Experimental Observation and Numerical Prediction of Induction Heating in a Graphite Test Article

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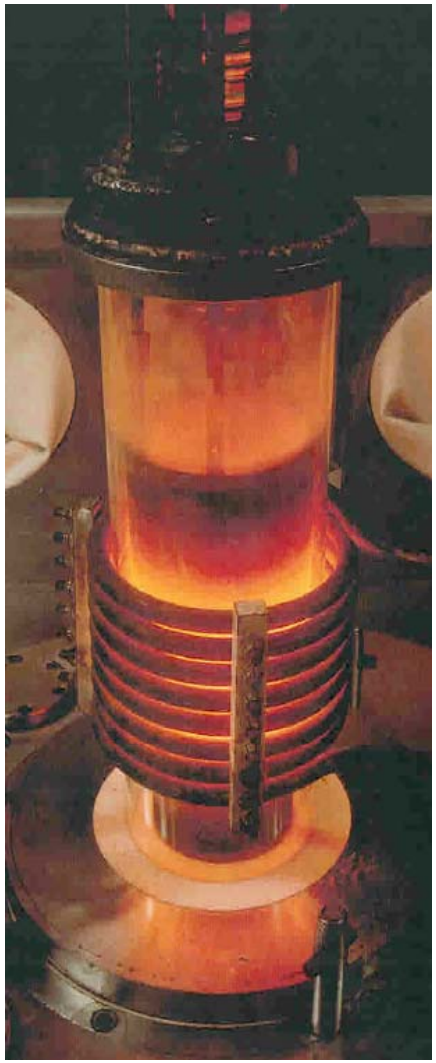
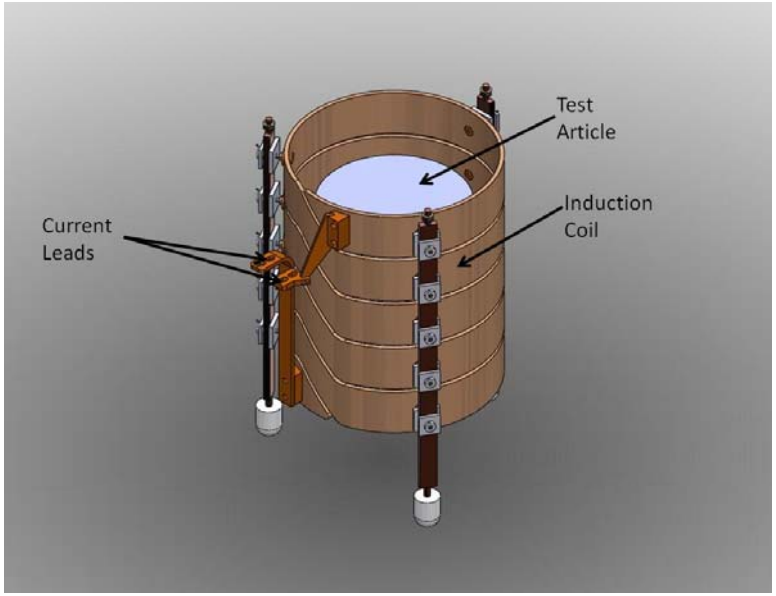
Outline

- **Introduction to plutonium casting at Los Alamos National Laboratory (LANL)**
- **Specific operational issues associated with the mold portion of the furnace**
  - Non-uniform heating of molds
  - Imperfect alignment of molds with the induction coil
- **Use of experiments and COMSOL Multiphysics to understand the induction heating process**
  - Comparison of experiments and modeling
- **Future work**

Plutonium Casting uses a Gravity Casting Furnace

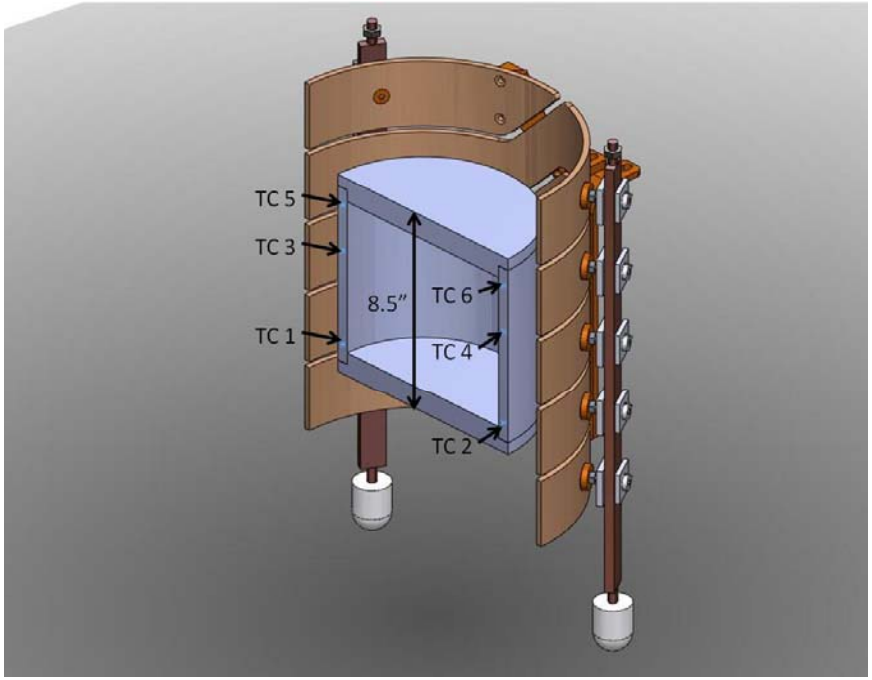
- **Molten plutonium is produced by induction heating in a tantalum crucible**
- **Molds are pre-heated by induction heating with a coil that is not water cooled**
- **Both induction coils operate at 9600 Hz**





Modeling and Simple Experiments Used to Understand the Induction Heating Process

- **In operation, molds typically see 10 to 20 deg. C temperature differences around the circumference**
  - Have been attributed to misalignment of the mold in the induction coils or variations in material properties and geometry
- **These temperature differences can affect heat transfer and microstructure of the casting**
- **A simple cylindrical test article has been studied numerically and experimentally**
  - Graphite test article is instrumented with thermocouples

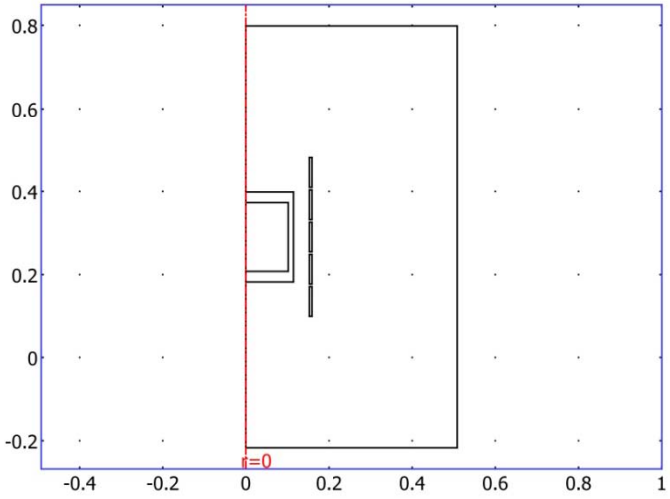


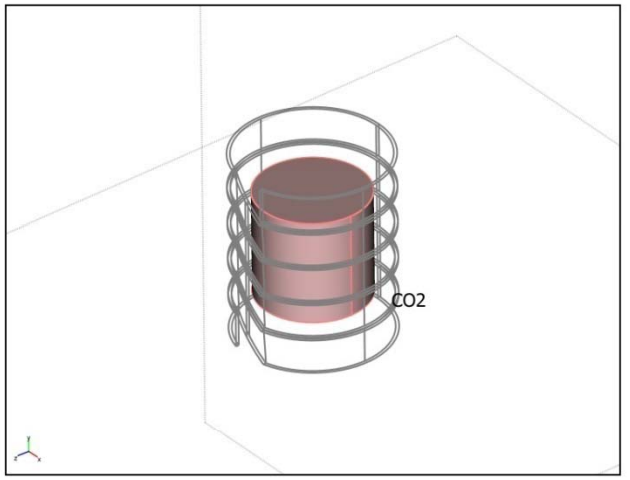
COMSOL Multiphysics has been Used to Model the Transient Warm-up of the Test Article

- **Two and three dimensional models have been built with the pre-defined induction heating couplings**
  - Induction currents application mode: time-harmonic solution for magnetic vector potential (parametric in time)
    - Surface current boundary condition on the inner surface of the coil
  - Heat transfer application mode: transient solution for temperature distribution in the coil and test article
    - Volumetric heating in the graphite from induction currents calculation
    - Surface heat flux due to resistive losses in the skin depth of the coil

$$\dot{q}'' = J_s^2 \Big/ \left(2\sigma_{cu}\delta_{cu}\right)$$

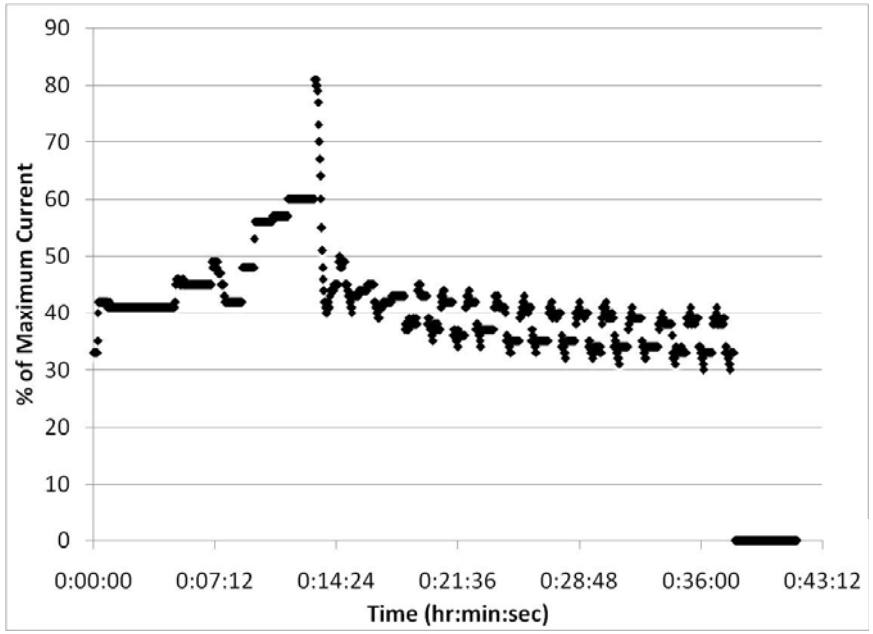
    - Surface to surface radiation throughout

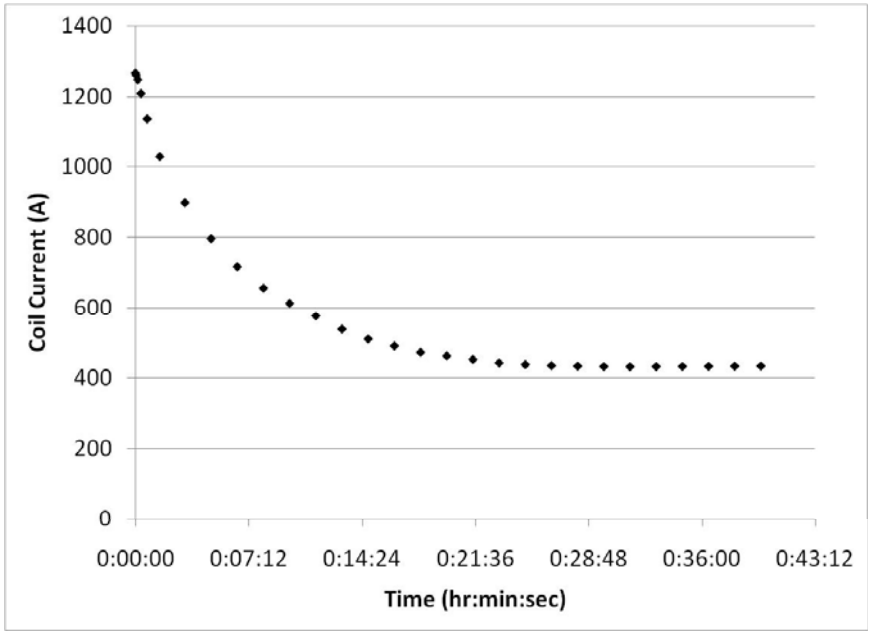




Current in the Induction Coil is Determined by a Controller in the Furnace

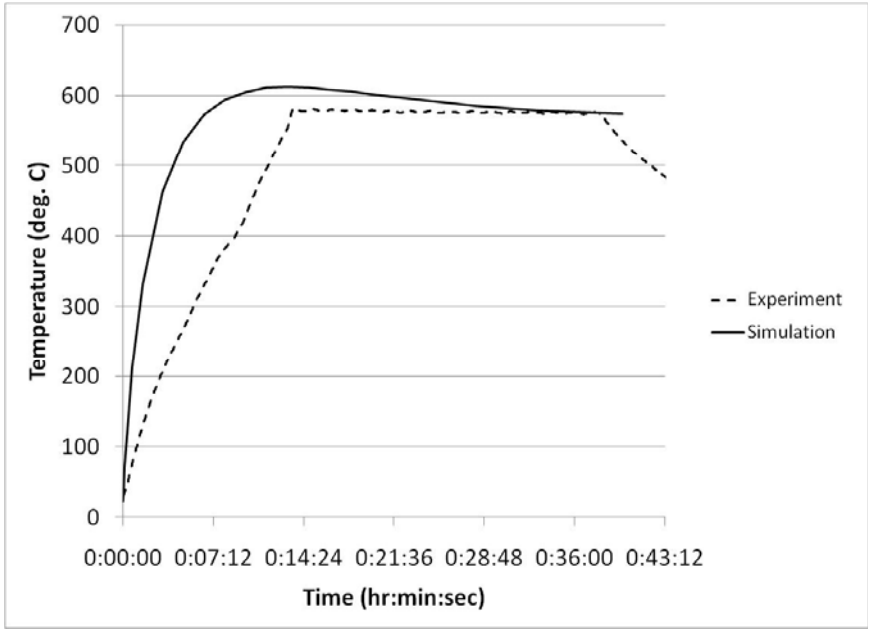
- **Step Control used in the furnace**
- **PID control simulated in 2-D Comsol model and used as an input in 3-D Comsol model**

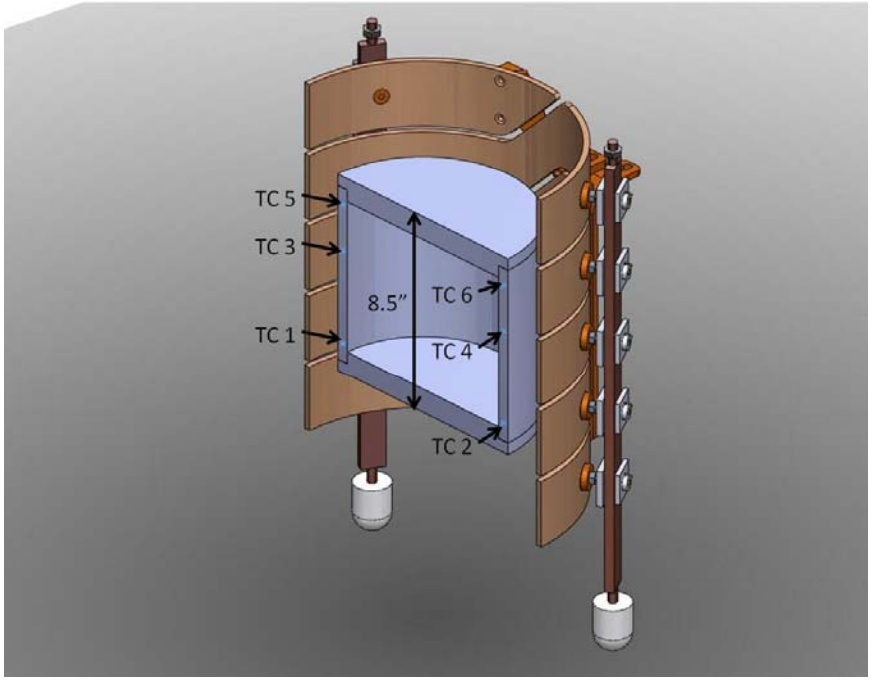




Simulate PID Control Gives a Warm-up with Similar Rise Time, Overshoot, and Settling Time

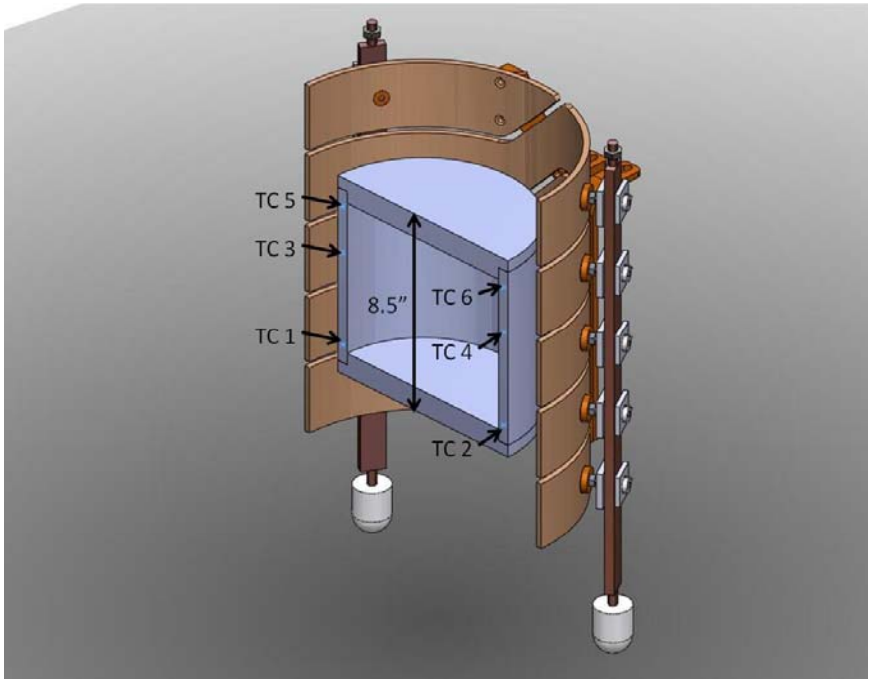
- **Control point is the average of two of the thermocouples on the graphite body (TC 3 and TC 4)**

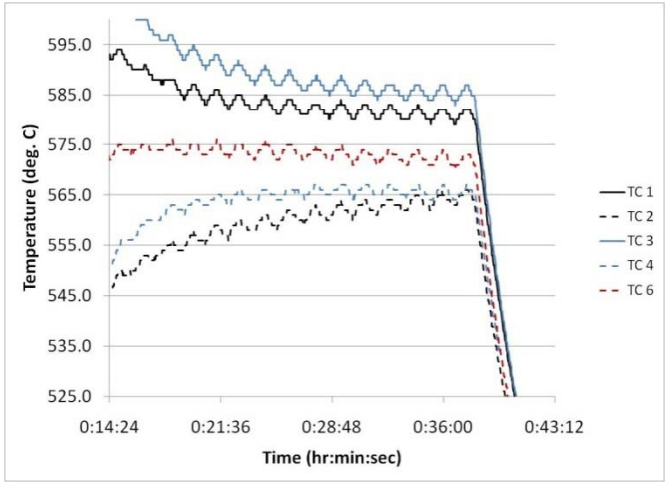


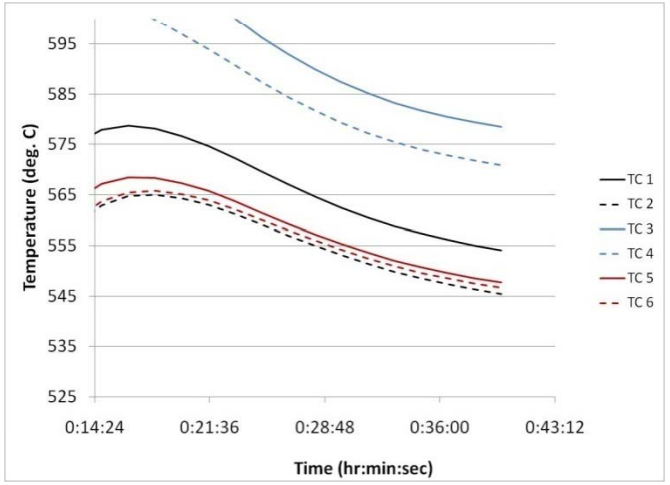


Results Show Side with Odd Numbered Thermocouples is Typically 10-15 deg. C Higher Temperature

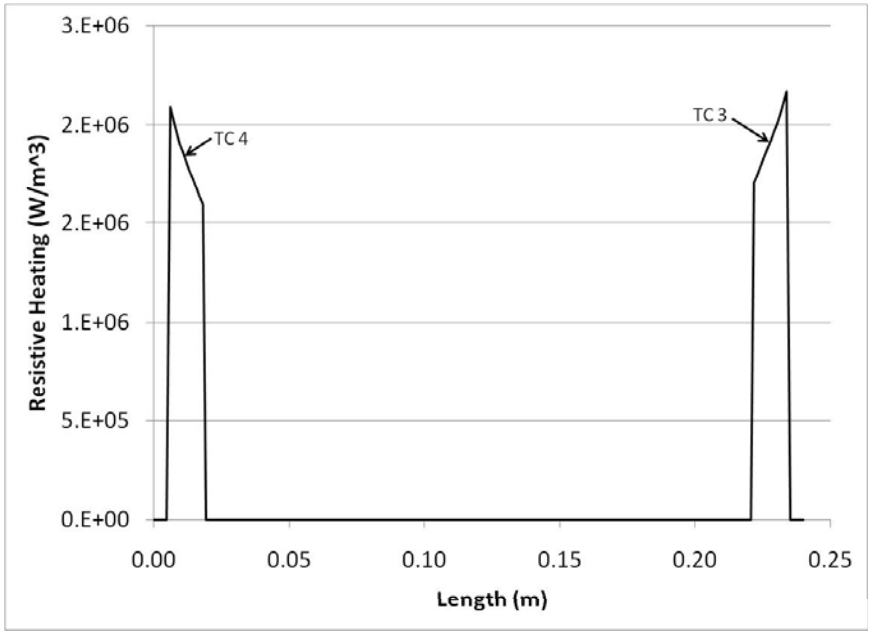
- **End effects are not accounted for in the simulations**

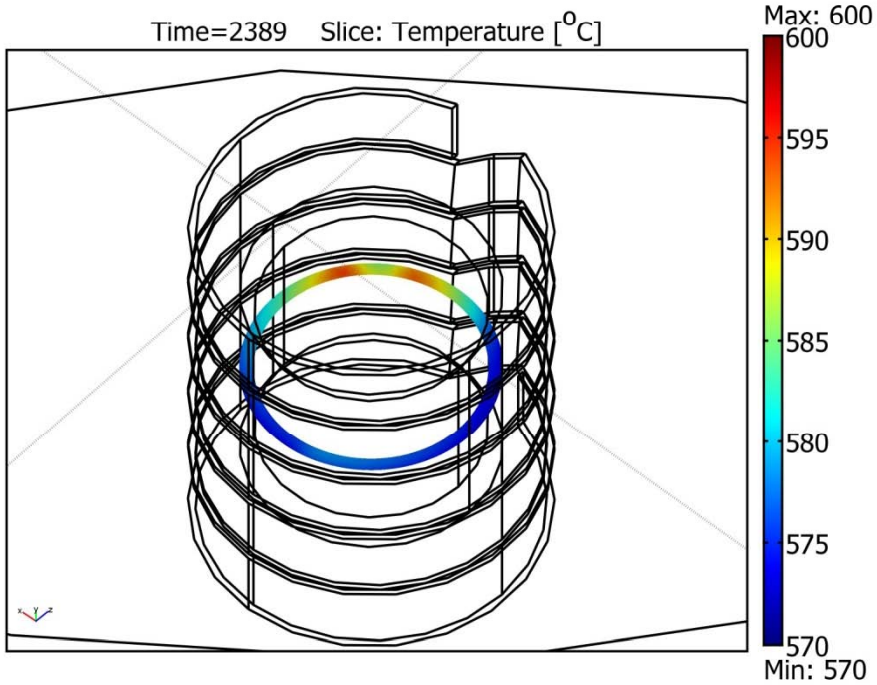






Resistive Heating and Temperature Distribution Show Non-Uniform Heat Generation Due to the Coil Design





Preliminary Modeling Studies Suggest that Coil Redesign is Required to Eliminate Non-Uniform Heating

- **Future work will include:**
  - Updating COMSOL models to include:
    - test article stand
    - more realistic radiation boundaries in the furnace
- **Experiments and COMSOL simulations of the test article at various locations in the induction coil**
- **Design and analysis of new coils to provide:**
  - Uniform mold heating
  - More flexibility in operations

Questions