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Passive Strategy with Integrated Passive Safety System (IPSS) for DBAs in SBO

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1. Introduction

Removing decay heat is one of the most important issues in safety of nuclear engineering. In the Fukushima accidents, the initial problem was an occurrence of tsunami. It was connected into a station black out (SBO) which lost AC power in site. Finally, SBO with human error induced the failure of decay heat removal. The occurrence of SBO and the failure of decay heat removal imply the questions for solving them.

In order to prevent and mitigate SBO, some solutions have been proposed after the Fukushima accident. First of all, physical protection is enhanced to prevent external risks. For example, the tsunami barrier was modified to be higher from 7.5 m to 10 m. The second is to add electrical redundancy to prevent a total loss of electrical power. AAC diesel generators and movable diesel generators are examples for emergency conditions to supply AC power in site. Bunker concept which was proposed in Europe is a representative example. The bunker concept was analyzed to be applied in Beznau nuclear power plant [1]. The third solution is to make a cooling redundancy. Integrated passive safety system (IPSS) proposed in 2011 is a representative design adding big water tanks outside containment on a top of auxiliary building as a heat sink and water supplier [2]. Three methods are each merit and demerit.

After the design concept of IPSS was proposed, main functions were analyzed to be verified. With the simulated performances of IPSS in conservative conditions, passive counterstrategies to cope with design based accidents (DBAs) were proposed and described in a basic condition of a SBO.

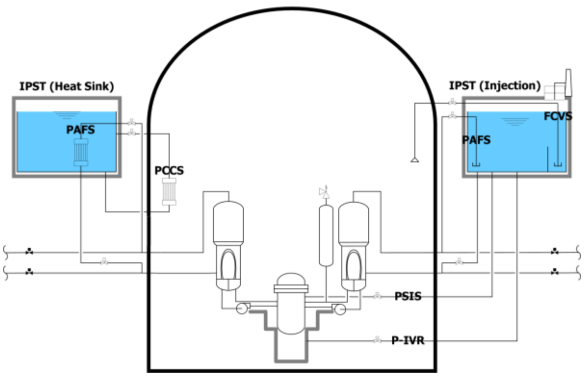

Fig. 1. IPSS on a loop-type PWR

2. DBAs in SBO

OPR1000 is set to be a reference reactor as a Korean representative reactor. The SBO condition is assumed with the failure of turbine driven auxiliary feedwater pumps and the failure of early AC power restoration. Also, it is assumed that there is no supply of alternative AC power. Each DBA is occurred with a SBO at 0 second.

Fig. 2 shows a CDF composition induced each initial accident in OPR1000 [3]. Core damage frequency dominantly consists of single DBAs. Also, SBO is the second contributor for core damage.

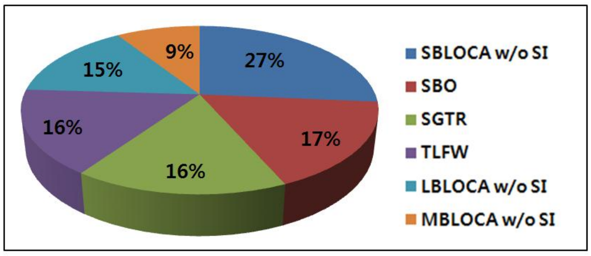

Fig. 2. CDF induced initial accidents in OPR1000 [3].

2.1 Loss Of Coolant Accidents

Loss of coolant accident (LOCA) is the most dominant accident shown in Fig. 2. LOCAs are induced by a break or loss in reactor coolant system. In a view of the break size, larger break size causes larger natural depressurization from the location of the break in a primary system. The LOCAs in SBO were simulated varying with the break size in a cold-leg [4]. In the simulations, passive safety injection system (PSIS) of IPSS was adopted to supply water into reactor vessel.

Gravity injection from an integrated passive safety tank (IPST) into reactor vessel is wholly dependent on the pressure of reactor coolant system. Based on the results of the simulation, it is proven that PSIS can cover the pressure in LOCAs that the break sizes are larger than 2 inches. In LB- and MB-LOCAs, passive safety injection by gravity is possible by PSIS. In cases of SBLOCA which the break sizes are lower than 2 inches, passive decay heat removal system (PDHR) can remove decay heat by supplying water from IPST into steam generators. As the pressure is high and the inventory of coolant sufficiently remains, the supply into reactor vessel is impossible.

Consequently, passive safety strategy consists of two specific operations of passive safety systems. By checking and estimating the pressure in pressurizer, operators have to make a decision to operate a passive system. The operation is initiated by valves on passive pipes.

2.2 Decrease in Heat Removal by the Secondary System

Main feedwater line break (MFLB), main steam line break (MSLB) and loss of normal feedwater flow (LOFW) are included in a case of decrease in heat removal by the secondary system.

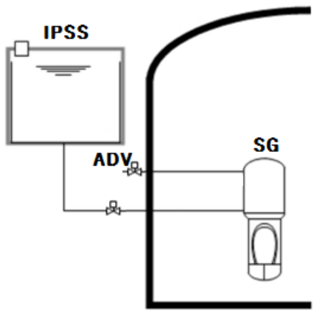

Fig. 3. Passive decay heat removal in IPSS

Fig. 3 shows the second concept of passive decay heat removal system in IPSS. If a SBO with failures of TDPs occurs, the heat could not be removed in steam generators in spite of remaining a sound reactor coolant system. Also, operating pressure in the secondary circuit is too high around 70 atm to supply water by gravity injection. Therefore, a depressurization in the secondary system is needed. Atmospheric dump valves (ADVs) become open to decrease the secondary system pressure with the isolation of steam generators. It is estimated that it would take about five minutes by opening two ADVs to decrease pressure from 70 atm to atmospheric level. After reaching the design pressure of PDHR, valves on a line in PDHR system are operated to be open. By removing decay heat in steam generator, a natural circulation is formed in reactor coolant system with higher heat sink (steam generator) and lower heat source (reactor vessel). Finally, it achieves to decrease peak cladding temperature (PCT).

2.3 Steam Generator Tube Rupture

Steam generator tube rupture (SGTR) is also one of the main contributors for CDF. The risk of SGTR is deeply related with the risk of the release of radioactive materials. That is because the radioactive materials from a core can be directly transported to the containment outside through steam generator. Accordingly, if SGTR occurs, the damaged steam generator has to be isolated. Proposed passive strategy is also based on that one steam generator has to be isolated and the other has to be used for heat sink. In the undamaged steam generator, the depressurization is needed to supply water from IPST by gravity shown in Fig. 3. The passive strategy for SGTR in SBO using PDHR of IPSS is proposed as follows.

1) Occurrence of SGTR
2) Preventing a loss of feedwater (Closing MSSV and SG blowdown isolation valves in two SGs)
3) Estimating an undamaged SG
4) Totally isolating (Closing MSIVs, MSIV bypass valves, ADVs, Main FIVs, Aux. FIVs and IVs to steam supply for TDPs)
5) Partially isolating the undamaged SG (Close of MSIVs and FIVs)
6) Depressurization of the undamaged SG (Opening ADVs)
7) Passive injection of coolant from IPST (Opening PDHR valves in IPSS)

3. Conclusions

In this paper, the strategies of coping with DBAs in SBO were proposed by the design with IPSS. Current nuclear power plants adopt emergency strategies using fire truck as a provision of steam generator cooling. However, it has a lot of limitation like water inventory, preparedness and accessibility. In the case of passive strategy by the application of IPSS, faster actions and more efficient performances can be achieved. The application of IPSS implies the preparedness of big water tank which can be used as water supplier, heat sink and filtering medium.

The proposed strategies are set under the conservative conditions without AC power. In order to set more realistic and acceptable strategy, the proposed passive strategy has to be combined with the current strategies. The combined strategies can avoid the reiteration and complexity in accidents. Accordingly, the set of operation mode considering action priority with estimating specific conditions is the further work of this research.

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