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

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Outline

- Background
- Description of TREAT
- Description of the detailed RELAP5-3D model
- Validation results
- Conclusions

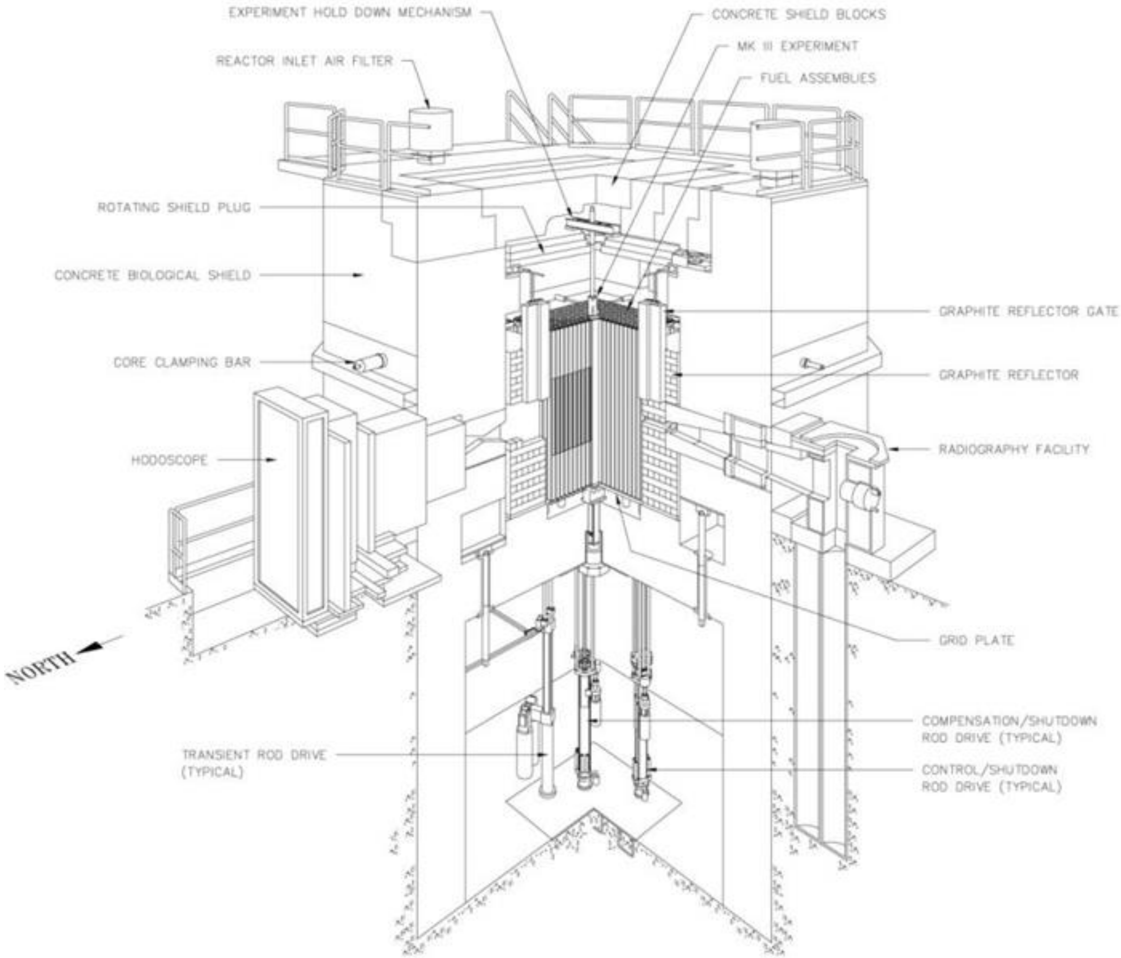
Background

- The Transient Reactor Test (TREAT) facility has been 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 simple RELAP5-3D point kinetics model of TREAT was developed and validated previously as described at the 2015 IRUG meeting
- A more detailed RELAP5-3D model is the subject of this presentation

Description of TREAT

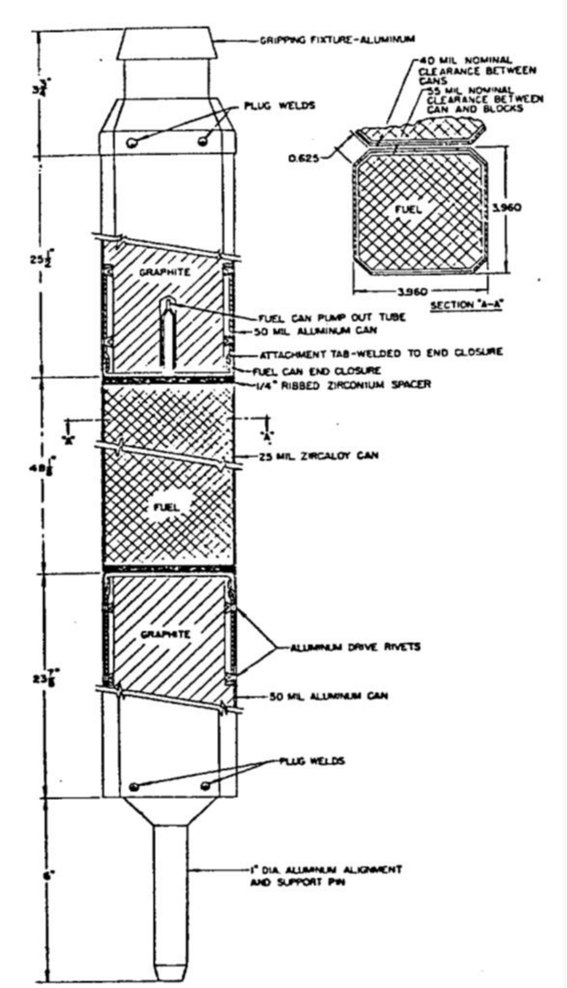
- TREAT is a dry reactor that went critical in 1959
- Operations were suspended in 1994
- The reactor was restarted this fiscal year
- Driver core is made up of urania dispersed in graphite blocks encapsulated by Zircaloy cans
- Square layout with 361 positions that are filled with fuel or dummy assemblies
- 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
- More that 50% of the flow area is located near the corners, while the wetted perimeter of the corners is less than 20% of the total

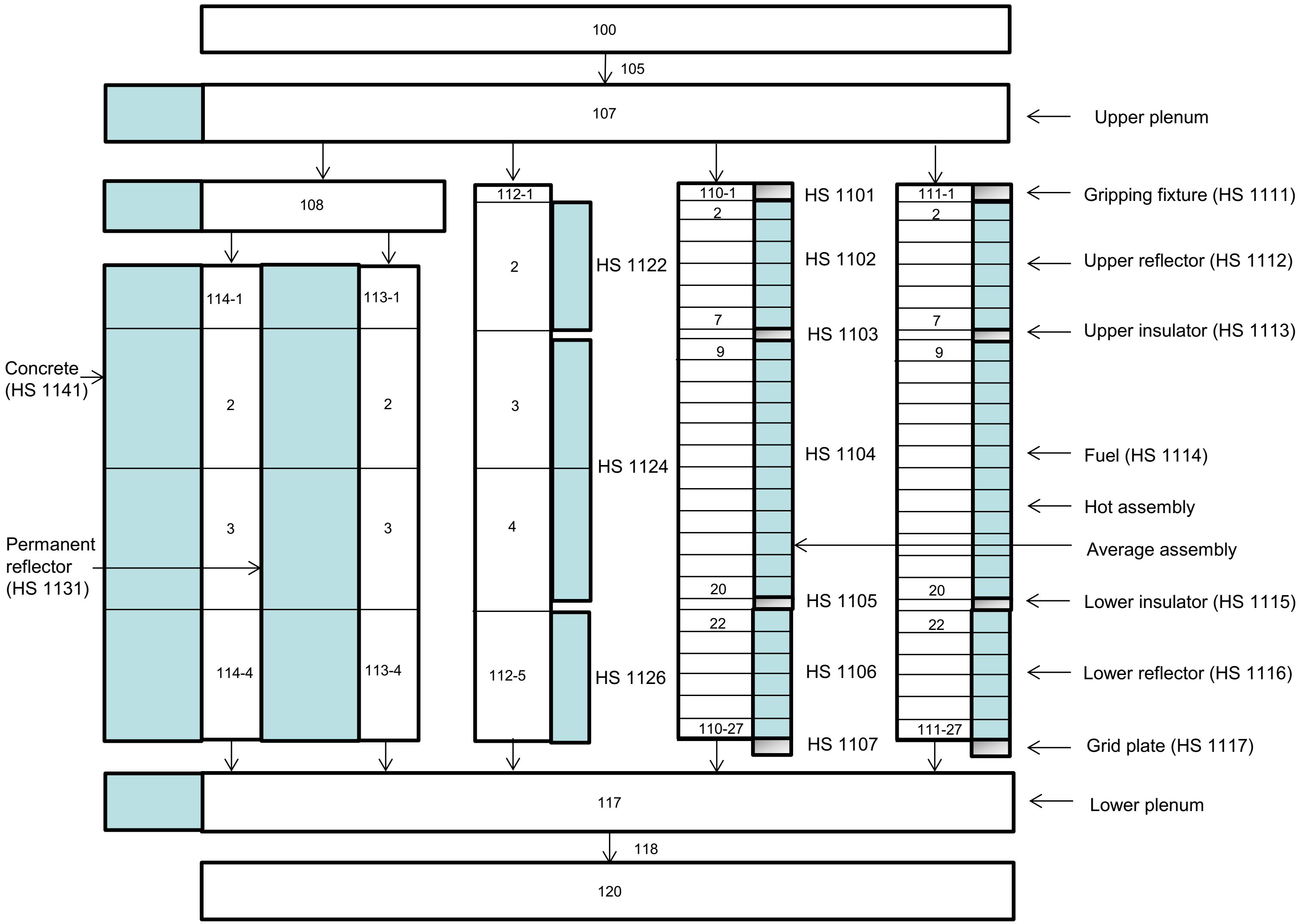
Description of TREAT (cont'd)

- 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 detailed RELAP5-3D model

- The detailed RELAP5-3D model was developed to calculate the reactor response during experiments and accidents
- The model represents hot and average fuel assemblies, the reflectors, and the concrete
- The model accounts for
  - Reactivity feedback
  - Axial conduction in the fuel elements using a conduction enclosure model
  - Forced convection cooling due to blower operation
  - Natural convection cooling in the event of blower failure
- The model monitors oxidation of the Zircaloy can at the peak power location in the hot fuel assembly

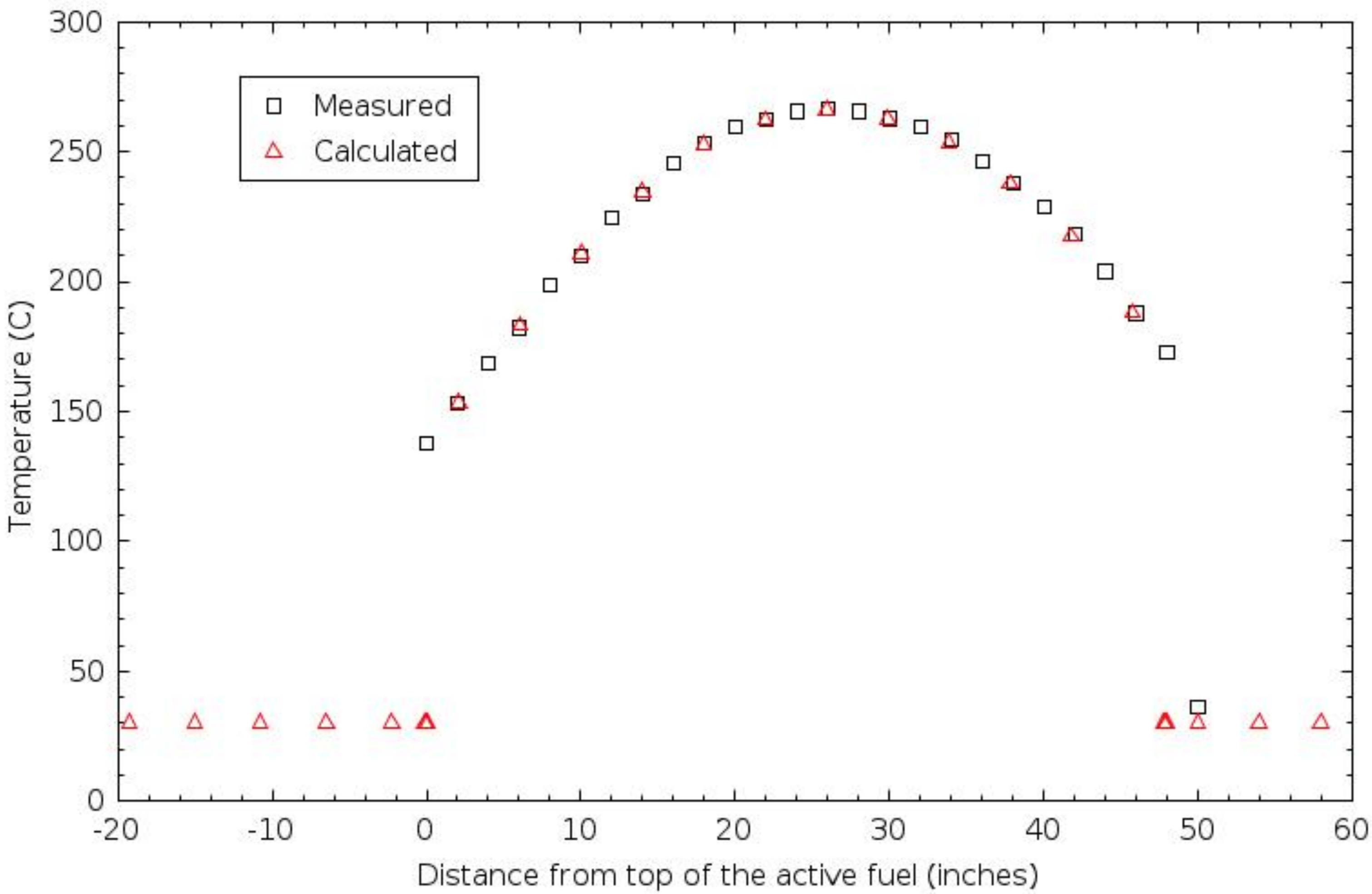
Description of the RELAP5-3D model (cont'd)



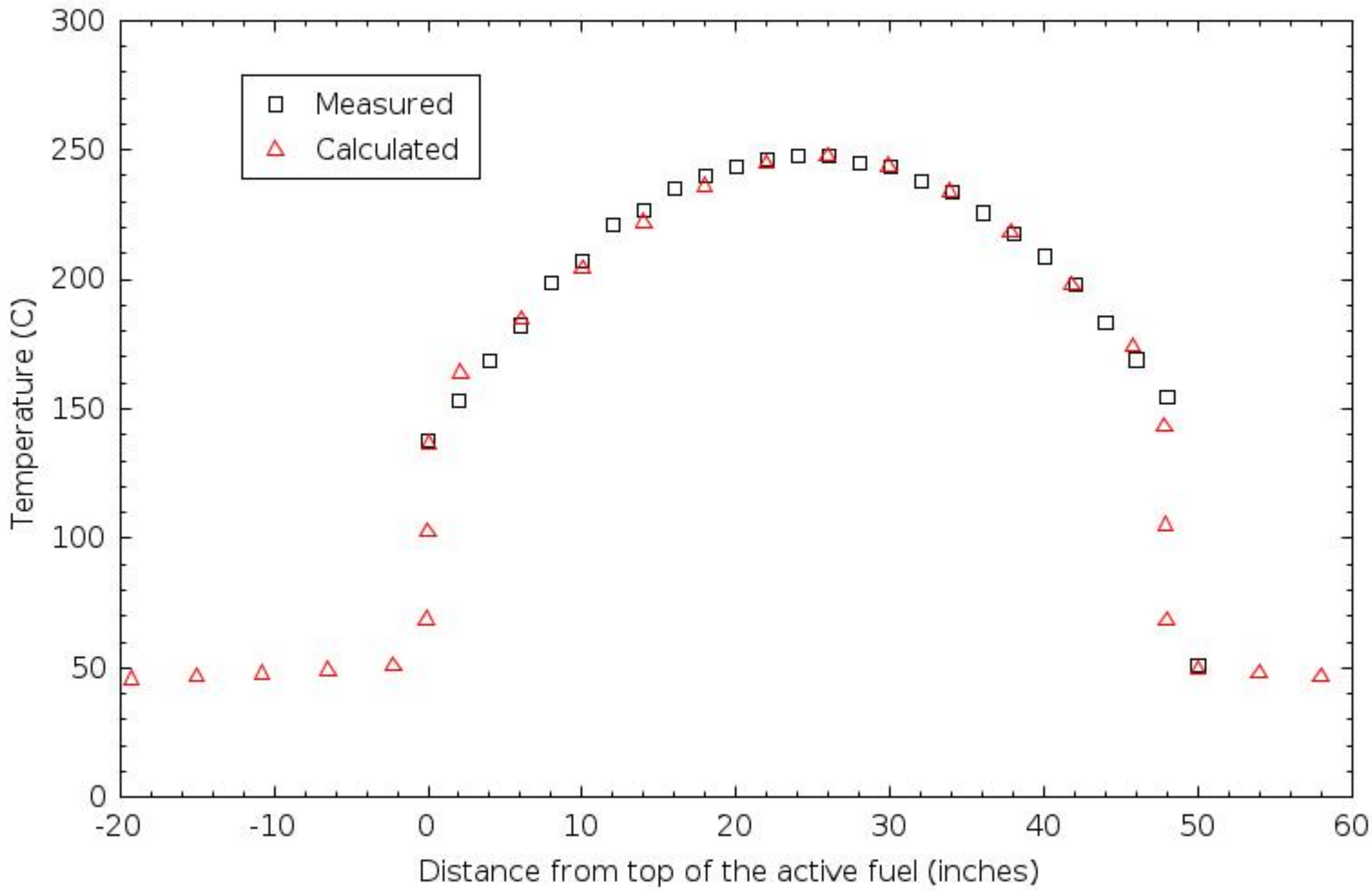
Validation results were generated for a historical cooldown test

- Test initiated by an unshaped reactivity transient that established the initial axial temperature distribution
  - Axial conduction was the dominant heat transfer mechanism prior to 87 minutes, when the blowers were turned on
  - Forced convection to air was the dominant heat transfer mechanism after 87 minutes
- The model was adjusted to match temperature measurements
  - The axial thermal conductivity of the fuel was reduced from a nominal value of 21 W/m-K to 13 W/m-K
  - The axial thermal conductivity of the insulators was set at 0.15 W/m-K
  - The heat transfer coefficients were multiplied by a fouling factor of 0.45
    - Most of the heat transfer area is cooled by a relatively small fraction of the flow that probably sees much worse than average heat transfer conditions

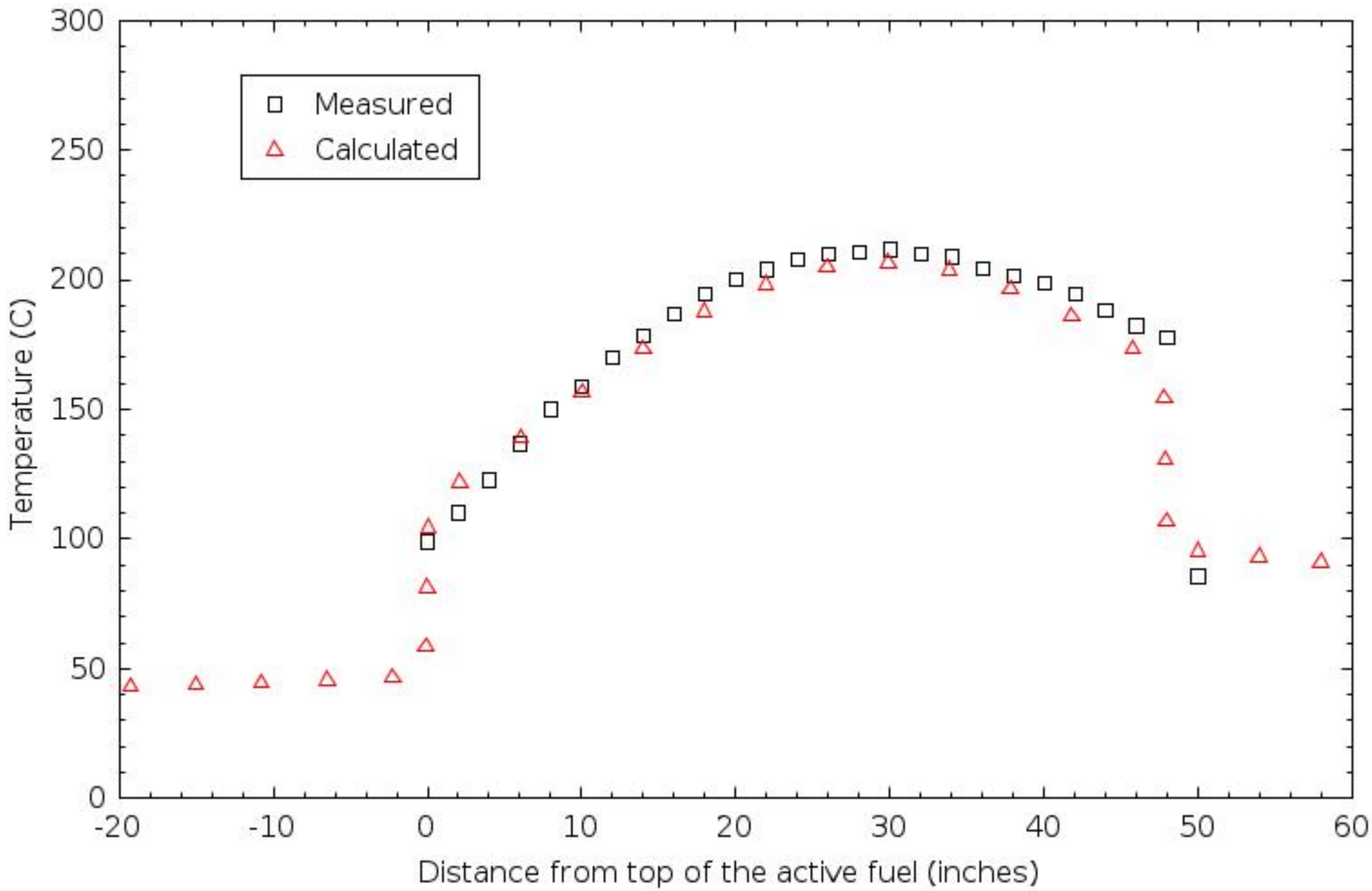
Axial temperature profiles in the historical cooldown test at 0 min



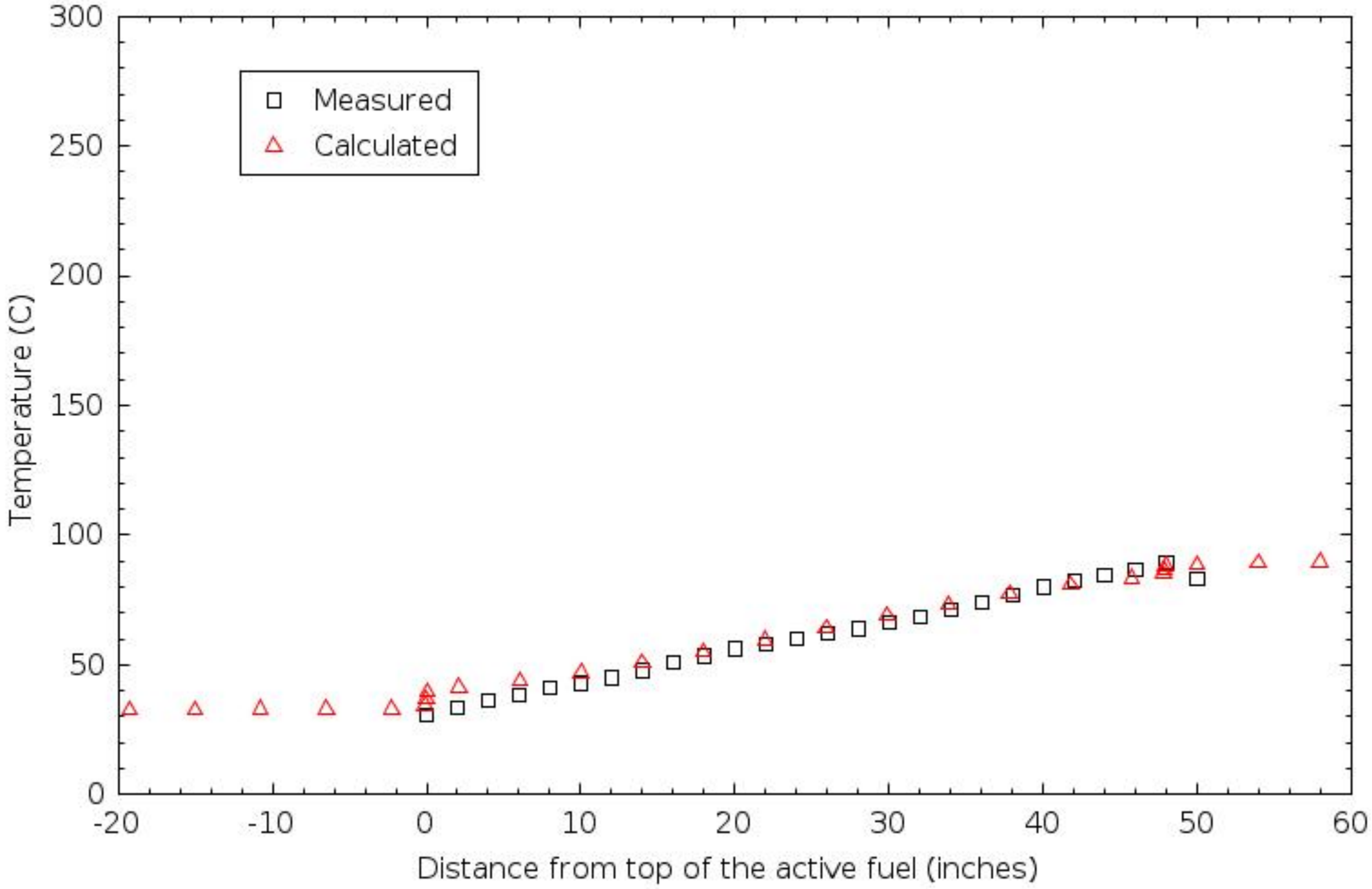
Axial temperature profiles in the historical cooldown test at 85 min



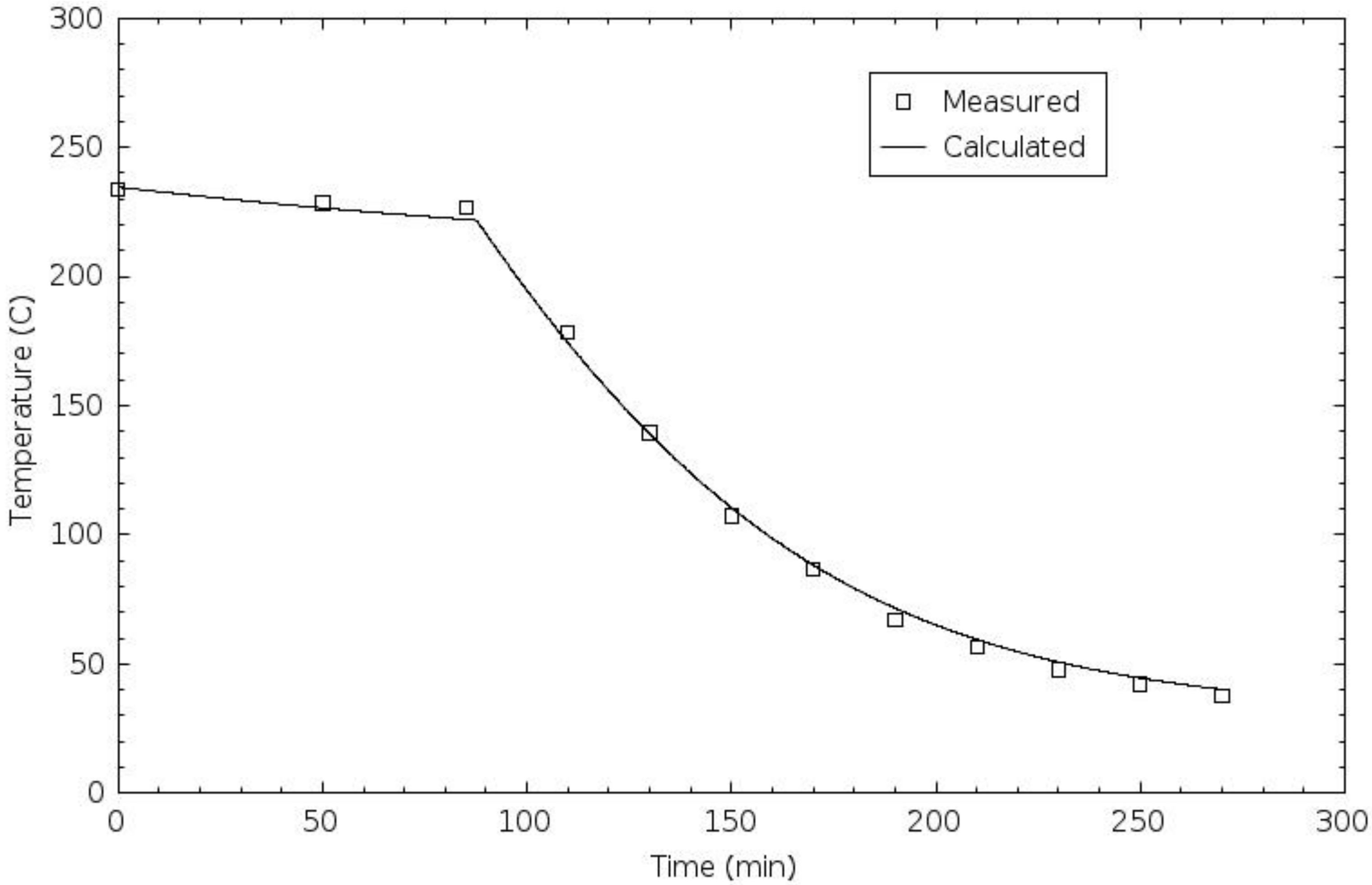
Axial temperature profiles in the historical cooldown test at 110 min



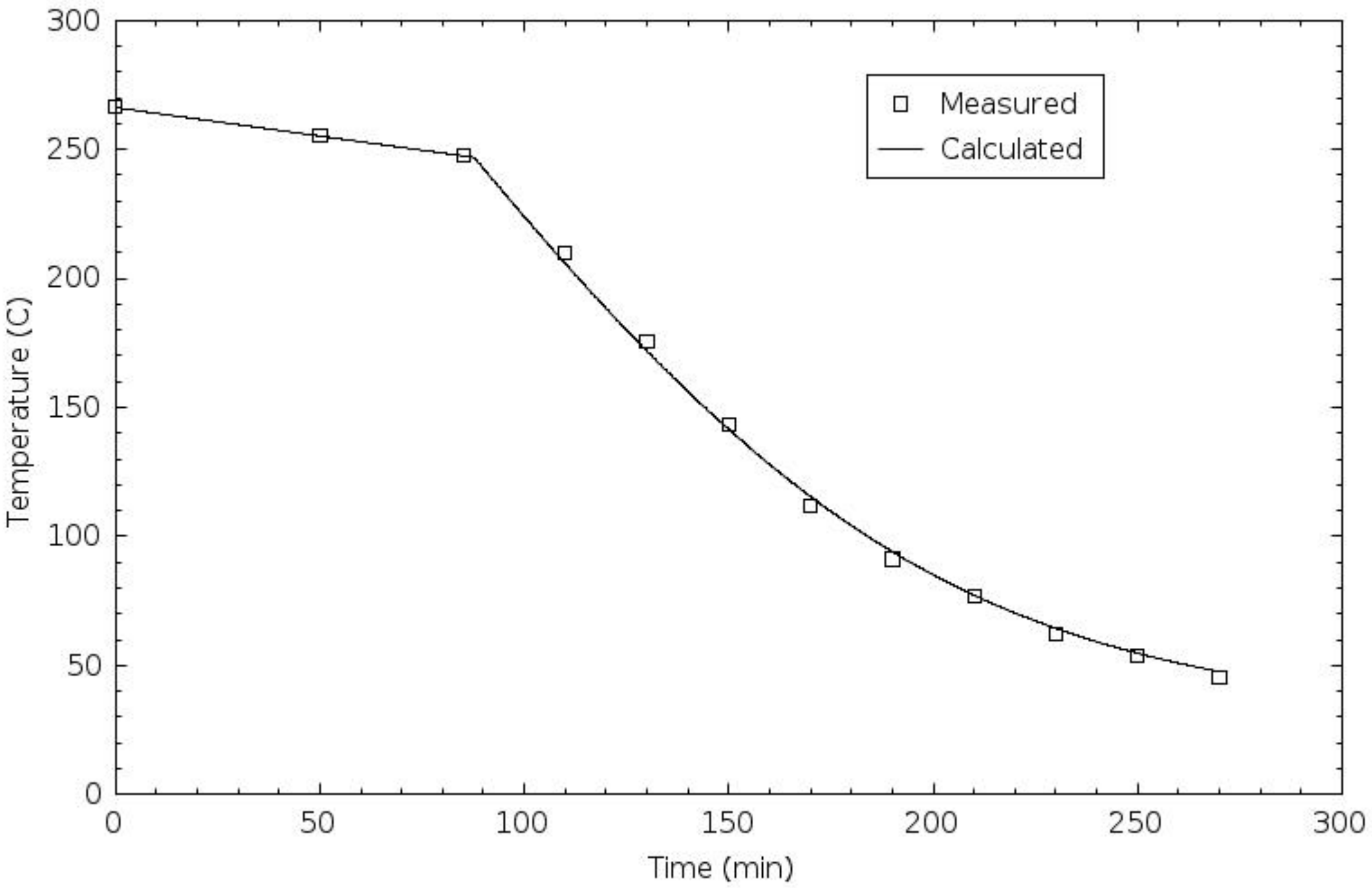
Axial temperature profiles in the historical cooldown test at 230 min



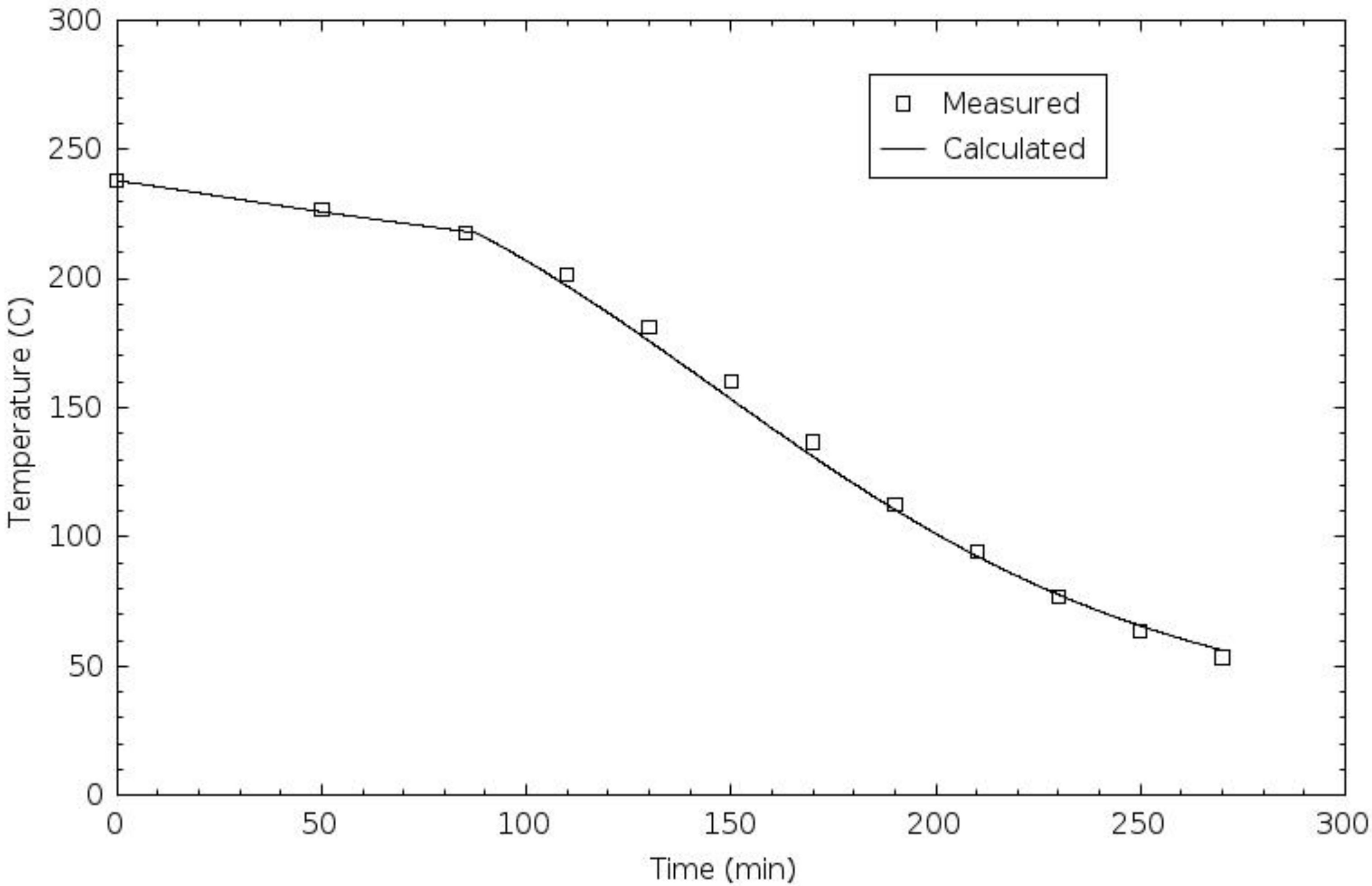
Temperature versus time 14 inches from the top of the active fuel in the historical cooldown test



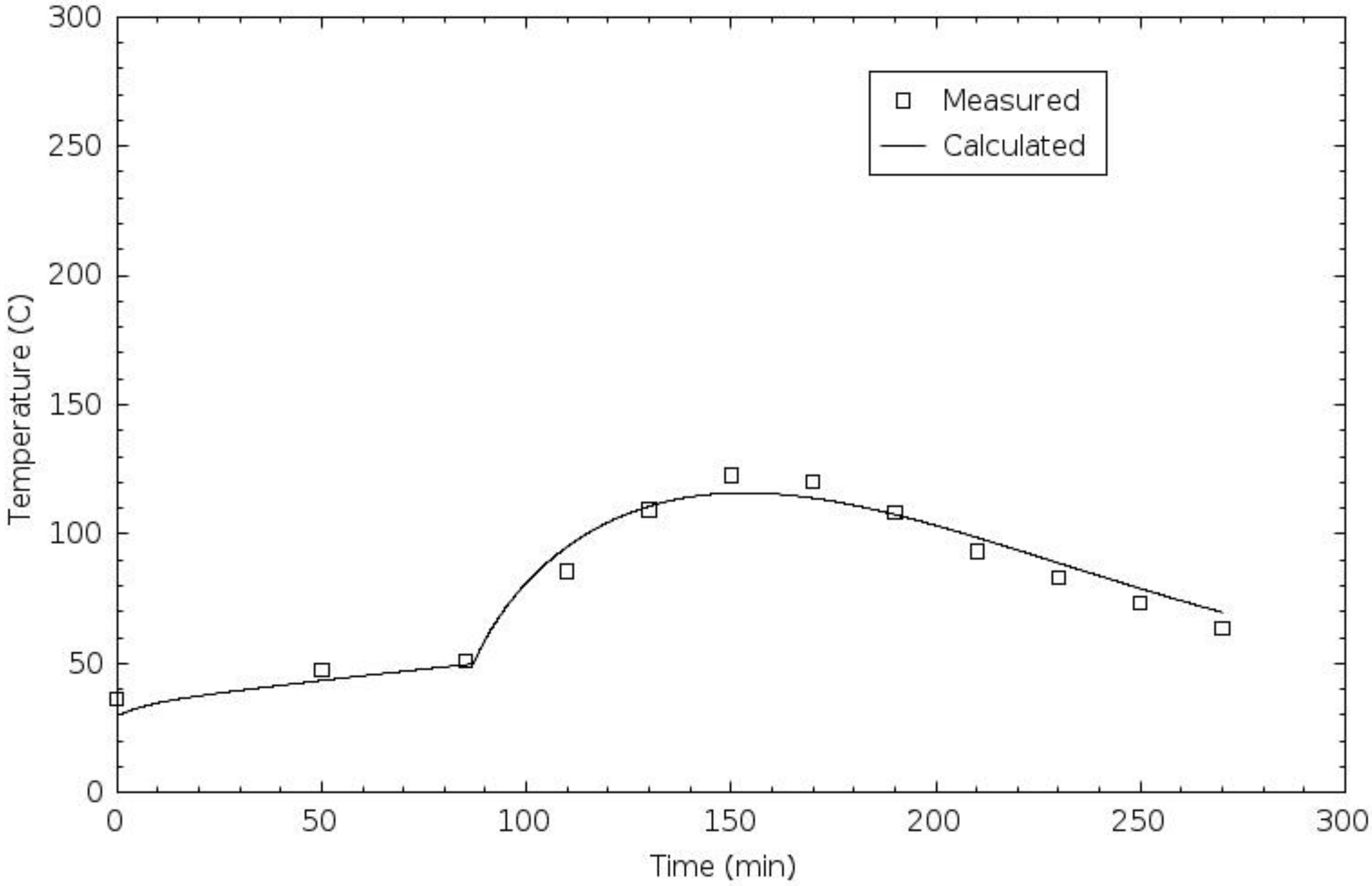
Temperature versus time 26 inches from the top of the active fuel in the historical cooldown test



Temperature versus time 38 inches from the top of the active fuel in the historical cooldown test



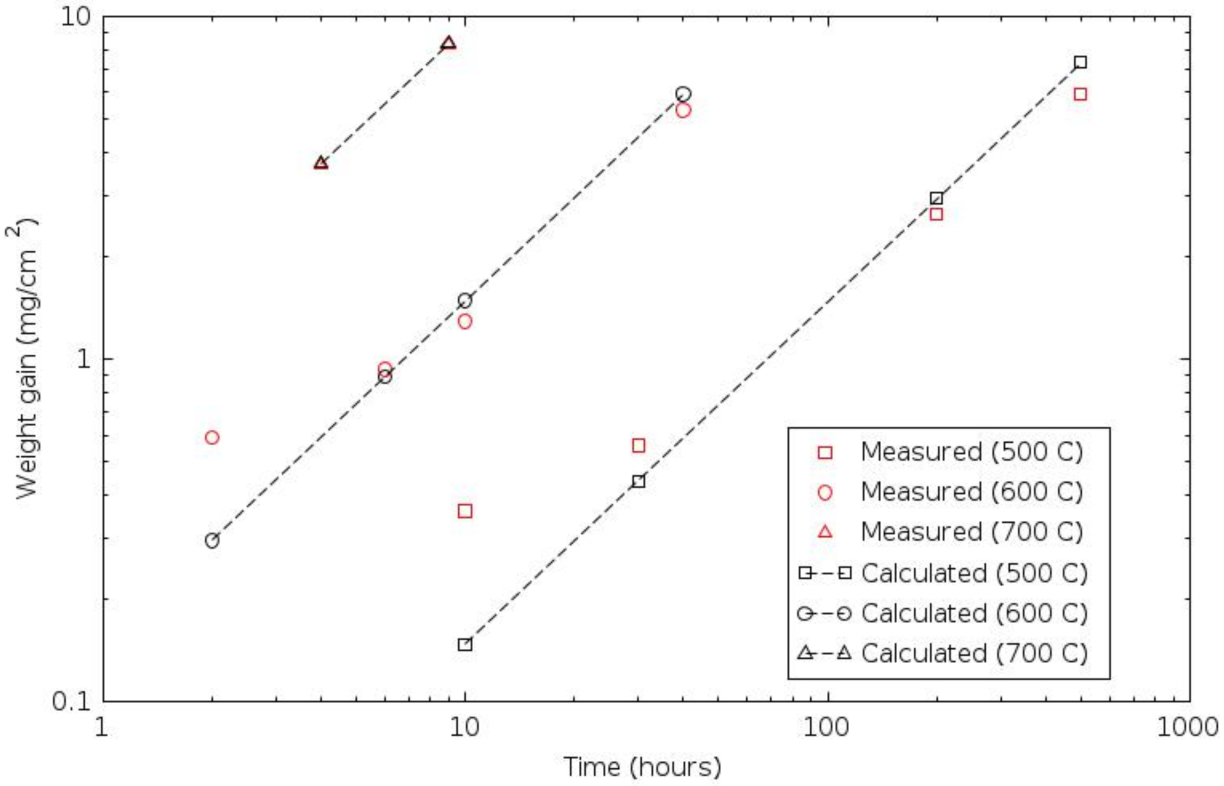
Temperature versus time 50 inches from the top of the active fuel in the historical cooldown test



Zircaloy oxidation model

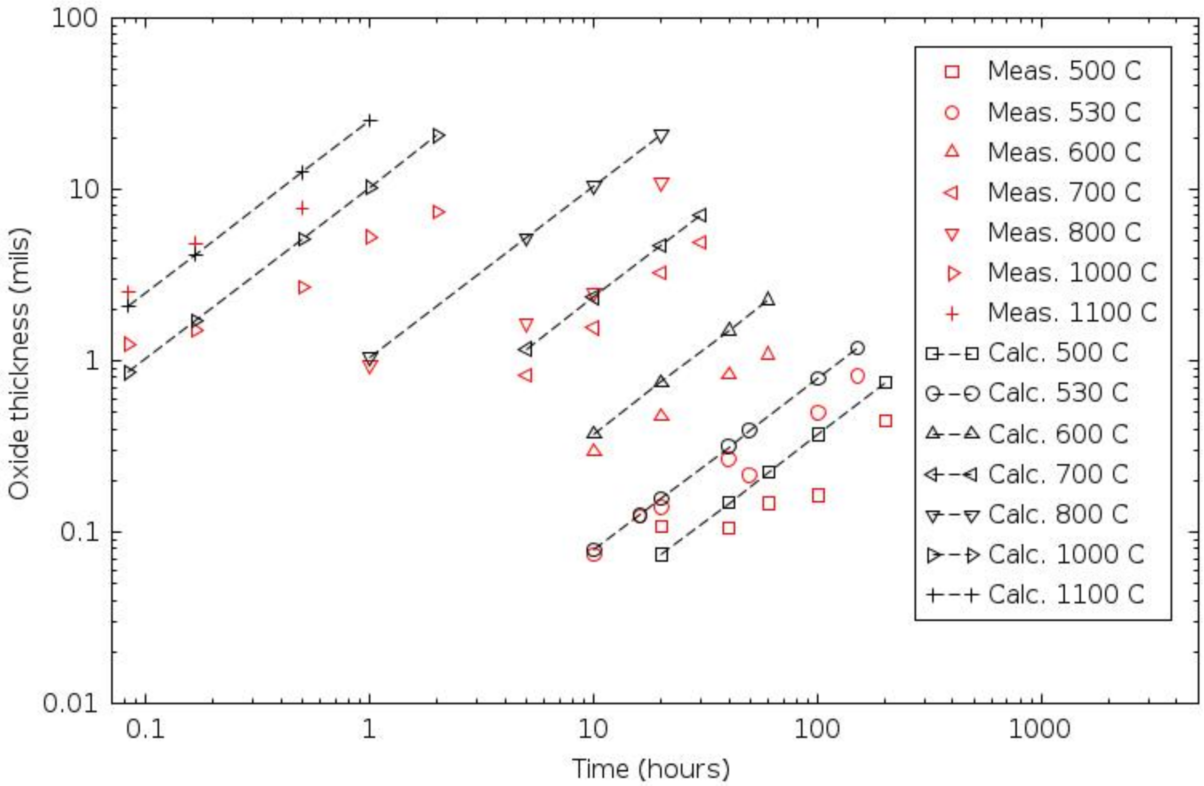
- The oxidation model for TREAT is:
  - $W_{gain} = A\ t\ e^{(-Q/(RT))} = 8.5E6\ t\ e^{(-3.10E4/(1.9872\ T))}$, where W_{gain} is the weight gained due to oxidation (mg/cm^2), t is time (hr), and T is the temperature (K)
  - The model is based on oxidation measurements of Zircaloy-2, which is conservative for TREAT, which has Zircaloy-3
- The RELAP5-3D metal-water reaction model is based on parabolic, not linear, kinetics
- The control system was used to monitor the oxidation of the Zircaloy can at the peak power location

Oxidation of Zircaloy-2 samples



- Slope changes in measured curves are due to a transition between reaction regimes
- The pre-transition regime was characterized by a reaction rate between parabolic and cubic
- The post-transition regime was linear
- The model is based on the linear, post-transition data

Oxidation of Zircaloy-3 samples

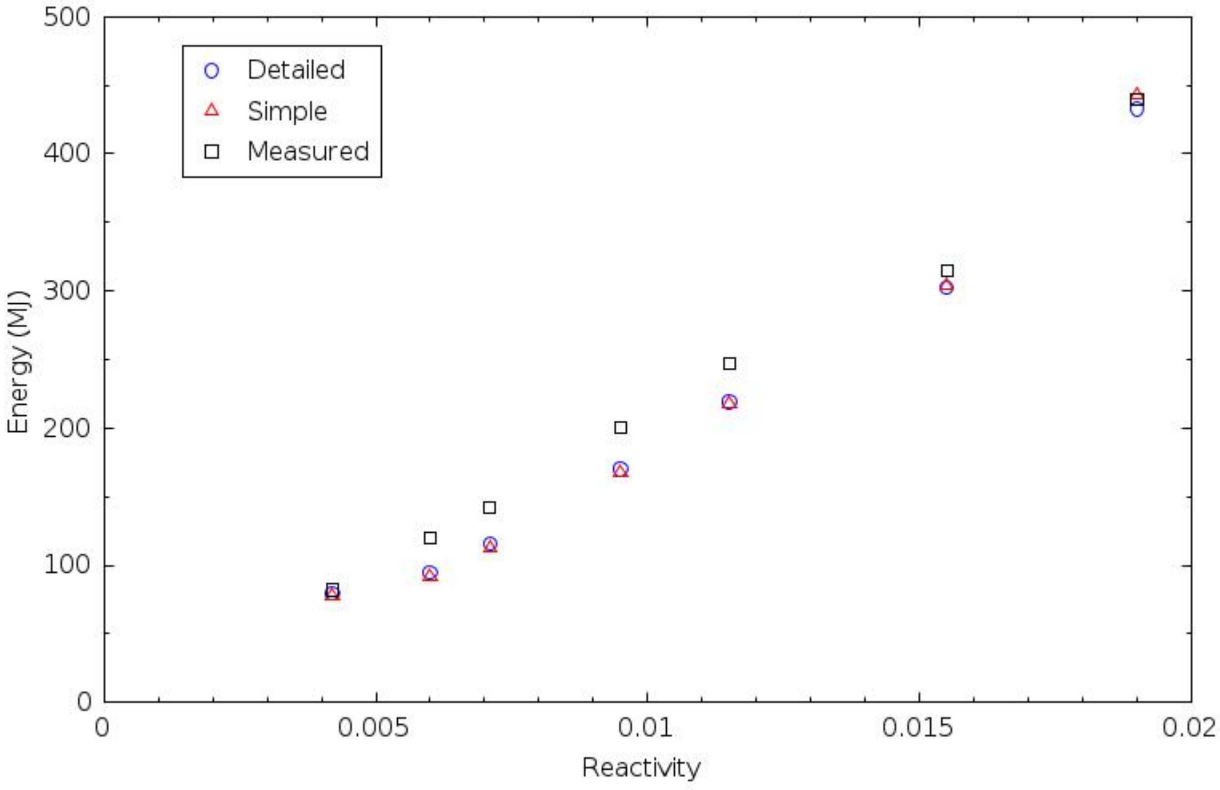


- TREAT fuel assemblies are clad with Zircaloy-3, not Zircaloy-2
- The calculated oxide thickness exceeds the measured value for 24 of 28 points
- Therefore, the model is conservative

Validation results were generated for a wide range of reactivity insertions

- 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$
- Results were similar to those obtained previously with the simple model

Both models produced a reasonable representation of the historical data



- The energy deposition in was 11% low, on average, with the detailed model
- The calculated results with the detailed model were generally a little better than those obtained previously with the simple model

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Conclusions

- The detailed RELAP5-3D model was validated using data from cooldown, oxidation, and reactivity insertion experiments
- Adjustments were made to the detailed model to match measured cooldown data
  - The axial thermal conductivities of the fuel and insulators were adjusted to match measured core temperatures prior to blower operation
  - The convective heat transfer coefficients were lowered to match measured cooldown rates when the blowers were operating
  - After these adjustments, the quantitative agreement between the calculated and measured temperatures is reasonably good
  - The model captures all of the significant trends observed in the test

Conclusions (cont'd)

- The RELAP5-3D model monitors the oxidation of the Zircaloy can at the peak power location in the hot fuel element
  - The model is based on oxidation measurements of Zircaloy-2 samples in the post-transition regime
  - The model was validated for TREAT applications using oxidation data from Zircaloy-3 samples
  - The calculated oxide thickness exceeded the measured value for 28 of the 32 data points
  - Therefore, the model is conservative with respect to the calculation of oxidation of the TREAT cladding

Conclusions (cont'd)

- The detailed model generates results that are in reasonable agreement with measured values of maximum core power, energy deposition, and maximum fuel temperature for a wide range of reactivity insertions
- The detailed and simple models produce similar results for the reactivity insertion experiments
  - Since the simple model runs much faster, it is more suitable for programmatic analyses to support experiments
  - The detailed model is better suited to simulate the long-term response of the reactor during experiments and accidents
  - Therefore, the detailed model is more suitable for reactor safety calculations