Estimated Available Time for SBLOCA with Safety Injection Failure in APR1000

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1. Introduction

Operator action plays an important role in ensuring the safe shutdown of nuclear reactors. Accurate estimation of operator action time is therefore important in the safety analyses, particularly for scenarios involving multiple failure of safety systems.

Operator actions have been credited based on pre-defined action times for specific plant conditions in accordance with ANSI/ANS-58.8. While this approach has provided a practical framework for operational planning, it does not explicitly verify that sufficient physical time exists for successful execution under varying thermal-hydraulic conditions.

The U.S. NRC [1] has previously highlighted the importance of ensuring the availability of adequate response time before crediting operator actions. Moreover, the latest revision of ANSI/ANS-58.8 [2] emphasizes that sufficient time margin should be available to credit operator actions, calculated as shown in (1).

$$Performace\ Time = (time\ from\ cue\ until\ action\ completed) \quad (1)$$

$$Available\ Time = (time\ from\ cue\ until\ analysis\ requires\ the\ action\ completed)$$

$$Margin = \frac{(Available\ Time) - (Performance\ Time)}{(Available\ Time)} \times 100\%$$

This analysis identifies the key operator actions under a Small Break Loss of Coolant Accident with Safety Injection Failure (SBLOCA with SIF) in the APR1000 standard design and evaluates the available time.

The results provide a reference for ensuring sufficient time margin for operator actions credited in the plant's design and Emergency Operating Procedure (EOP).

2. Method of Analysis

The SPACE computer code [3] is used to simulate the NSSS thermal-hydraulic system responses. As part of the best estimate methodology, normal operating conditions and nominal design values are assumed.

To simulate the accident, A 2 inch rupture in the Reactor Coolant Pump (RCP) discharge of the cold leg is assumed with the coincident loss of all active safety injection.

The operator actions considered in the APR1000 standard design, hereby called the Base Case of SBLOCA with SIF, are:

(1) RCP Trip
(2) Passive Auxiliary Feedwater System (PAFS) Actuation

In the Base Case, both operator actions are assumed at 30 minutes after reactor trip, as a grace period to diagnose the accident and perform the required actions in accordance with the EOP.

The sequence of events for the Base Case is shown in Table I and analysis results demonstrate that the Reactor Coolant System (RCS) successfully reaches Shutdown Cooling System (SCS) entry conditions with no fuel heat-up.

Table I: Sequence of Events for Base Case

Time (s)	Case 1
0	SBLOCA with SIF
62	Reactor Trip (LPP)
65	Turbine Trip
1,862	Operator action - RCP trip - PAFS Actuation
2,292	SIT initiated
5,200	SCS entry conditions reached

The analysis consists of two steps. The first step is a sensitivity analysis to identify the key operator actions from in the Base Case. The second step is a quantitative evaluation of the available time.

In this analysis, the available time is assumed as the time from reactor trip due to SBLOCA with SIF until the time by which the required actions must be completed to ensure that the acceptance criteria is not exceeded.

3. Results

3.1 Identification of key operator action

The results of the sensitivity analysis performed to identify key operator actions from the Base Case are shown in Table II.

Table II: Operator Action Sensitivity Analysis

Operator Action	Base Case	Case 1	Case 2
RCP Trip	O	X	O
PAFS Actuation	O	O	X

3.1.1 Case 1

The sequence of events for Case 1 is presented in Table III and the major thermal-hydraulic behavior is presented in Fig. 1 and Fig. 2. Following event initiation, SBLOCA depressurizes the RCS to Low Pressurizer Pressure (LPP) trip setpoints and the reactor is tripped. At 30 minutes after reactor trip, PAFS is manually actuated through operator action, initiating secondary side heat removal. At 5,485 seconds, the RCS successfully reaches SCS entry conditions with no fuel heat-up.

Table III: Sequence of Events for Case 1

Time (s)	Case 1
0	SBLOCA with SIF
62	Reactor Trip (LPP)
65	Turbine Trip
1,862	Operator action - PAFS Actuation
2,301	SIT initiated
5,485	SCS entry conditions reached

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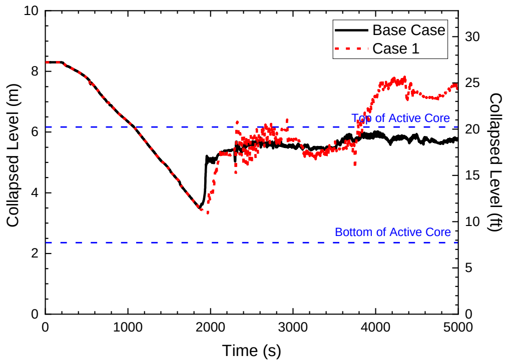

Fig. 1 Core Collapsed Level (Case 1)

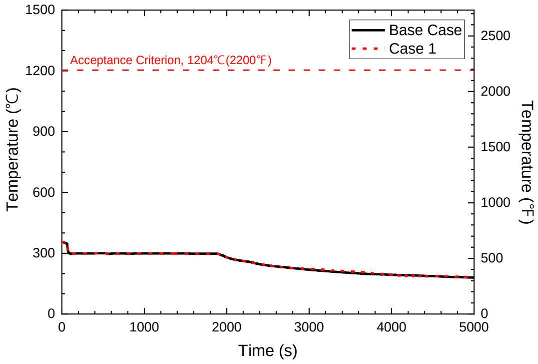

Fig. 2 Fuel Cladding Temperature (Case 1)

3.1.2 Case 2

The sequence of events for Case 2 is presented in Table IV and the major thermal-hydraulic behavior is presented in Fig. 3 and Fig. 4. Following event initiation, SBLOCA depressurizes the RCS to Low Pressurizer Pressure (LPP) trip setpoints and the reactor is tripped. At 30 minutes after reactor trip, The RCPs are tripped through operator action. Meanwhile, Case 2 fails to remove decay heat and replenish the RCS inventory, and the Peak Cladding Temperature (PCT) exceeds the acceptance criteria of 1,204℃ [4] at 4,882 seconds after event initiation.

Table IV: Sequence of Events for Case 2

Time (s)	Case 2
0	SBLOCA with SIF
62	Reactor Trip (LPP)
65	Turbine Trip
1,862	Operator action - RCP trip
3,470	Fuel heat-up begins
4,882	PCT exceeds 1,204℃

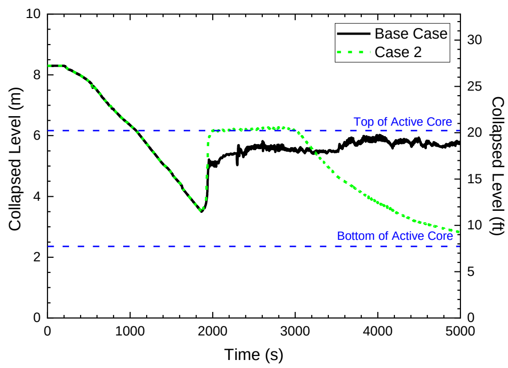

Fig. 3 Core Collapsed Level (Case 2)

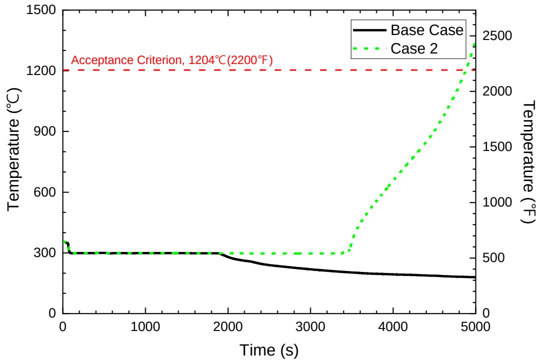

Fig. 4 Fuel Cladding Temperature (Case 2)

Results show that the manual actuation of PAFS is a key operator action under SBLOCA with SIF, whereas RCP trip is not critical in the successful mitigation of the accident.

However, continuous operation of the RCPs under a LOCA event is not realistic, as the continuous loss of RCS inventory and depressurization could lead to the loss of RCP Net Positive Suction Head (NPSH), which may degrade pump performance and eventually lead to failure. Therefore, RCP trip operator action remains to be considered in the analysis.

3.2 Available Time of key operator action

Based on the sequence of events in Table IV, the time constraint for manual PAFS actuation is 3,408 seconds, the time from reactor trip (62 s) to the onset time of fuel heat-up (3,470 s). In order to account for the system response time (e.g., valve stroke time, flow delivery to the steam generators), operator action must be completed within approximately 55 minutes (3,300 s) after reactor trip.

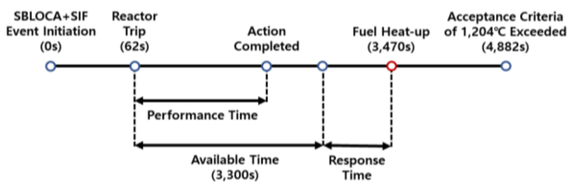

Fig. 5 Operator Action Available Time

Table V, Fig. 6 and Fig. 7 shows the results of performing manual PAFS actuation at the available time of 55 minutes in Case 2, which is labeled as Case 3. Results show that operator action successfully prevents significant fuel degradation.

Table V: Sequence of Events for Case 3

Time (s)	Case 3
0	SBLOCA with SIF
62	Reactor Trip (LPP)
65	Turbine Trip
1,862	Operator action - RCP trip
3,300	Operator action - PAFS Actuation
3,671	SIT initiated
6,652	SCS entry conditions reached

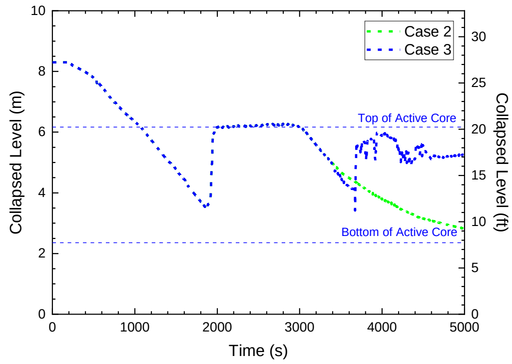

Fig. 6 Core Collapsed Level (Case 3)

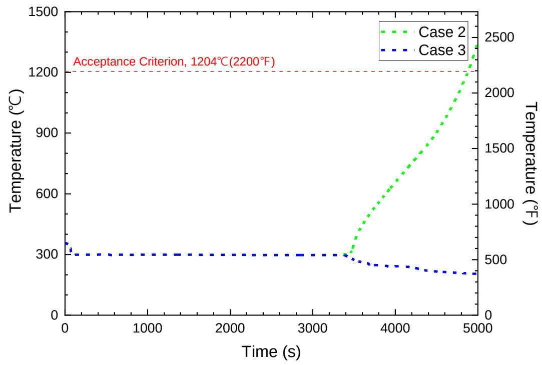

Fig. 7 Fuel Cladding Temperature (Case 3)

4. Conclusions

This analysis identifies the key operator actions under a Small Break Loss of Coolant Accident with Safety Injection Failure (SBLOCA with SIF) in the APR1000 standard design and evaluates the available time.

The key operator action required for the successful mitigation of SBLOCA with SIF is the manual actuation of PAFS, and the available time is estimated at 55 minutes.

The operator action available time may be evaluated for other DEC-A scenarios as well to identify scenario-specific time margins. Such results may serve as a reference in further development of the EOPs for APR1000 and Dukovany Nuclear Power Plant 5&6.

ACKNOWLEDGEMENT

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REFERENCES

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