Long Term Cooling Analysis Considering In-Vessel Downstream Effect Using MARS

Shah Asad Ullah Amin
Korea Institute of Nuclear Safety (KINS)
Korea Advance Institute of Science and Technology (KAIST)

Young Seok Bang
Group Head Reactor Safety Department
Korea Institute of Nuclear Safety (KINS)

Scope of Generic Safety Issue 191

- Scope of Generic Safety Issue 191 (GSI-191)
  - Various concerns associated with the operation of the ECCS and the CSS in the recirculation mode
  - These concerns include debris generation associated with a postulated high energy piping break
  - Debris transport to the containment sump when the ECCS is operated in the recirculation mode, and
  - Effects of debris that might pass through the sump strainers on downstream components and fuel regions that is termed as **In-Vessel Downstream Effect**.

Introduction

- In Korea, test regarding In-vessel downstream effect has been performed by Korea Hydro & Nuclear Power Company (KHNP)
- Test reports have been submitted to KINS, a regulatory body in Korea.
- KINS has been verifying the test results that they met the safety criteria defined by USNRC.
- This research present the methodology to review the tests performed by KHNP.

Introduction

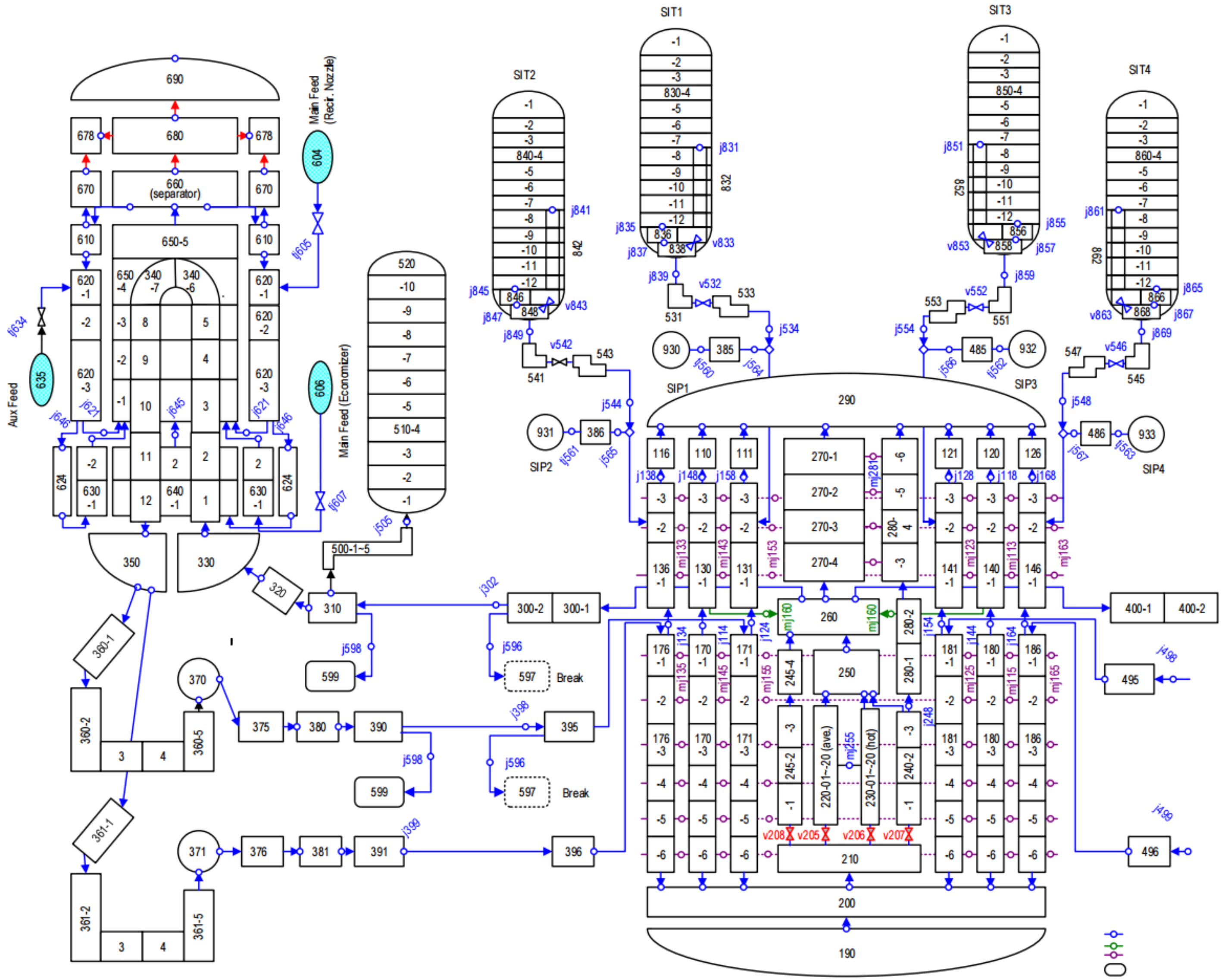
- Approach
  - MARS-KS1.3, a thermal hydraulic code, has been selected to develop the methodology for evaluation of test results.
- Acceptance Criteria
  - Acceptance criteria for the in-vessel downstream effect, as described in WCAP-16793-NP Rev 2, are as follows:
    - Cladding temperature during recirculation should be < 800 °F (426.66°C)
    - Thickness of the deposition layer of debris should be < 50 mils (1.27mm) on any fuel rod

Modeling Scheme

- To meet the criteria < 800^0F, sufficient flow through the core should be maintain in the post LOCA recirculation phase.
- To maintain the sufficient flow the available driving head should be greater than pressure drop resulted from the debris deposition.
- There were two problems, using the MARS a thermal hydraulic code.
  - Modelling of the debris blockage at the core inlet.
  - Modelling of the chemical deposition layer on the fuel surface.

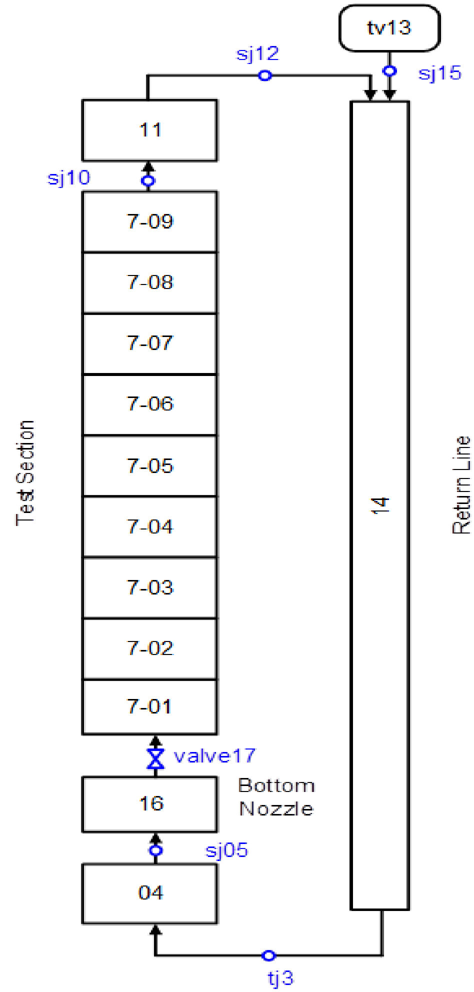
Hydraulic Modeling

. Bang et al



Modeling of Debris Pressure Drop

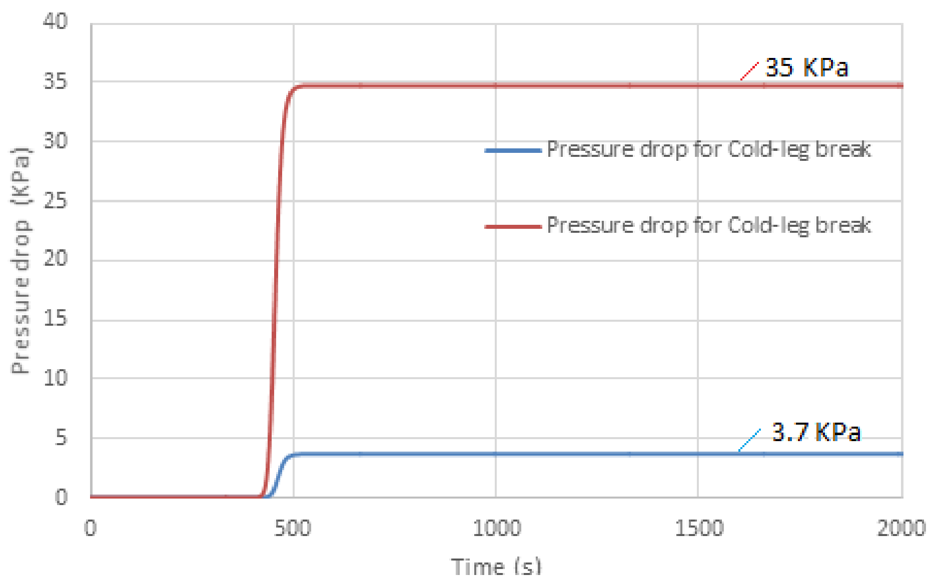
- To achieve the pressure drop for debris, a test model was simulated.
- A single fuel assembly model was simulated as shown in Figure.
- Flows of 77.6 lpm (HLB) and 11.4 lpm (CLB) of a single fuel assembly were selected from the KHNP test report.
- A servo valve with a controlled gate area was introduced to model the debris blockage.



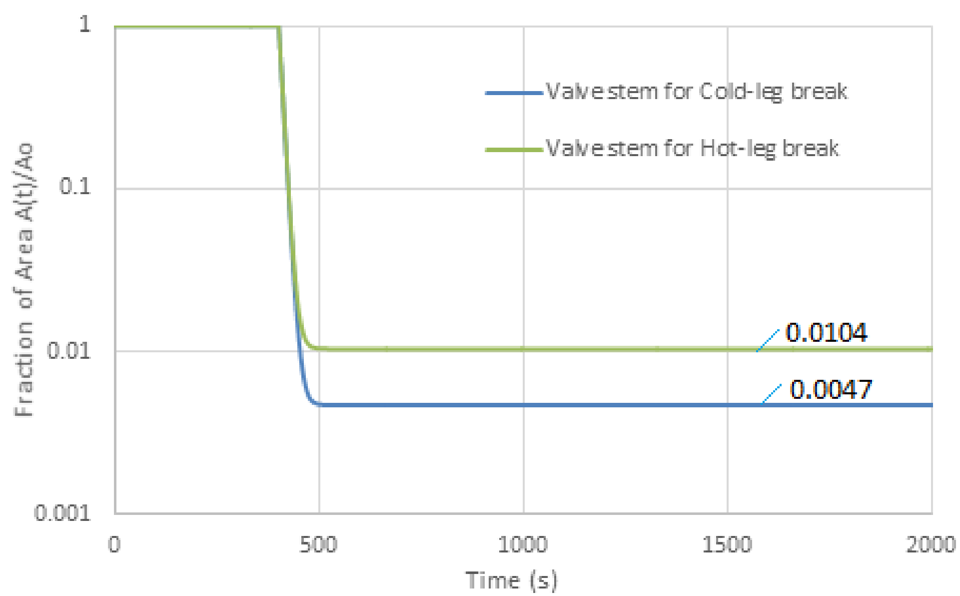
Modeling of Debris Pressure Drop

- Valve areas corresponding to the Pressure Drop due to debris 34KPa (HLB) and 3.7KPa (CLB) were calculated.

$$\text{Area ratio (A)} = A(t)/A_o = \text{MIN}\left[1, A_N + \text{abs}\left(e^{k(tb-t)}\right)\right]$$

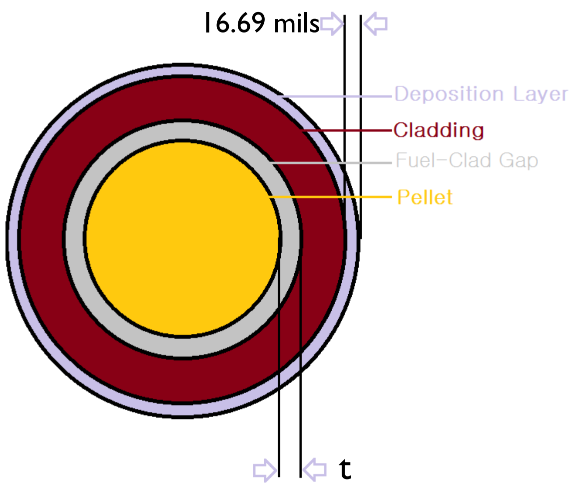


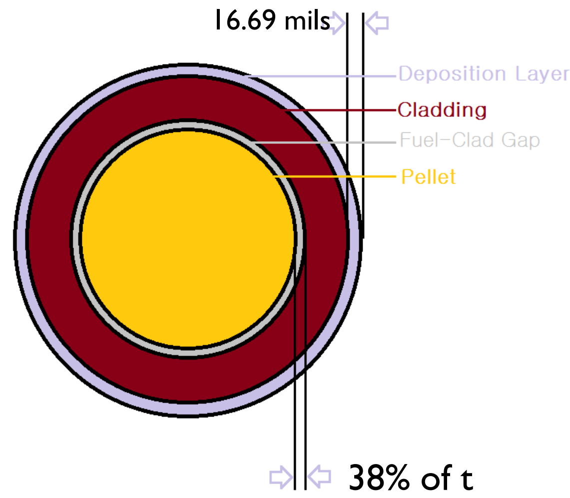
Pressure Drop Due to Debris

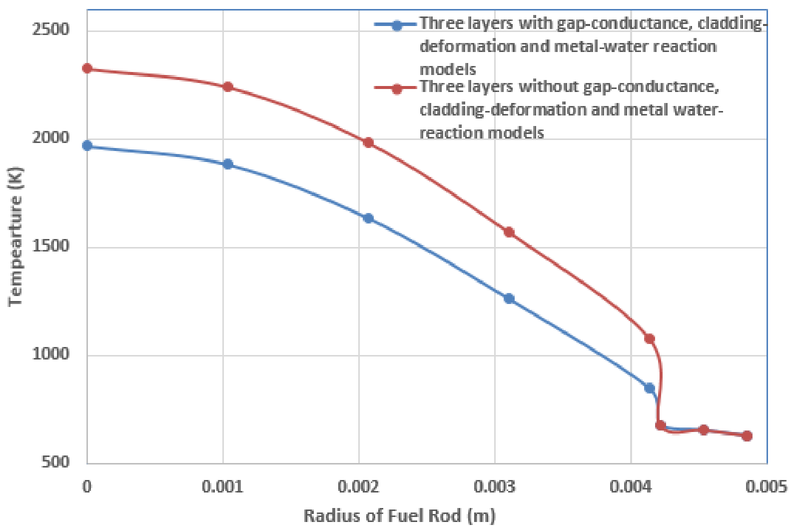


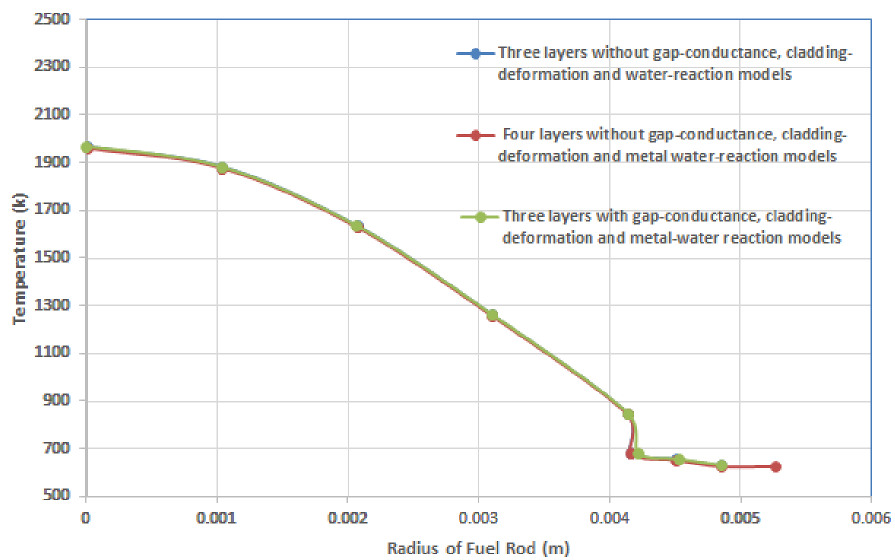
Area ratio (A) for Servo Valve

Chemical Deposition Layer Modelling









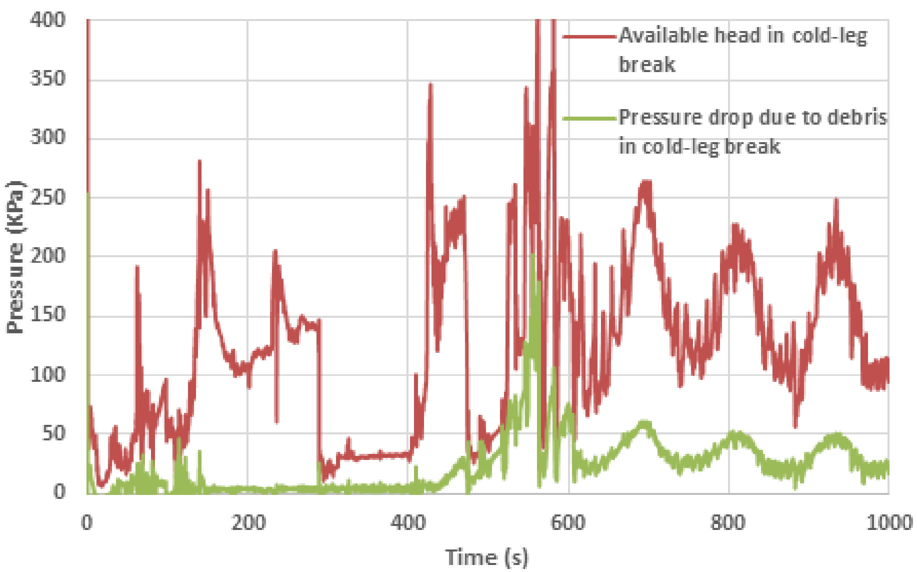
Chemical Deposition Layer Modeling

- Thermal Conductivity
  - The value of thermal conductivity was calculated by Linear Interpolation from the data provided in WCAP-16793-NP
  - 20% uncertainty was considered conservatively in the value. [0.634824 x (1-0.2)] = 0.5078 W/m/K

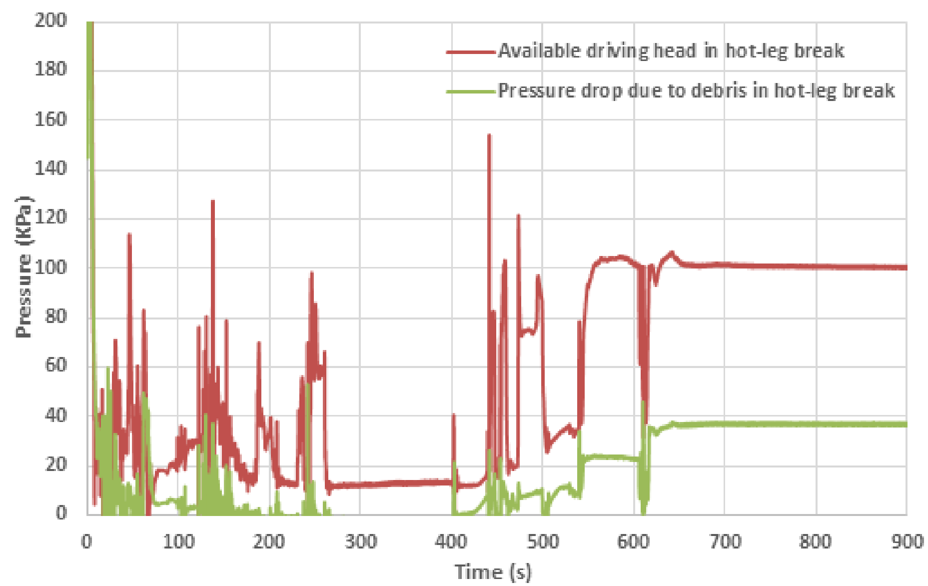
- Volumetric Heat Capacity
  - The value of volumetric heat capacity was not available. So the value of 2076 KJ/m^3K was selected on the basis of sensitivity analysis.

Results

- To met the safety criteria of peak clad temperature < 800°F, there should be a sufficient flow in the core.
- Pressure head available > Pressure drop due to debris blockage effect
- The available head in both cases is greater than the pressure drop due to the effect of debris blockage in cold-leg and hot-leg break.
- Debris Ingression was assumed conservatively to be at t=400 sec.



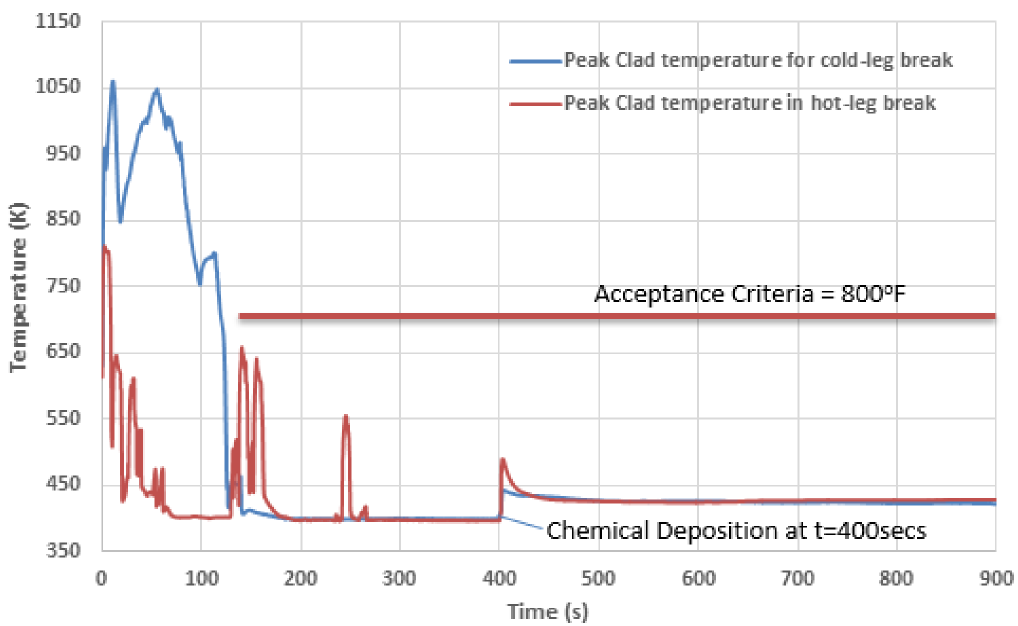
Cold-Leg Break



Hot-Leg Break

Results

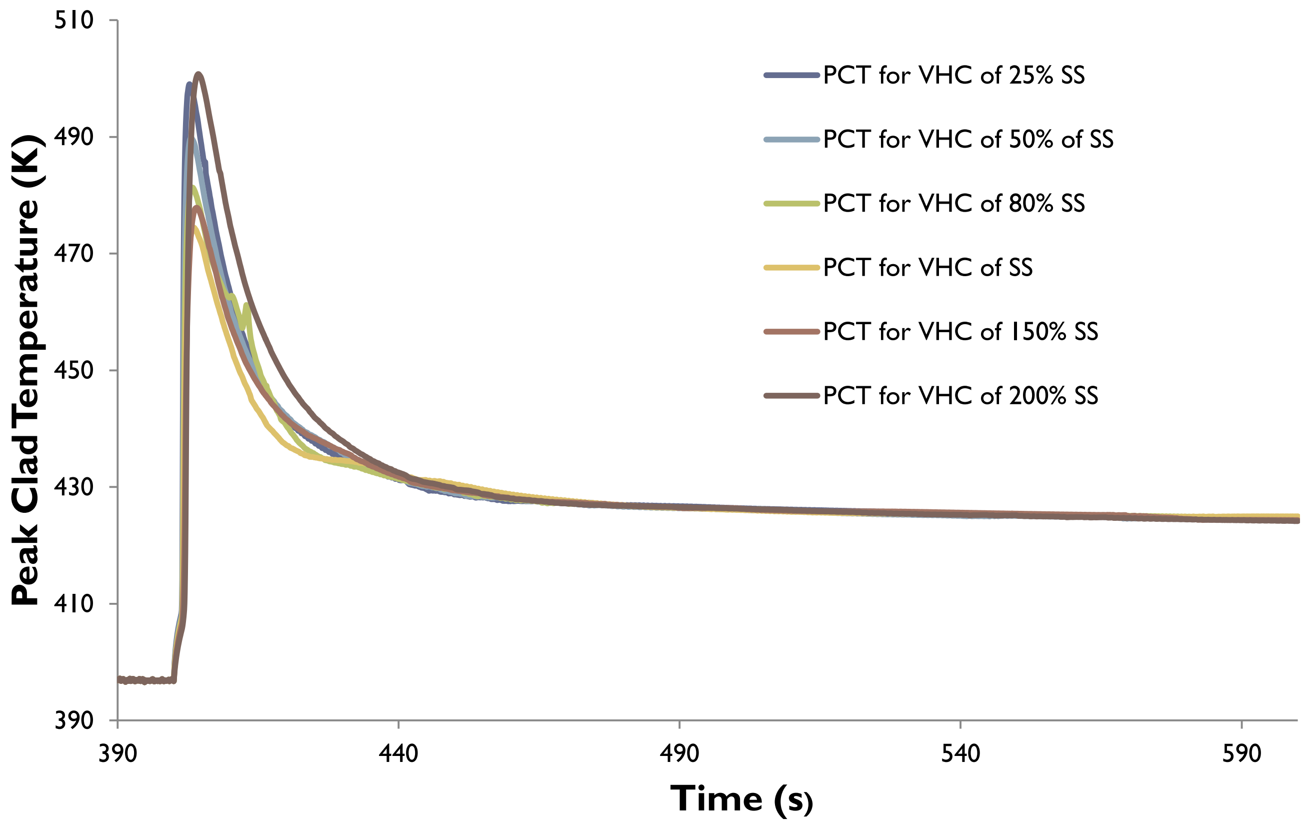
- There is a certain peak of temperature of about 40 K in the cold-leg break case and 80 K in the hot-leg break case due to uncertainty in Volumetric Heat capacity.



Peak Clad Temperature

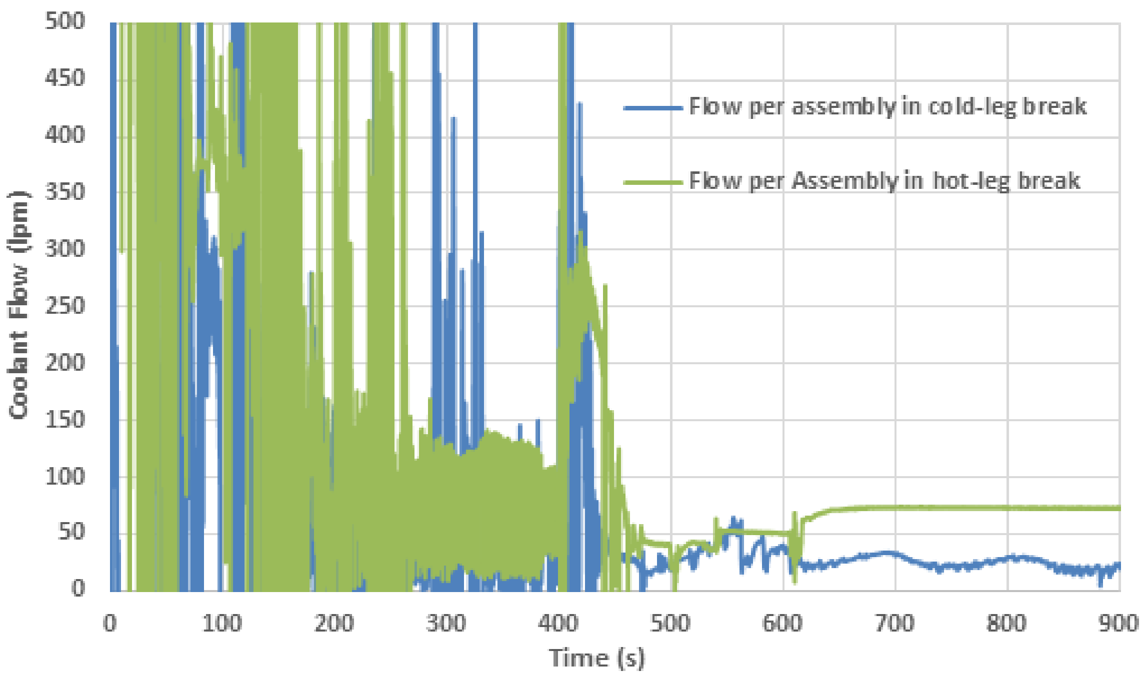
Sensitivity Analysis

- Different values of Volumetric Heat Capacities (VHC) gives different peaks of temperature.
- The converging response of the temperature is same for different values of volumetric heat capacities.



Results

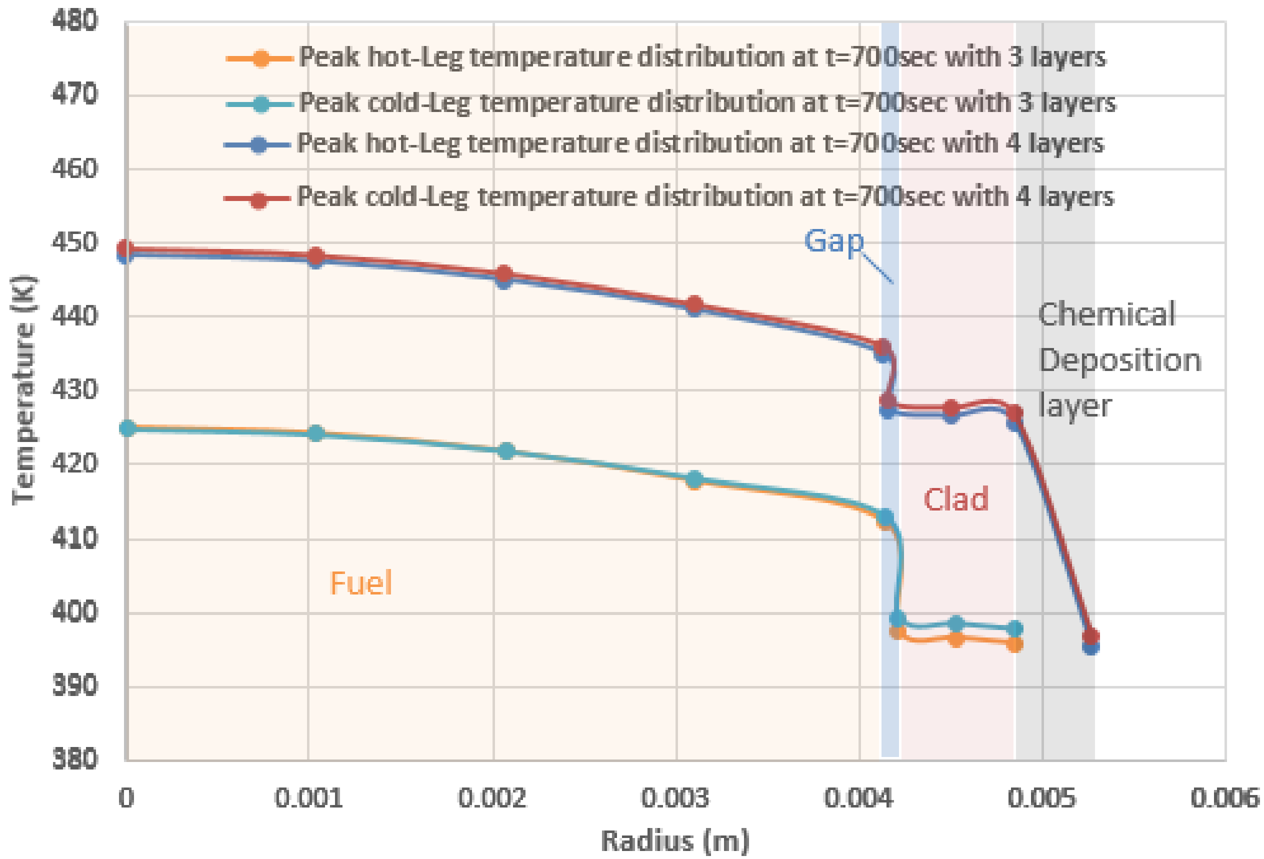
- The flow in the cold-leg break is lower than the hot-leg break. The oscillation in the cold-leg break flow is due to the variation in the driving head.



Flow per Assembly (lpm)

Results

- Fuel rod radial temperature profiles.
- It clearly shows that in the case of the debris chemical deposition layer the temperature profile for the fuel rod is less than 30 K above the three-layer case.
- The shift is due to the thermal resistance of the fourth debris deposition layer.



Conclusion

- Considering the pressure drop across the active core and the debris deposition on the fuel surface, the calculated peak cladding temperature is well below the acceptance criteria of 800 °F .

- This clearly indicates that the use of thermal hydraulic code effectively evaluate the safety margin during the long-term cooling analysis considering the in-vessel downstream effect.

Future Consideration

- However, there were some conservative assumptions regarding the thickness of the deposition layer, calculation of pressure head available, the volumetric heat capacity, and thermal conductivity of the debris deposition layer.

- Thus method can be improved by altering the MARS-KS1.3 source code to provide the mean of modelling of fourth layer without turning off the gap-conductance, metal-water reaction and cladding deformation model.

THANK YOU