Evaluation of the Operator Actions to Maintain the Fuel Integrity during the Small Break LOCA with Safety Injection Failure for Westinghouse type 2-loop Plant

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CONTENTS

1. INTRODUCTION

- Accident Management Plan (AMP)
  - Accident mitigation strategies for Nuclear Power Plant (NPP) during multiple failure accident
    - Small Break Loss Of Coolant Accident (SBLOCA) with Safety Injection (SI) failure
    - Evaluation to mitigate the NPP transient condition keeping not to grow up into severe accident
- Westinghouse Type 2-Loop Plant
  - 2 steam generators
  - Power Operated Relief Valves (PORVs) connected to the pressurizer (PZR) & steam generators (SGs)
    - To maintain the system pressure by discharging coolant during abnormal condition
- Operator Actions
  - To maintain the reactor system safe, appropriate operator actions on right time should be performed.
  - *Some trials to find the right operator actions using PORV and RCP*
- **Fuel Cladding Temperature**
  - To demonstrate the result of operator actions during SBLOCA with SI failure

2. METHODOLOGY

- Best estimated analysis
  - Control systems model
    - Pressurizer Pressure Control System (PPCS), Pressurizer Level Control System (PLCS), Steam Generator Level Control System (SGLCS) and Steam Dump Control System (SDCS) composed with PORVs
    - Realistic simulation using the RELAP5/Mod3.3 code
    - Nominal design value of 100% reactor power is assumed.
- The 2-inch break area in the cold leg
  - The limiting size of the small break is 2-inches in view point of the core damage frequency.
  - Break flow of the cold leg is used with Henry-Fauske critical flow model.
- High Head Safety Injection (HHSI) and Low Head Safety Injection (LHSI)
  - HHSI as means of the coping facility for SBLOCA is assumed not working, but LHSI working if the Reactor Coolant System (RCS) pressure is less than LHSI pump shutoff head.

2.1 Node Diagram for RELAP5
& Initial Conditions for Steady State

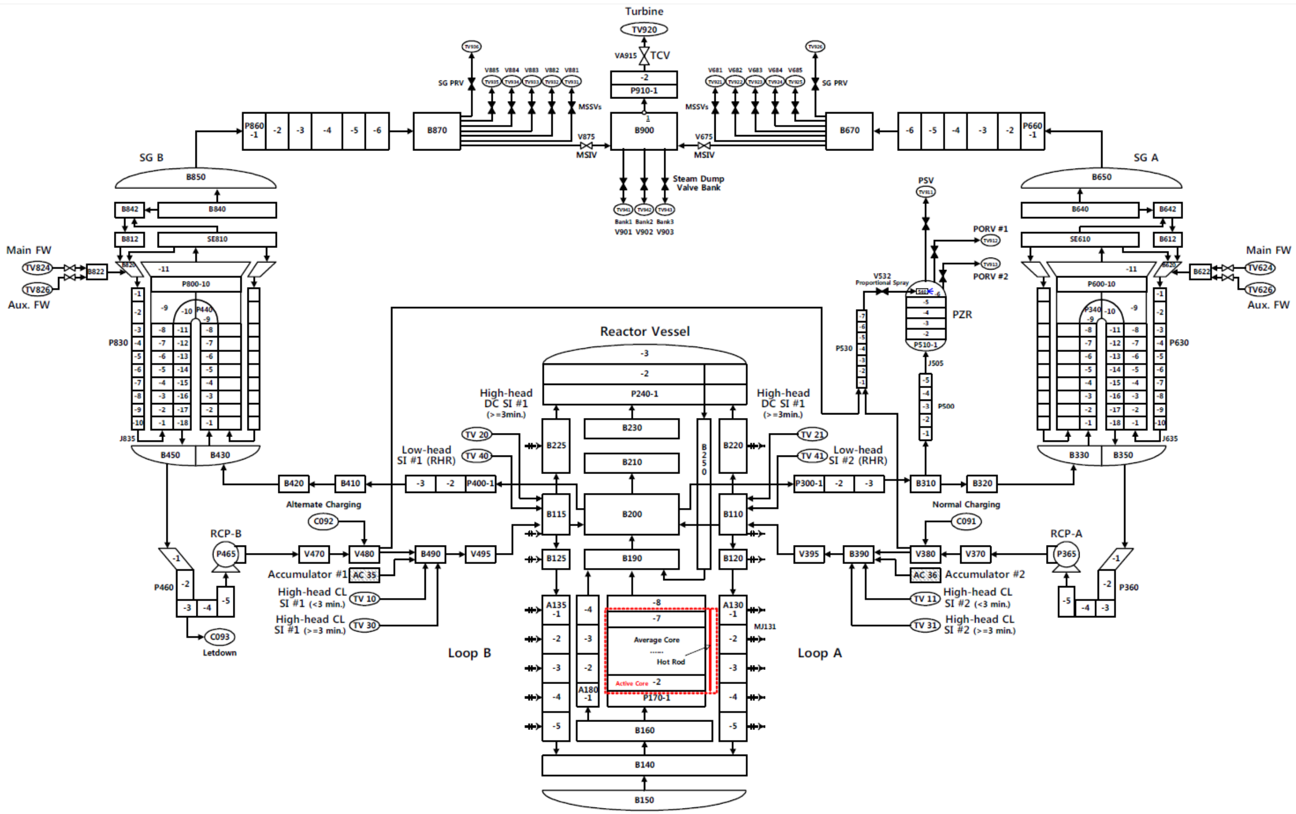

Table I. Initial Conditions		
Parameter	Design Value	Analysis Value
Core Power, MWt	1,876	1,876
PZR pressure, MPa(a)	15.51	15.51
RCS flow rate, kg/s	8,832.5	8,836.9
Core inlet temperature, K	560.59	560.59
Secondary pressure, MPa(a)	6.3	6.33
Secondary steam flow rate, kg/s	1028.2	1041.8
PZR level, %	60	60
Steam Generator level, % NR	50	50

2.2 Sensitivity for Operator Action

- Operator actions
  - SG PORV Open
    - To depressurize RCS & bleed the core with makeup water from Safety Injection System (SIS) or Residual Heat Removal System (RHRS)
    - PORV of the Steam Generator (SG) steam is discharging, then the RCS pressure is started to decrease if the operator can open the PORV effectively.
    - Some of PORV open times and open methods by operator are applied to depressurize the RCS.
  - RCP Trip
    - Heat removal by RCP from the core after the accident is not conservative assumption for the traditional accident analysis. However, the appropriate operator action by means of maintaining core integrity should be evaluated.

Table II. Operator Action

	SG PORV Open (minutes)	Open Method (°C/hour)	RCP Trip (minutes)
Case 1 (Reference)	30	Full Open	X
Case 2	30	Full Open	10
Case 3	20	55.55	10
Case 4	15	55.55	10

3. RESULTS

- Reactor system behaviors and operator actions during the SBLOCA with SI failure
  - For reference case (Case 1)

Table III. Sequences of Event of the Reference Case

Sequences	Time (second)
Event Start	0.0
Reactor Trip	22.0
Safety Injection Actuation Signal	27.0
HHSI injection fail	39.0
PZR depletion	41.0
Auxiliary feedwater injection	87.0
SG PORV open	1800.0
MSSV Isolation Signal	1805.0
SIT injection	1831.0
Peak Cladding Temperature	1924.0
LHSI injection stat	2719.0
RCS condition reaches the RHRS operating condition	2820.0

3. RESULTS

- The RCS pressure decreases by the break location in cold leg.
- Reactor trip occurs by low PZR pressure at 22.0 seconds.
- Void fraction start to increase maintaining RCS pressure.
- Operator action to open a PORV connected with one of SG.
  - For Case 4, the RCS depressurization with cooling rate of 55.55 ° C/hr. However, the RCS pressure does not reach Low Head Safety Injection (LHSI) injection pressure.
  - For Case 1 and Case 2, the RCS pressure is depressurized to enough to reach LHSI actuation condition.

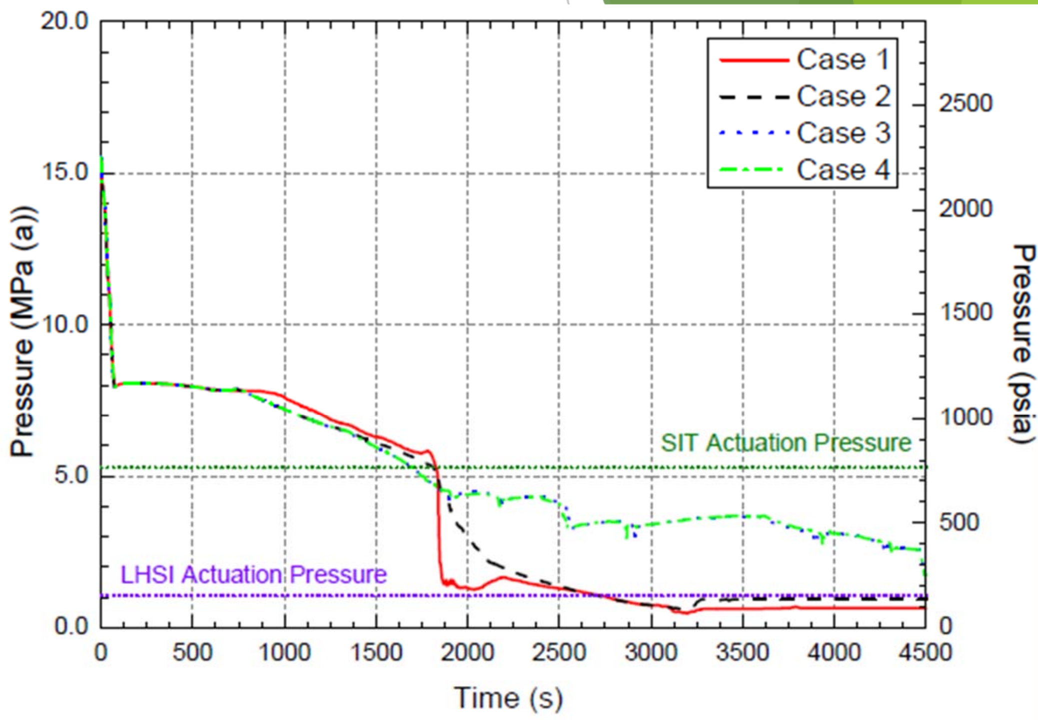

Figure 1. RCS Pressure

3. RESULTS

- PZR pressure level decreases & is depleted.
- The makeup water from Safety Injection Tank (SIT) is started to be injected and LHSI is actuated.
- RCS pressure and temperature decrease effectively.
  - For all cases, SIT water is injected inconsistently for a short time.
  - For Case 1 and 2 the LHSI injects large amount of makeup water at about 3,000 seconds. Thereafter, a small amount flow form LHSI injected continuously.

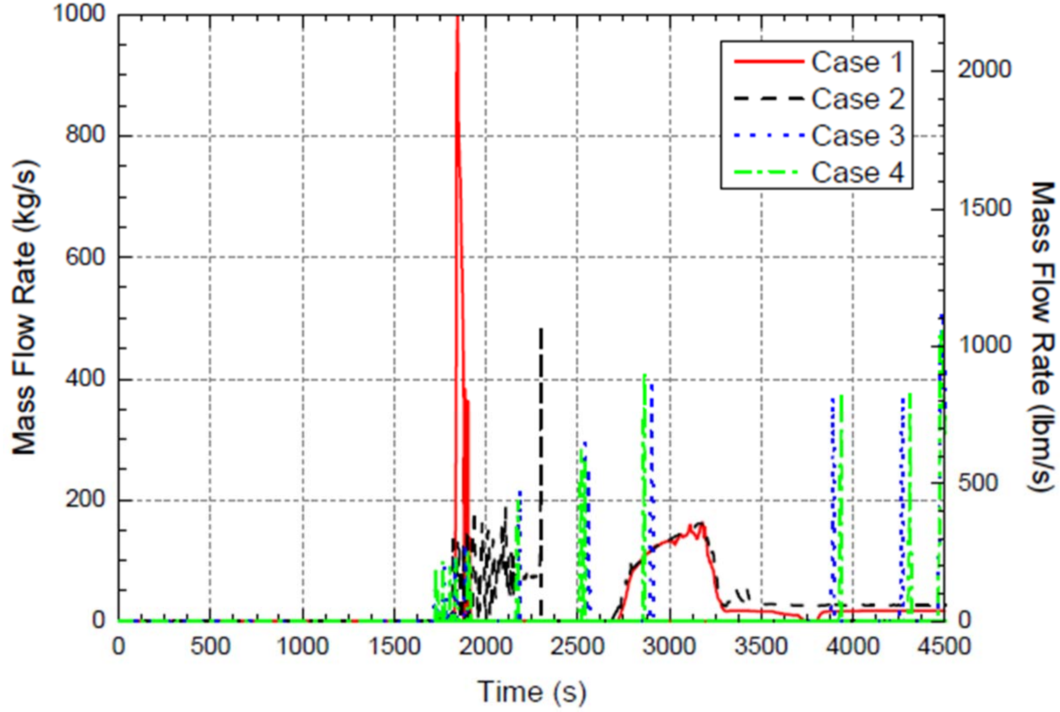

Figure 2. SIT and LHSI injection

3. RESULTS

- RCS inventory decreases & is started to be recovered by the makeup water from SIT and LHSI.
  - For Case 1, not tripped RCP flows reactor coolant continuously then core collapsed level decreases rapidly more than other cases.
    - However, the core collapsed level is recovered to top of the active core at about 2,000 seconds by the safety injection from the SIT.
    - Since the SIT finished to inject makeup water, core collapsed level decreases again until LHSI is started to cover the core level.
    - As the end of the large amount of the LHSI flow, <u>a small amount of LHSI water flow is balanced with break flow.</u> In this reason, the core collapsed level could be maintained on stable.
  - For Case 3 and Case 4, core collapsed is varied with water injection from SIT without LHSI injection. In these cases, the RCS cooling is not stable
    - Break flow is larger than injected water.

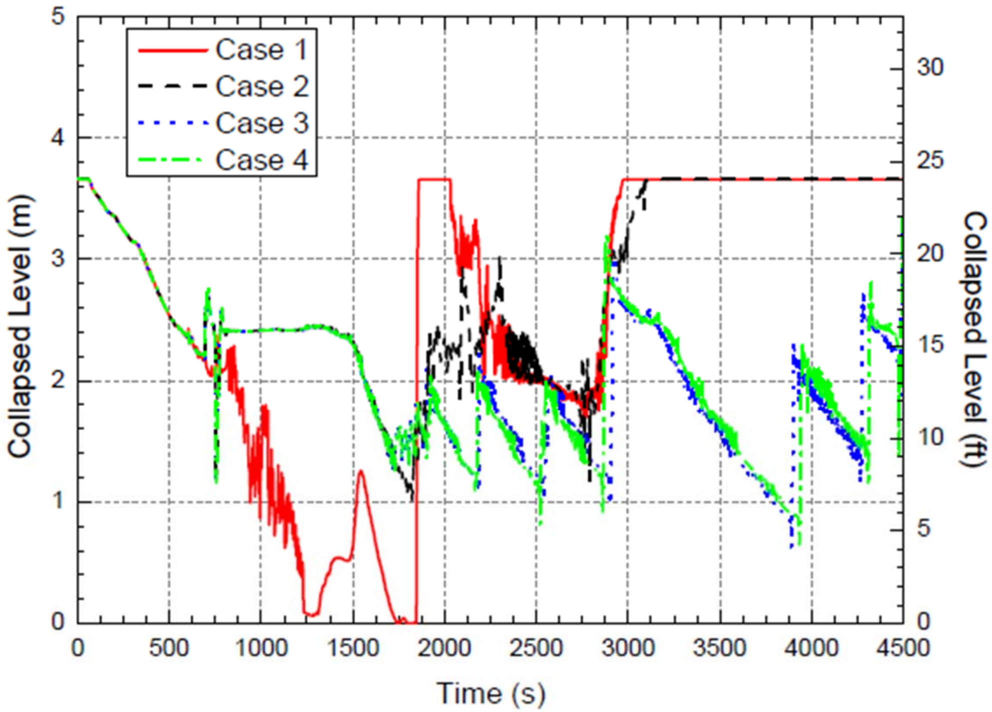

Figure 3. Core Collapsed Level

3. RESULTS

- For Case 1, core collapsed level decreases under the bottom of the active core from 500 to 3,000 seconds.
  - It is predicted to fuel dry out in this interval, the continuous core flow by RCP prevents rapid heat up
- For Case 2, the core collapsed level of the Case 2 does not decrease rapidly, the fuel is heated up obviously owing to the RCS thermal hydraulic conditions such as pressure, temperature and core flow.
- For Case 3 and Case 4, the core collapsed level remains over the bottom of the active core.
  - However, the RCS temperature and pressure are not decreased enough to prevent fuel heat up.
  - The time that peak temperature occurs are related to water injection from SIT and unstable to maintain core cooling ability during SBLOCA with SI failure.

<u>Case 1 is most effective operator actions for SBLOCA with SI failure.</u>

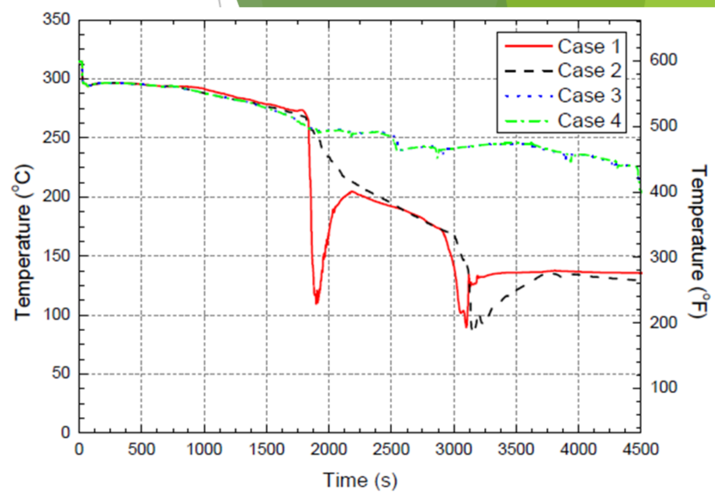

Figure 4. RCS Temperature

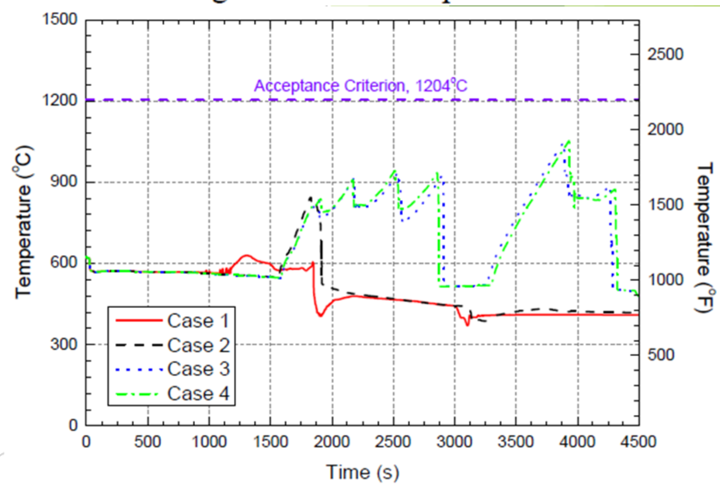

Figure 5. Fuel Cladding Temperature

3. RESULTS

- Case 1 : The RCS pressure and temperature reach RHRS condition at 2,820 second, then reactor system goes into the stable shutdown state, finally.
- Case 2 : The operator actions are effective to maintain reactor system on stable during this event.
- Case 3 & Case 4 : The fuel cladding temperatures do not exceed the acceptance criteria.

4. CONCLUSIONS

- *SBLOCA with SI failure as one of the multiple failure events had been evaluated with various operator actions using the best estimated methodology.*
- *Analyses for the Westinghouse type 2-loop plant has shown that if the operator fully open SG PORV without any other actions at 30 minutes after the initiation of this event, the SIT, LHSI and RHRS could successively provide stable core cooling ability.*

Thank You!