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Developing Optimal Procedure of Emergency Outside Cooling Water Injection for APR1400 Extended SBO Scenario Using MARS Code

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1. Introduction

Recent Fukushima accident shows the importance of mitigation capability against extended SBO scenarios. In Korea, all nuclear power plants incorporated various measures against Fukushima-like events. For APR1400 NPP, outside connectors are installed to inject cooling water using fire trucks or portable pumps. Using these connectors, outside cooling water can be provided to reactor, steam generators (SG), containment spray system, and spent fuel pool. In U.S., similar approach is chosen to provide a diverse and flexible means to prevent fuel damage (core and SFP) in external event conditions resulting in extended loss of AC power and loss of ultimate heat sink [1].

Hence, hardware necessary to cope with extended SBO is already available for APR1400. However, considering the complex and stressful condition encountered by operators during extended SBO, it is important to develop guidelines/procedures to best cope with the event. In this study, we examined optimum operator actions to mitigate extended SBO using MARS code. Particularly, this paper focuses on analyzing outside core cooling water injection scenario, and aimed to develop optimal extended SBO procedure.

2. Analyzing Extended SBO Situation Using MARS Code

2.1 MARS Model Implementation

To evaluate the effectiveness of outside cooling water injection, MARS SBO input deck [2] was modified. For APR1400, two independent outside connectors are provided to primary and secondary system. Four time dependent volumes and junctions are added to model the connectors (Fig. 1).

RCP seal leakage is the one of the important phenomena during SBO event. The RCP seal leakage is modeled with valves in front of RCP component. Valve flow area is adjusted to fit RCP seal leakage rate in RCP technical manual [3] (120gpm/pump at 155.0 kg/cm^2).

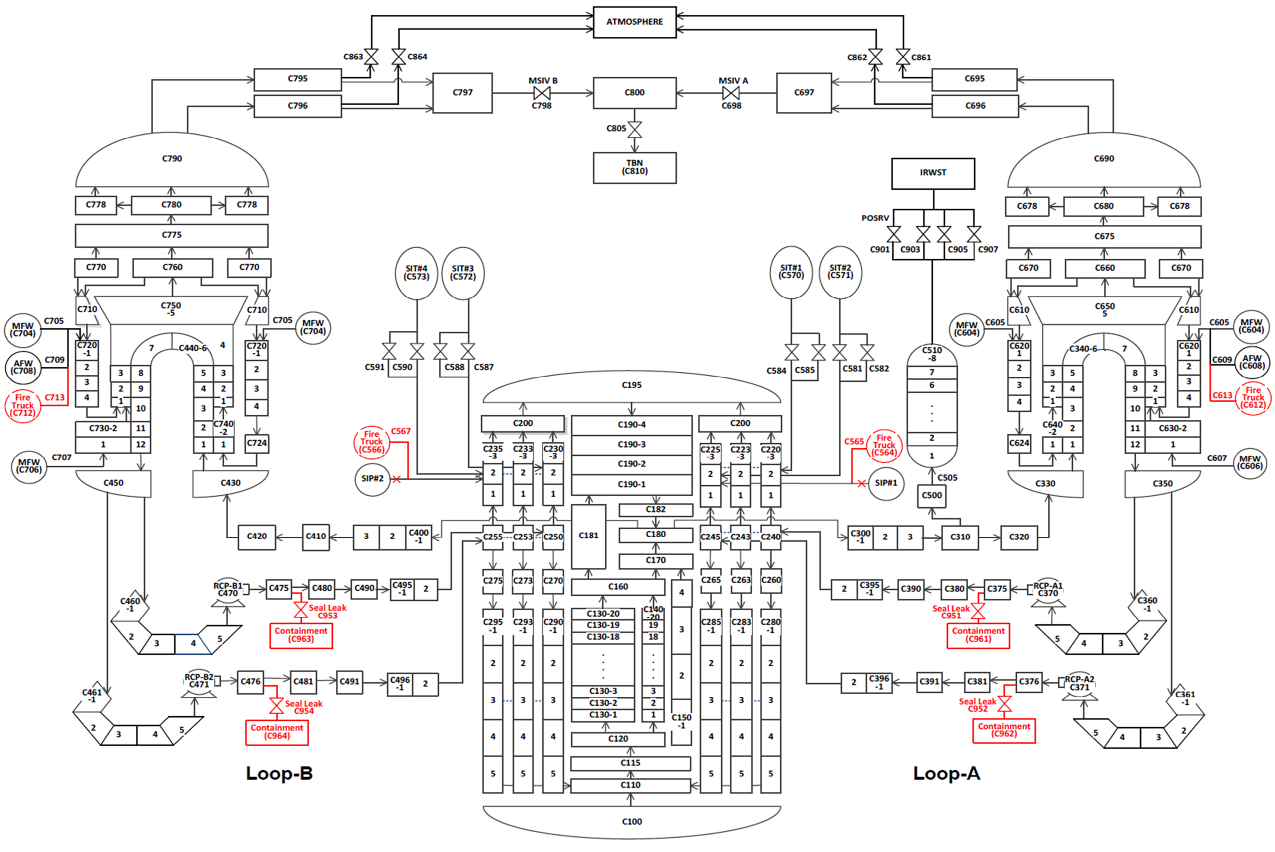

Fig. 1. MARS Nodalization Diagram for Extended SBO Scenario

2.2 Extended SBO Scenario Analysis

The extended SBO scenarios considered in this study is shown in Table 1. All AC power source is not available after the SBO, including alternate AC diesel generator (AAC DG). Only turbine driven auxiliary feedwater pump (TD AFP) can supply cooling water when the battery power is available. 8 hour is assumed for station battery life.

RCP seals can maintain function for a maximum of 30 minutes, if seal leak-off valves are closed by operator within 1 minute following the simultaneous loss of seal injection and cooling water [3]. RCP seals are assumed to fail at 3 minute in this scenario conservatively, assuming operator fails to close the leak-off valve.

Various operator actions in responding to this scenario have been examined using MARS code. The optimum operator actions identified are discussed in the next section.

Table 1. Extended SBO Accident Scenario

Time	Event
0	SBO accident happens.
	TD AFPs supply water to SGs.
	2nd side pressure are maintained by ADVs.
3 min	RCP seal leak starts (120gpm/RCP).
	PZR pressure and level rapidly decreases.
1.5 hr	Operator opens ADVs (30%) to cooldown.
	SIT water is injected (43bar/625psi).
8 hr	TD AFPs are Not available due to station battery discharge.
	Operator opens ADVs (100%) to depressurize 2ry system.
	Emergency outside waters are injected.

3. Optimal Procedure of Outside Water Injection

To use SIT water, cooldown operation is desirable. Operator starts cooldown procedure at 1.5 hour by depressurizing secondary side.

To decide cooldown rate, SG water level, main steam pressure, temperature and RCS cooldown rate should be considered. In this case, one ADV opening area of each train is selected to 30% for cooldown. For this opening area, TD AFP flow rate is 12kg/sec to each SG. At this flow rate, SG inventory would not deplete without additional flow control by operators.

At 8 hour, calculated steam condition is 7.53kg/cm^2, 167℃. This result meets TD AFP operable condition of 4.92kg/cm^2, 157.7℃ (70psig, 316°F). Also average RCS cooldown rate is approximately 19℃/hr. It satisfies the cooldown rate limit in EOP [4]. Assuming automatic controls are not available, this ADV opening area and TD AFP flow rate can be a guide to cope with this situation.

As RCS pressure decreases, SIT water is injected after 18 minute of cooldown start. In spite of RCP seal leakage, top fuel location maintains cooling for 8 hours with SIT water. At 8 hour, TD AFP stops and outside water should be injected. One ADV of each train is fully opened to depressurize, and outside flow is introduced. Primary and secondary pressure decreases are shown in Fig. 2 and Fig. 3.

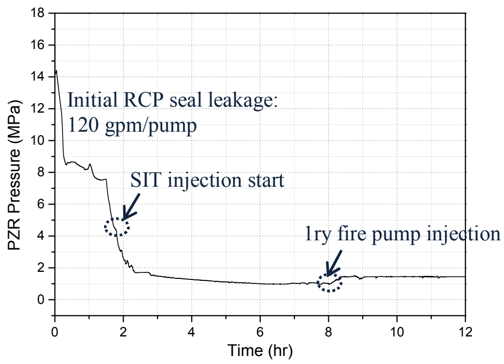

Fig. 2. Pressurizer Pressure

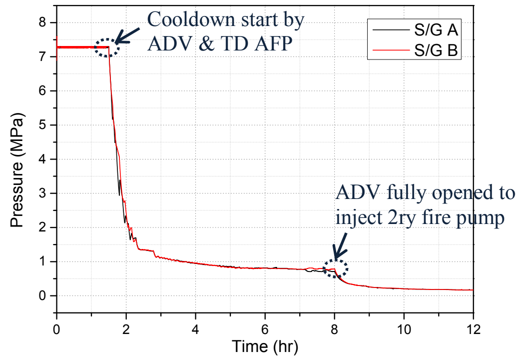

Fig. 3. Steam Generator Pressure

Fire truck components are implemented using typical A-1 level fire pump data (maximum discharge pressure: 15kg/cm^2). It is sufficient to fill RCS, and flow rate of RCP seal leakage and fire pump injection can be balanced. In this scenario, primary fire pump can be injected to RCS without using POSRV.

4. Conclusions

Supplying outside emergency cooling water is the key feature of flexible strategy in extended SBO situation. An optimum strategy to maintain core cooling is developed for typical extended SBO. MARS APR1400 best estimate model was used to find optimal procedure. Also RCP seal leakage effect was considered importantly.

REFERENCES

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