Validation of a RELAP5-3D Point Kinetics Model of TREAT

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Outline

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- Description of the RELAP5-3D model
- Validation results
- Conclusions

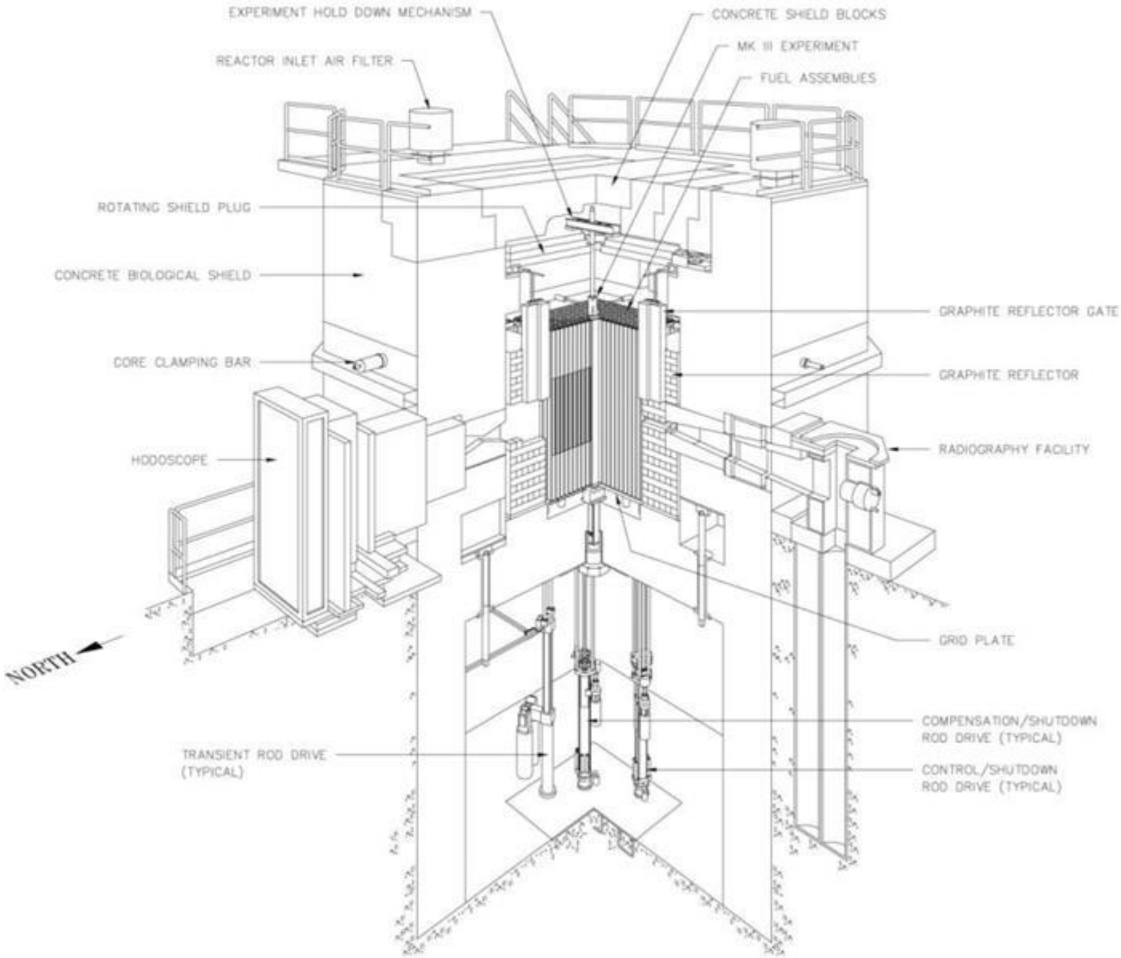
Background

- The Transient Reactor Test (TREAT) facility is being restarted to test accident tolerant fuels for light water reactors that are designed to have better performance than traditional Zircaloy-clad UO_2 fuel during normal operation and accidents
- New experiments will be performed in the next few years to test proposed fuel concepts and provide data for assessment of advanced multi-physics computer codes
- Calculations are required now to demonstrate that the experiments will meet program objectives and can be performed safely
  - The advanced multi-physics computer codes are not ready yet
  - The safety calculations for the first experiments will be performed with RELAP5-3D
- A RELAP5-3D point kinetics model of TREAT was developed and validated

Description of TREAT

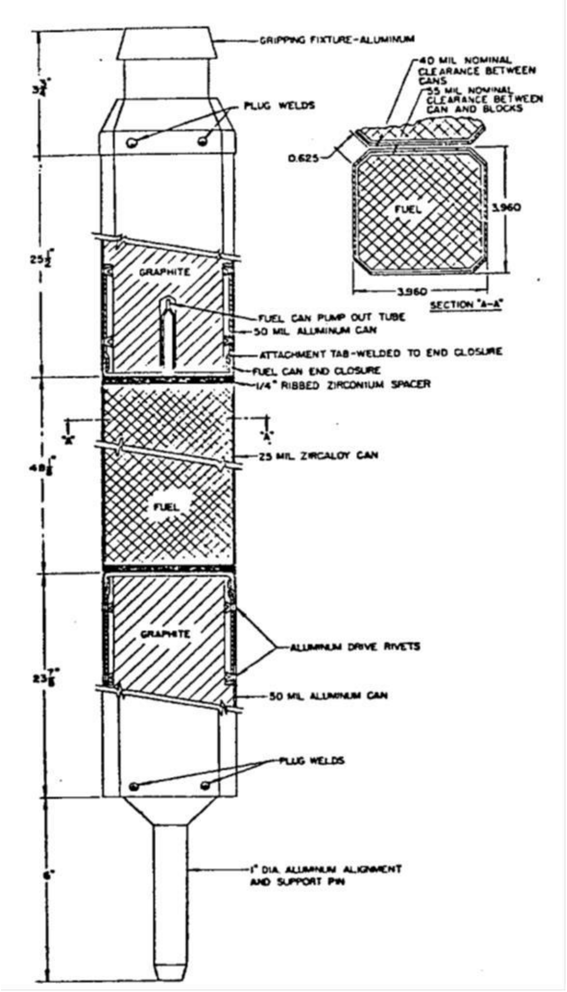
- TREAT is a dry reactor that went critical in 1959
- Operations were suspended in 1994
- Driver core is made up of urania dispersed in graphite blocks encapsulated by Zircaloy cans
- Square layout with 361 positions that are filled with fuel or dummy assemblies
- The size of the core varies from small to large (~ 150 to 340 fuel assemblies)
- Dummy assemblies are located around the periphery of the core and are filled with graphite for additional reflection
- Experiments are placed in the center of the core

Description of TREAT (cont'd)



- Core is set on a square gridplate
- Core is surrounded by graphite reflectors
- A small amount of cooling is provided by downflow of air
- The heat capacity of the graphite provides the primary heat sink during transients
- Reactivity control provided by three banks of control rods

Description of TREAT fuel assembly



- Each fuel assembly is a 4x4" "square" that contains fuel, a gas gap, and a Zircaloy can
- The gas gap was evacuated during manufacture
- Active core is 48" tall
- There is a small gap between fuel elements for air flow

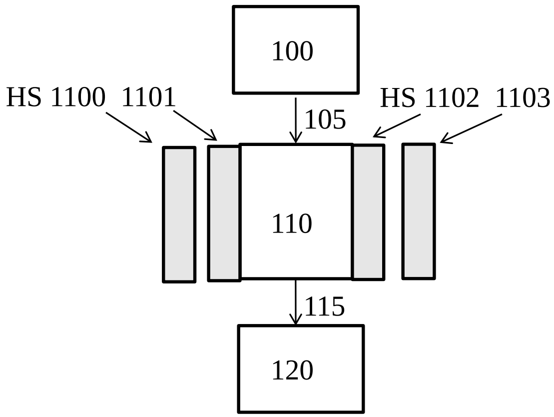
Description of TREAT (cont'd)

- TREAT can perform two types of transients
  - Unshaped transients
    - The only reactivity addition is that required to initiate the experiment
    - The reactor power responds naturally due to thermal feedback
  - Shaped transients
    - The transient rods are moved during the test to obtain a desired power curve
    - The reactor power responds to the rod movement and the thermal feedback

Description of the RELAP5-3D model

- The RELAP5-3D model was developed to calculate the reactor power during experiments
  - The reactor power is needed to support other analyses required to demonstrate that the experiments will meet operational objectives and that they can be performed safely
- The model calculates the temperature of an average fuel assembly to supply thermal feedback to the point kinetics model
- The model also calculates the temperature at the hot spot to determine the margins to thermal limits

Description of the RELAP5-3D model (cont'd)

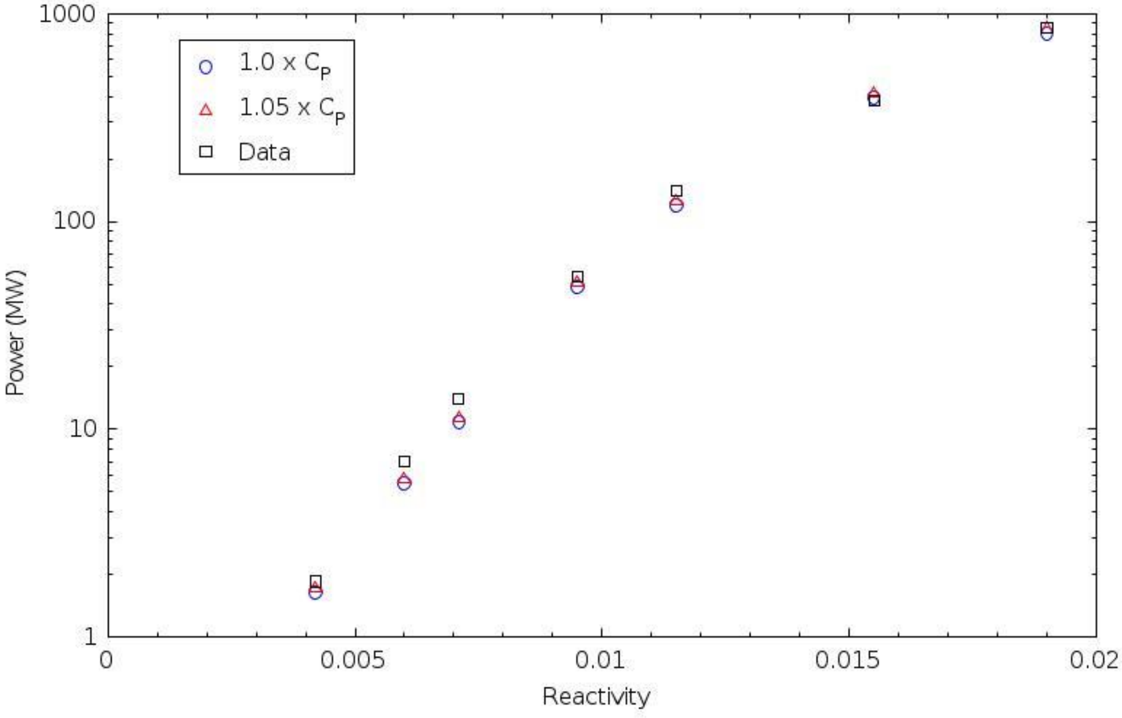


- The model is very simple
- One heat structure represents all the fuel in the core
- Another heat structure represents all the Zircaloy cans
- Radiation between the two average heat structures is accounted for
- Conduction across the gap is neglected
- Two similar heat structures are used to represent the hottest fuel in the core
- A cylindrical heat structure is used to represent the square assemblies
- Distortions are accounted for by adjusting the heat transfer coefficient at the outer surface of the can and the thermal conductivity of the Zircaloy
- The point kinetics model is based on information from the SAR
- The model of the transient rods is based on a fit to reactivity measurements taken in the M8 half-slotted core, the last core used before operations were suspended in 1994

Validation results were generated for a wide range of reactivity

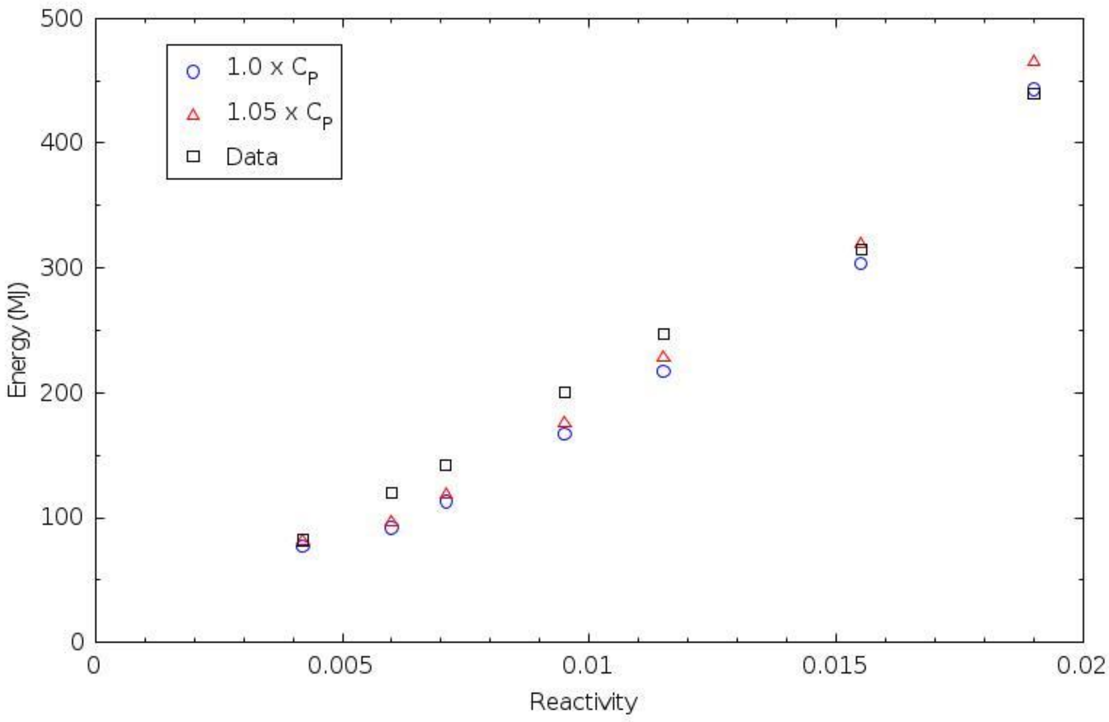
- Seven unshaped experiments conducted around1960
  - Initiated by near step insertions of reactivity in relatively small cores (~ 150 fuel assemblies)
  - Reactivity insertion varied from 0.42 to 1.90% (0.58 to 2.65$)
- Two experiments conducted during the early 1990's with the M8 half-slotted core (338 fuel assemblies)
  - Test 2857
    - Unshaped transient initiated by a near step insertion of reactivity (3.85% or 5.36$)
  - Test 2871
    - Shaped transient with a total reactivity insertion of about 6% or 8.4$

The model produced a reasonable representation of the historical data



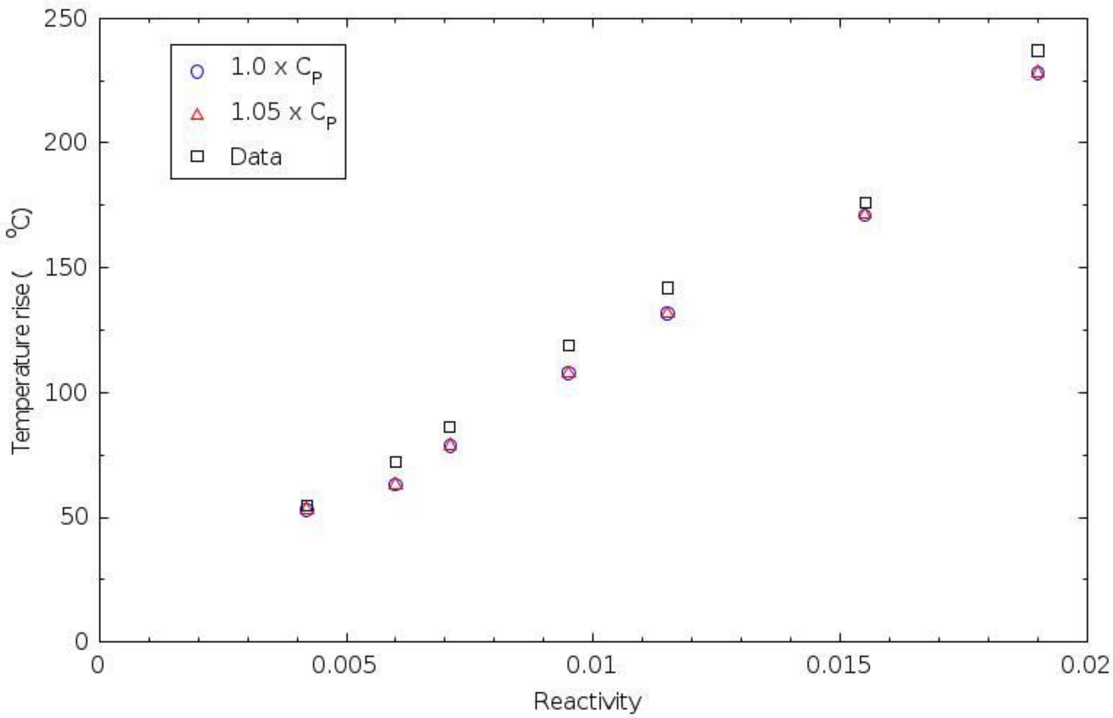
- The peak power in the base calculations was 12% low, on average
- A 5% increase in the heat capacity of the fuel resulted in a 5% rise in the peak power

The model produced a reasonable representation of the historical data (cont'd)



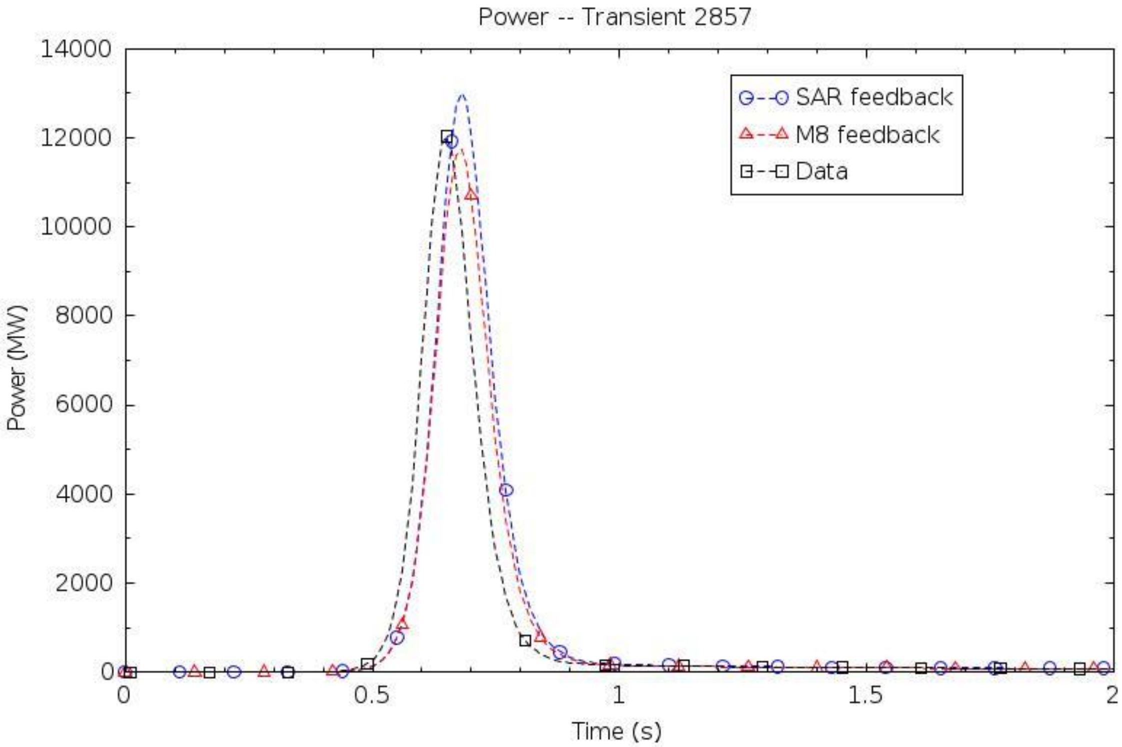
- The energy deposition in the base calculations was 12% low, on average
- A 5% increase in the heat capacity of the fuel resulted in a 5% rise in the energy deposition

The model produced a reasonable representation of the historical data (cont'd)



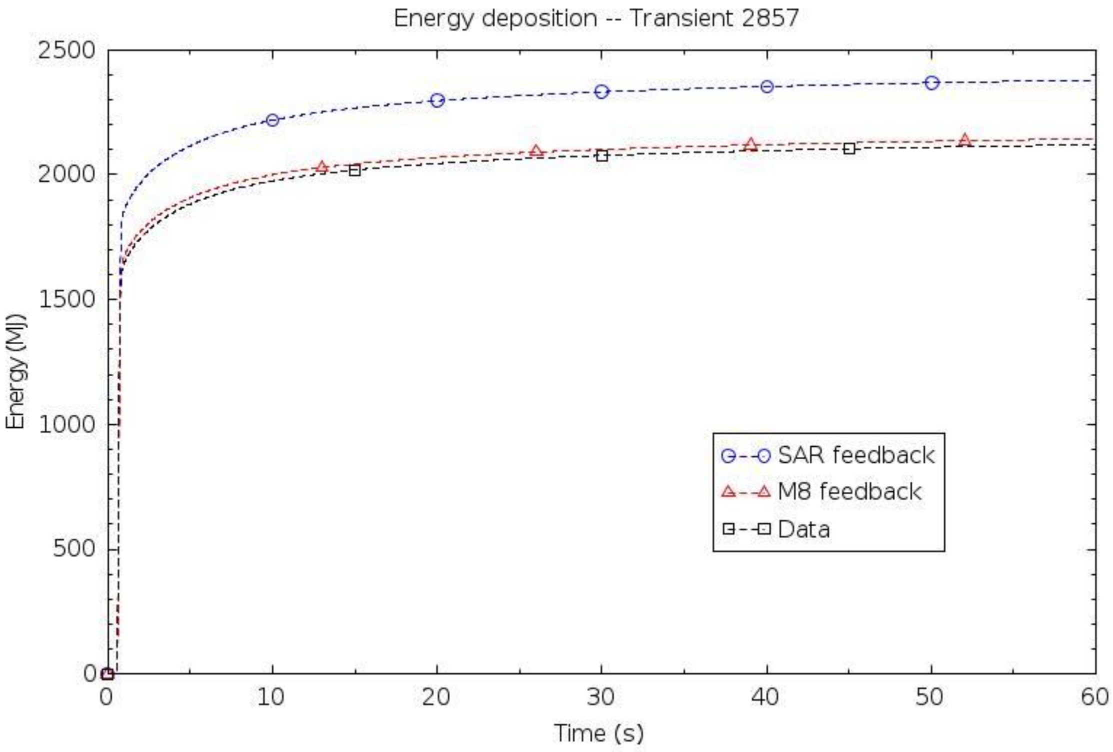
- The fuel temperature rise in the base calculations was 7% low, on average
- A 5% increase in the heat capacity of the fuel resulted in a negligible effect on the temperature rise of the fuel

The model produced a reasonable representation of Test 2857



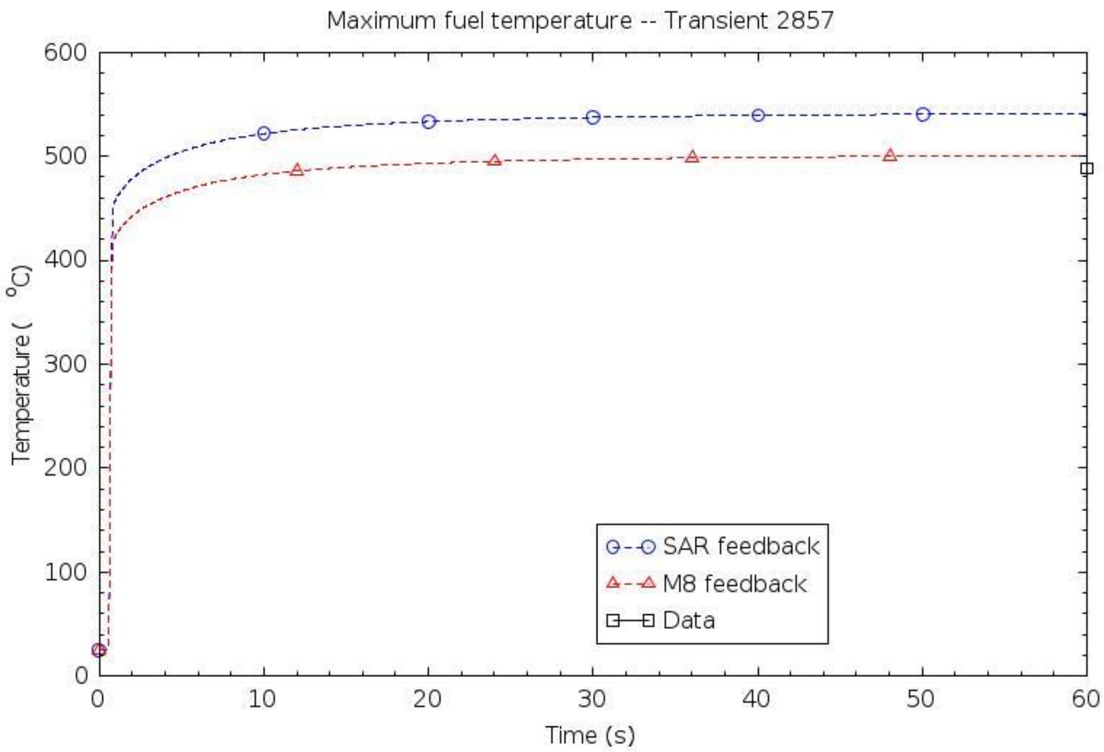
- Calculations were performed with two feedback tables, one from the SAR and one generated specifically for the M8 core
- The M8 feedback table produced about 5% more feedback at a given temperature
- The calculated peak power was 8.3% too high with the SAR feedback table and 2.3% too low with the M8 feedback table

The model produced a reasonable representation of Test 2857 (cont'd)



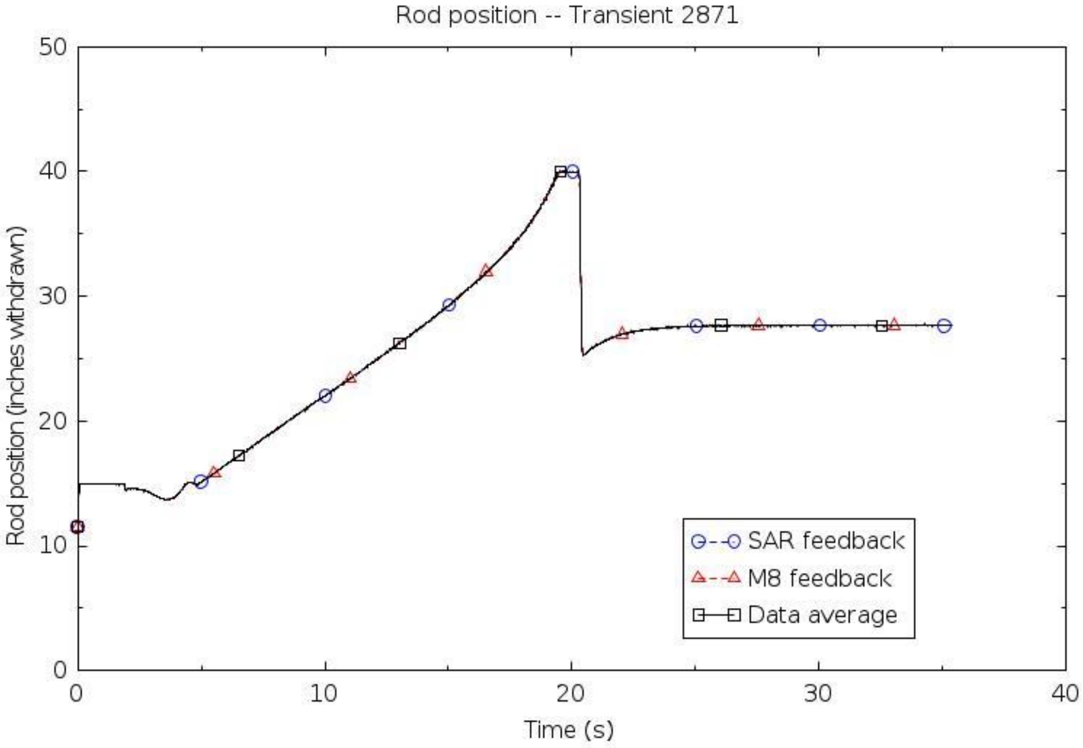
- The calculated energy deposition at the end of the test was 12.2% too high with the SAR feedback table and 1.1% too high with the M8 feedback table
- The variation in the various sources of data was about ±10%

The model produced a reasonable representation of Test 2857 (cont'd)



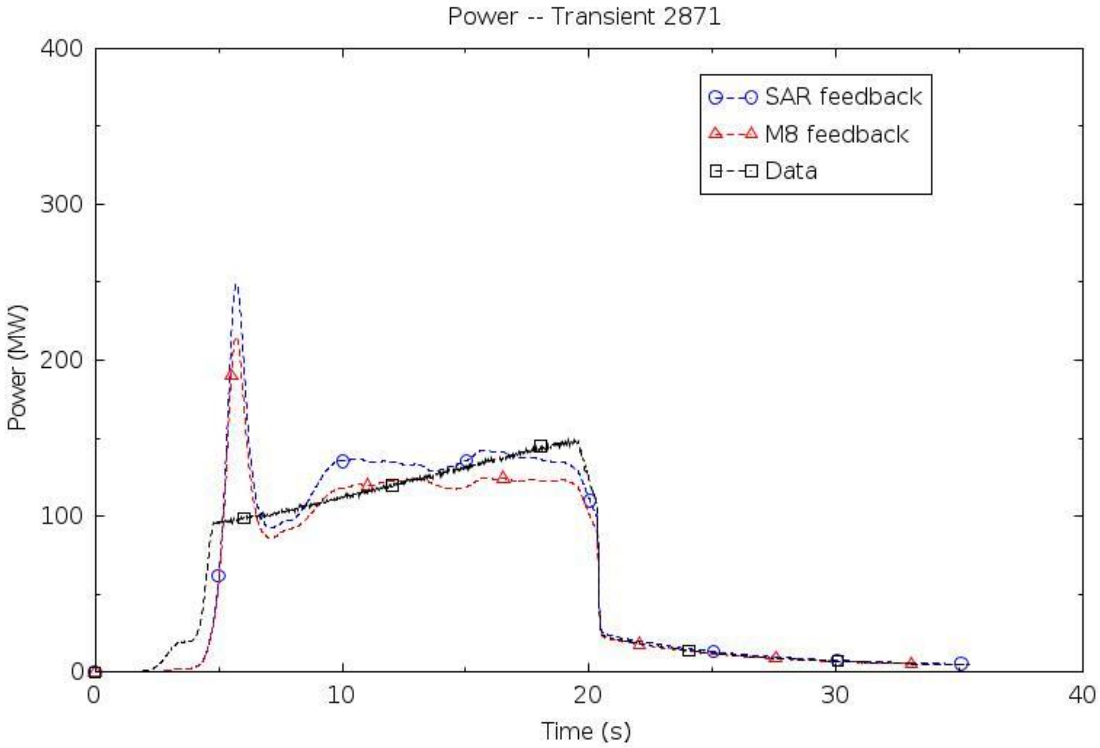
- Transient fuel temperature data are not available
- The maximum calculated fuel temperature was 53°C too high with the SAR feedback table and 12°C too high with the M8 feedback table

Test 2871 was a shaped transient



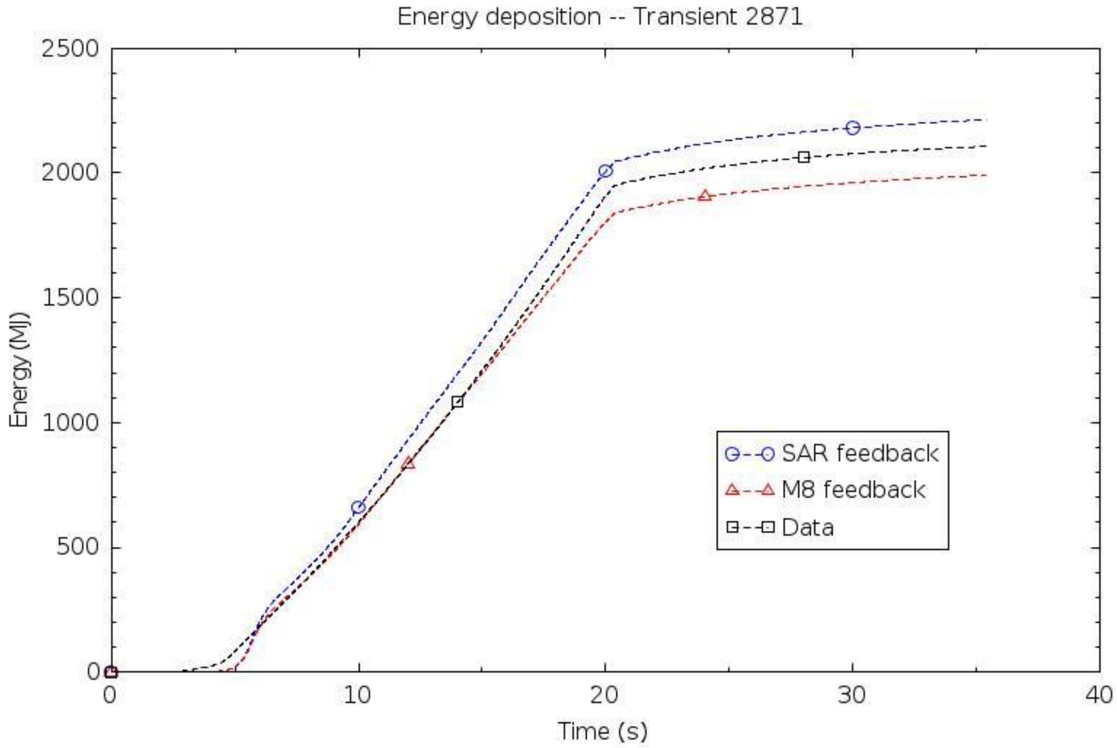
- The transient rods were moved during the test to obtain a desired power shape
- The transient rods were fully withdrawn near 20 s

The calculated trends in reactor power were not in good agreement with the data in Test 2871



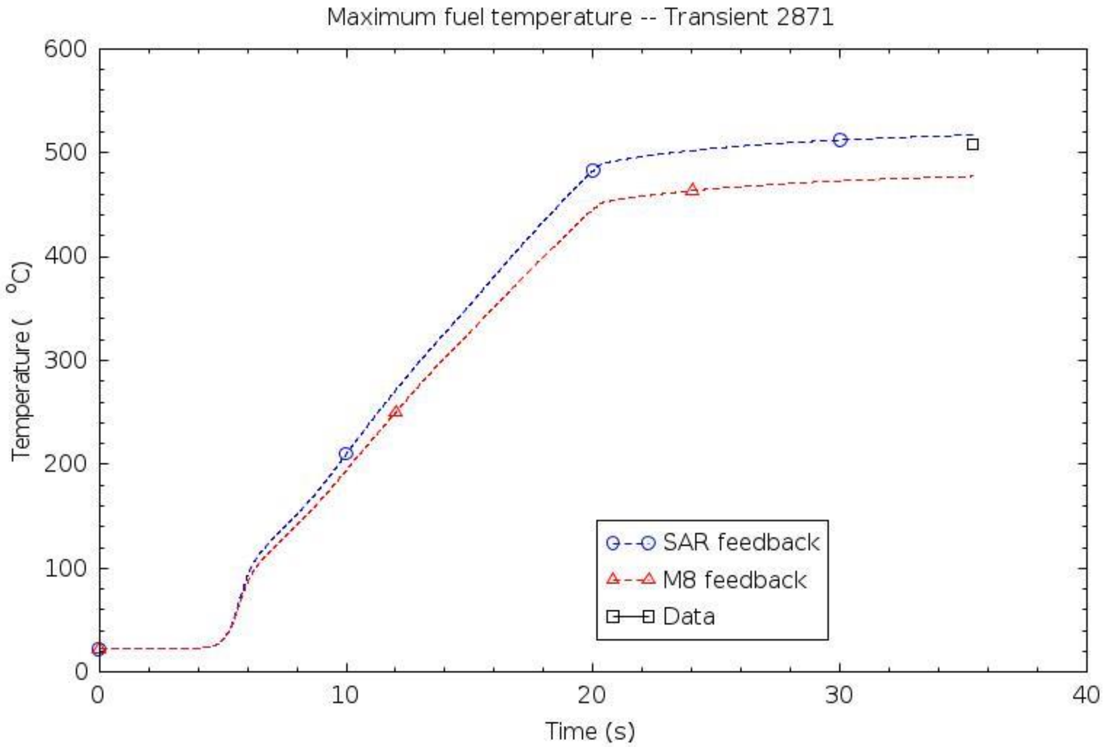
- The calculated peak power was too high with both feedback tables
- The calculated increase in power was not nearly as linear as observed in the test

The model represented the energy deposition in Test 2871 reasonably well



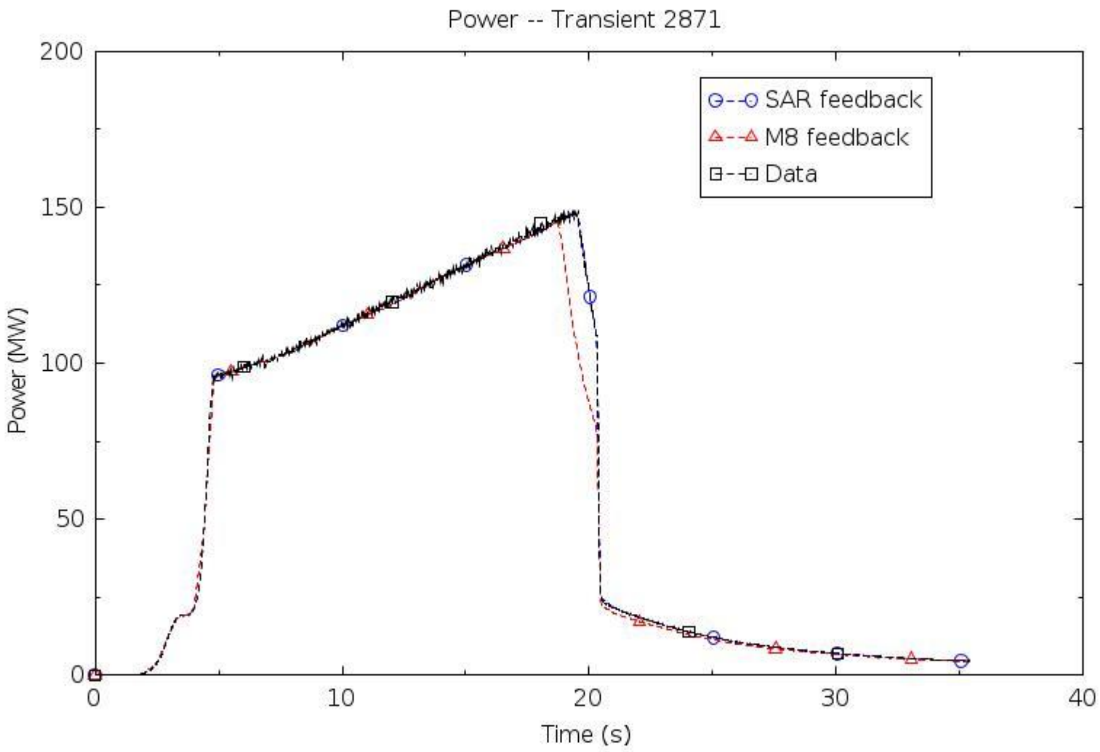
- The calculated energy deposition at the end of the test was 5.0% too high with the SAR feedback table and 5.5% too low with the M8 feedback table
- The variation in the various sources of data was about ±10%
- The discrepancy in the power shape from the previous curve had a small effect on the final energy deposition

The model represented the maximum fuel temperature in Test 2871 reasonably well



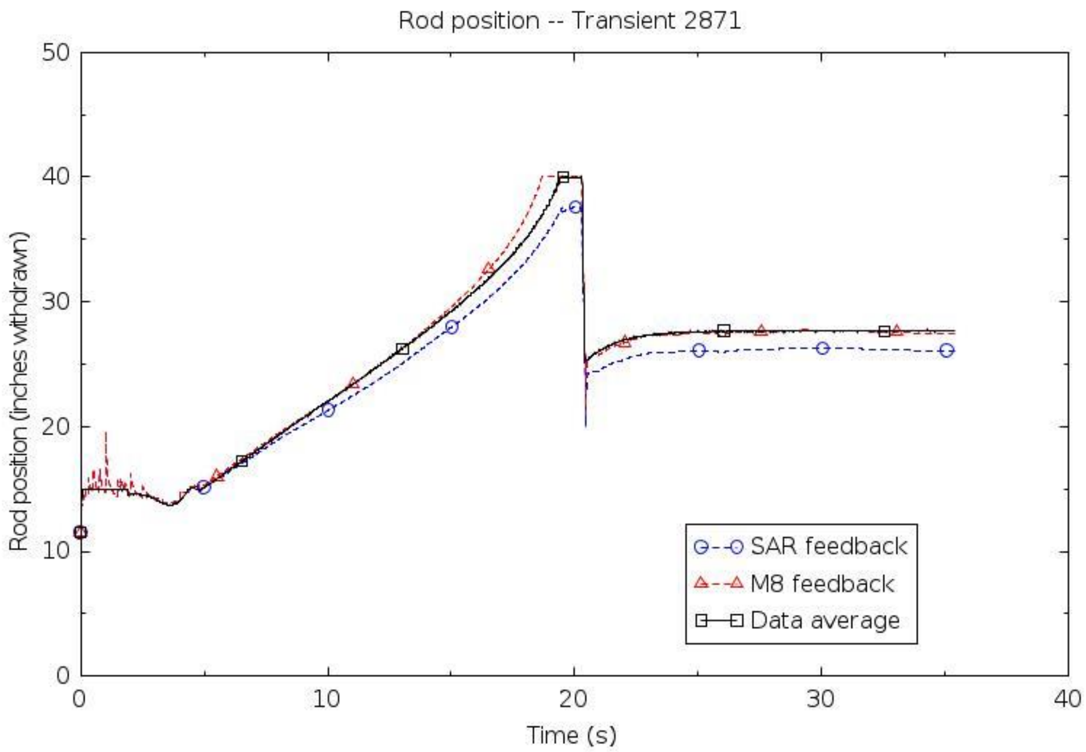
- Transient fuel temperature data are not available
- The maximum calculated fuel temperature was 9°C too high with the SAR feedback table and 31°C too low with the M8 feedback table

Sensitivity calculations were performed to determine the movement of the transient rods required to match the measured power



- The required rod position was obtained using the inverse kinetics component of the control system
- The calculated position of the transient rods was then used in the point kinetics model to calculate reactor power
- These calculations were all performed in a single RELAP5-3D calculation
- The rods were fully withdrawn at 18.7 s with the M8 feedback curve

Calculated transient rod position required to match the power response in Test 2871



- More reactivity insertion is needed before 5 s; the fit of the reactivity of transient rods under estimates the worth of rod movement in this region
- The average calculated and measured values differed by less than 0.5 inch before 5 s
- The spikes in power are caused by slope changes in the input power curve; the code linearly interpolates between table points
- The calculated positions bound the measured values after 5 s

Conclusions

- The RELAP5-3D model generates results that are in reasonable agreement with measured values for a wide range of reactivity insertions
- The RELAP5-3D model with the SAR feedback table is expected to provide conservative estimates of maximum values of core power, energy deposition, and fuel temperature for new experiments in the M8 core