Thermal-Hydraulic Analysis of Seismically-Induced Loss of Coolant Accidents Involving Double Ended Guillotine Breaks in the Inpile Tubes at the Advanced Test Reactor

IRUG User Presentations

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Gable Roth
Nuclear Safety Analyst
Idaho National Laboratory

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Objectives

- ATR Overview
- ATR Primary Coolant System Design
- ATR Experiment Loop Design
- Details of RELAP use
- Previous analysis
- Updated analysis
- Conclusions

Reactor Description

Reactor Type

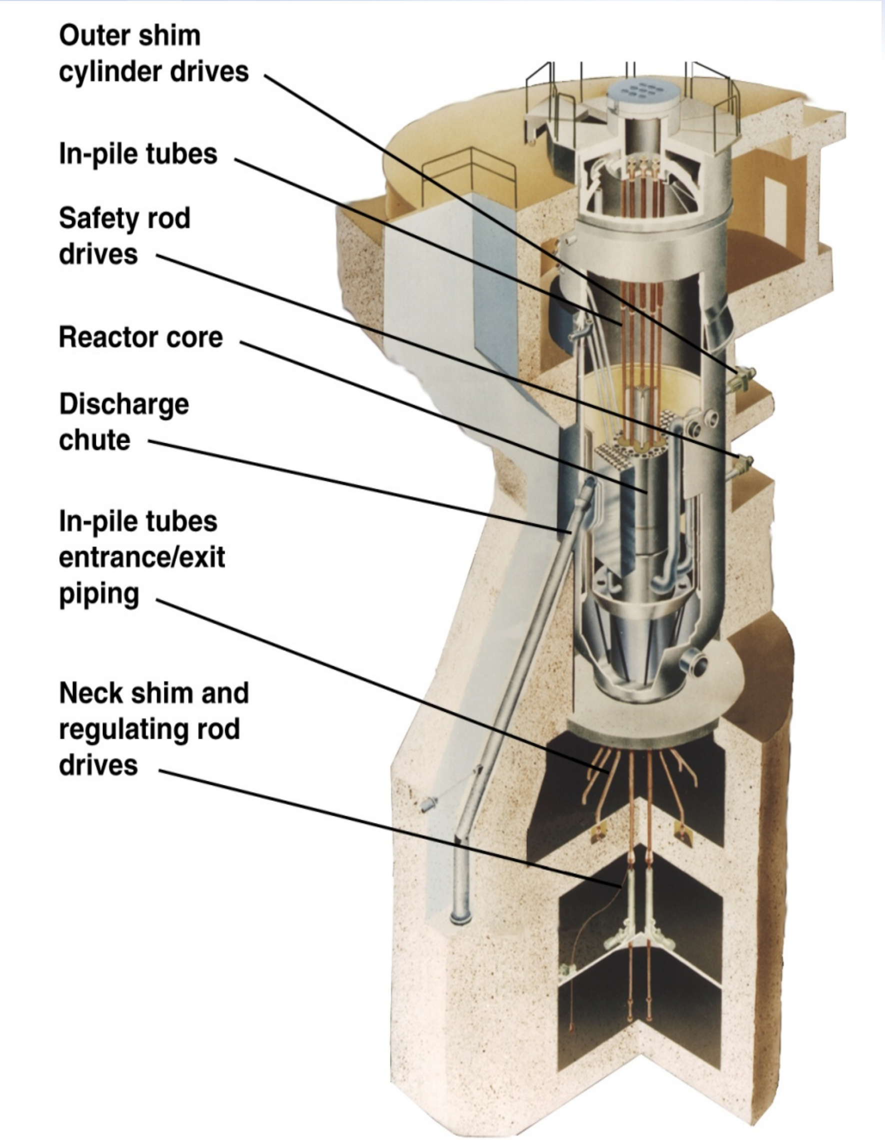
- Pressurized, light-water moderated and cooled; beryllium reflector
- 250 MW_t (Full Power)

Reactor Vessel

- 12 ft (3.65 m) diameter cylinder
- 36 ft (10.67 m) high stainless steel

Reactor Core

- 4 ft (1.22 m) diameter and height
- 40 fuel elements, curved-plate, aluminum-clad metallic U-235
- Highly enriched uranium matrix (UAlx) in an aluminum sandwich plate cladding



ATR Operating Condition Comparison to PWR

Operating Conditions	ATR	PWR (typ.)
Power (MW_{th})	250	2,000 – 4,000
Power density (kW/ft^3)	28,000	1,550
PCS pressure (psig)	355	2,250
Inlet/Outlet temp. (°F)	125/170	550/600
PCS flow rate (gpm)	48,000	300,000
Coolant mass (lbm)	600,000	450,000
Coolant mass/power ratio (lbm/MW)	2,400	170
Decay heat (MW @ 10s, 1 day)	13, 1.3	135, 19
Fuel enrichment (% ^{235}U)	93	2 – 4
Fuel mass (lbm)	90	180,000
Fuel temp. (°F)	460	2,000 – 3,000
Fission-product inventory	--	10 × ATR

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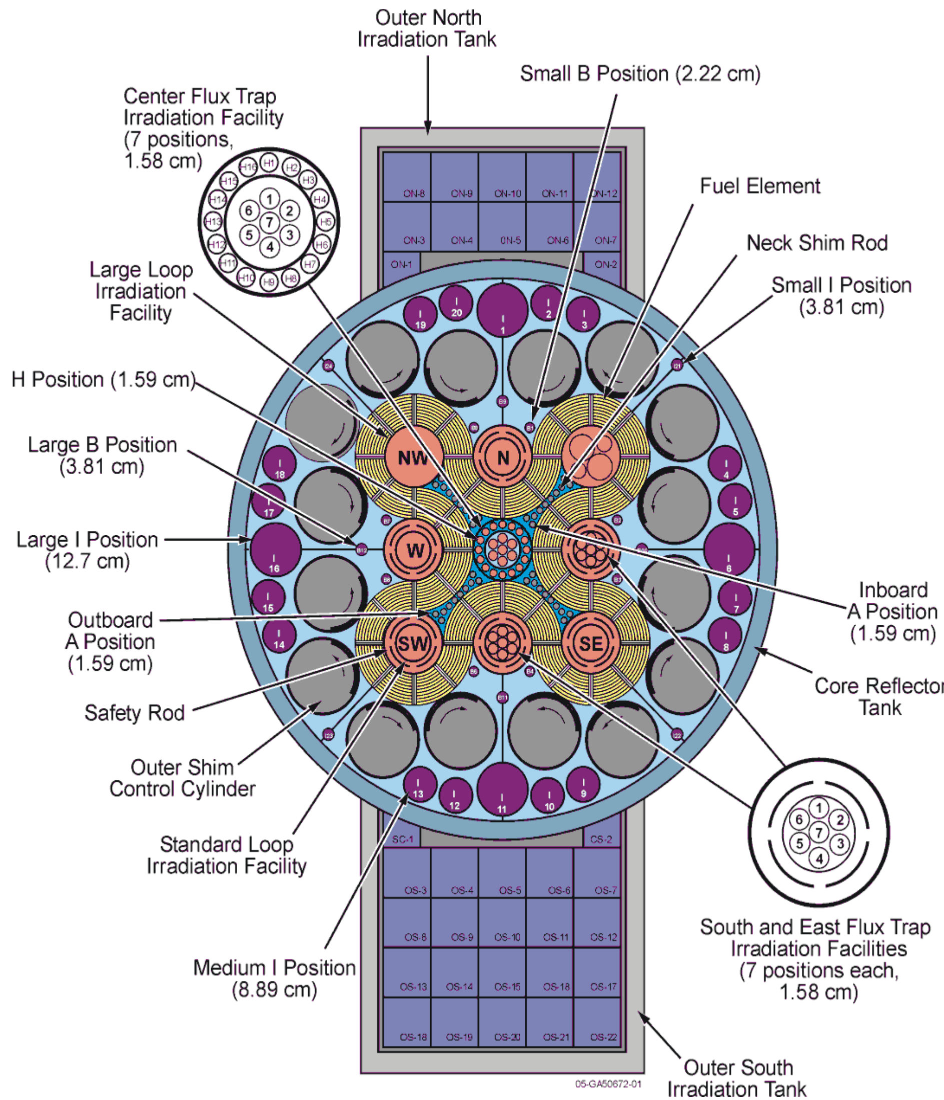
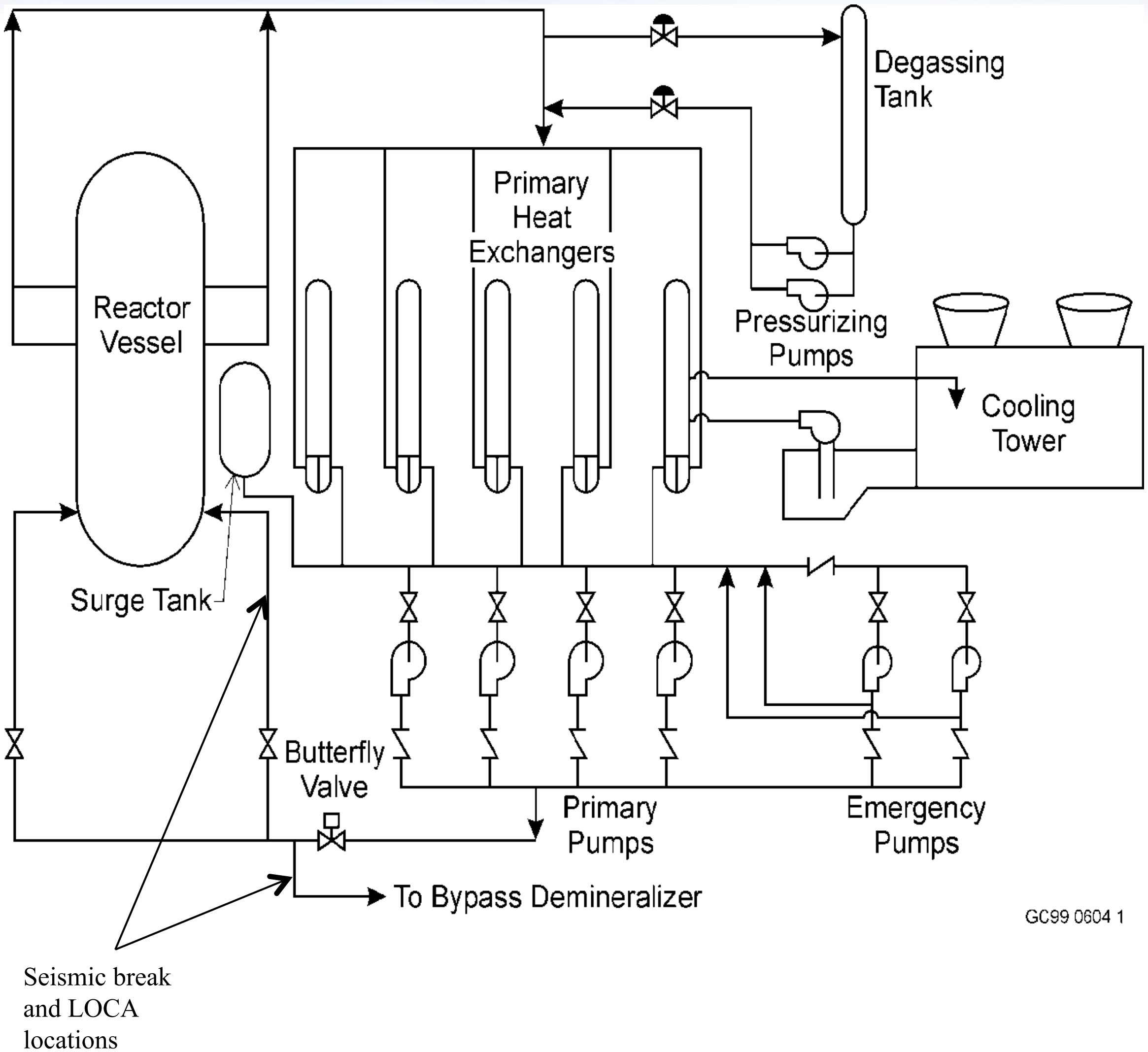
ATR Core Cross Section, Test Positions

- Test size - up to 5.0” Dia.
- 77 irradiation positions:
  - 3 open flux traps
  - 6 inpile tubes
  - 68 positions in reflector
- Approximate Peak Flux:
  - 1 x 10^{15} n/cm^2-sec thermal
  - 5 x 10^{14} n/cm^2-sec fast
- Hafnium Control Drums
  - Flux/power adjustable across core
  - Maintains axial flux shape

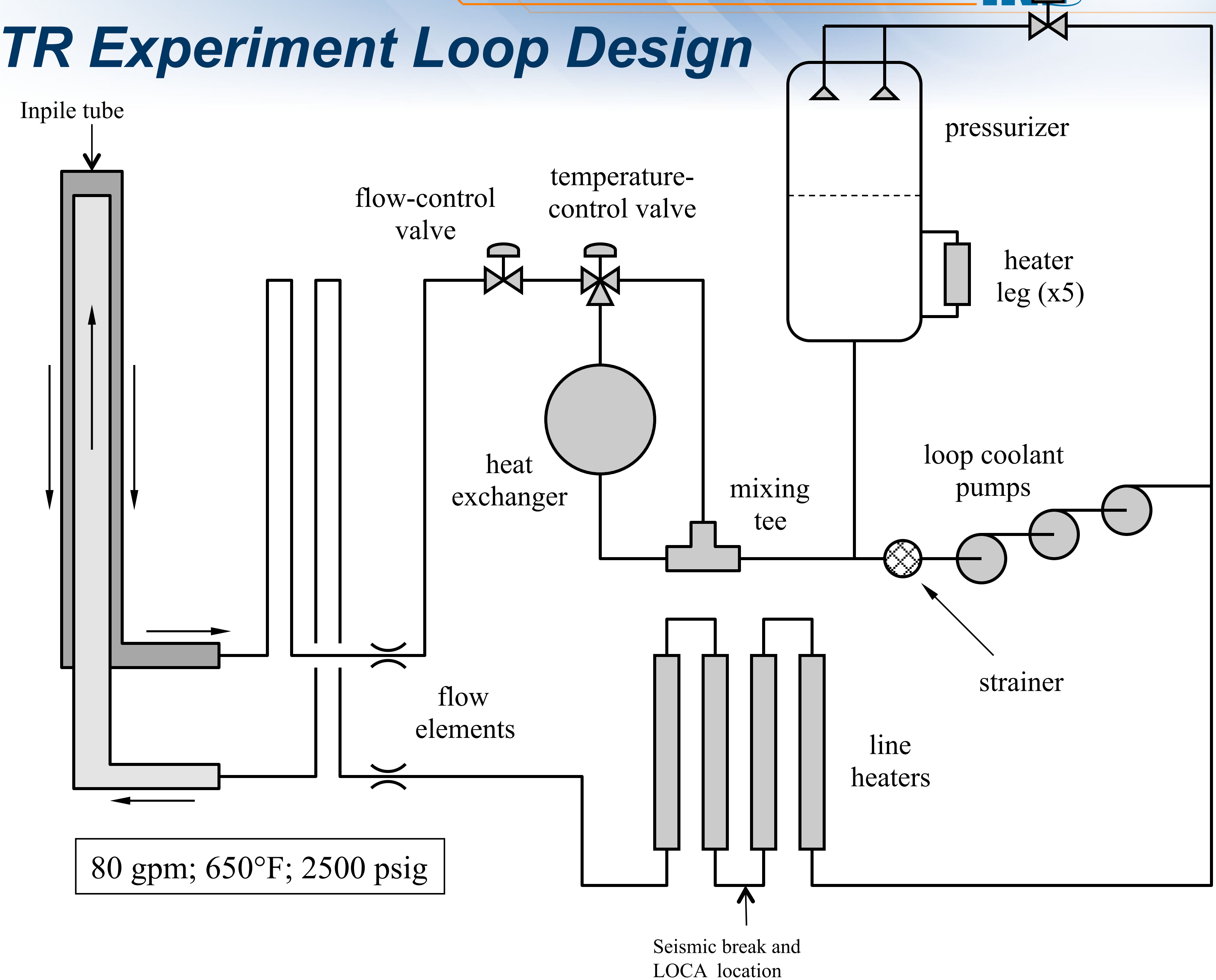


ATR Primary Coolant System Design

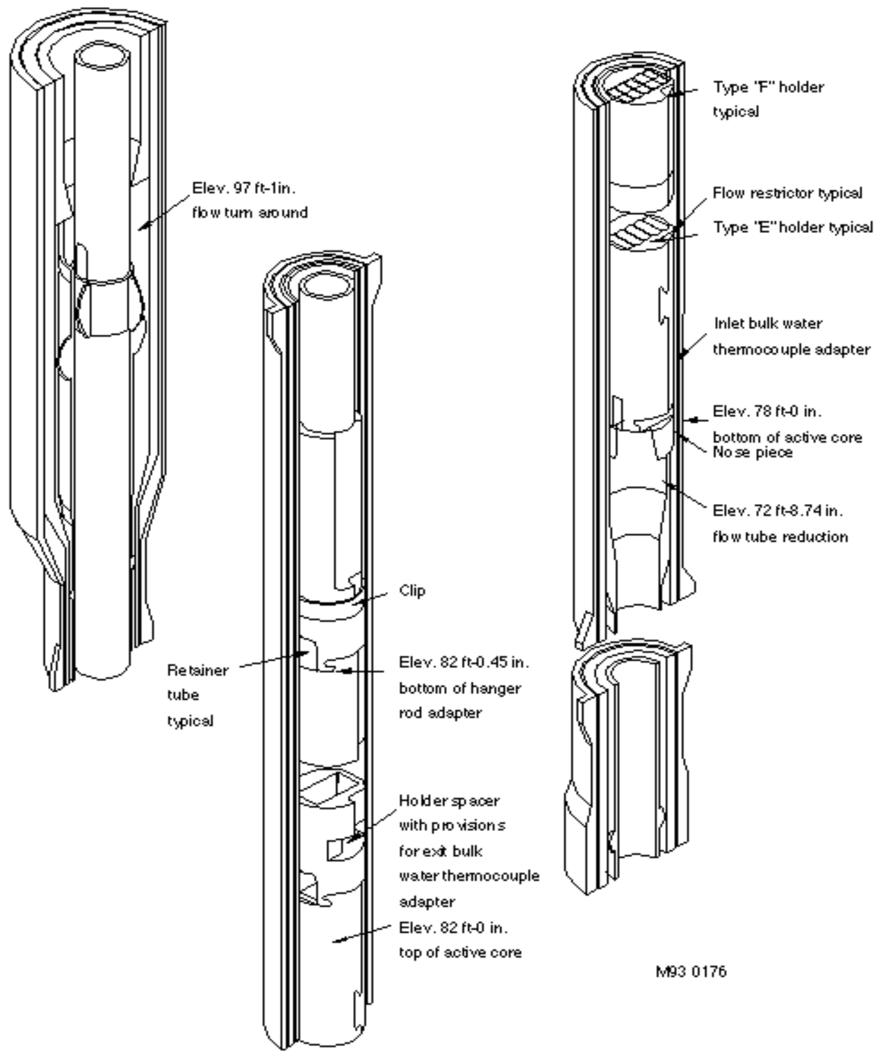
- Forced-flow, moderate-pressure, low-temperature, demineralized light water in a closed loop.
- Pressure drop 100-psi (77-psi) across the core during 3-PCP (2-PCP) operation.
- Nominal core inlet/outlet pressures are 360/260 psig (3 PCP) or 360/283 psig (2 PCP) respectively.
- Nominal core inlet/outlet temperatures are 125/170°F (i.e., below saturation temperature at atmospheric pressure).
- The ATR is designed to operate in the single-phase flow regime and is therefore not normally susceptible to flow instabilities. The core inlet subcooling is nominally greater than 300°F (170 *K).*

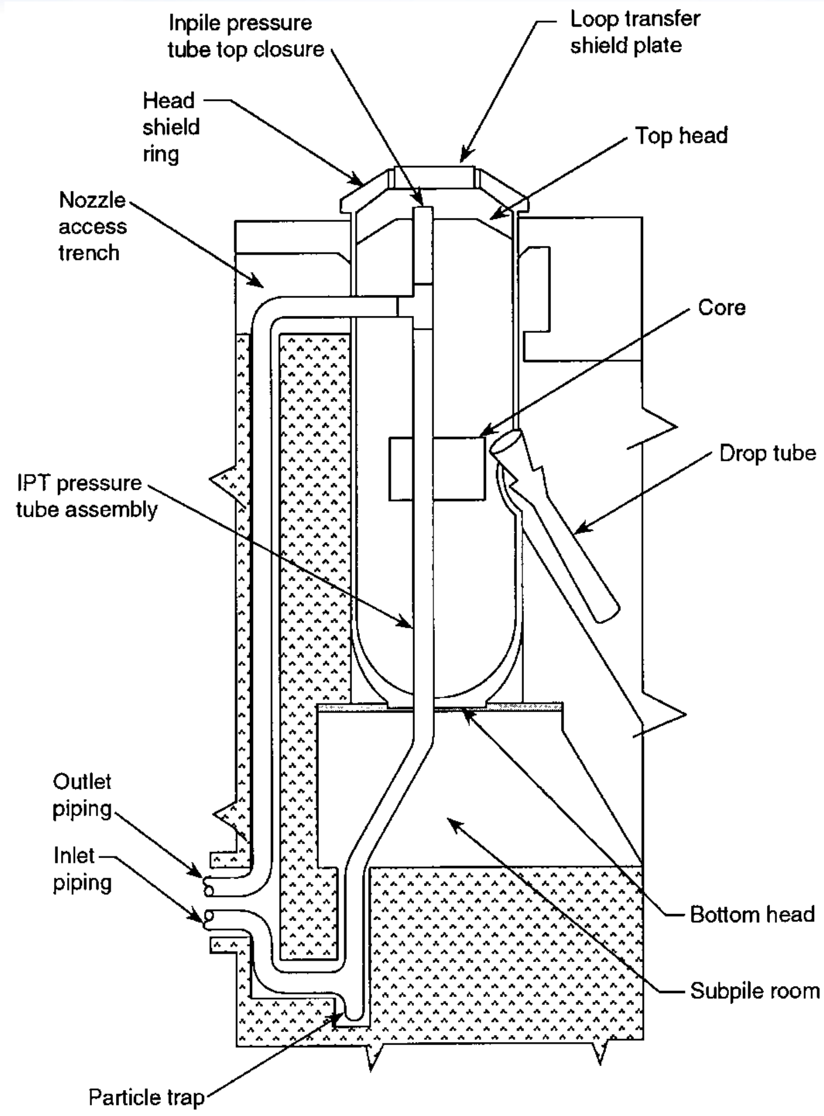


ATR Experiment Loop Design



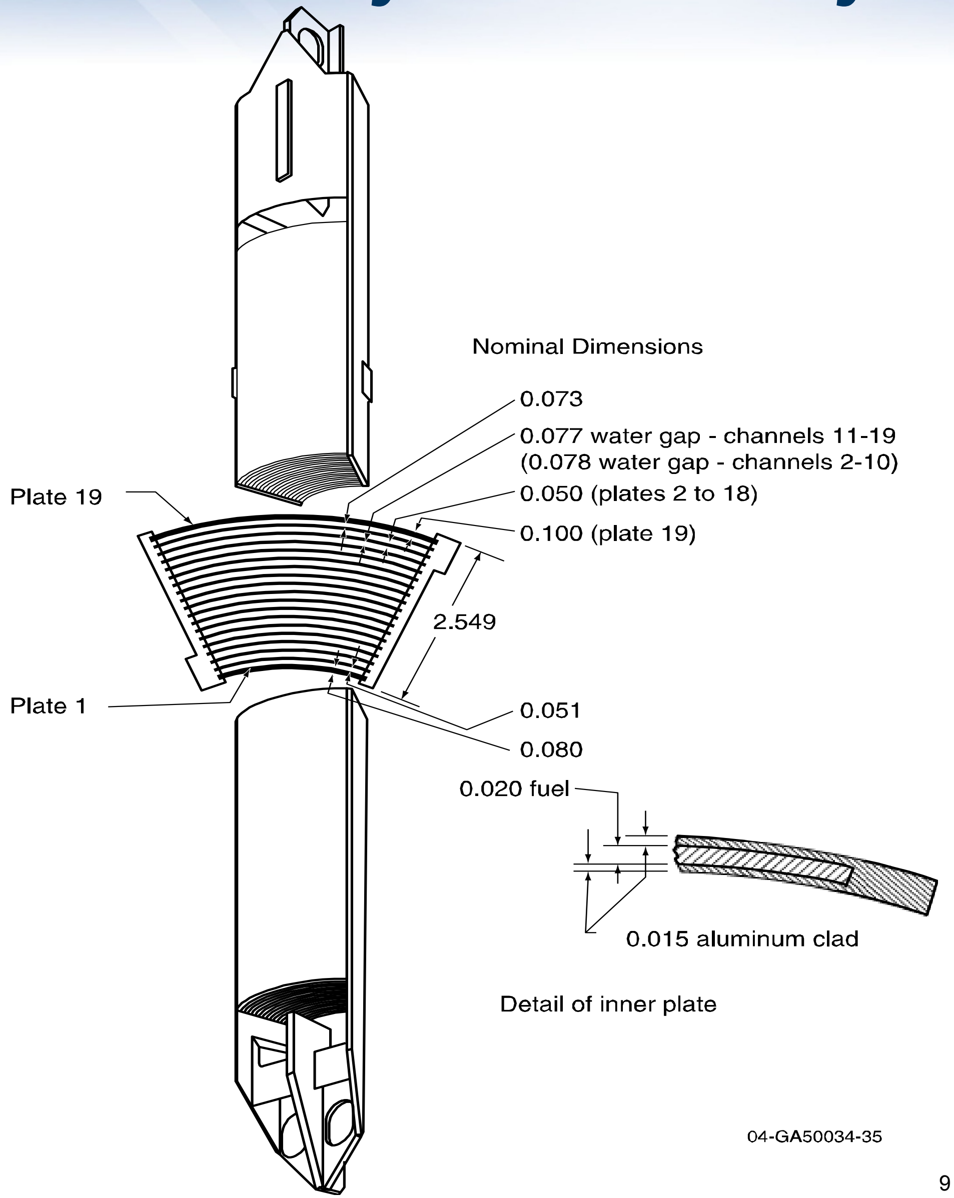
ATR Standard Inpile Tube (SIPT) Design





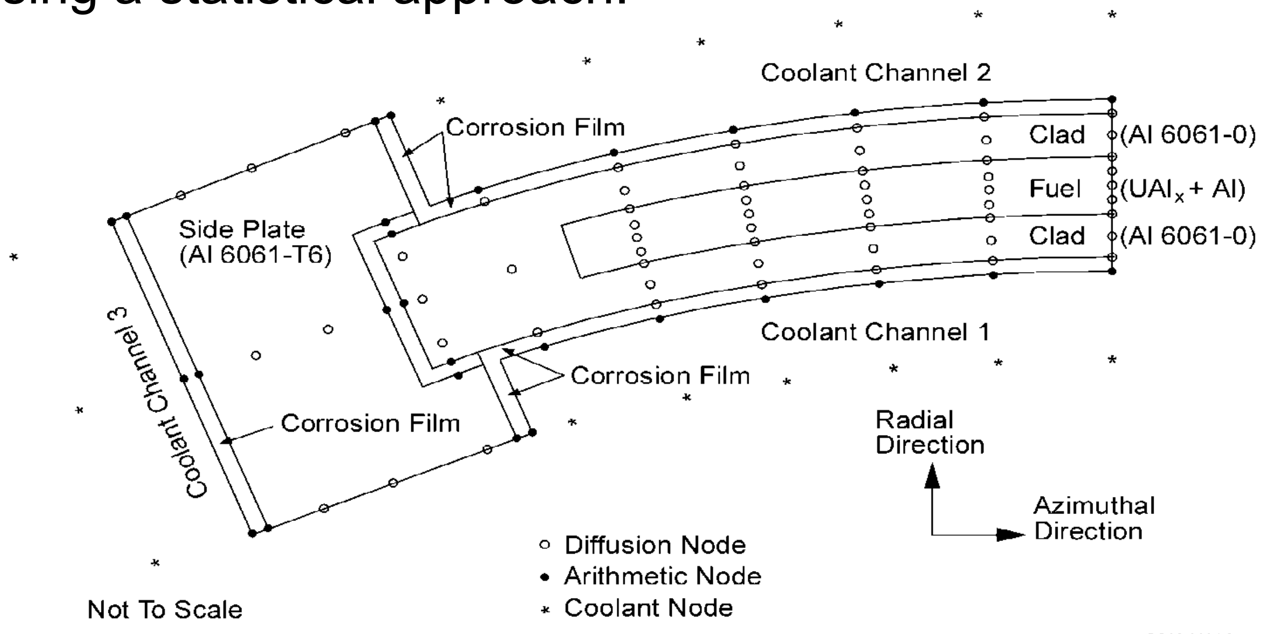
PCS LOCA Thermal-Hydraulic Analysis Summary

- Condition 4 fault, an earthquake was assumed to cause a 1-in. reactor inlet break, a 2.5-in. rupture of the bypass demineralizer inlet line.
- Overall response of the reactor was calculated with the RELAP5 code, and core safety margins were calculated with the ATR-SINDA and SINDA-SAMPLE fuel plate models.
- Core power, top-of-core pressure, core pressure drop, and hot channel inlet and outlet enthalpy as functions of time were obtained from RELAP5 for input into SINDA and SINDA-SAMPLE.
- RELAP5 determines the “hot fuel element” of the 40 fuel elements.



PCS LOCA Thermal-Hydraulic Analysis Summary

- The ATR-SINDA fuel plate model computes the temperature distributions in any of the 19 fuel plates of the “hot” ATR fuel element as determined from RELAP5.
- ATR-SINDA determines the limiting fuel plate (of the 19 fuel plates) in the hot fuel element.
- ATR-SINDA simulates one-half of the fuel plate (azimuthally) and a portion of the adjoining side plate.
- The SINDA-SAMPLE model computes the various safety margins using a statistical approach.



RELAP

- RELAP5 Mod 2.5 and Mod 3
- Support ATR Safety Analysis
- Used in conjunction with ATR-SINDA and SINDA-SAMPLE
  - ATR-SINDA is used to calculate the thermal-hydraulic response of the limiting subchannel, called the hot stripe, adjacent to the limiting fuel plate and to perform multi-dimensional heat transfer calculations
  - SINDA-SAMPLE is used to compute the thermal safety margins for the limiting subchannel of the limiting fuel plate using a statistical approach
- Different accidents analyzed include
  - Loss of Coolant Accident (LOCA)
  - Loss of Commercial Power
  - Reactivity Insertion Accidents

Previous Seismic LOCA Analysis

- Determine the effects of seismic breaks and leakage in the Advanced Test Reactor (ATR) experiment loop piping
- Limiting break was a double ended offset shear of a ½ inch pipe in the drain manifold at the heater legs
- Two loss of commercial power accidents were analyzed:
  - 4.0$ void worth and 9.6$ safety rod worth
  - 5.0$ void worth and 12.0$ safety rod worth

Previous Method of Analysis

- Focused analysis on “early” and “late” phase of the transient
  - Early: 1 to 150 seconds (Worst Case)
  - Late: 1800 to 2100 seconds

Previous Analysis Results

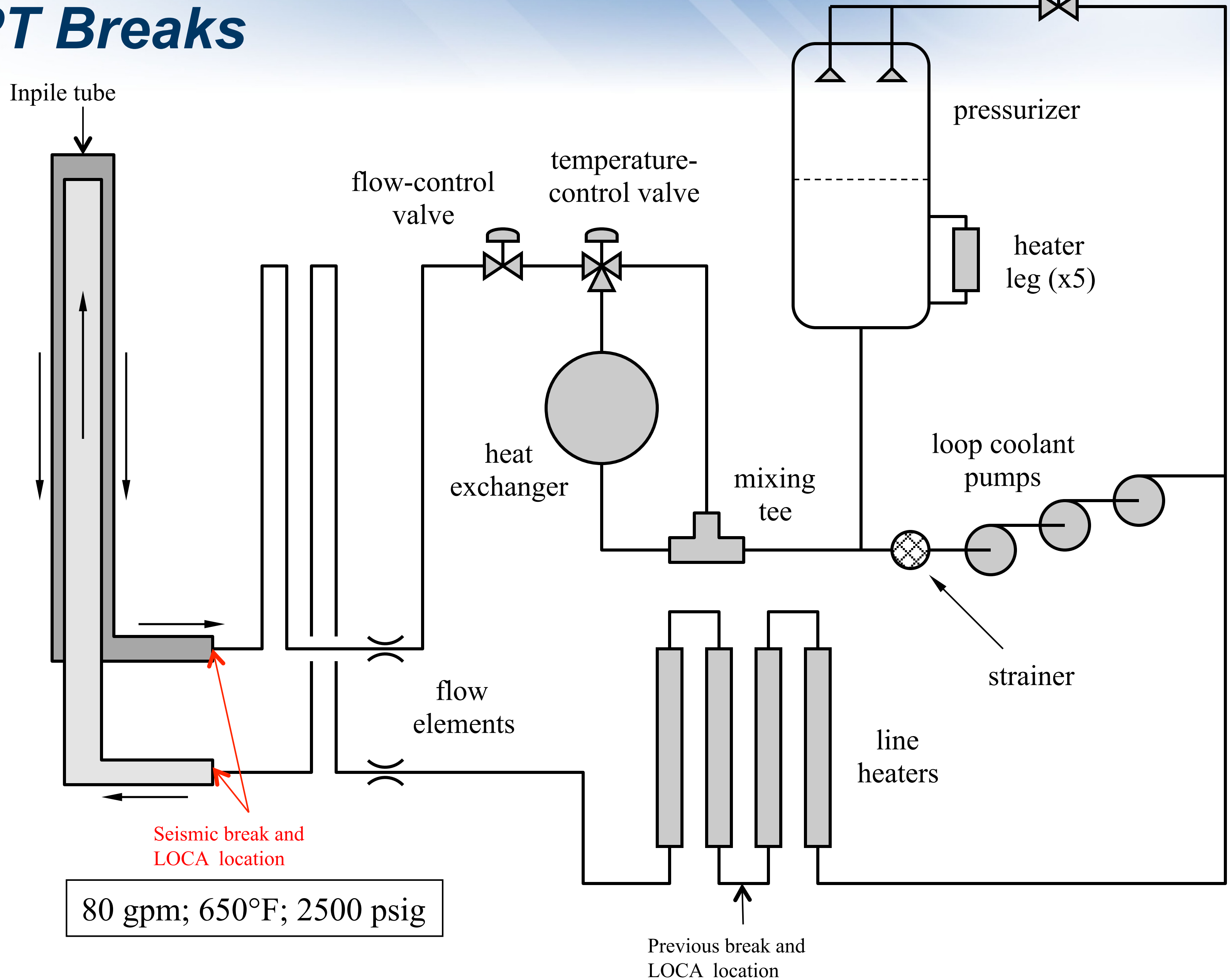
Safety Margin Summary

Case	Minimum Safety Margin	
	CHF (σ)	FI (σ)
4.0$ void worth/9.6$ safety rod worth LOCA w/bounding sensitivity case	3.34	2.72
5.0$ void worth/12.0$ safety rod worth LOCA w/bounding sensitivity case	3.52	3.75

Updated Analysis

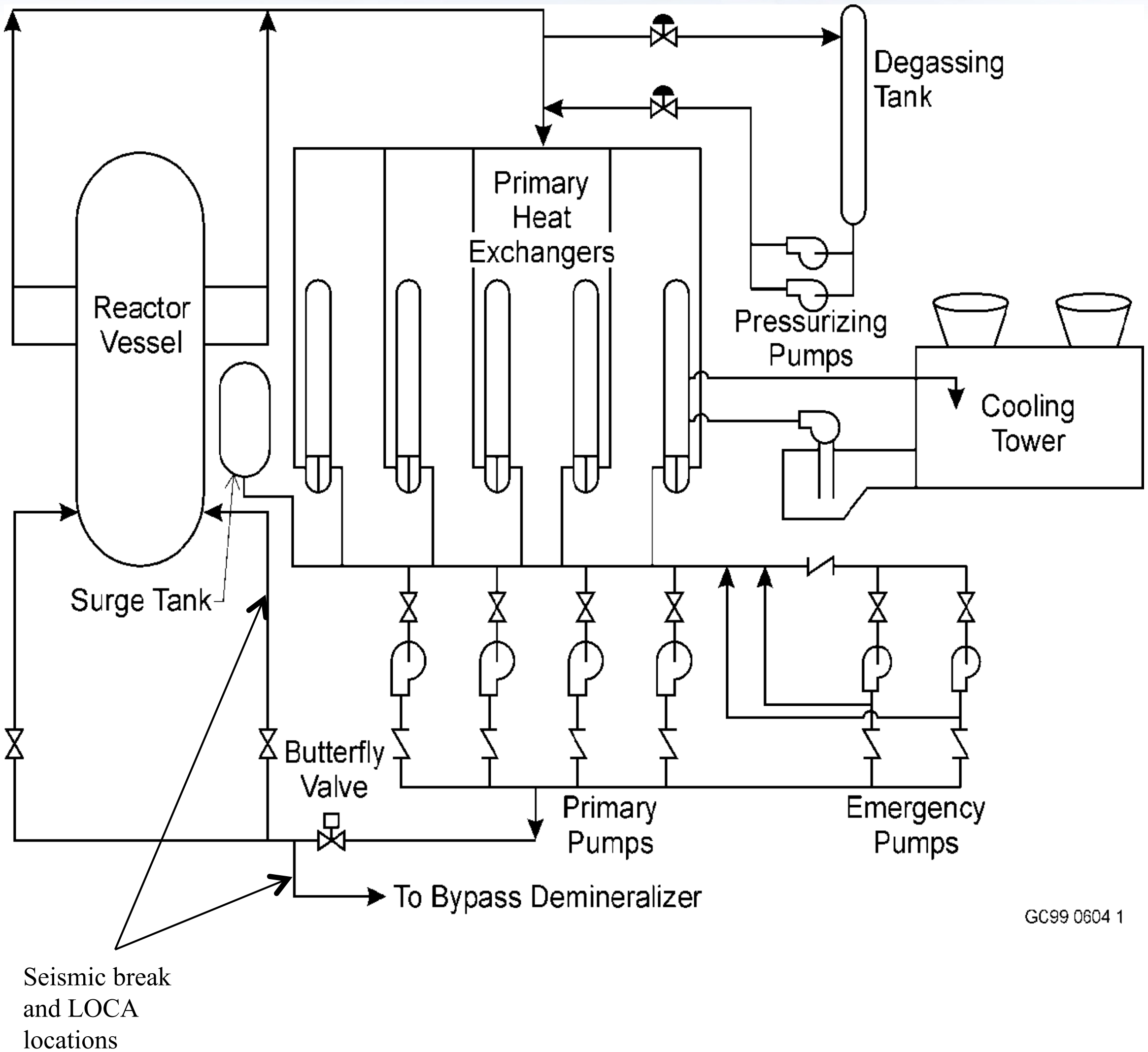
- Previous Analysis neglected to take into account how the heat from the loops affected the reactivity insertion
- Analyzed a different break location to support worst case for pressurizer collapse
- Sensitivity study indicated that the 4.0$ case is more limiting
- Early phase was selected as the most limiting
- Minimal additional changes

IPT Breaks



80 gpm; 650°F; 2500 psig

ATR Primary Coolant System Design



Method of Analysis

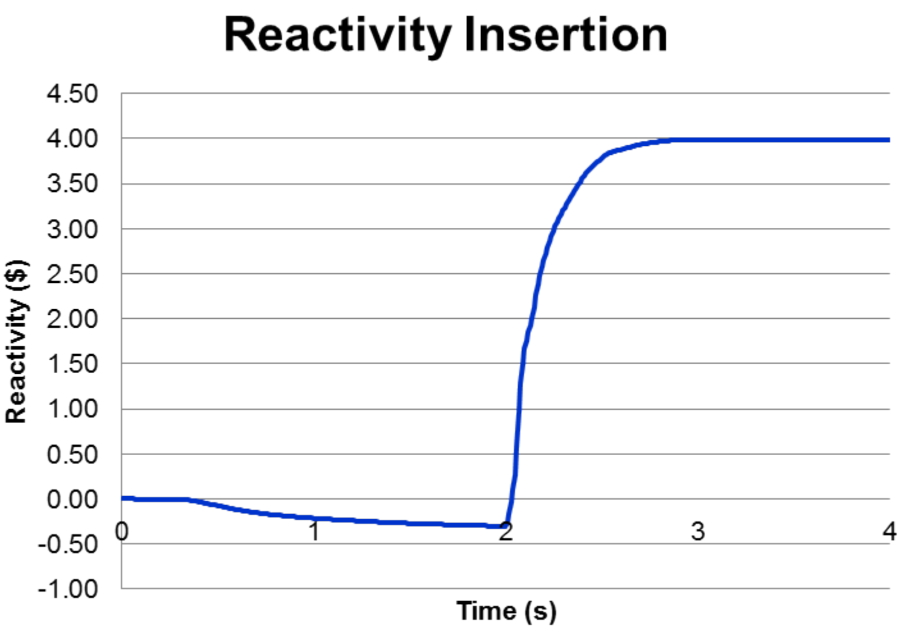
- 0.0 to 2.0 seconds was a null transient
- RELAP5 Mod 3 was used to get reactivity insertion information from the loops which was then used in Mod 2.5
- Used a restart deck
- 3% Power Addition
- Compared loop blowdowns with reactivity step insertions
- All loops are assumed to fail; total void worth of all loops is either 4.0$ or 5.0$
- Results from Mod 2.5 were run through ATR-SINDA and SINDA-SAMPLE
- Also analyzed Condition 2 and Condition 3 events

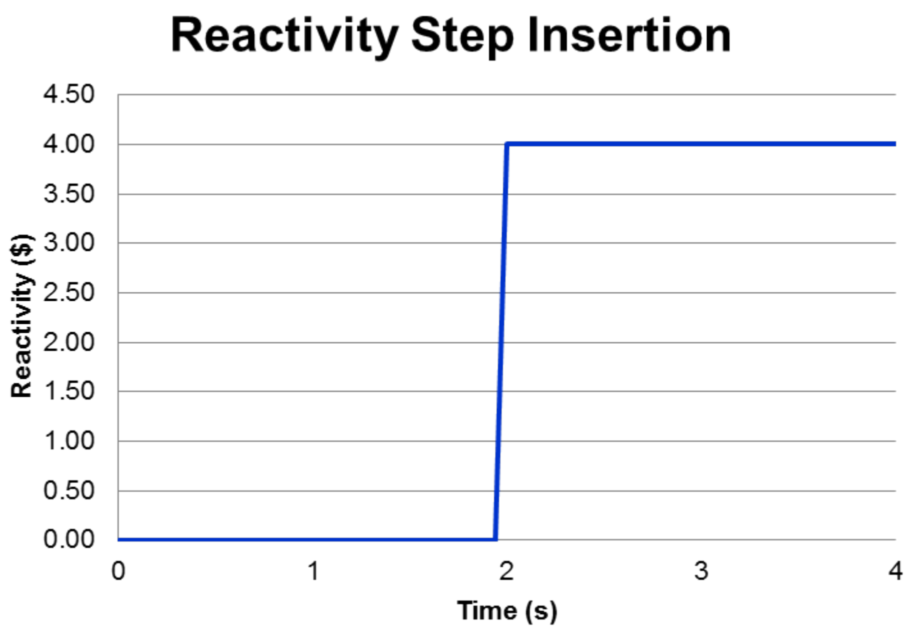
3% Addition Condition 4

- Analysis supports a 3% Effective Plate Power increase for ATR analysis
- This is done in the ATR-SINDA deck by multiplying the power by 1.03

Case	Minimum Safety Margin	
	CHF (σ)	FI (σ)
4.0$ void worth/9.6$ safety rod worth LOCA w/bounding sensitivity case	3.34	2.72
4.0$ with 3% Addition	3.32	2.37
4.0$ Updated Analysis also with 3% addition	3.27	1.62

4.0$ Condition 4 Step Insertion





Case	Minimum Safety Margin	
	CHF (σ)	FI (σ)
4.0$ No Step	3.27	1.62
4.0$ Step	**3.27**	**1.61**

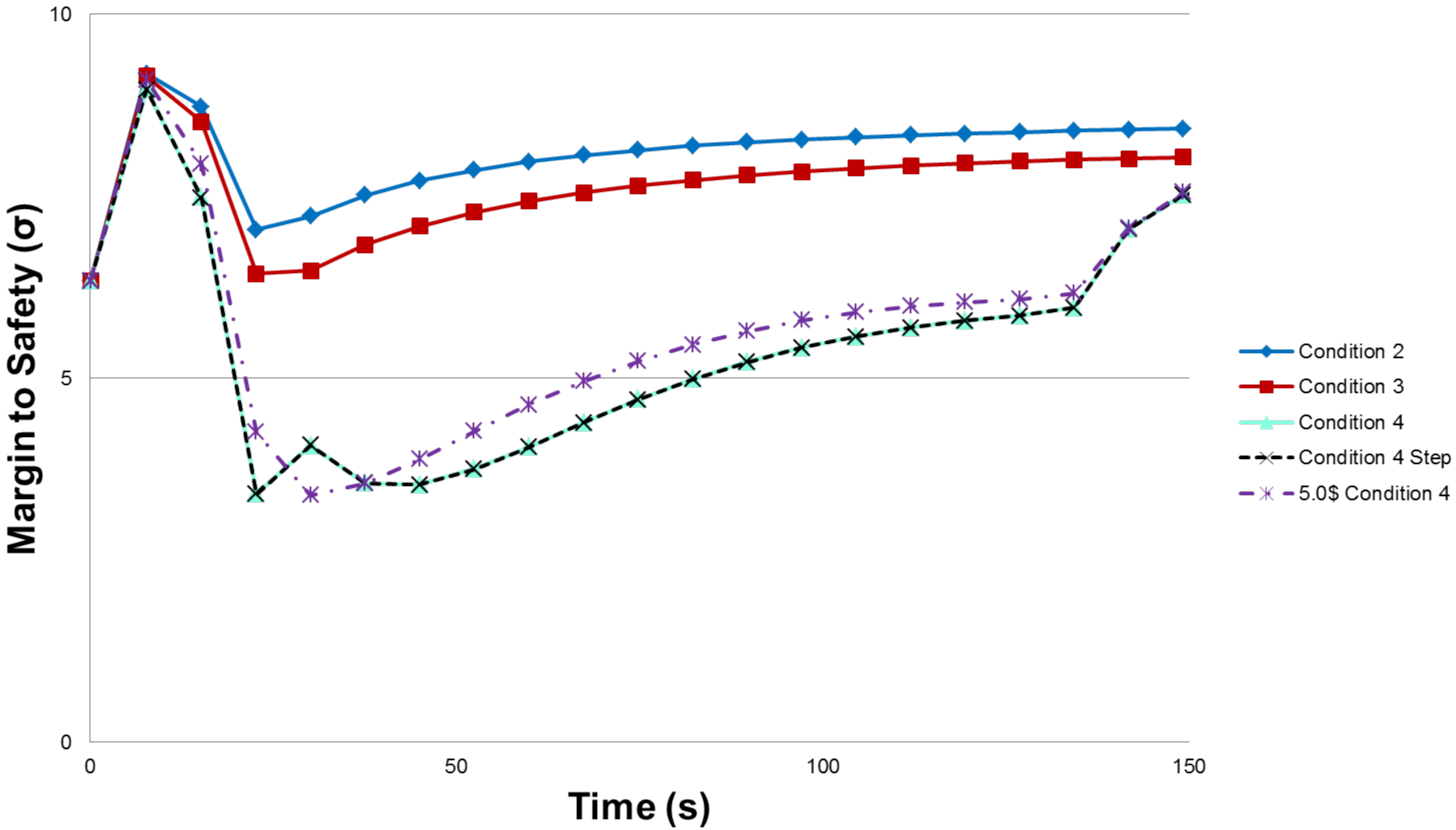
Updated Analysis Results

Safety Margin Summary

Case	Minimum Safety Margin	
	CHF (σ)	FI (σ)
Condition 2	6.98	12.80
Condition 3	6.25	9.25
5.0$ Condition 4	3.34	2.84
Condition 4 Step	**3.27**	**1.61**

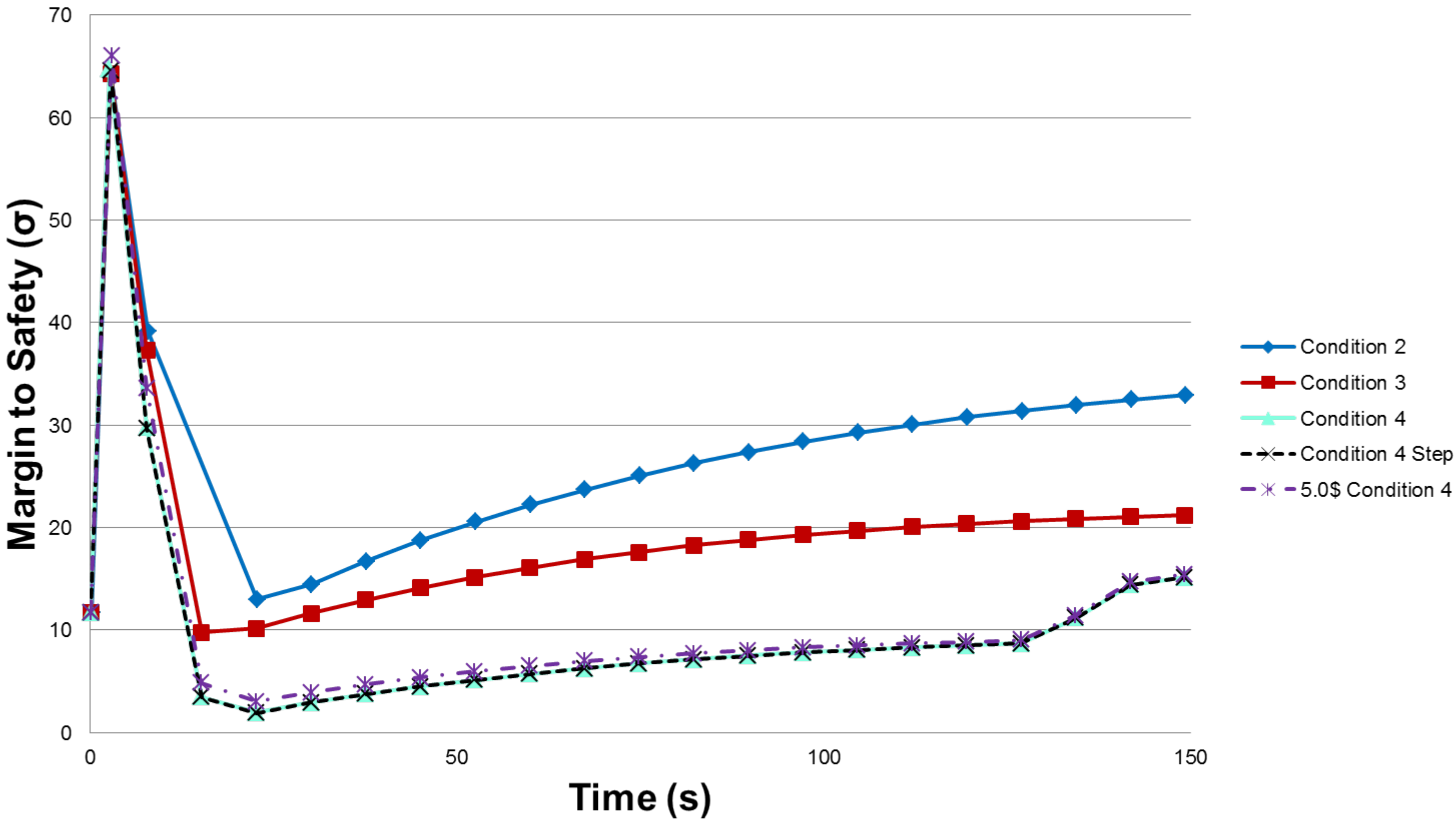
Previously accepted FI margin 1.64
Fuel melt is still unlikely

CHF Plots



10
5
0
0
50
100
150
Margin to Safety (σ)
Time (s)
Condition 2
Condition 3
Condition 4
Condition 4 Step
5.0$ Condition 4

FI Plots



Margin to Safety (σ)
70
60
50
40
30
20
10
0
0
50
100
150
Time (s)
Condition 2
Condition 3
Condition 4
Condition 4 Step
5.0$ Condition 4

Conclusions

- Original analysis neglected to include reactivity insertion contribution from loops
- Analyzed step insertion with 3% power increase and a new break location
- Safety margins lower than before but still acceptable

Questions?