



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

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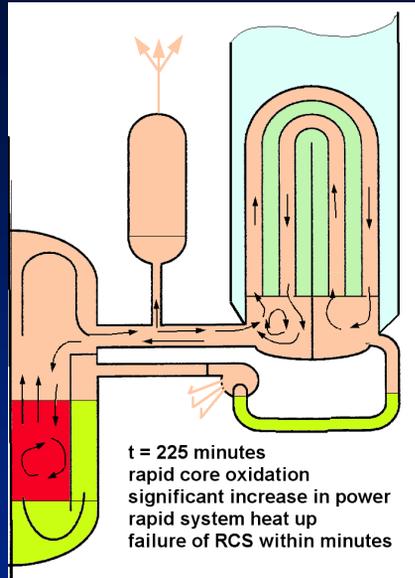
Introduction

- 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.

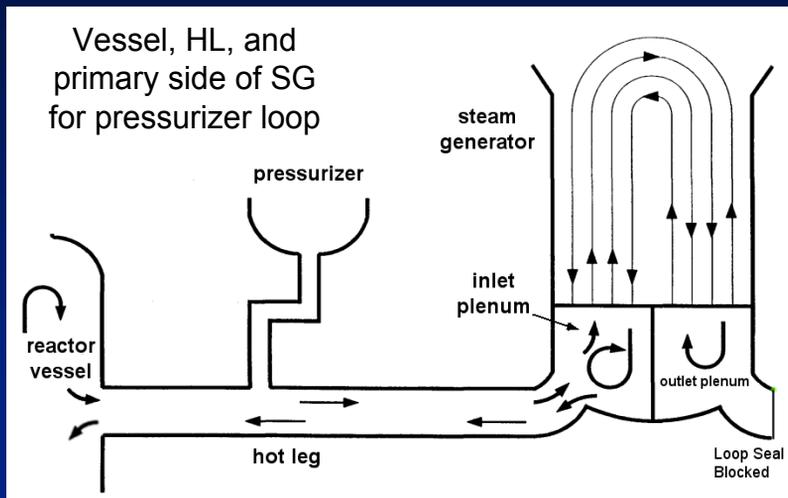
An Example

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 dries 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.



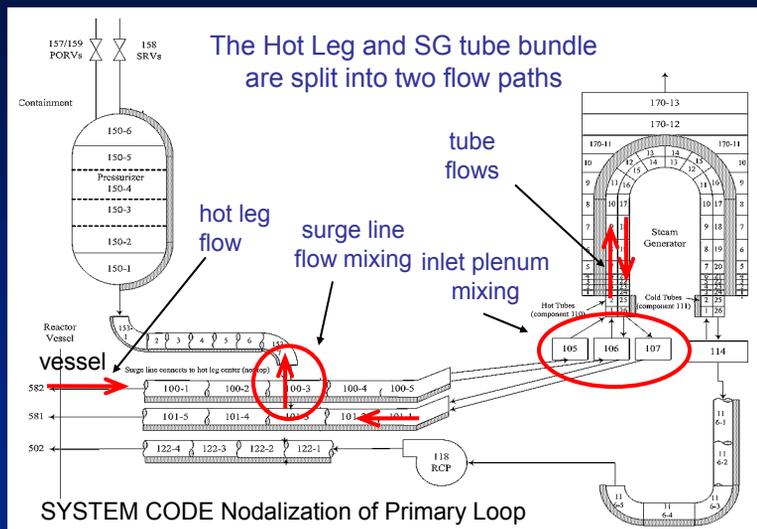
Flow Pattern of Interest



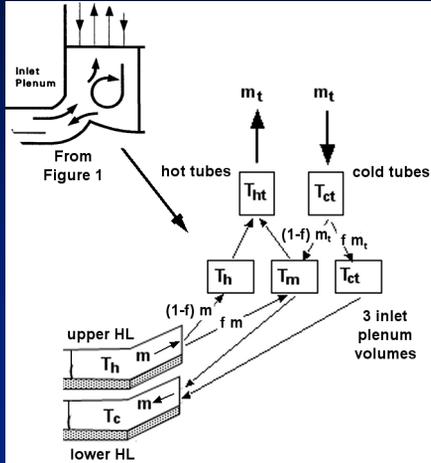
System Code Modeling Challenge

- 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



Inlet Plenum Mixing Model



T_h and T_c measured at the end of the HL near the SG inlet plenum.

T_{ht} and T_{ct} 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 (T_m) in the inlet plenum.

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

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

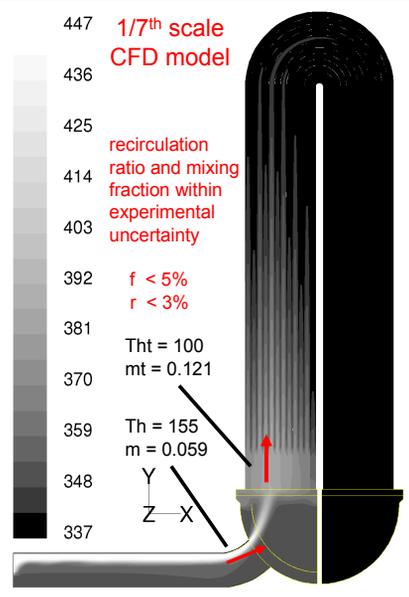
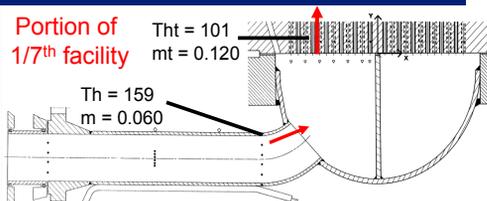
where,

$$r = m_t / m = \text{recirculation ratio}$$

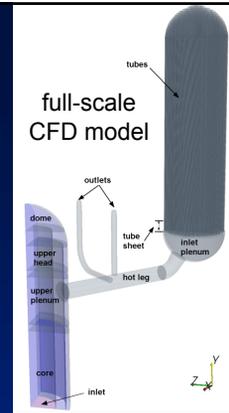
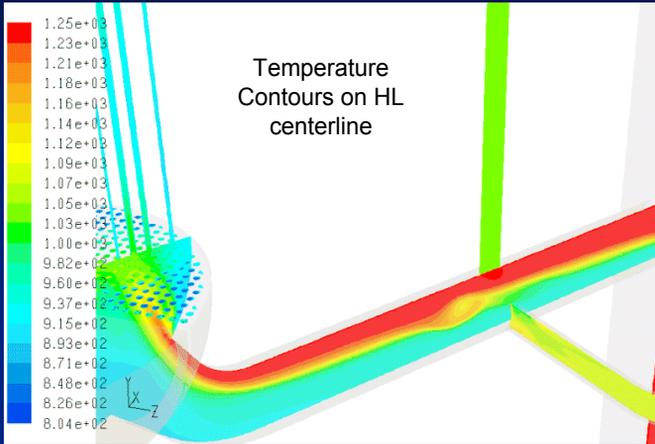
$$f = \text{mixing fraction}$$

Application of CFD

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

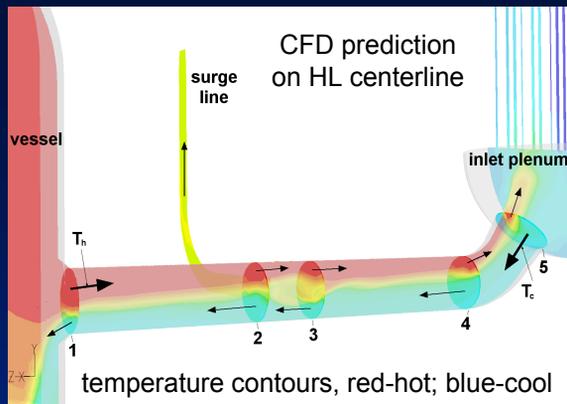


CFD Method Extended to Full-Scale



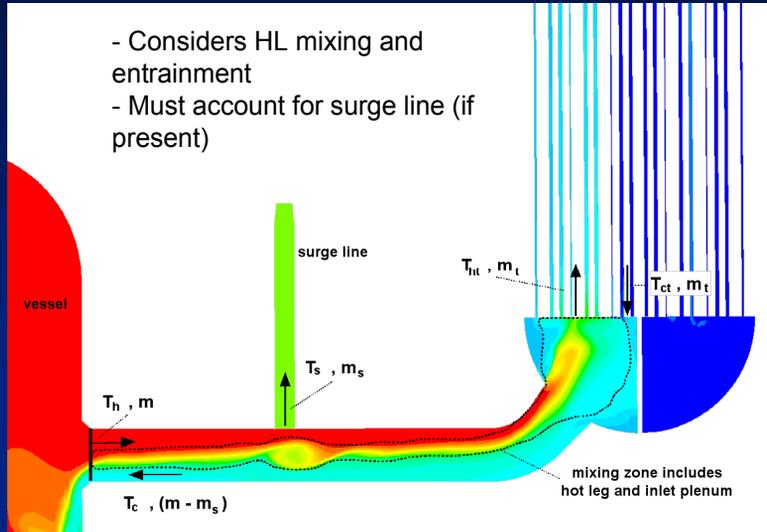
HL Mixing and Entrainment considered

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



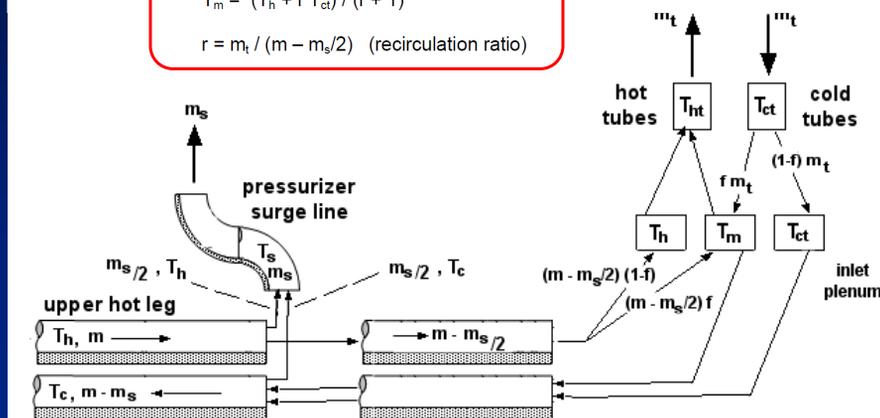
11

The Updated Mixing Model

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

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

$$r = m_t / (m - m_s/2) \quad (\text{recirculation ratio})$$



12

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

13

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.

14

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.

Questions ?