Evaluation of the Passive Auxiliary Feedwater System to Mitigate the Loss of Ultimate Heat Sink Accident for APR1000

Hyoung Kyoun Ahn*, Dong Min, Kim, Seok Jeong Park, Jae Young Huh

Safety Analysis Group, KEPCO-E&C, 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, Rep. of KOREA

Corresponding author:hkahn@kepco-enc.com

CONTENTS

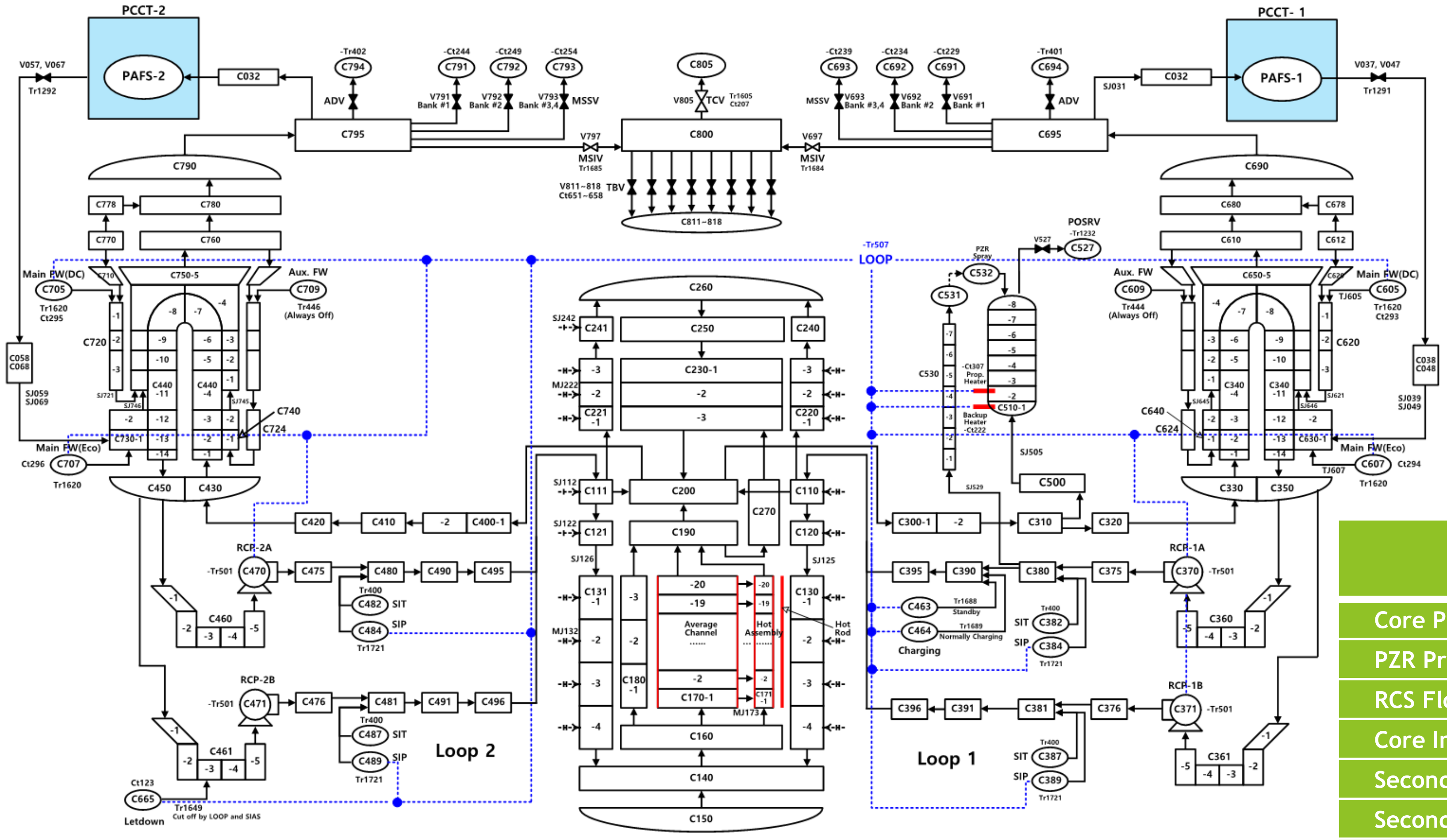
1. INTRODUCTION

- Design Extension Condition (DEC)
  - Accident mitigation strategies for Nuclear Power Plant (NPP) during multiple failure accident
    - Loss of Ultimate Heat Sink (LOUHS) during Normal Operation
    - Evaluation to mitigate the NPP transient condition keeping not to grow up into severe accident
- APR1000 Nuclear Power Plant
  - 2 steam generators
  - Engineered Safety Features
    - Safety Injection System (SIS), Shutdown Cooling/Containment Spray System (SCS/CSS)
    - Passive Auxiliary Feedwater System (PAFS)
    - Safety-Depressurization and Vent System (SDVS)
- Operator Actions
  - For mitigating the RCS to shutdown cooling entry condition
  - *Simple operator action by PAFS compared with commertial Auxiliary Feedwater System*
- **Acceptance Criteria**
  - RCS integrity and fuel peak cladding temperature

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 SPACE Code
    - Nominal design value of 100% reactor power is assumed.
- The LOUHS Assumptions
  - The Loss of Essential Service Water System (ESWS) & Circulating Water System(CWS)
    - Component Cooling Failure of 1st & 2nd System
    - Turbine Trip, Feedwater Pump Stop
    - Inducing Loss of Condenser Vacuum [Initiation Condition]
  - Reactor Trip by High Pressurizer Pressure Trip
  - Charging Pump Working
  - Operator Action at 30 minutes

2.1 Node Diagram for SPACE Code & Initial Conditions for Steady State



Parameter	Design Value	Analysis Value
Core Power, MWt	2,815.0	2,815.0
PZR Pressure, MPa	15.5	15.5
RCS Flow Rate, kg/s	15,309	15,304
Core Inlet Temperature, K	600.4	599.9
Secondary Pressure, MPa	7.5	7.5
Secondary Steam Flow Rate, kg/s	803	798
PZR Level, %	52.6	52.2
Steam Generator Level, % WR	79.0	79.0

2.2 Operator Action

- Operator actions
  - ADV Open
    - For the case with AFWS, AFWS is actuated then operator should open Atmospheric Discharge Valve (ADV) to decrease the RCS pressure and temperature.
    - For the case with PAFS, operator do not need to open ADV.
  - RCP Stop & Safety Injection Isolation
    - RCP stop & safety injection iolsation are assumed to stop at 30 minutes by the operator action due to conservative safety analysis.
  - Charging Pump Stop & Auxiliary Charging Pump Actuate
    - Loss of ESWS → CP heat exchanger not available → To actuate the Auxiliary Charging Pump (ACP)
  - Reactor Coolant Gas Vent System (RCGVS) for RCS natural circulation

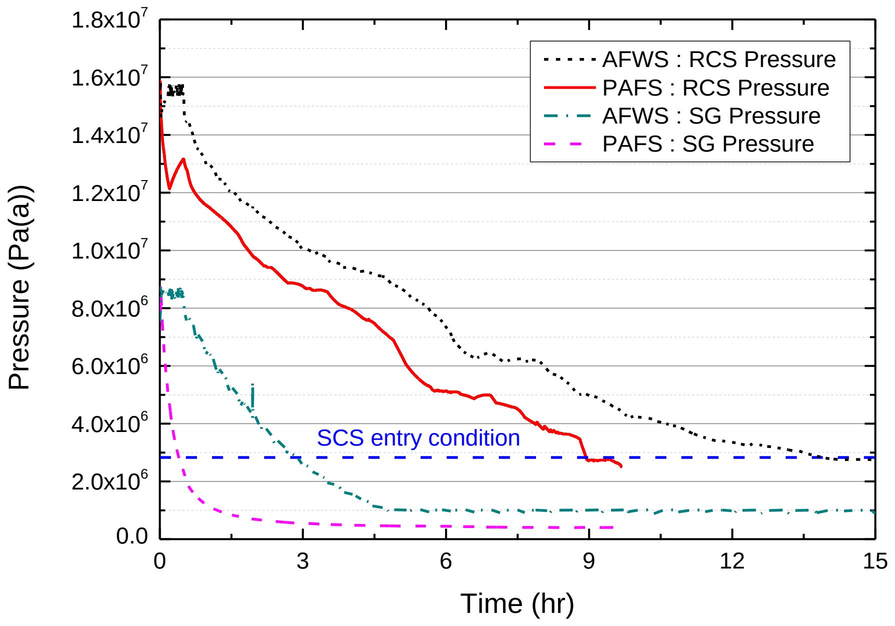
3. RESULTS

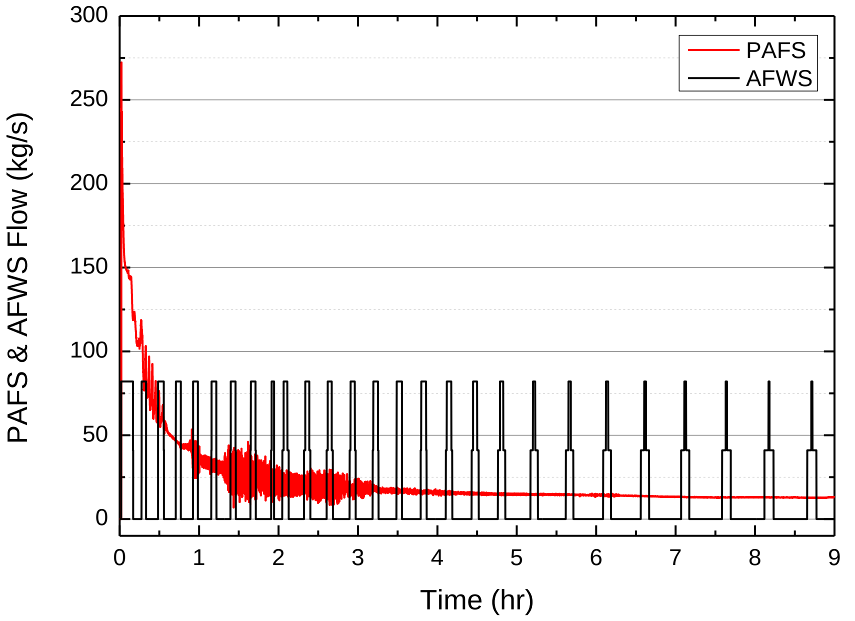
- Reactor system behaviors and operator actions during LOUHS
  - Case with PAFS

Sequences	Time (second)
LOUHS Occurs Loss of ESWS, CWS FWP Trip Letdown Isolation	0.0
Reactor Trip by LSGL	41
MSSV Open	48
PAFS Actuation	74
Operator Action - RCP Trip - CP Trip - ACP Actuation - RCGVS Open	1,800
SCS Temperature Entry Condition Reached (350 °F)	9,620
SCS Pressure Entry Condition Reached (410 psia)	32,180

3. RESULTS

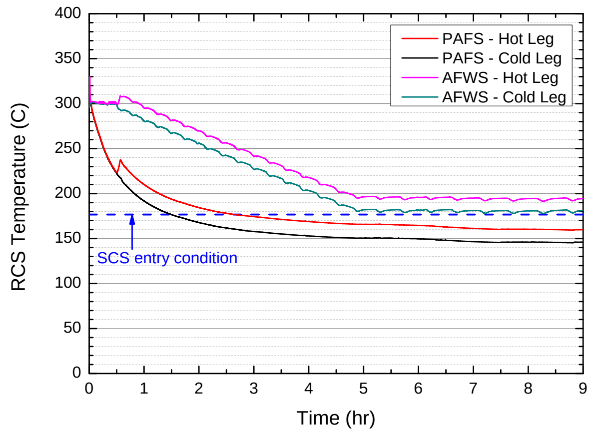
- Loss of cooling function of ESWS induces the Loss Of Condensate Vacuum (LOCV) with the feedwater pumps trip.
- At the 41 seconds, the reactor trip occurs by the Low Steam Generator Level (LSGL) signal.
- RCS depressurization
  - For the case with PAFS
    - RCS pressure increases from 700 seconds when the safety injection pump is actuated by the low pressurizer pressure signal to 1,800 seconds when the operator action is assumed.
  - For the case with AFWS
    - RCS pressure is not decreased by the secondary system even though discharging coolant through pilot operated safety and relief valve (POSRV), and the RCS depressurization is delayed until operator action is performed. Therefore, the time that RCS pressure is reached to the SCS entry condition is slower than about 5 hours of the case with PAFS.

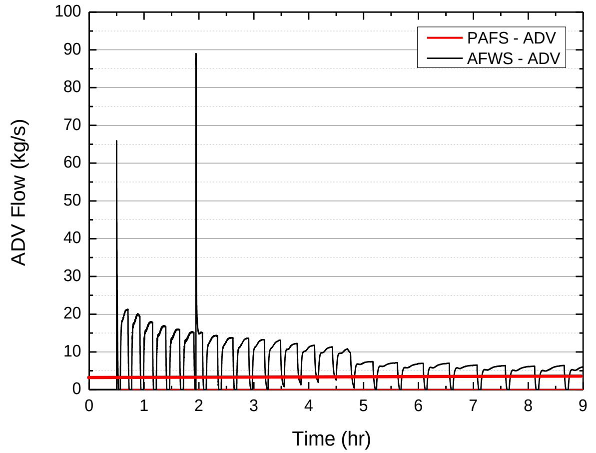


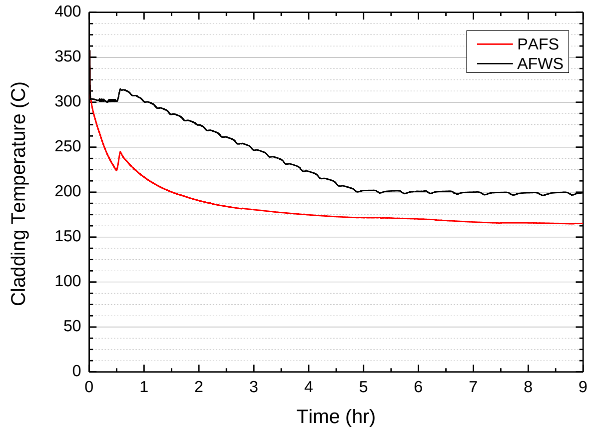


3. RESULTS

- RCS temperature decrease
  - For the case with PAFS
    - The hot leg temperature rises for a short time due to the decreased charging flow but it is cool down continuously and reached the shutdown cooling entry temperature.
    - Decreasing the RCS coolant temperature by the PAFS, the fuel is cooled well and the fuel integrity remains.
    - After the RCP trip by operator, RCS flow is decreased then the temperature difference from the hot leg and cold leg increases.
  - For the case with AFWS
    - Operator should open the ADV to depressurize RCS after 30 minutes.
    - RCS temperature begins to decrease, however, it is reached to the SCS entry temperature condition very slowly.
- PCT is maintained to be safe for the case with PAFS & AFWS
  - It has more safety margin to mitigate LOUHS that the case with PAFS in a view of operator action.







4. CONCLUSIONS

- *LOUHS as one of the multiple failure events had been evaluated with PAFS & AFWS using the best estimated methodology.*
- *Analyses for the APR1000 has shown that if the mitigation time of the case with PAFS is shorter than the time of the case with AFWS.*
- *PAFS is more effective to stabilize RCS during LOUHS than commercial auxiliary feedwater system.*

Thank You!