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CORRELATING INCIDENT HEAT FLUX AND SOURCE TEMPERATURE TO MEET ASTM E1529 REQUIREMENTS FOR RAM PACKAGING COMPONENTS THERMAL TESTING

PVP2021- 62039

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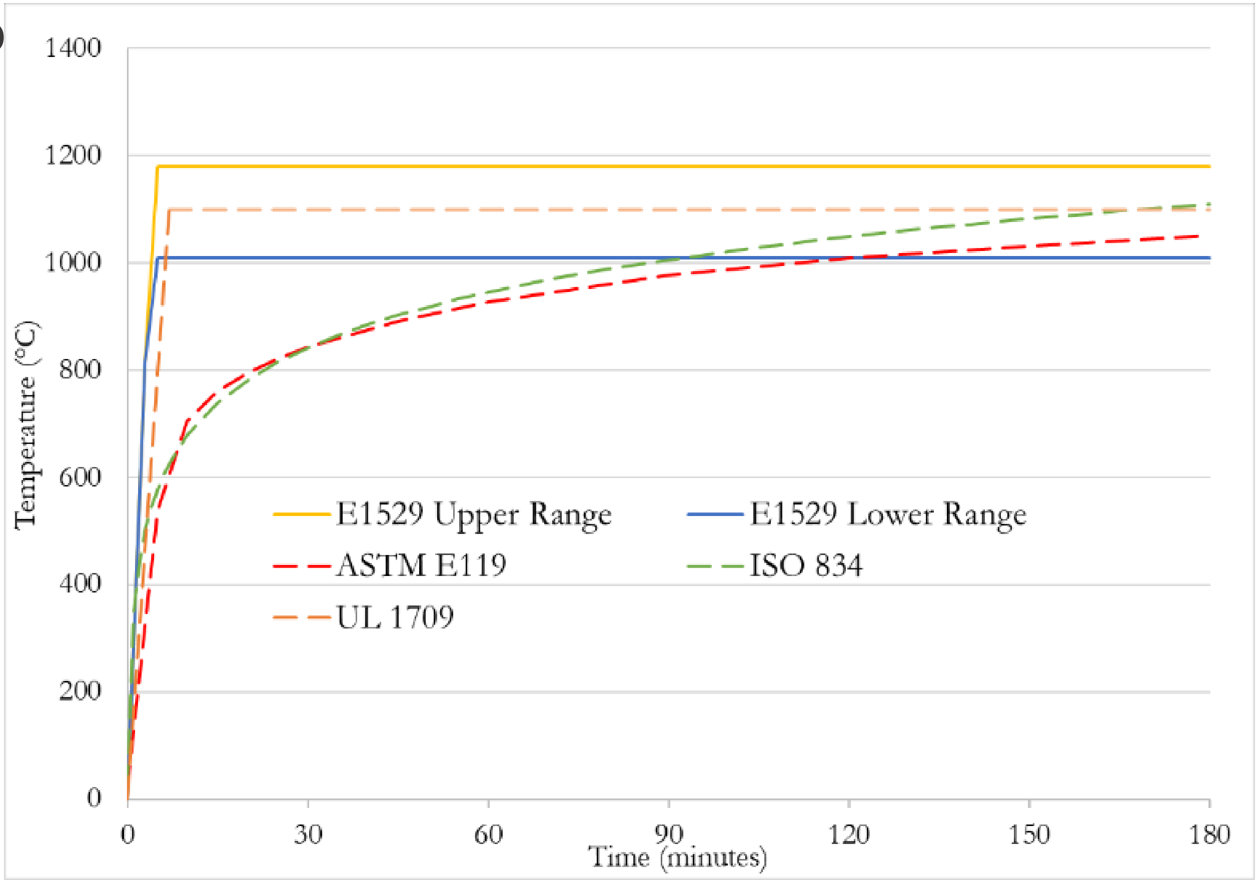
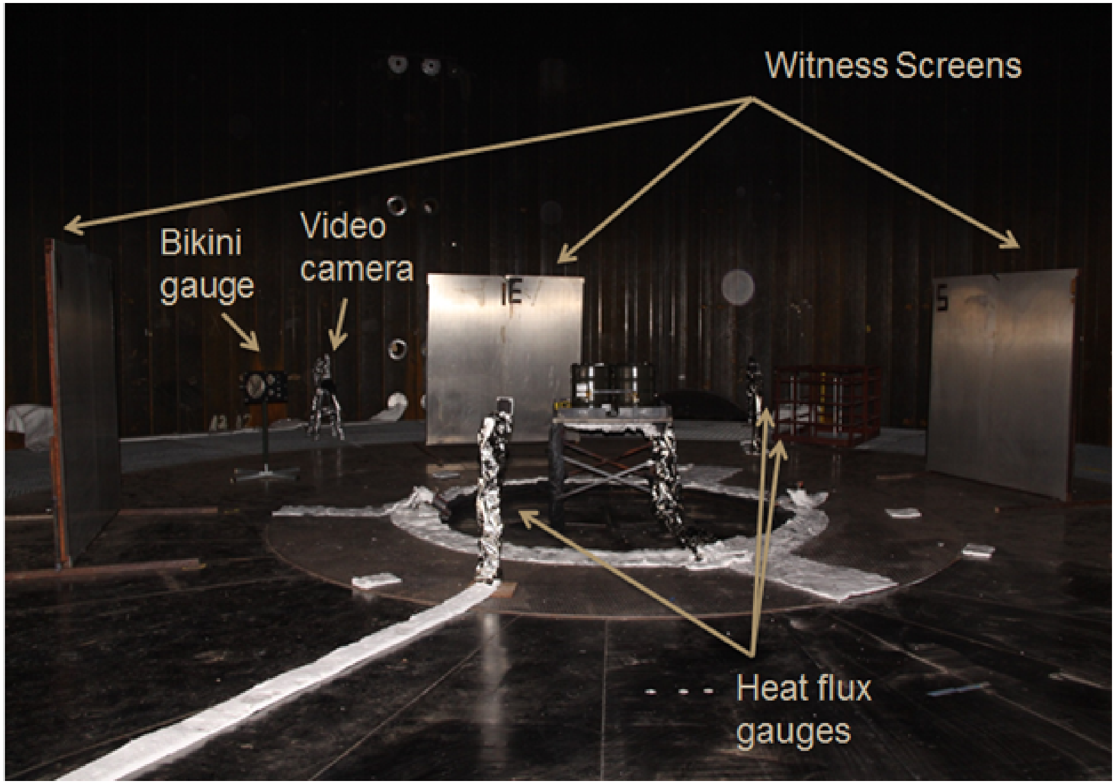
Introduction and Standardized Thermal Testing

- Standardized fire resistance testing is used to determine integrity of vessels and hardware
- There are several standardized time-temperature curves that various committees and authorities adopt
- While some of these standardized time-temperature profiles specify just the temperature, ASTM E1529 also specifies a heat flux requirement
- The heat flux is an important metric when simulating for example a hydrocarbon pool fire
  - A candle and a hydrocarbon pool fire might have the same temperature, but the emitted heat flux is orders of magnitude different



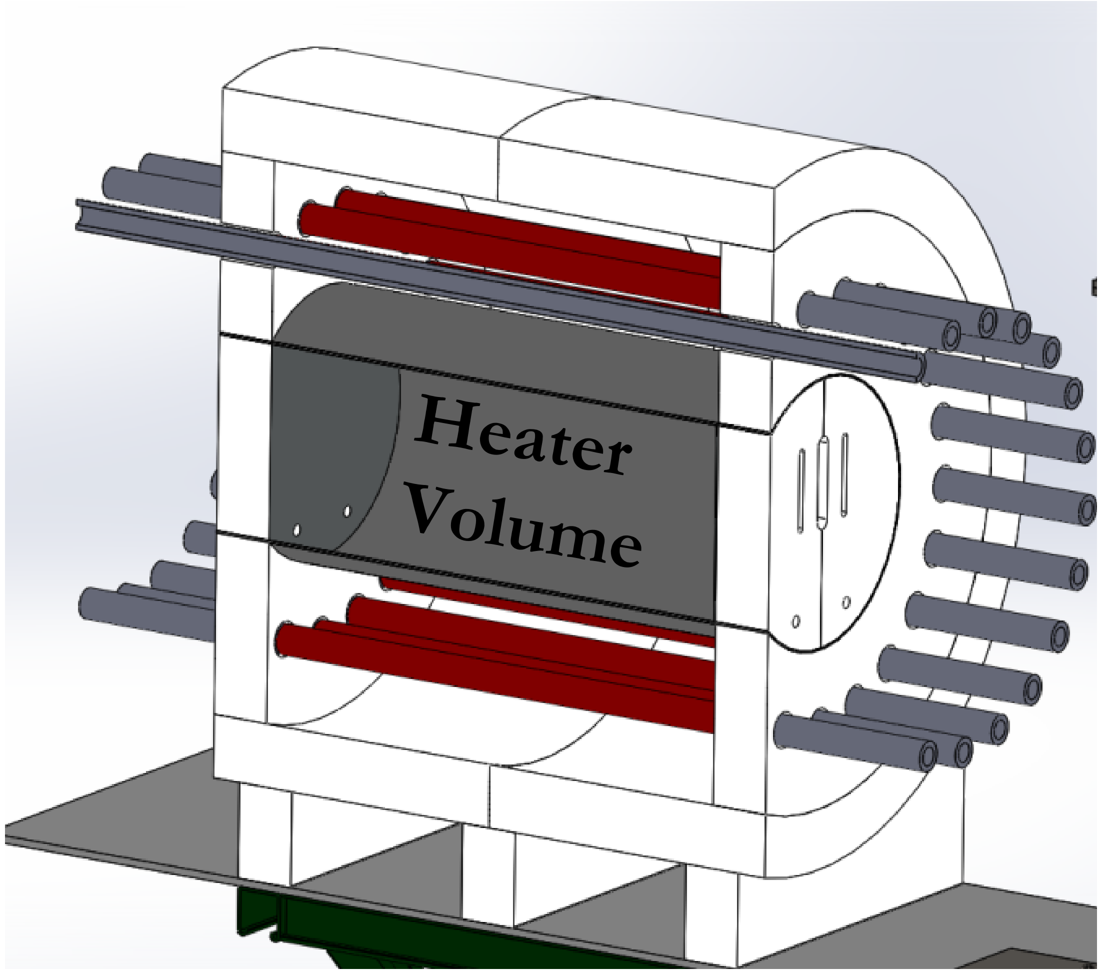
Common Calibration Methods

- Directional Flame Thermometers (DFTs) can be used to calibrate and verify a thermal environment
  - These are passive sensors and are used to record information rather than provide live data
  - Inverse Filter Functions can be programmed to provide real time data but are difficult to implement
- Typically, DFTs have dimensions of 4 in. x 4 in. x 1.41 in. (102 mm x 102 mm x 35.8 mm)
  - Can be difficult to implement based on packaging constraints



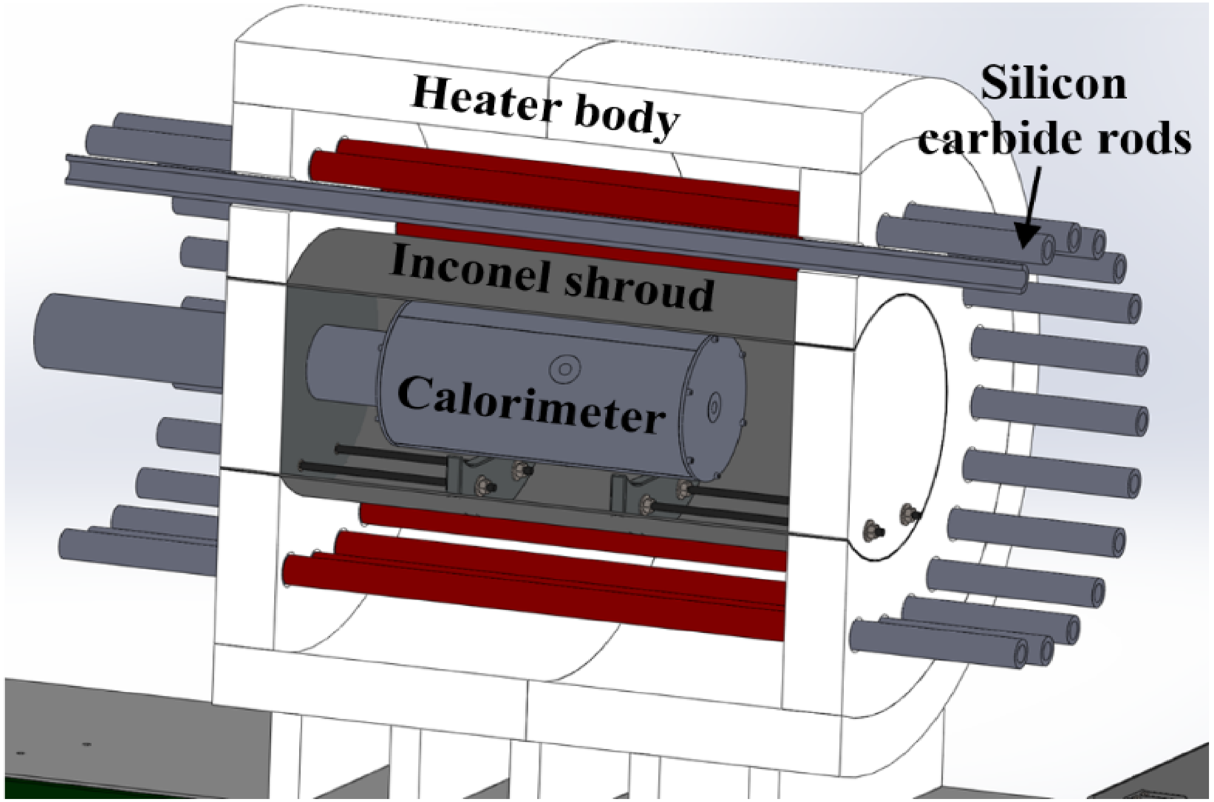
Heated Environment Space Constraints

- Limited heater volume does not allow for fielding both unit under test as well as heat flux instrumentation
- Additionally, potential volatility of unit under test may lead to damage to heat flux instrumentation, which may be cost prohibitive if several tests are going to occur



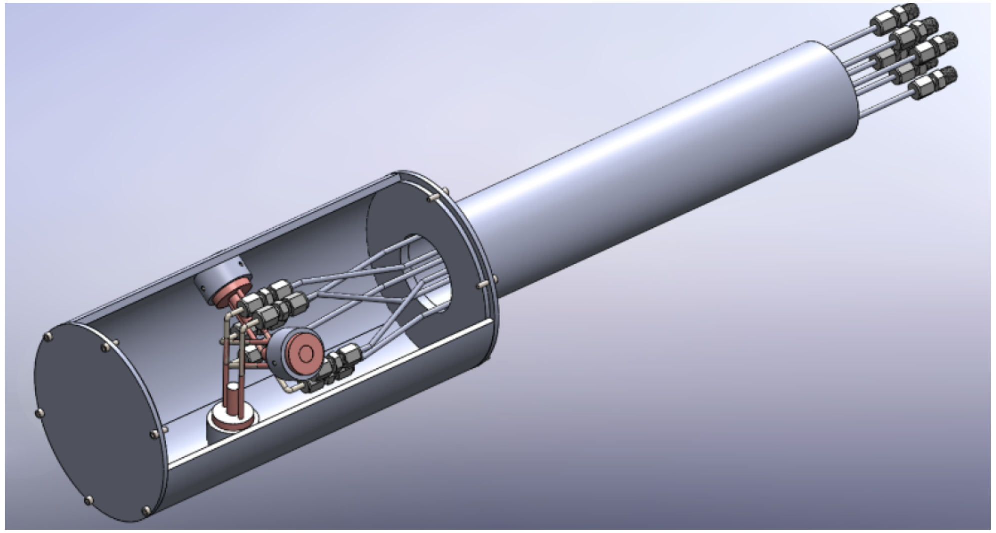
Proposed Method

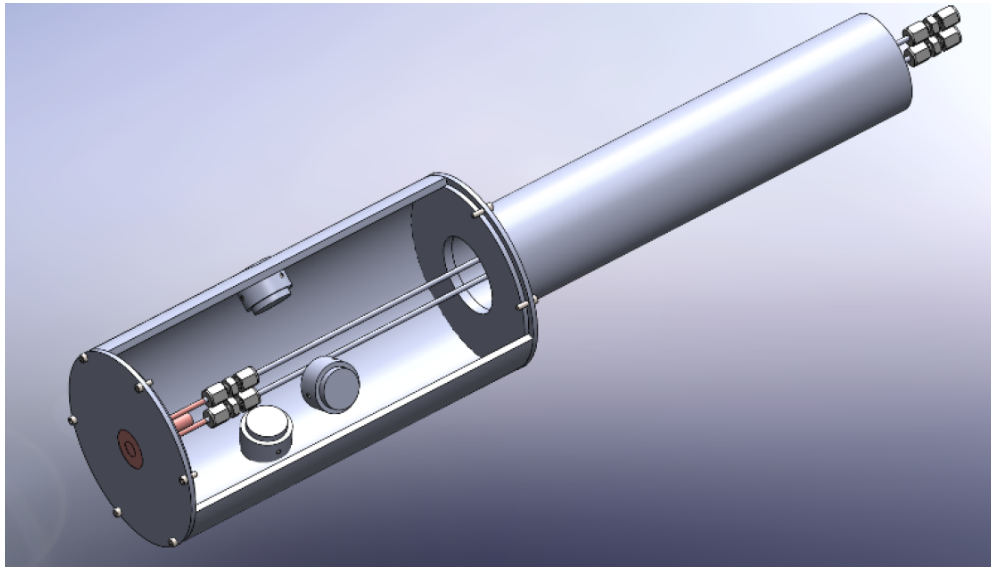
- Use of a shroud and calorimeter configuration
  - The shroud can be placed in a heated environment such as an oven, pool fire, or in this case surrounded by silicon carbide heating elements
  - Placing the shroud between the test specimen and thermal environment will create a more uniform heating environment
- Water cooled Gardon-style gauges are installed into a calorimeter that matches the test specimen as close as possible
  - The incident/cold-wall heat flux vs. the absorbed/net-heat flux measured by DFTs
- Correlating the incident heat flux to the shroud temperature gives the ability to control the heat flux in test without requiring heat flux gauges on the test article/in thermal environment



Calorimeter Design and Control

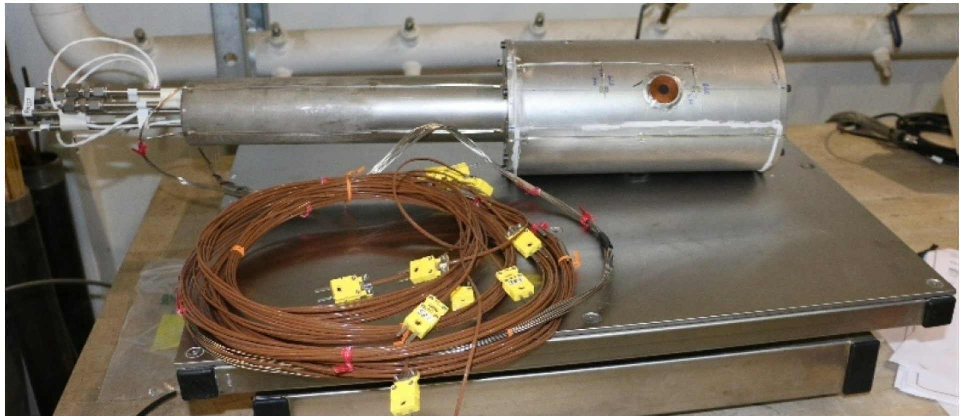
- The calorimeter was designed to mimic the test specimen as closely as possible
- Critical metrics include the material, surface properties, thermal mass, geometry and placement in the thermal environment:
  - Two shells made from 316L stainless steel formed a nominally 5 in. (127 mm) diameter and 10 in. (254 mm) in length cylinder with a 0.19 in. (4.83 mm) wall thickness
  - Alumina powder was used inside of the vessel to match the payload of the test specimen
  - Wide-angled water-cooled SB gauges are installed in either a radial configuration pointing outward every 120º or from the end of the calorimeter
  - The calorimeter rests on 2 Alumina Type SALI saddles that are ½" thick which ensures it is centered both concentrically and along the length of the heater assembly

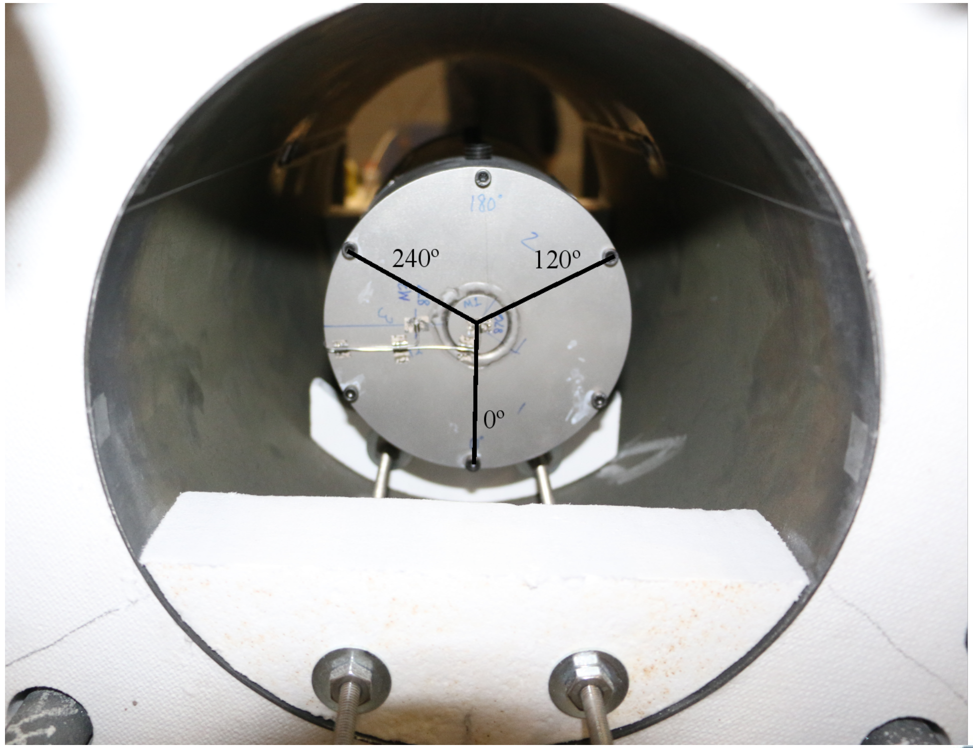




Calorimeter Design and Control Cont.

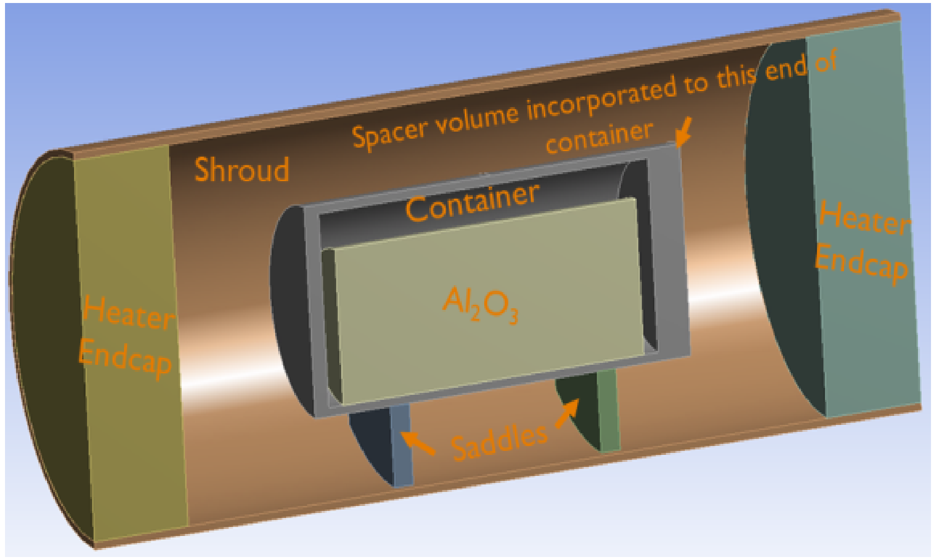
- The heater has 21 total silicon carbide heating elements
  - They are batched into groups of 7
- Type-K thermocouples are placed on the inner portion of the shroud to measure the real time temperature
  - These are used to monitor the temperature of the shroud and adjust the heater power input to meet the ASTM E1529 temperature requirements
- The heater power set points are predetermined and programmed into the control system to change at specific time steps
  - Once the temperature and heat flux requirements are met the system is switched over to a closed loop system where the power requirement is adjusted based on the real time shroud temperature
  - Ensures minor variations in heater assembly can be compensated for

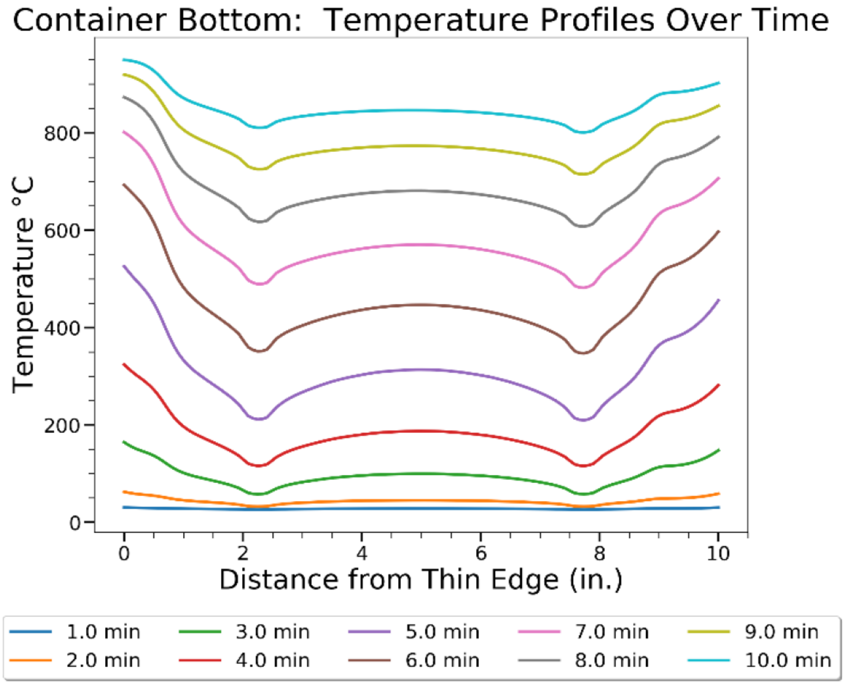




Thermal Modeling

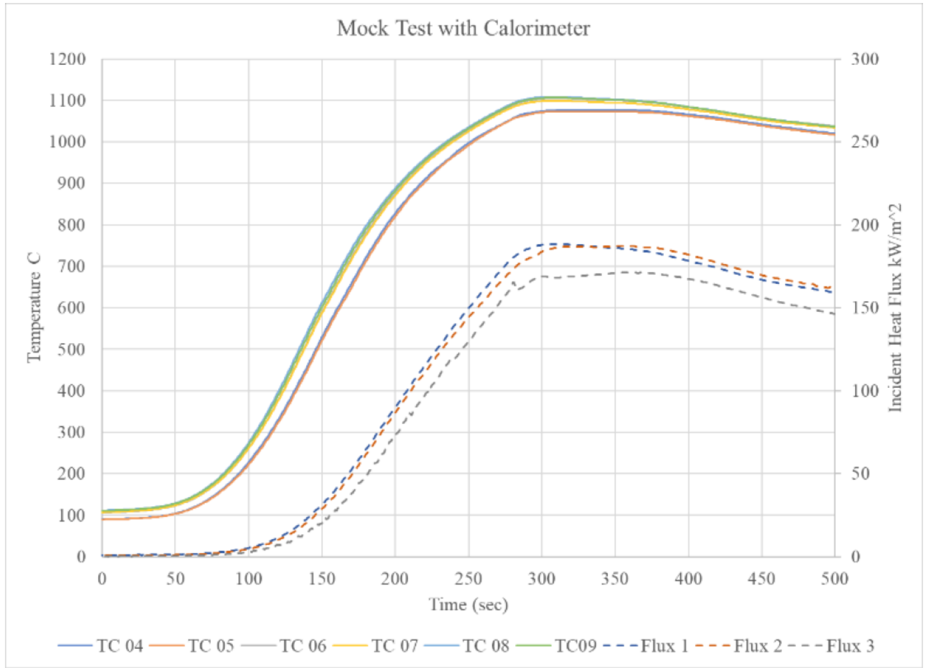
- Thermal finite element analysis was conducted to ensure the support saddles did not have adverse effects on the test during the transient heat-up phase
- Simplified geometry was simulated in ANSYS 2019 R2
- The contour plot of the bottom of the container is shown in the plot during the transient phase in the first 10 minutes of heat up
- Several iterations were made:
  - Modifications were made to the model that resulted in reflective heater endcaps and support saddles in order to homogenize the incident flux on the vessel





Experimental Validation

- The calorimeter was used in a Mock to measure and correlate the heat flux with the shroud temperature
- The required 1850ºF (1010℃) to 2150ºF (1180℃) environment temperature at 5 minutes is met as well as the measured flux requirement of 50,000±2,500 Btu/ft^2·h (158±8 kW/m^2)
- Due to the interface between the saddles and the shroud, the heat flux along the bottom slightly lower at this point compared with the top readings
- Follow-on work in PVP paper titled *3013 Container Fire-Induced Pressure Response and Failure*



Conclusions & Acknowledgements

- The proposed calorimeter is modular with different gauge configurations that can be changed using different sized shells to better match a specific test specimen
- This calibration method uses a shroud with a known temperature setpoint and does not require a heat flux gauge to be present during the test
- The shroud also establishes a boundary condition that can be used for further analysis and modeling efforts

- This work was funded by SRNS/NNSA IEW 4375203013 Container Fire-Induced Pressure Response and Failure Characterization

- More information can be found in: PVP2021-62039 *Correlating Incident Heat Flux and Source Temperature to meet ASTM E1529 Requirements for RAM Packaging Components Thermal Testing* SAND2021-3721 C