# A Study of Invasive RCS Depressurization under SBO/SBLOCA in OPR1000-IPSS

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## 1. Introduction

After the Fukushima accident, nuclear power plants (NPPs) need to retain abilities to deal with multiple beyond design basis accidents (BDBAs). For that, several supplementary safety systems for current NPPs in operation have been suggested. The Integrated Passive Safety System (IPSS) is one of the supplements operated by natural phenomena [1]. With two elevated water tanks of IPSS, IPSS offers passive safety injection system (PSIS) and secondary passive decay heat removal (PDHR) with gravitational head and containment cooling and preservation under SBO.

Previous studies proved successful coping capability of IPSS under SBO/LBLOCA and failure results under SBO/SBLOCA [2, 3]. Due to the limited capacity of current RCS depressurization system, further RCS depressurization is inevitable to achieve PSIS operation.

This paper suggests invasive RCS depressurization methods on a primary circuit to overcome the capacity limitation. So that water through PSIS inject to the depressurized primary circuit for core cooling, finally to attain the ultimate goal, preventing the core damage.

## 2. Methods and Results

OPR1000 has two safety depressurization systems (SDS) to decrease RCS pressure manually. However, OPR1000 as well as many generation Ⅲ reactors have limited capacity of RCS depressurization through the SDS. Due to the limit, SBLOCA cannot be coped with only low pressure safety injection (LPSI) pumps under loss of high pressure safety injection (HPSI) pump in OPR1000. To operate IPSS-PSIS, RCS pressure should reach below 4 bar, much lower than 11 bar of LPSI operating pressure. Consideration of an extra depressurization method, which much effective and invasive and its evaluation is needed.

### *2.1 The Conceptual Design*

As a reference to decrease RCS pressure further, Automatic Depressurization System (ADS) in AP1000 is considered. Not like usual generation Ⅲ reactors, AP1000 handles LOCA with passive coolant injection following by RCS depressurization. Four valves in ADS offer four stages for primary depressurization. ADS 1 to 3 are located on the top of a pressurizer while ADS 4, a squib valve, is on a hot leg. The valves provide sequential RCS depressurization and ADS4 helps RCS pressure reaches below the operating pressure of the passive safety injection system.

We suggested the concept of the squib valve as a solution of further RCS depressurization for IPSS, so that the sequential depressurization can be brought to OPR1000 with combined operation of SDS and ADS4. However, the effectiveness of ADS4 has been evaluated in case of not only the sequential operation but solo operation.

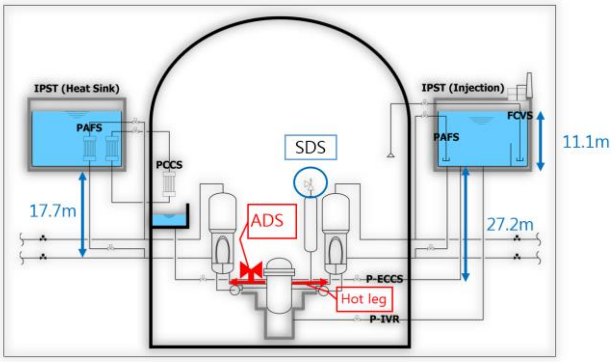


Fig. 1. Atmospheric Depressurization System in OPR1000-IPSS. [4]

### *2.2 The Evaluation Method*

As an evaluation method, MARS code calculates the effectiveness of the passive safety injection based on SBO/SBLOCA in OPR1000. MARS, a multi-dimensional thermal-hydraulic system code, was developed by restructuring and reinforcing the RELAP5/MOD3.2.1.2 and COBRA-TF codes [5]. MARS nodalization of Ulchin 3 and 4 is used to describe the accident and the operation of SDS and ADS4.

11 cases are suggested for the design evaluation, as shown in Table 1. To determine the effectiveness of ADS4, opening ADS4 at 10, 40, 80, 120 and 150 bar of RCS pressure was calculated from 1 to 2 inches of LOCA by MARS code. In the table, cases were named with their depressurization method and opening RCS pressure. Also MARS simulated combined depressurization of a SDS and ADS4 under SBLOCA.

Time line of the sequential depressurization is constructed based on strategies to shorten actuation time of SIT injection with SDS besides 1SDS50-ADS80 and

1SDS80-ADS80.

Table I: Case Categorization

| | SDS Opening Pressure (bar) | ADS4 Opening Pressure (bar) |
|---|---|---|
| ADS10 | n/a | 10 |
| ADS40 | n/a | 40 |
| ADS80 | n/a | 80 |
| ADS120 | n/a | 120 |
| ADS150 | n/a | 150 |
| 1SDS50-ADS10 | 50 | 10 |
| 1SDS50-ADS40 | 50 | 40 |
| 1SDS50-ADS80 | 50 | 80 |
| 1SDS80-ADS10 | 80 | 10 |
| 1SDS80-ADS40 | 80 | 40 |
| 1SDS80-ADS80 | 80 | 80 |

*2.3 Code Results and Discussion*

MARS code simulated 11 cases of 1 and 2 inches of LOCA. The code results with the pressurizer pressure, peak cladding temperature and mass flow rate of IPSS by time offered insights into depressurization strategy.

Table Ⅱ shows time records of LOCA with ADS4 opening at 10, 40, 80, 120 and 150 bar. It reports that 1 inches of LOCA damaged the core while there was no failure with ADS4 opening at 120, 150 bar. 2 inches of LOCA resulted in core damage under 10 and 40 bar of ADS opening. The results proved that larger LOCA and fast depressurization prevent core damage. Smaller LOCA and late depressurization leads to core damage with no safety injection water by following insufficient RCS depressurization in OPR1000-IPSS

Table Ⅲ reassures that smaller LOCA and late depressurization caused core damage. The sequential operation of SDS and ADS4 was evaluated under 50 and 80 bar of SDS opening and 10, 40 and 80 bar of ADS4 opening. With combined operation of SDS and ADS4, 1 inches of LOCA recorded core damage under designated opening sequence except the case of 1SDS80-ADS80. The results from the tables proved that extreme RCS depressurization started to deal with 1 inches of LOCA before RCS pressure reached to 80 bar.

When ADS4 released steam at timing of 80 bar of RCS pressure, it could not depressurize enough for PSIS-IPSS operation. However, opening SDS and ADS4 at the same time increased depressurization capacity of RCS and prevented core damage of OPR1000 under 1 inches of LOCA. For 2 inches of LOCA, core was damaged in the case of 1SDS50-ADS10. No core damage was shown in other cases such as 1SDS50-ADS40. It indicates two insights of operational strategy on SDS and ADS4. First, opening ADS at 10 bar is too late to prevent core damage due to late injection of PSIS-IPSS. After SIT injection at 40 bar, there is no safety injection under SIT dry-out. If blank time from SIT to next low pressure safety injection is long, it makes the effectiveness of SIT water is disappeared, coolant in reactor vessel started to boil and RCS pressure increase again. Since opening signal of ADS was 10 bar of RCS pressure, RCS pressure never reached to 10 bar under 1SDS50-ADS10 because the created steam in the core interferes RCS depressurization under 10 bar. Second, sequential operation of SDS and ADS offers is effective for late depressurization, compared with the case of ADS opening.

In addition, sensitivity evaluation of ADS opening time was conducted in sequential operation with SDS. If SDS opened before SIT injection and ADS opened after SIT injection, there is no significant advantage on opening ADS at 30 bar compared with opening ADS at 20 bar. Since SIT injection starts 40 bar in OPR1000, the effectiveness of SIT water still remains until 20 bar, before dry-out of SIT. While SIT water is cooling the core, core temperature and pressure decrease clearly.

Table Ⅱ: Time Records of Core Damage with ADS Opening

| | 10 bar | 40 bar | 80 bar | 120 bar | 150 bar |
|---|---|---|---|---|---|
| 1” | 5,591 sec | | | No Damage | |
| 2” | 2,861 sec | | No Damage | | |

Table Ⅲ: Time Records of Core Damage with SDS and ADS Opening

| | SDS50-ADS10 | SDS50-ADS40 | SDS50-ADS80 | SDS80-ADS10 | SDS80-ADS40 | SDS80-ADS80 |
|---|---|---|---|---|---|---|
| 1” | 5,694 sec (RCS P=4.48 bar) | | | | | No Damage |
| 2” | 2,958 sec | No Damage | | | | |

## 3. Conclusions

ADS4 was suggested to increase depressurization capacity of a primary loop to operate IPSS-PSIS under SBO/SBLOCA. From simulations, ADS4 showed successful depressurization for SBLOCA with fast RCS depressurization in early phase of LOCA. However, all suggested cases were proved a capability of PSIS-IPSS to deal with SB/MBLOCA under SBO with certain operational timing of SDS and ADS4. The code results proved importance of coolant injection during early phase of LOCA. For ADS4 opening cases, the most successful cool-down was conducted when ADS4 opened at 80 bar and 120 bar for 1 and 2 inches of LOCA, respectively. 3. However, the sequential operation of SDS and ADS4 has higher probability to offer sufficient RCS depressurization after the early phase of LOCA. Based on ADS4 actuation time, depressurization strategies for IPSS-PSIS should be defined as a further study.

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