Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-19, 2017

Examination of SBO Emergency Operating Procedures of APR1400 using MARS code

*Shin Eom, Seung Jong Oh **
KEPCO International Nuclear Graduate School, 1456-1 Shinam-ri, Seosaeng-myeon, Ulju-gun, Ulsan, Korea
**Corresponding author: sj.oh@kings.ac.kr*

1. Introduction

For APR1400, the emergency operating procedure (EOP) for SBO is to maintain hot standby condition until power is recovered [1]. This assumes that offsite power will be restored within a reasonable time. All CE designs adopt the same procedure. Westinghouse design uses controlled cooldown using secondary-side feed and bleed operation.

With the Fukushima accident, the capability of NPPs against extended SBO becomes one of the important safety issues. To cope with the extended SBO, portable equipment is placed at sites [2]. We have examined the optimum approach to cope with longer term SBO with easy transition to use portable equipment. Hwang et al., [3] utilized secondary feed and bleed operation using turbine-driven auxfeed (TDAFW) pump to controlled RCS cooldown to maintain core cooling for a long time before portable equipment introduction. He developed optimum mitigation procedure (OMP) which minimize operator action. Kim et al [4] conducted sensitivity study to find the optimum range of auxfeed flow and atmospheric dump valve (ADV) opening for the secondary side feed and bleed operation.

In this study, we compare the RCS condition for the case of following EOP with that of secondary feed and bleed operation (OMP). The result will be useful for making an improvement in procedures to coping with SBO in APR1400.

2. Modeling of APR1400 using MARS

Similar to previous study [4], the Multi-dimensional Analysis of Reactor Safety (MARS) code is used to model APR1400. The code was developed by Korea Atomic Energy Research Institute (KAERI). The code's backbones are the RELAP5/MOD3.2 and COBRA-TF codes of USNRC [5].

2.1. MARS SBO Model

The nodalization of RELAP5 input deck for large break loss of coolant accident is used as a starting point. To model RCP seal leakage, four valves are added to the discharge piping of RCP. The flow area of these valves was adjusted to match the preset RCP seal leakage rate. To model secondary cooldown, ADV junction is added. The flow area is sized as 138.6kg/s at 70.31kg/cm^2. For SBO scenario, turbine-driven auxiliary feedwater pumps are available. The design flow rate is 41.0 liters/s. The control valves for TDAFW flow is powered by a DC battery. It is assumed that they can be controlled as long as DC power is available. Figure 1 shows the MARS nodalization of APR1400. The steady state reached with the MARS code is shown in Table 1. They match with the design condition of APR1400 reasonably.

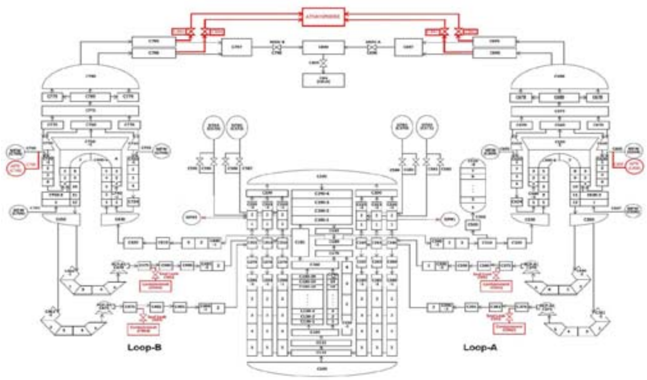

Fig. 1. MARS nodalization diagram for extended SBO Scenario

Table 1. Steady state conditions of APR1400 and extended SBO steady state calculation

Major parameter	APR1400	Extended SBO
Primary system		
Power (MWt)	3983	3923
Pressurizer pressure (MPa)	15.50	15.56
Core inlet temp. (K)	564.45	564.67
Core outlet temp. (K)	597.35	601.41
Secondary system		
SG pressure (MPa)	6.90	6.90
Steam temp. (K)	558.05	558.09
Feedwater temp. (K)	505.35	499.82

2.2. Extended SBO scenario

EOP scenario starts with loss of all power. At time zero, the reactor is tripped. Mainfeed water pumps to steam generators stop at time zero. TDAFW pump will start automatically based on the steam generator level. It injects auxfeed water when the level reaches 22% wide range and stops the injection when the level reaches 44% wide range. After 30 minutes, operators manually control ADV to maintain RCS average temperature at 291.6℃. Operator tries to maintain primary side pressure at 158Kg/cm^2. Ideally, the plant maintains this hot standby condition till offsite power is recovered.

The optimum approach chosen for this study is the one developed on previous study [3]. It was developed to minimize the operator action while performing controlled RCS cooldown. It started the same as the above scenario with loss of all power. The auxfeed flow rate is reduced from 41kg/s to 8kg/s to avoid on/off operation after 30 minutes. ADVs of SG open 30% after 90 minutes. These two actions would maintain the SG water level within 22-44% wide range.

In this study, we ran MARS code for 8 hours since the DC power is available for 8 hours. RCP seal leakage is one of uncertain parameters for extended SBO scenario. The manual for RCP of APR1400 states 120gpm/pump as the maximum seal leakage. Hence, 120gpm/pump seal leakage is used in this study.

3. Result

The primary pressure and RCP seal leakage flow rate are shown in Figure 2 and Figure 3, respectively. The primary pressure for EOP case stays high since the controlled cooldown has not been conducted. However, with the RCP leakage flow, it is difficult to maintain RCS pressure and it dropped to 10MPa in 30 minutes. The pressure variation after 30 minutes is due to the on/off operation of TDAFW pump. The flow rate of seal leakage of EOP case is predicted lager than the OMP case. This is due to higher RCS pressure. After 2 hours, the seal leakage rate drops below the OMP case. This is due to the two-phase condition in cold leg for EOP case. Secondary pressure behaviors are shown in Figure 4. For the EOP case, the MSSVs are cycling open/close to release pressure from SGs.

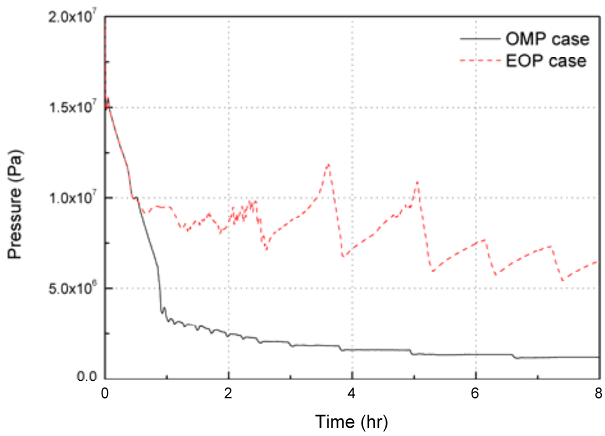

Figure 2. Primary-side Pressure

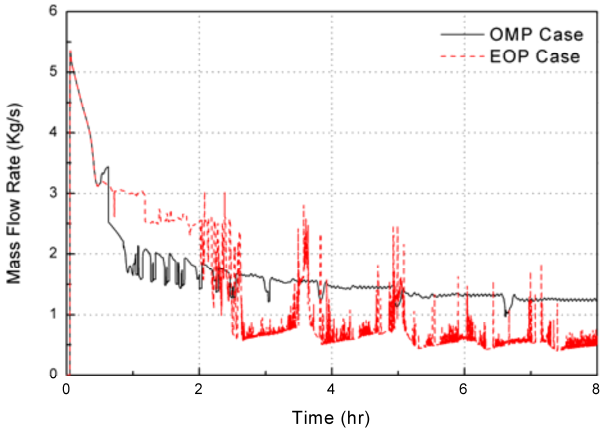

Figure 3. RCP seal leakage flow rate (1RCP)

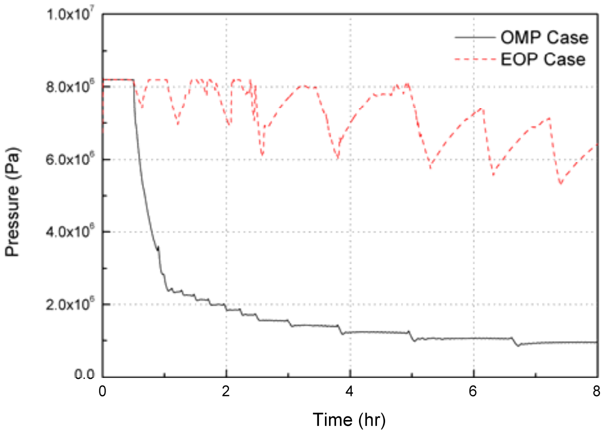

Figure 4 Secondary-side pressure

The calculation results for core collapsed level are shown in Figure 5. In case of EOP, the collapsed level starts to drop after one hour into the transient. This is consistent with the two-phase condition observed in seal leakage flow and the cold leg for EOP case. For OMP case, the level is maintained throughout the transient. From this figure, one can conclude that EOP procedure is valid only if the power is recovered within one hour.

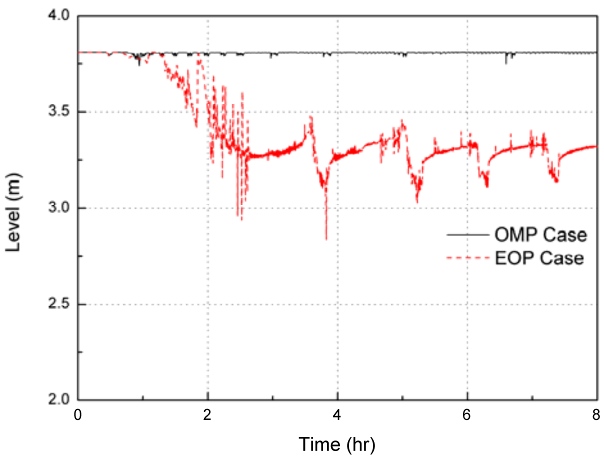

Figure 5. Core collapsed level

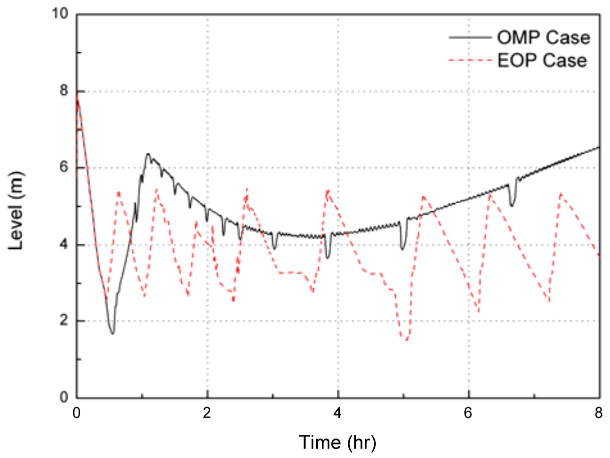

Figure 6. SG water level

Figure 6 shows the behavior of SG levels during the transient calculation. For OMP case, the auxfeed flow rate is reduced from 41kg/s to 8kg/s and maintained at 8kg/s. For EOP case, it was cycled on/off throughout the transient. Hence, the level of SG for EOP case also cycled throughout the transient.

4. Summary and Conclusion

In this study, we examined the RCS behavior for SBO scenario for APR1400. Assuming that the DC power is available for 8 hours, MARS runs are made for 8 hours for the two cases: one following the current EOP and the other following the optimum procedure (OMP) developed for extended SBO. For the case of high RCP leakage (120gpm at RCS pressure of 155kg/cm^2), EOP approach is applicable if the offsite power is recovered within one hour. The seal leakage makes it difficult to maintain RCS pressure and core would be uncovered after one hour. OMP approach shows that core is covered for 8 hours and it is ready to be connected to portable pumps with RCS pressure below 2.5MPa.

RCP seal leakage under extended SBO is one of uncertain parameters. We used the highest value from the RCP manual. With the heightened interest in seal leakage, WOG reported that the seal leakage for Westinghouse-type pump varies from 21 to 480gpm (WOG 2000 Model). The parametric study of RCP seal leakage flow would be useful to further validate the above conclusion.

REFERENCES

[1] Korea Hydro & Nuclear Power Co., Ltd., Shin-Kori Unit 3,4 NPP, "Station Blackout Emergency Operation Procedure, EOP-07, Rev. 0 (2011).
[2] NEI 12-06, "Diverse and Flexible Coping Strategies (FLEX) Implementation Guide," Rev. 0, (2012).
[3] J.R. Hwang, S.J. Oh, "Developing Optimal Procedure of Emergency Outside Cooling Water Injection for APR1400 Extended SBO Scenario Using MARS Code," KNS, (2013).
[4] W.B. Kim, S.J. Oh, et al, "Extended Station Blackout Analyses of an APR1400 with MARS-KS," Nuclear Technology & Radiation Protection, (2016).
[5] KAERI, MARS code manual, KAERI/TR-2812/2004, (2009).