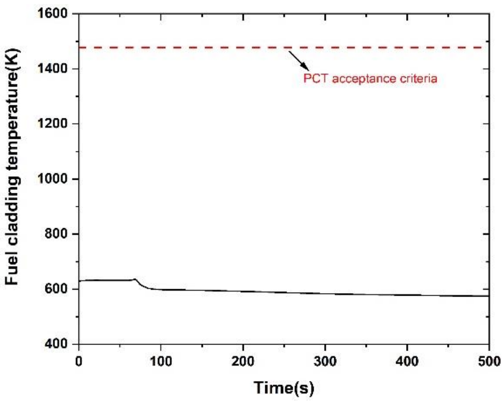

Fig. 7. Fuel cladding temperature

4. Conclusions

In this study, the transient phenomena of ATWS for OPR1000 was analyzed using SPACE code. As mentioned above, the DPS is installed on OPR1000 which have the function of reactor trip for mitigation during ATWS. The analysis results for Shin-Kori units 1 and 2 and the DPS specific set-points demonstrated that the peak pressures reached in the RCS would remain below the 3,200 psig of ASME service level C limit proposed in SECY-83-293. Additionally, the PCT also not exceeds 1,477.59 K (2,200 °F).

ACKNOWLEDGMENTS

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REFERENCES

[1] U. S. NRC, Amendments to 10 CFR 50 related to ATWS Events, SECY-83-293, 1983.