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Impact on the PSV Stuck Open according to the Henry-Fauske Model Modification in RELAP5/MOD3.3

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1. Introduction

As notified in the NuSTEP meeting in July, 2014 [1], the different steam flow rate at critical condition between patch 3 and 4 of RELAP5/MOD3.3 [2] are observed due to the modification of Henry-Fauske (H-F) model.

Since the critical flow area of pressurizer safety valve (PSV) is determined based on the steam flow, different flow areas are calculated by patches. Two different flow areas discharge same amount of design steam flow at the design condition but they provide the different flow rate during low pressure condition or two-phase mixture discharge. To evaluate the effect of the H-F model modification, the PSV stuck open event during a PSV popping test is selected since it involves the two-phase discharge.

In the present PSA practice for dealing with the variety of different plant operating states (POSs) during low power and shutdown (LPSD) operations, especially PSV popping test is performed during the POS2 of the overhaul period for OPR1000.

To analyze thermal hydraulic behaviors of PSV stuck open event during POS2, RELAP5/MOD3.3 is used adopting the H-F critical flow model.

In this paper, the impact on the PSV stuck open analysis during POS2 according to H-F critical flow model modification is investigated.

2. Method of PSV Area Determination

The PSV flow area is determined based on the design steam flow rate at the critical condition. The calculated PSV flow areas using the patch 3 and 4 of the RELAP5/MOD3.3 are different due to the H-F model modification [1].

The PSV area is determined as follows:

- Build the test condition of the design steam flow rate. (68.75 kg/s @ 17.237 MPa)
- Applying the Henry-Fauske (H-F) critical flow model, an iterative test is performed to get the PSV area at the design flow rate.

The calculated PSV areas for patch 3 and 4 are compared in Table I. The area from patch 4 is much smaller than patch 3 due to the larger steam flow rate as predicted in the NuSTEP meeting [1].

Table I PSV areas by patch

Parameter	Patch 4	Patch 3
PSV area (m^2)	0.001711	0.002242

3. Analysis Method

The PSV stuck open event is simulated for the Hanul Nuclear Power Plant Units 3 and 4 (HUN 3&4). The nodalization of RELAP5/MOD3.3 is shown in Figure 1.

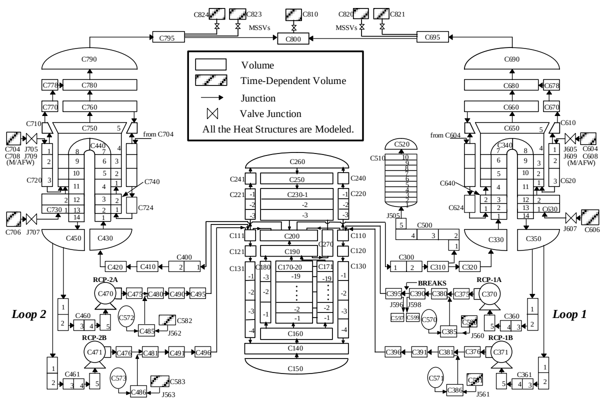


Figure 1 Nodalization for HUN 3&4 POS2 Analysis

3.1 Cases analyzed

Two cases of SITs availability are analyzed with two different areas using RELAP5/MOD3.3 patch 4 with the H-F critical flow model. Areas provided in Table I are used as “smaller area” (0.001711 m^2) and “larger area” (0.002242 m^2).

SITs injection success and failure conditions are selected to compare the results since SIT is important parameter on the success criteria of PSA model.

3.2 Major assumptions and initial conditions

During POS2, plant is cooled down using turbine bypass valves (TBVs) or atmospheric dump valves (ADVs) to the shutdown cooling entry condition.

Major assumptions used in the PSV stuck open analysis are as follows:

- one PSV is opened during the popping test.
- high pressure safety injection pumps are assumed to be inoperable.

- fuel cladding is failed when its temperature is over 1477 K.
- low pressure safety injection (LPSI) pump is operated automatically when the reactor coolant system (RCS) pressure is reached 1.45 MPa. Note that LPSI pump is operated automatically but not actuated during the range of analysis.
- SIT injects the coolant into the RCS by gravitational force. The SIT injection pressure is assumed its nominal gas pressure of 4.31 MPa.

To simulate the POS2 analysis, time dependent decay heat power based on an average duration of 5-hrs after reactor shutdown is used. The other initial conditions such as pressurizer (PZR) level, PZR pressure, steam generator (SG) level, SG pressure and RCS temperature follow PSV popping test conditions [3]. Table II shows initial conditions of the event.

Table II Initial conditions for PSV stuck open analysis

POS	POS2
Initial Event	PSV LOCA
Decay Heat	26.5 MWt (5-hrs after reactor shutdown)
RCS Initial Conditions	Pressure : 13.89 MPa Average Temperature: 568.75 K
	Normal Operating Level (PZR level of 50 %)
Secondary System Initial Conditions	Normal Operating Level (SG level of NR 44 %)
	TBVs are used to cool down, ADVs are closed

4. Analysis Results

Figure 2 shows the transient behaviors of the case without SITs injection and Figure 3 shows those of the case with SITs injection.

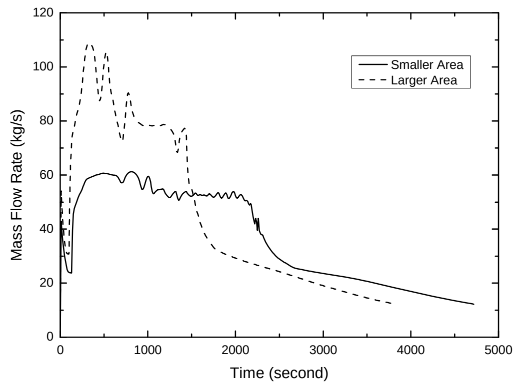
Figure 2(a) shows that the PSV mass flow rate of the “smaller area” case is less than that of the “larger area” case. Due to the less discharge of coolant inventory during the two-phase discharge in the “smaller area” case, the RCS pressure and core level decrease slower than those of the “larger area” case as shown in the Figure 2(b) and 2(c). Less depletion of the coolant in the “smaller area” case than the “larger area” case delays the fuel failure. The fuel cladding failure is expected at about 4,500 seconds for the “smaller area” case whereas at 3,600 seconds for the “larger area” case as shown in the Figure 2(d).

However, for the case with SITs injection as shown in the Figure 3(b), the RCS pressure of the “smaller area” case is still not reached to the SIT injection pressure before the fuel failure as in the case without SITs injection. As a result, cases with and without SITs are exactly same behaviors for the “smaller area” case, since the RCS pressure is maintained higher than SIT injection pressure (4.31 MPa). On the other hand, in case of the “larger area”, SIT is successfully injected into the RCS because RCS pressure is decreased below the SIT injection setpoint before fuel failure as shown in Figure 3(b) due to the increased mass flow as in Figure 3(a). RCS cool down using one ADV is considered after SIT injection. The fuel in the “larger area” case keeps its integrity for about 9,200 seconds and it is about 5,000 seconds longer compared with the “smaller area” case.

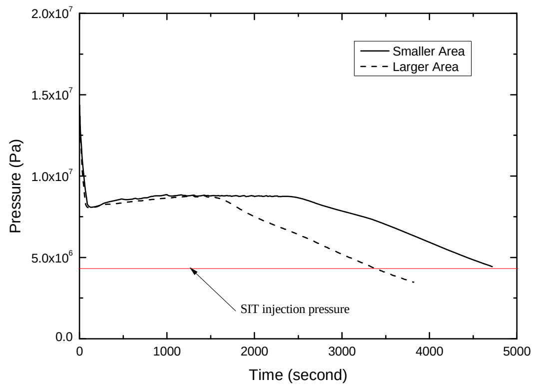
Table III compares core uncover time and fuel failure time.

Table III Comparison of core uncover and fuel failure time

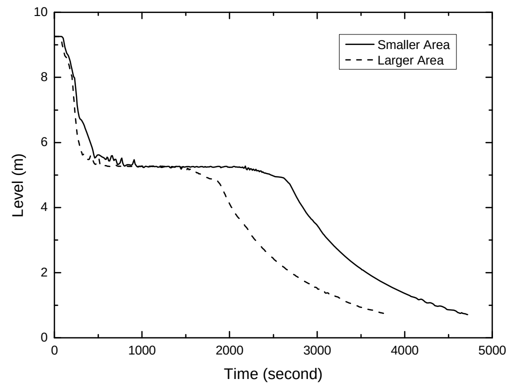
	SITs injection failure		SITs injection success	
	smaller area	larger area	smaller area	larger area
Core uncover time	2882 sec.	2066 sec.	2882 sec.	2066 sec.
Fuel failure time	4488 sec.	3605 sec.	4488 sec.	9263 sec.



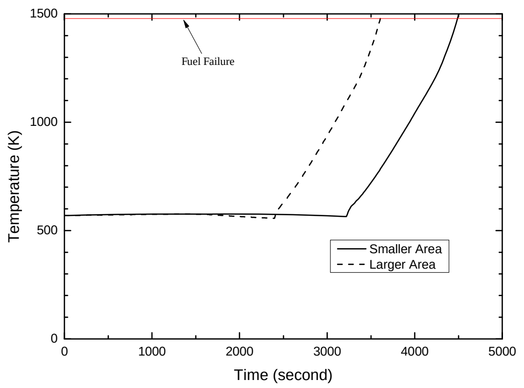
(a) PSV mass flow rate



(b) RCS pressure

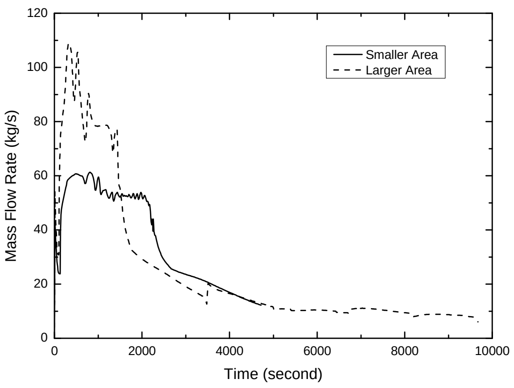


(c) Core level

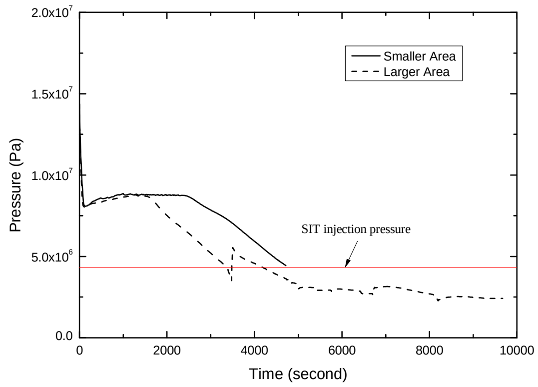


(d) Fuel cladding temperature

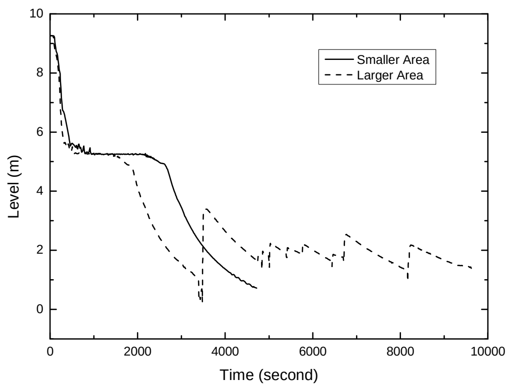
Figure 2 Comparison of major parameters for the case without SIT injection



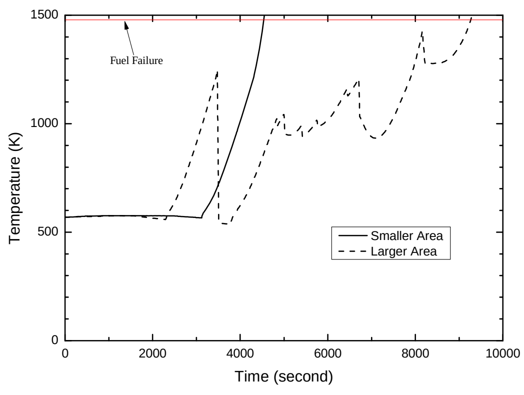
(a) PSV mass flow rate



(b) RCS pressure



(c) Core level



(d) Fuel cladding temperature

Figure 3 Comparison of major parameters for the case with SIT injection

5. Impact on the LPSD PSA

In the current PSA model for a PSV stuck open, the SIT injection failure, the SIT injection success, and ADV cool down during the SIT injection conditions are considered. The success criteria of POS2 PSA are the actuation of SITs, cool down by ADV, and the LPSI system in the long term cooling. The results of the thermal hydraulic analysis shows that the fuel integrity is not guaranteed with and without SITs. Although SITs are available, ADV is required to cool down and depressurize the RCS to the LPSI setpoint to preclude core damage (CD).

The success path of the event is summarized in the event tree (Figure 4).

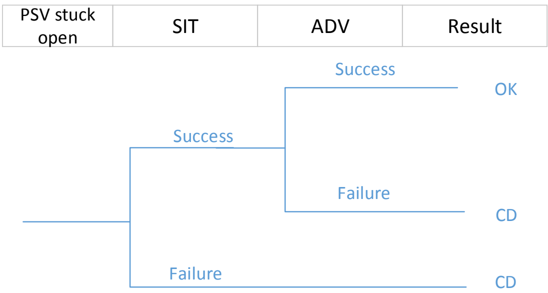


Figure 4 Simplified event tree of POS2 PSV stuck open

Therefore, ADV should be opened by the operator before fuel failure with sufficient time. The ADV opening time in the “larger area” case is 6,000 seconds based on the results of SIT success. However, in case of the “smaller area”, the ADV should be opened earlier than that in the “larger area” case in order to prevent fuel failure.

If the smaller area is used for the analysis of PSV stuck open, the ADV opening time could be shortened less than 4,500 seconds. It means that the allowed time decreases so that the operator opens an ADV. If the allowed time is short, the CDF may increase because the possibility of ADV opening failure by human error increases as operators get more pressure to perform the emergency action within short allowed time. Human error is evaluated as dominant factor which causes the core damage especially in LPSD PSA analysis for the human reliability analysis.

6. Conclusions

Due to the modification of H-F model in RELAP5/MOD3.3 patch 4, the critical steam flow rate is increased at high pressure and thus the simulated PSV area is decreased. The change in PSV flow area impacts on the thermal hydraulic behaviors of the PSV stuck open event during POS2. PSA modeling can be changed depending on the results of thermal hydraulic analysis.

The critical flow rate of two-phase mixture through the PSV needs to be justified and the flow rate should be adjusted to compensate the underestimation of the H-F model for the two-phase discharge.

REFERENCES

[1] Cheol Woo Kim, “Comparison of Critical Flow in RELAP5/MOD3.3 Patches,” 2014 NuSTEP Summer Meeting, July 16th, 2014.
[2] NUREG/CR-5355, Rev. P4, “RELAP5/MOD3.3 Code Manual”, Nuclear Systems Analysis Operations, Information Systems Laboratory Inc., October 2010.
[3] KHNP, “Operating Procedures of ULCHIN 3&4 Nuclear Power Plant”.