Evaluation of Variations in the ATR Axial Power Distribution on Core Safety Margins

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Outline

- ATR description
- Background
- Method
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- Conclusions

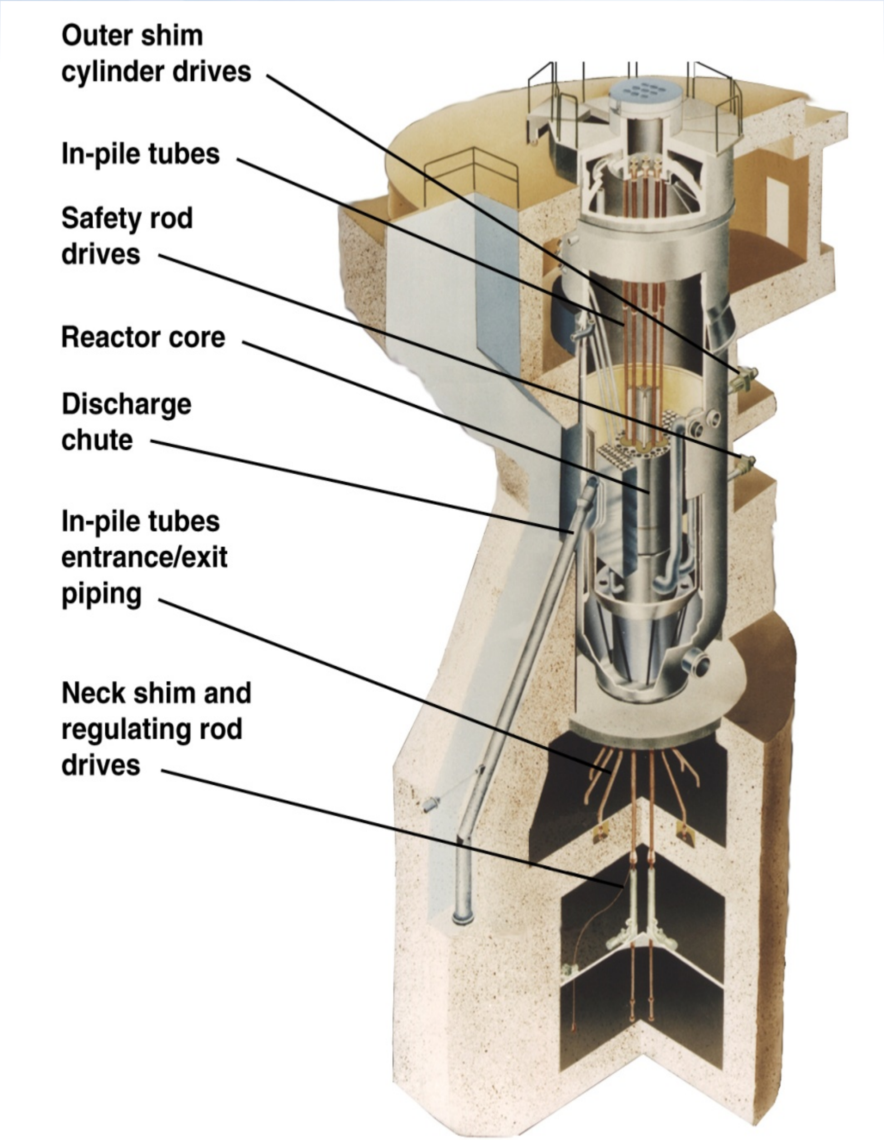
Reactor Description

Reactor Type

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

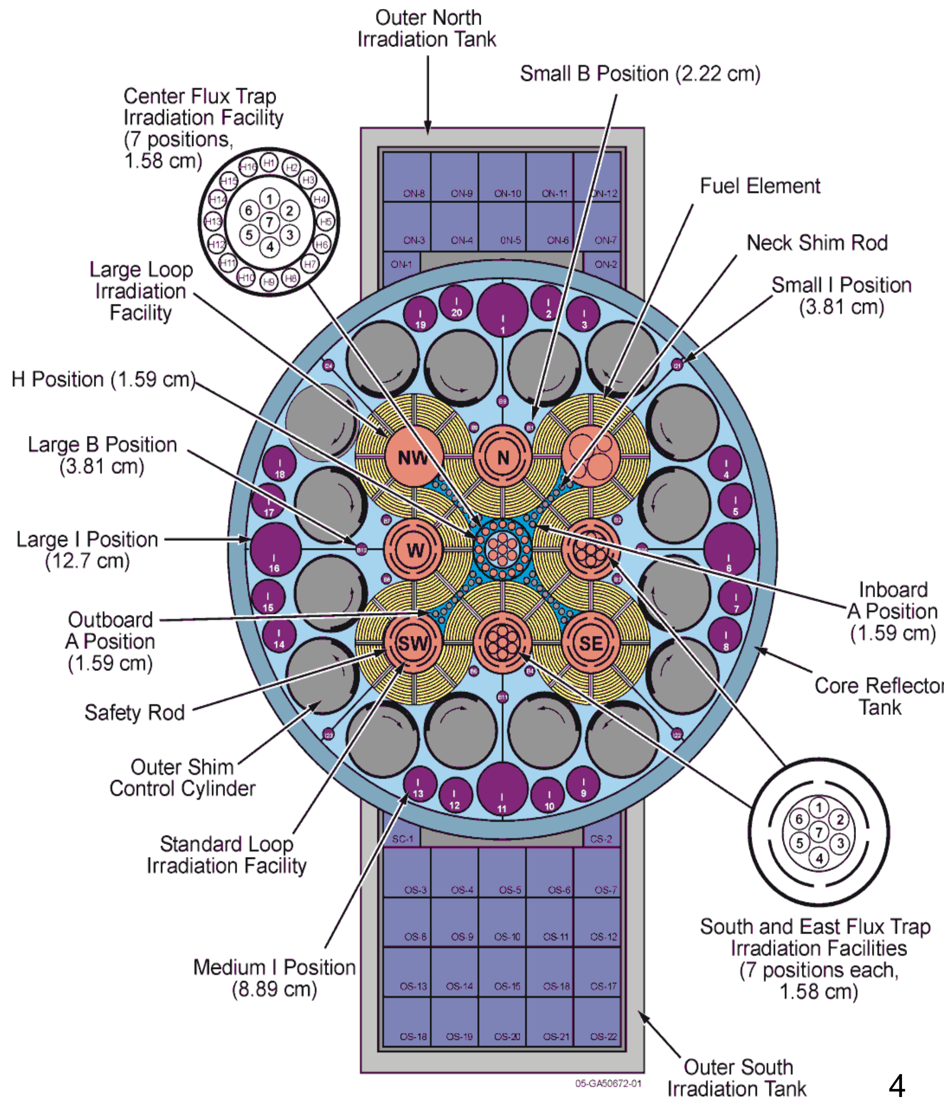
Reactor Core

- 40 fuel elements, curved-plate, aluminum-clad metallic U-235
- Highly enriched uranium matrix (UAlx) in an aluminum sandwich plate cladding



ATR Core Cross Section, Test Positions

- Test size - up to 5.0” Dia.
- 77 irradiation positions:
  - 3 flux traps
  - 6 in-pile 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



Background

- The current safety basis for the Advanced Test Reactor (ATR) is based on an assumed axial power distribution in the fuel
- Recent measurements in the ATR critical (ATRC) facility have shown that some loop experiments affect the axial power distribution in adjacent fuel elements
- An evaluation was performed to determine the effects of various axial power distributions on thermal safety margins for a limiting reactivity insertion accident (RIA)

A suite of codes is used to determine core thermal safety margins

- Safety limits are based on critical heat flux (CHF) and flow instability (FI)
- RELAP5/MOD2.5 and RELAP5/MOD3 are used to simulate the thermal-hydraulic response the reactor coolant system and to provide boundary conditions for detailed simulations of the limiting fuel plate
  - The principal boundary conditions include reactor power, inlet pressure, inlet temperature, and differential pressure across the fuel plate
- 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 mutli-dimensional heat transfer calculations

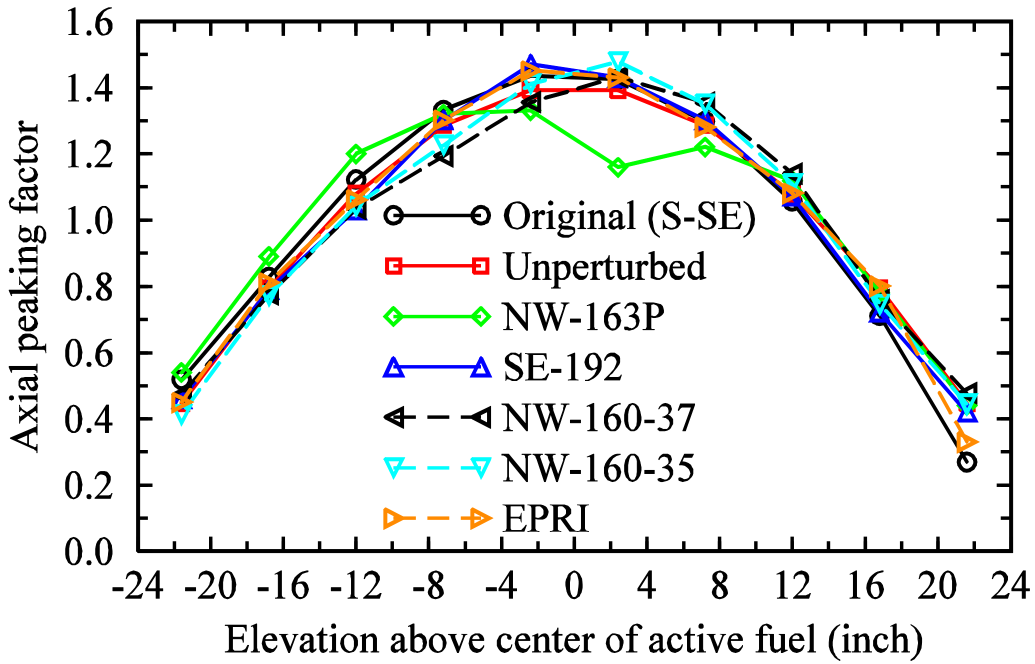
A suite of codes is used to determine core thermal safety margins (cont'd)

- SINDA-SAMPLE is used to compute the safety margins for the limiting subchannel of the limiting fuel plate using a statistical approach
  - Boundary conditions from RELAP5 and ATR-SINDA are used
  - Simplified thermal-hydraulic and heat transfer calculations are performed for 1200 samples or trials
  - Probability distributions are assigned for 45 important input parameters, such as the RELAP5 boundary conditions, plate geometry, material properties, etc.
  - Each input parameter is varied independently based on statistical sampling for each trial
  - The variations of the output are used to determine the thermal margins to CHF and FI
  - The thermal margins are expressed based on the number of standard deviations (σ) to CHF and FI

A suite of codes is used to determine thermal safety margins (cont’d)

- For some limiting transients, the worst trial from SINDA-SAMPLE is simulated with ATR-SINDA to demonstrate compliance with plant protection criterion
  - ATR-SINDA provides a more detailed and accurate heat transfer calculation than SINDA-SAMPLE

Seven different axial power variations were evaluated

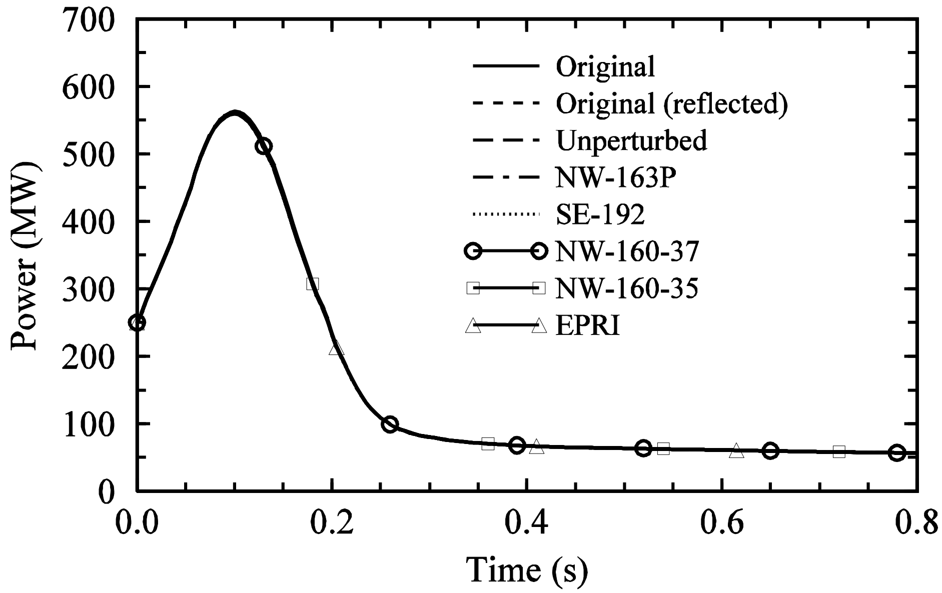


- The current safety basis assumes the original power distribution
- The unperturbed distribution is based on a cosine shape
- The other distributions are based on ATRC measurements for a particular experiment

Accident selection

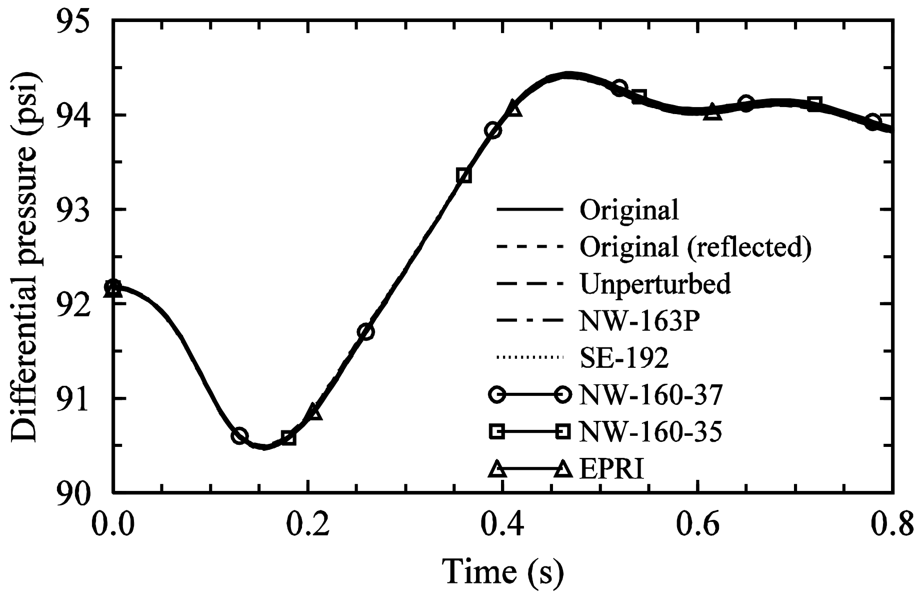
- The effects of the variations in the power distribution were determined for the most limiting RIA in the safety basis
- The RIA was initiated by a double-ended offset shear of the pump discharge piping in an experiment loop
  - The loop blowdown causes reactivity insertion and an overpower transient
- The experiment loop is hydraulically separated from the primary coolant loop
  - Therefore, the inlet pressure, inlet temperature, and differential pressure across the fuel plate remain relatively constant
  - The reactor power is the principal boundary condition that changes

Reactor power calculated by RELAP5



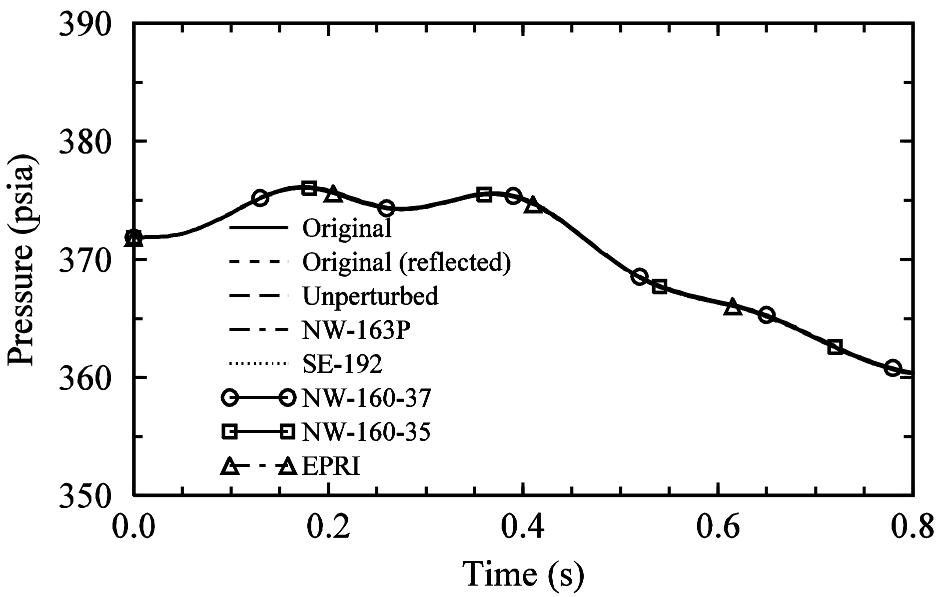
- The results were not sensitive to the axial power distribution
- The maximum effect on peak power was less than 1%

Core differential pressure calculated by RELAP5



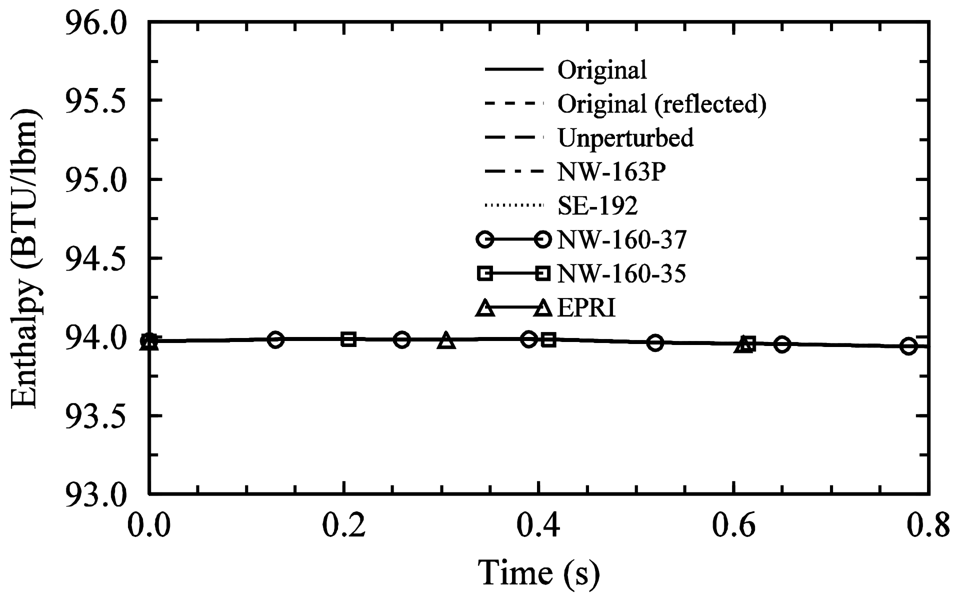
- The power excursion had a small effect on the differential pressure across the core
- The results were not sensitive to the axial power distribution

Inlet pressure calculated by RELAP5



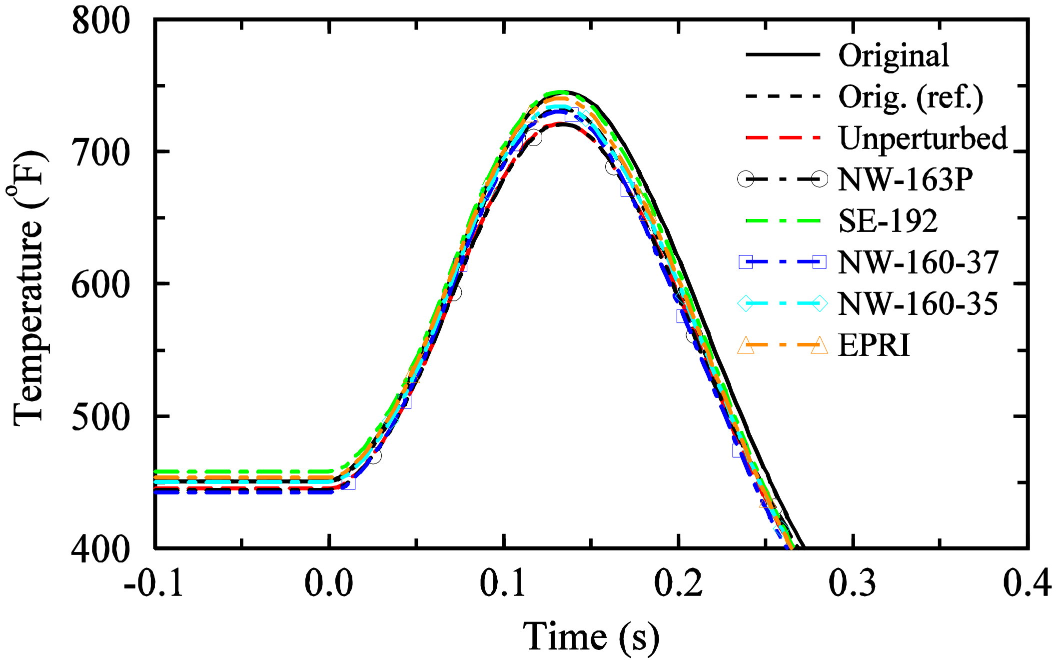
- The power excursion had a small effect on the inlet pressure
- The results were not sensitive to the axial power distribution

Inlet enthalpy calculated by RELAP5

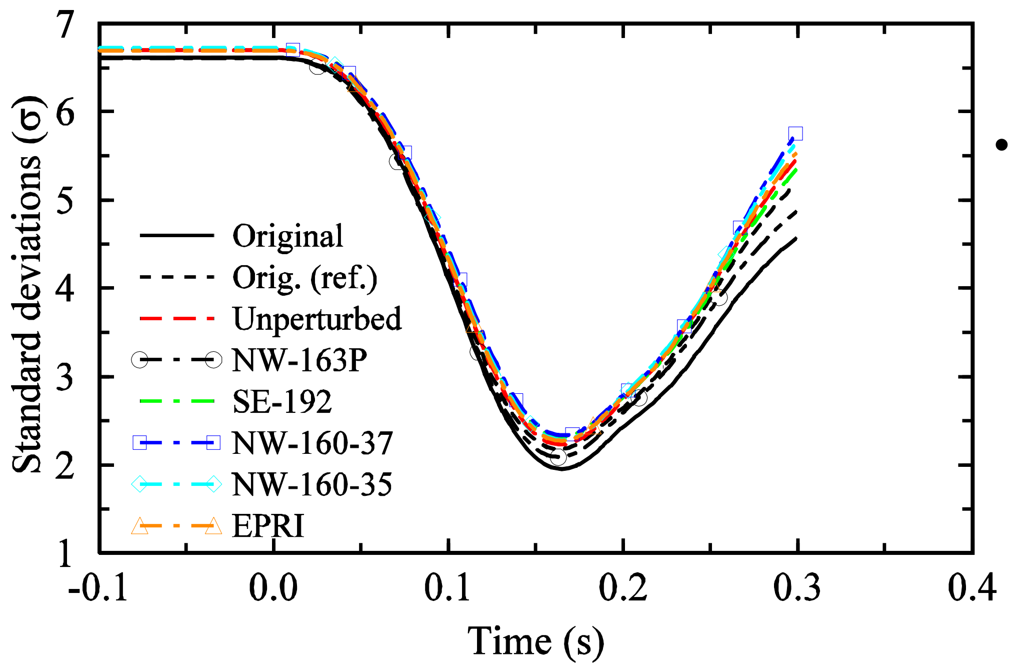


- The power excursion had a small effect on the inlet enthalpy
- The results were not sensitive to the axial power distribution

Maximum fuel temperatures from ATR-SINDA

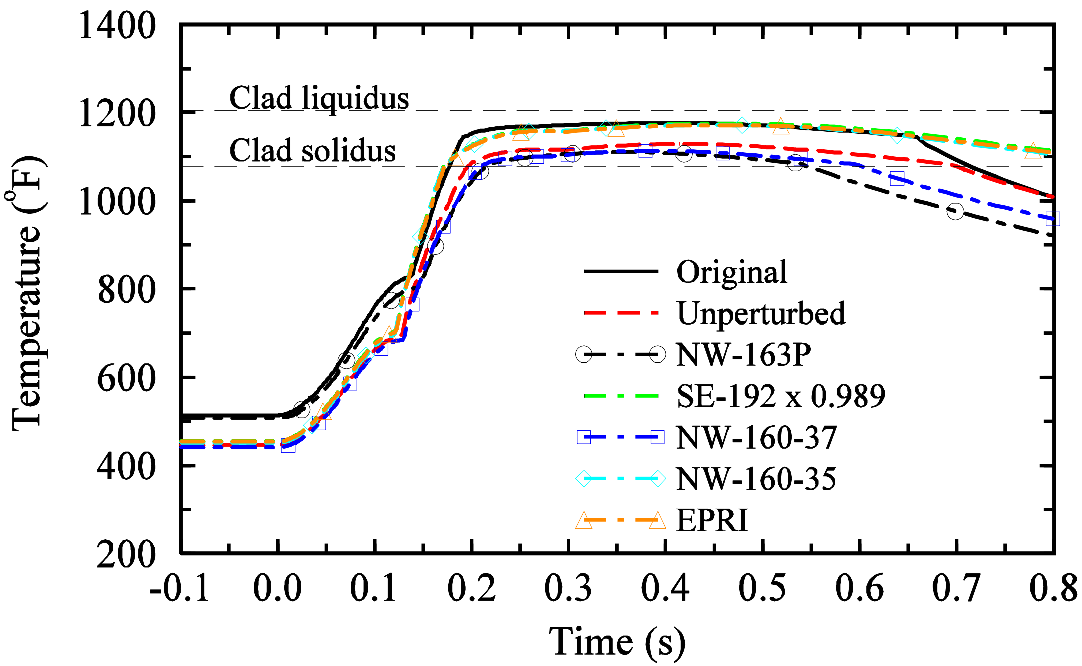


Margin to CHF from SINDA-SAMPLE



- The original power distribution was limiting in terms of the margin to CHF from SINDA-SAMPLE

Simulation of worst trial using ATR-SINDA



- The original power distribution was limiting in terms of maximum cladding temperature for all the distributions except one
- The power had to be reduced by 1.1% for one distribution so that the original distribution would be limiting

Criteria for bounding the effects of new power distributions were developed

- Maximum cladding temperatures that occur during the RIA are caused by CHF rather than FI
- The occurrence of CHF depends on the local axial peaking factor (determines the heat flux) and the CHF (depends on fluid velocity and subcooling)
- Variations in fluid velocity are small for this event
- The subcooling is determined by the sum of the power fractions for the axial nodes upstream of a given node
- Therefore, a new power distribution will be bounded by a previously evaluated distribution IF
  - The axial peaking factor AND the sum of power fractions between the inlet and the current node are less than the corresponding values from the SAME previously evaluated distribution

Conclusions

- The boundary conditions calculated by RELAP5 and passed to ATR-SINDA and SINDA-SAMPLE were insensitive to the axial power profile in the fuel elements
- ATR-SINDA and SINDA-SAMPLE calculations showed that the axial power profiles significantly affected safety margins
- The original axial power profile was generally limiting
- Criteria were developed to compare new axial power distributions with those evaluated here
- Additional analyses were recommended if a new power distribution is not bounded by one of the power distributions evaluated here