MODELING IMPROVEMENTS FOR SYSTEM CODE EVALUATION OF INLET PLENUM MIXING UNDER SEVERE ACCIDENT CONDITIONS USING CFD PREDICTIONS

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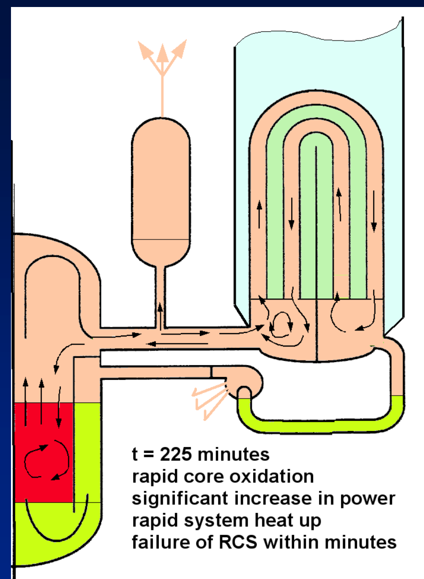
Introduction

- During certain postulated severe accident scenarios in a PWR with U-tube steam generators (SG), the core is uncovered and a three-dimensional counter-current natural circulation flow pattern is established in the reactor loops.
- This single phase flow of superheated steam (and hydrogen if present) carries heat away from the core and deposits the energy into the loop structures.
- These conditions can challenge the integrity of RCS components which can fail under high pressure and temperature conditions due to creep rupture.
  - The hot leg, pressurizer surge line, and SG tubes are potential failure locations.
  - This type of low probability scenario is studied due to the potential for containment bypass through the SGs.

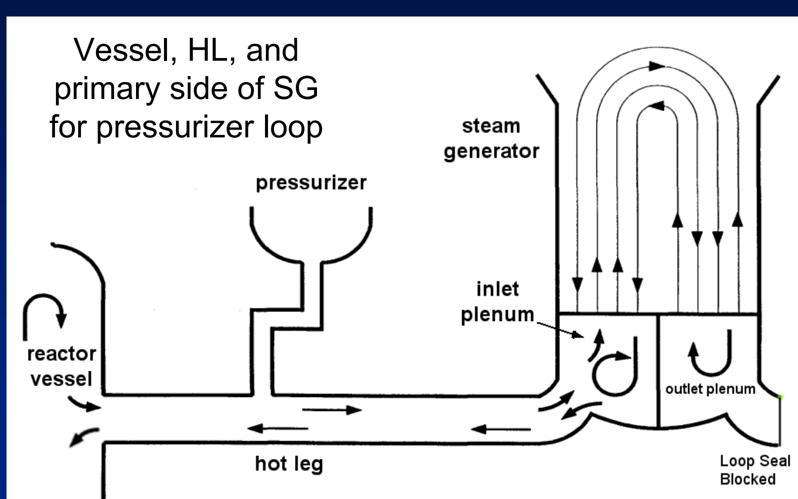
An Example

A Fast Scenario – multiple failures

- loss of offsite power, diesel generators, and all auxiliary feedwater systems
- Reactor coolant pump seal LOCA and secondary side boil off
- secondary system drys out, safety relief valves cycle, primary inventory drops
- loop circulation stops
- Inventory falls below hot legs, natural circulation of superheated steam begins, system heat up starts
- Core uncovers and oxidizes. Significant core energy from reaction, overall system heat up accelerates, temperature induced failures are expected.
- If High-Dry-Low conditions exist, the SG tubes are challenged.



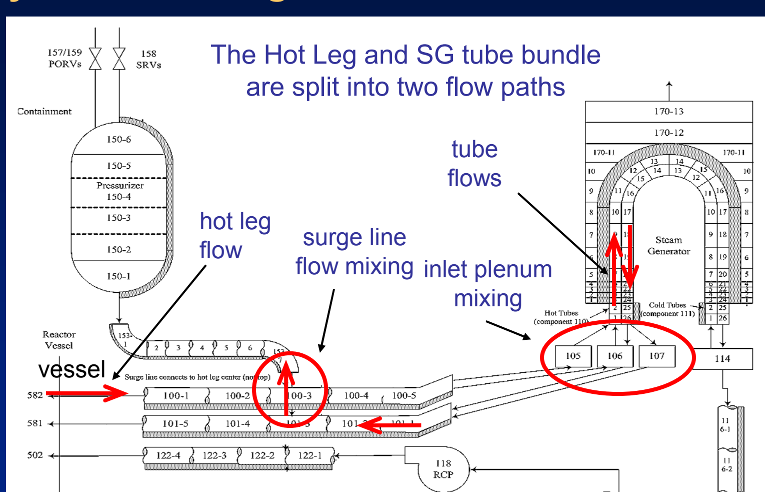
Flow Pattern of Interest



System Code Modeling Challenge

- Simulation of counter-current hot leg flow with 1D pipe components.
- Simulation of turbulent inlet plenum mixing and entrainment.
- Ensuring system code predictions are consistent with experimental observations and/or 3D CFD code predictions.

System Code regions of Interest



SYSTEM CODE Nodalization of Primary Loop

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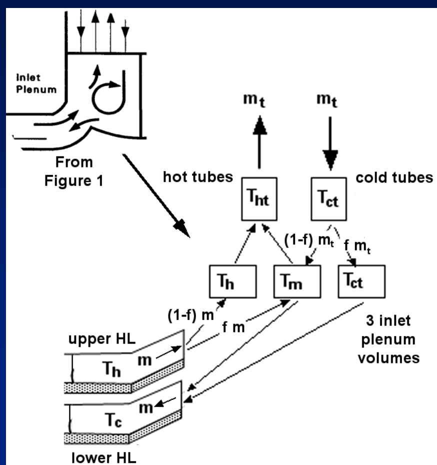
Inlet Plenum Mixing Model



Th and Tc measured at the end of the HL near the SG inlet plenum.

Tht and Tct measured at the tube entrance near the lower edge of the tube sheet.

The Mixing model is derived by applying conservation of mass and a first law of thermodynamics steady-state-steady-flow energy balance to the central volume (Tm) in the inlet plenum.

Tm = (Th + r Tct) / (r + 1)

f = 1 – r (Tht - Tm) / (Th – Tm)

where,

r = mt / m = recirculation ratio
f = mixing fraction

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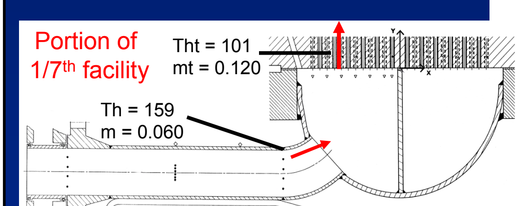
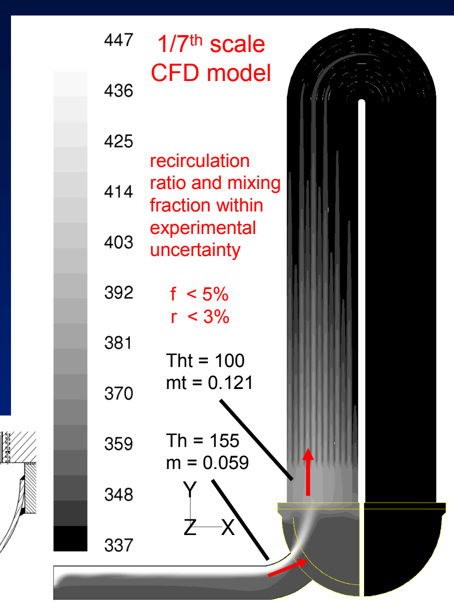
Application of CFD

- The CFD method was benchmarked at 1/7th scale and showed excellent agreement with the experiments.





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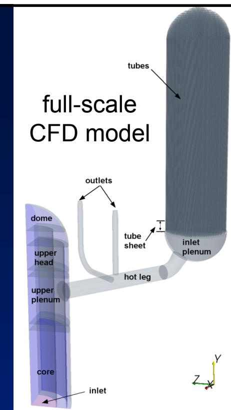
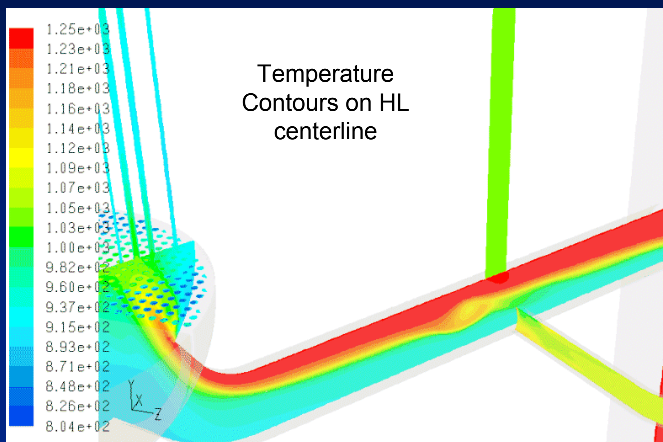
CFD Method Extended to Full-Scale





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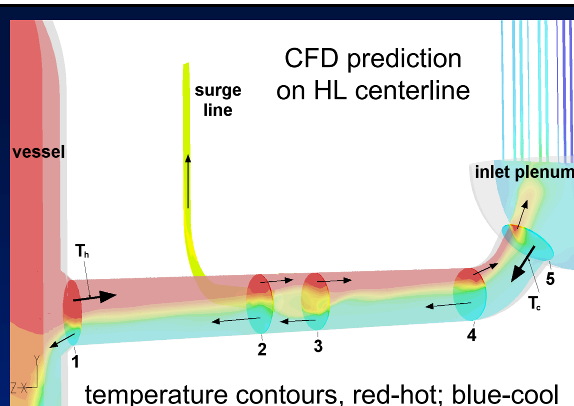
HL Mixing and Entrainment considered

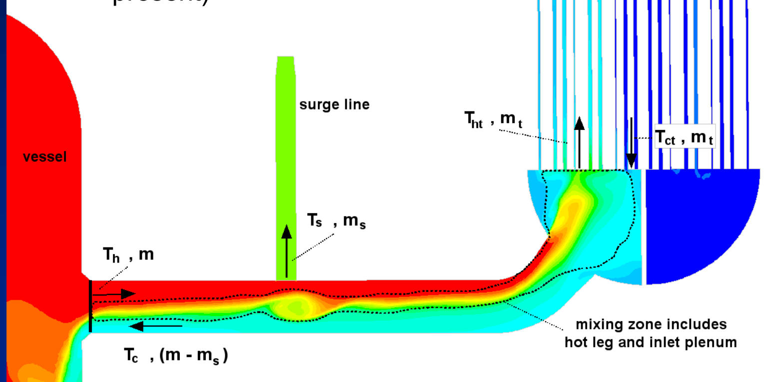


HL mixing is not considered in the original mixing model.

Hot upper flows from vessel to inlet plenum					
Location	1	2	3	4	5
Mass flow (kg/s)	4.46	5.14	4.42	4.95	5.60
Temperature (K)	1,231.6	1,203.2	1,213.1	1,152.4	1,105.5
Cooler return flows from inlet plenum to vessel					
Location	1	2	3	4	5
Mass flow (kg/s)	3.19	3.85	4.43	4.98	5.67
Temperature (K)	952.5	949.2	954.7	920.5	903.0

The Updated Mixing Region

- Considers HL mixing and entrainment
- Must account for surge line (if present)

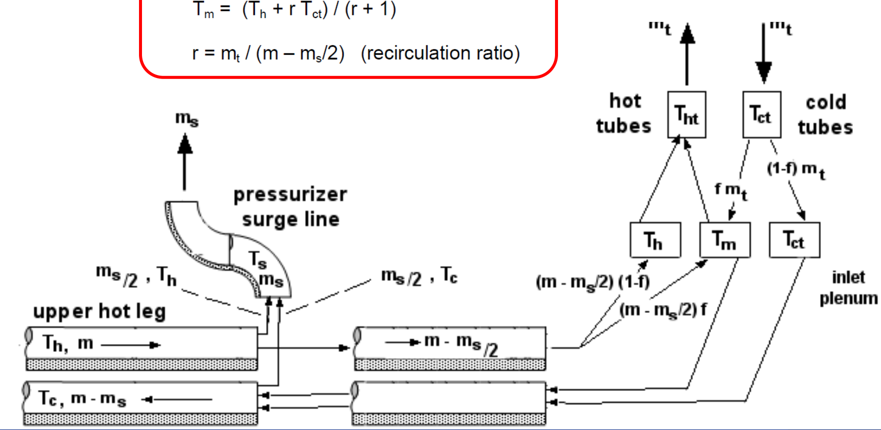


The Updated Mixing Model

$f = 1 - r\,(T_{ht} - T_m) / (T_h - T_m)$

$T_m = (T_h + r\,T_{ct}) / (r + 1)$

$r = m_t / (m - m_s/2)$ (recirculation ratio)



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Updated Mixing Model benefits

- Accounts for total mixing in the loop prior to flows entering the tube bundle.
  - mixing fraction is higher
- Accounts for entrainment in the hot leg as well as the SG inlet plenum
  - recirculation ratio is higher
- Provides a consistent approach for defining the hot leg mass flow and temperature.
  - previous approach not specific

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Application to System Codes

- The mixing model is used as a basis for adjusting system code models to be consistent with 3D predictions or experiments.
- The updated mixing model is applied in the same manner as the old model.
  - The difference is in the definition of the hot leg mass flow and temperature.
    - The system code analyst must choose volumes that are consistent with the approach.

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Summary and Conclusions

- The NRC Office of Nuclear Regulatory Research has recently applied an updated mixing model approach in system code predictions of severe accident natural circulation flows (NUREG/CR-6995).
- The improved model accounts for all of the mixing and entrainment in the loops and a side mounted pressurizer surge line, if present (NUREG-1922).
- It is recommended that future experimental or computational efforts in this area consider the updated mixing model approach when defining the mixing and recirculation ratios for this application.

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Questions ?