NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce
Building and Fire Research Laboratory

High-Temperature Guarded Hot Plate Apparatus – Location of Circular Heaters

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Outline

- NBS/NIST Development of Line-Heat-Source Guarded Hot Plate Apparatus
- Meter-Plate Locations for Circular Heaters
  - Single Line-Source Heater
  - Multiple Line-Source Heaters
- Radial and Axial Temperature Distribution
- Guard-Plate Locations for Circular Heaters
- Design of Meter-Plate Heaters for NIST 500 mm Guarded Hot Plate Apparatus
- Conclusions

How did we design the hot-plate heater patterns shown below?

"Theory can become a powerful design tool."

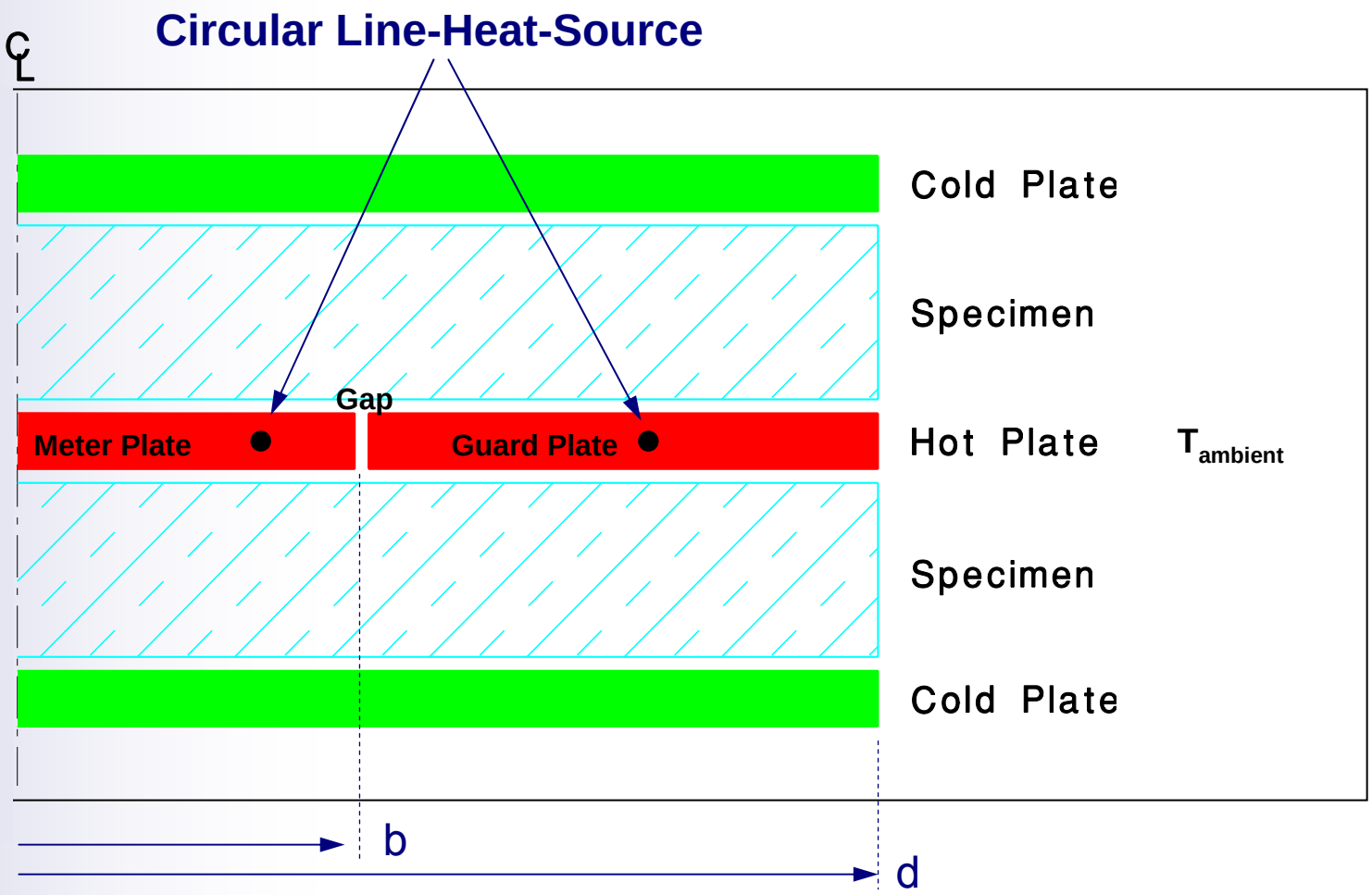
NBS/NIST Development of Line-Heat-Source Guarded Hot Plate

- Most Guarded Hot Plates have been Based on a Laminated Design with a Heater Sandwiched between Electrical Insulating Sheets Sandwiched between Metal Surface Plates
- Laminated Designs may have Problems, Especially at High Temperatures and/or in Vacuum:
  - Warping
  - Internal (non-uniform) Contact Resistance
  - Departures from Isothermal Conditions
  - Out-gassing
  - Electrical Leakage

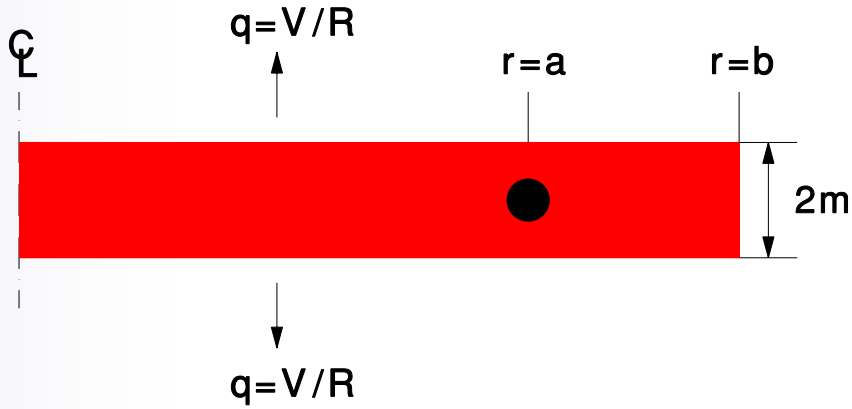
Original Concept of Line-Heat-Source Guarded Hot Plate

- Concept developed by Henry Robinson (late 1960s)
- Hahn, Siu, Peavy, Powell, and Flynn extended concept
  - 300 mm prototype (1st generation)
  - 1016 mm plate (2nd generation)
- Meter Plate and Guard Plate are Solid Metal
- Circular Heater(s) are Embedded in each Plate
- Most Problems of Laminated GHPs are Avoided

One Circular Heater in Each Plate



Meter Plate with One Circular Heater

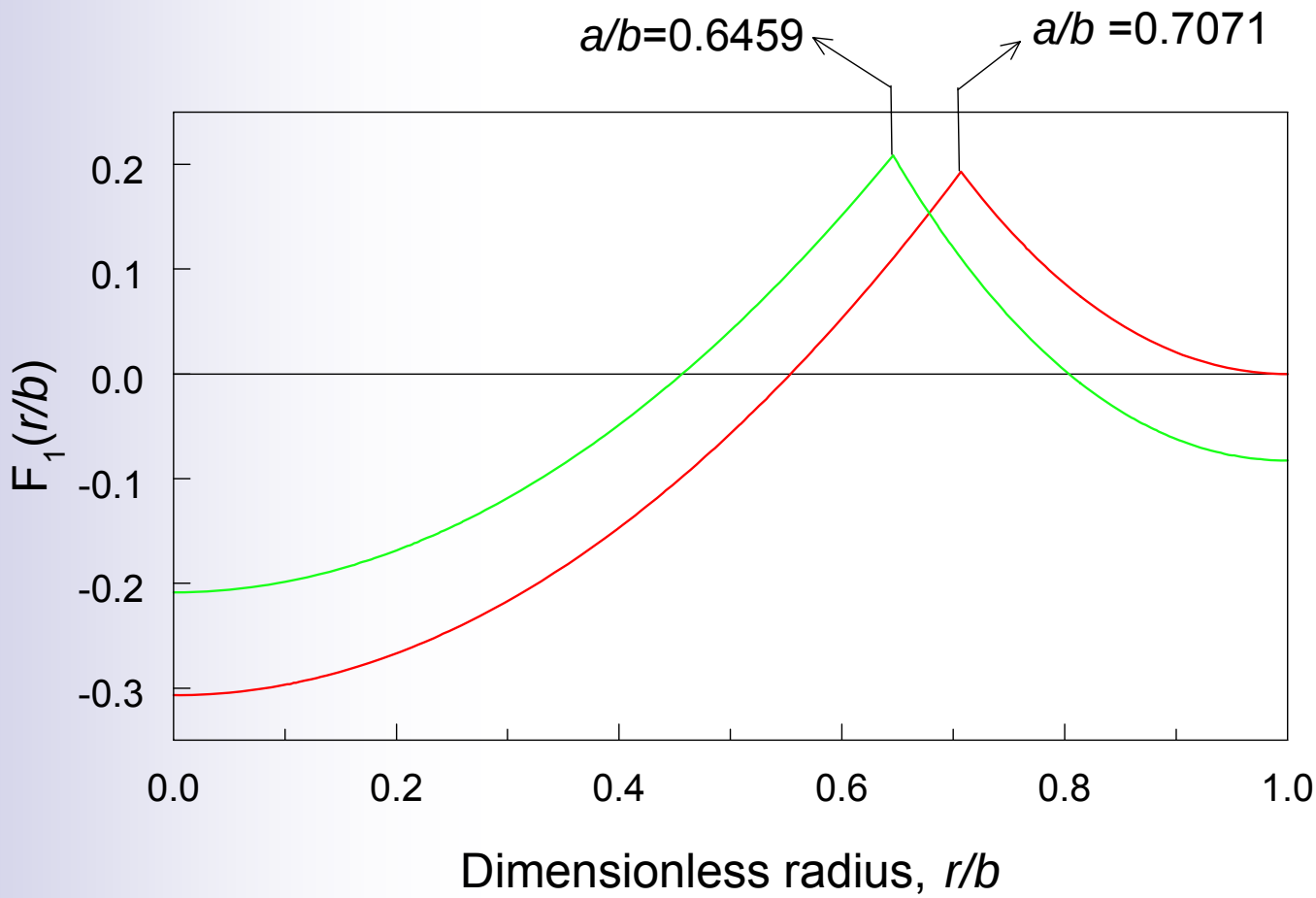


$$\frac{v(r)-V}{V} = \frac{b^2}{4m\lambda_p R} \bullet F_1\left(\frac{r}{b}\right) \quad ,$$

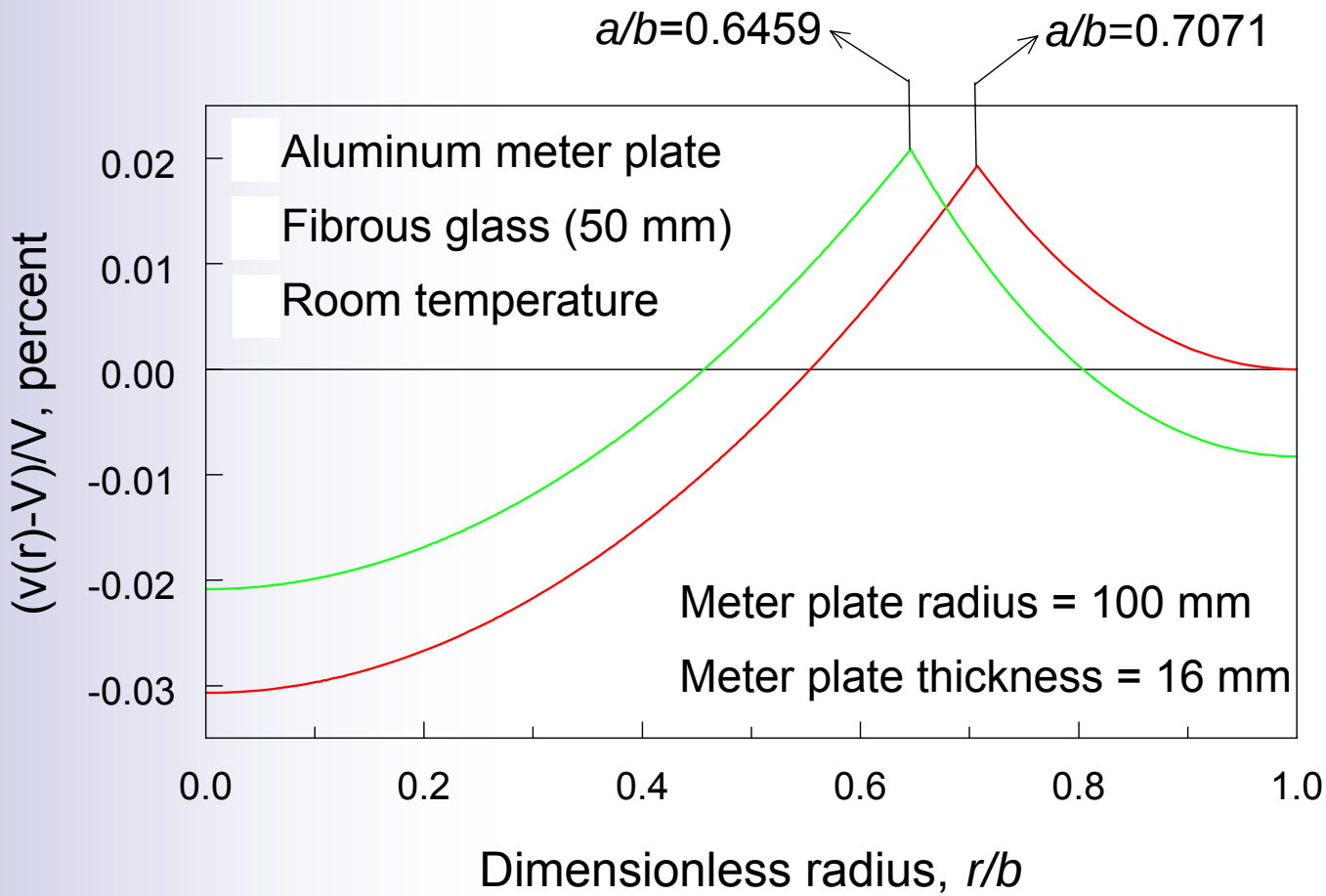
where:

$v(r)$ is radial temperature distribution;
V is the mean temperature difference;
λ_p is the thermal conductivity of the plate; and,
R is the specimen thermal resistance.

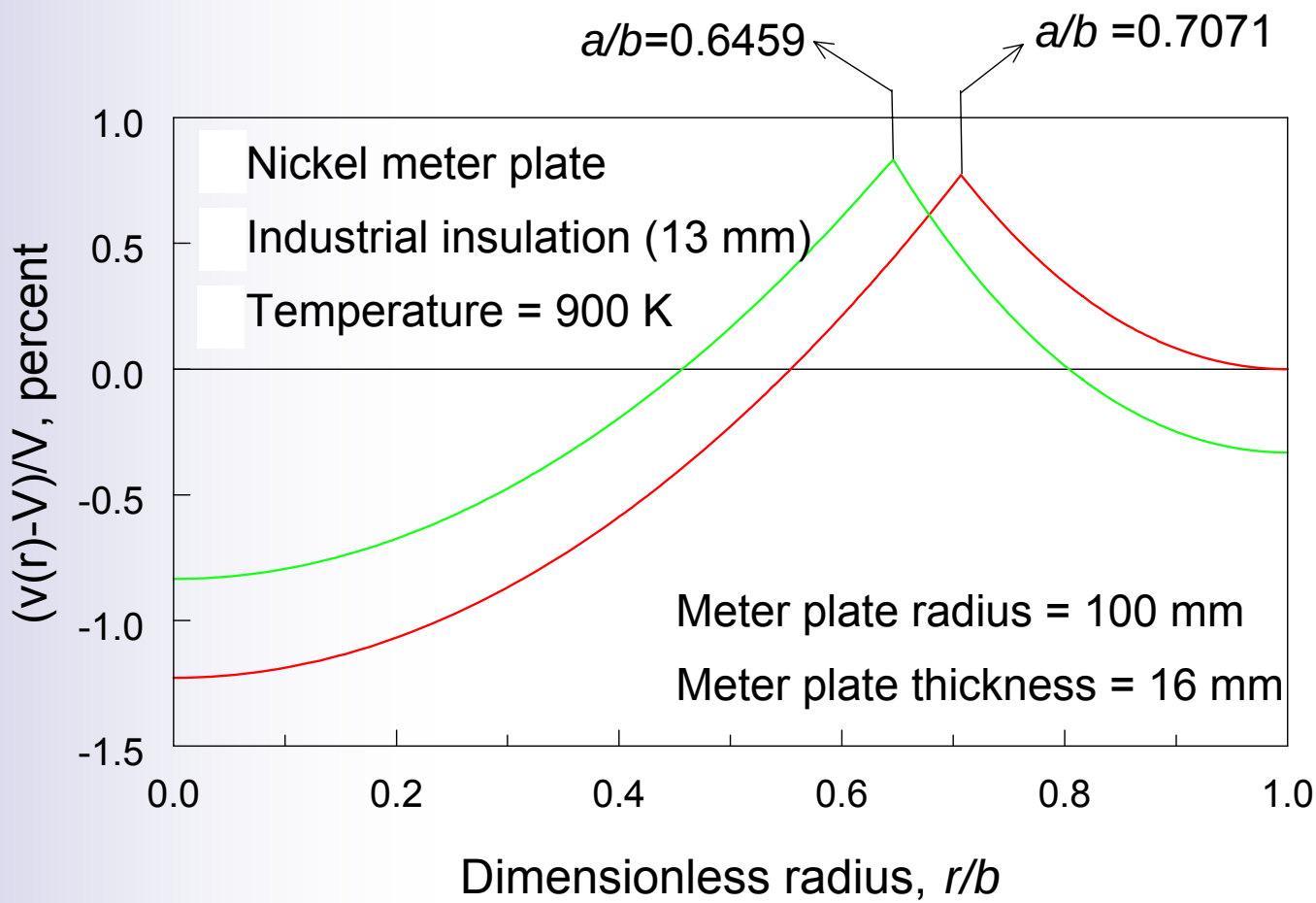
Meter Plate with One Circular Heater: Radial Temperature Variation



Percentage Variation for R ≈ 1.5, with Aluminum Meter Plate at Room Temperature



Percentage Variation for R ≈ 0.1, with Nickel Meter Plate at 900 K



Multiple Line-Source Heaters in Meter Plate

- Multiple Heaters are Required because of:
  - Lower Thermal Resistance of Specimens
  - Lower Thermal Conductivity Of Hot Plate Material
- Paper Provides Equations for Locations Such that the Gap Temperature Equals the Mean Plate Temperature
- Paper Provides Table of Locations Such that Each Region of the Meter Plate Has the Same Mean Temperature

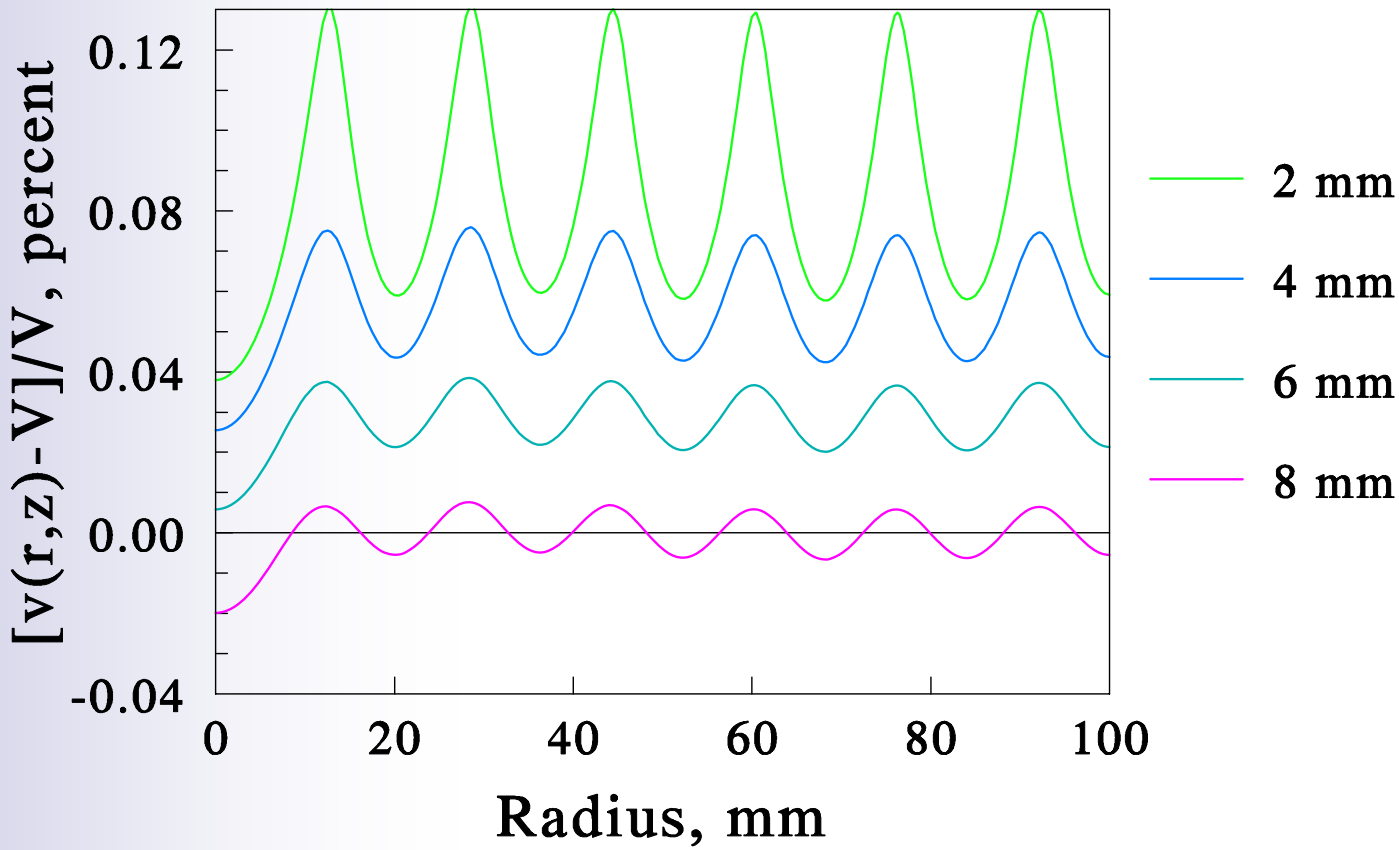
Radial and Axial Temperature Distribution in the Meter Plate

- An Analytical Solution is Given in the Paper for the Case of *n* Circular Heaters in the Meter Plate for the Following Conditions:
  - All Heaters of Equal Strength per Unit Length
  - Heaters Represented by Delta Functions at Mid-plane of Plate
  - Uniform Heat Flux from Plate into Specimens
  - Adiabatic Boundary at Guard Gap Location
- Solution is of the Form

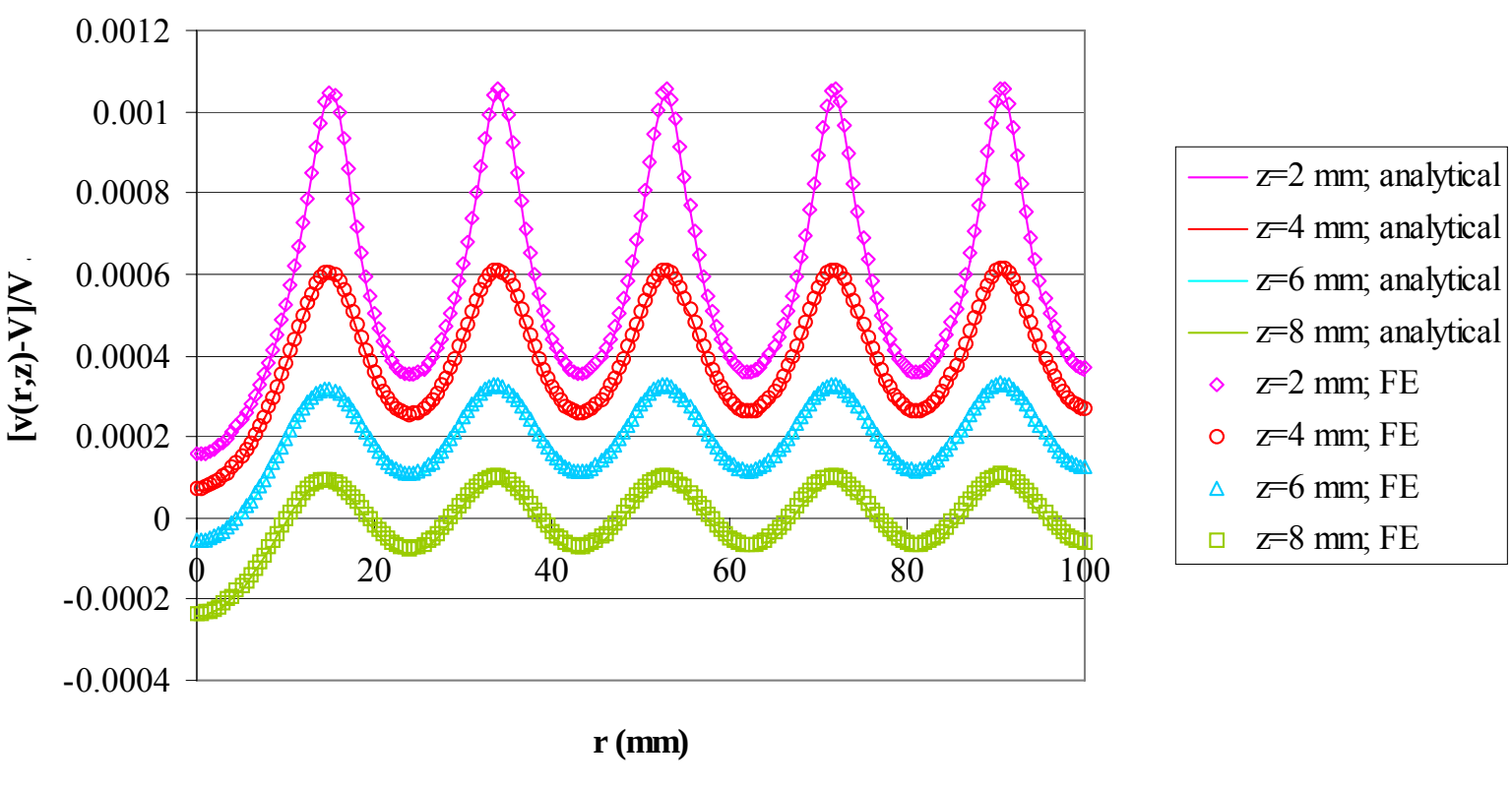
$$\frac{v(r,z)-V}{V} = \frac{1}{\lambda_p R} \cdot G_n\left(\frac{r}{b}, \frac{z}{b}\right) \quad ,$$

so that temperature variations scale inversely with $\lambda_p R$.

Percentage Variation for Nickel Meter Plate, Dimensioned as Before, with $\lambda_p R = 7$

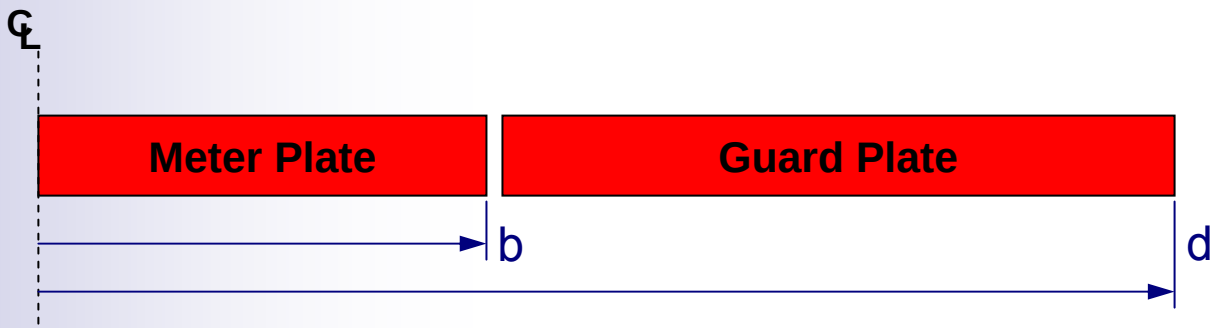


Comparison of Finite Element Solution to Analytical Solution in Meter Plate



Multiple Heaters in Guard Plate

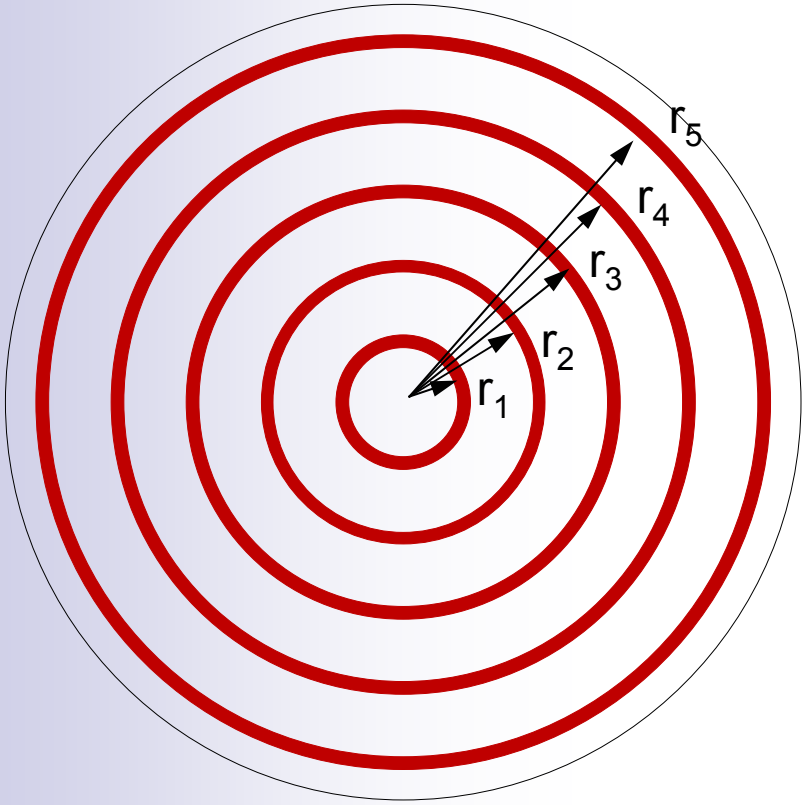
- Paper Provides Equations for Locations Such that the Gap Temperature Equals the Mean Guard Plate Temperature
- Paper Provides Table of Locations, for the Case where the Guard Diameter is 2.5 Times the Diameter of the Meter Plate, Such that Each Region of the Guard Plate Has the Same Mean Temperature



$$\frac{d}{b} = 2.5$$

Meter-Plate Heaters for NIST 500 mm Guarded Hot Plate

Start with Five Circular Heaters:

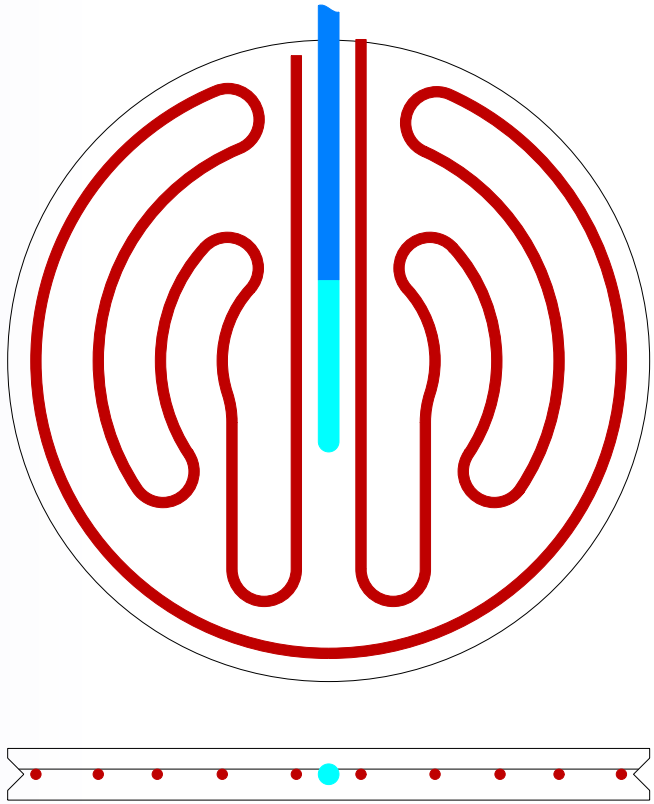


Radial Locations for Line Sources (n = 5)

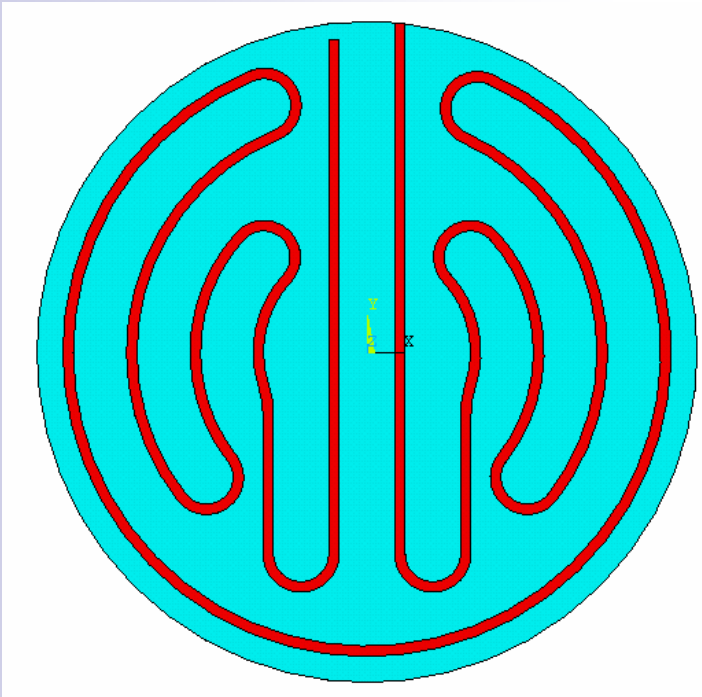
r_1 = 15.31 mm
r_2 = 34.08 mm
r_3 = 52.96 mm
r_4 = 71.83 mm
r_5 = 90.74 mm

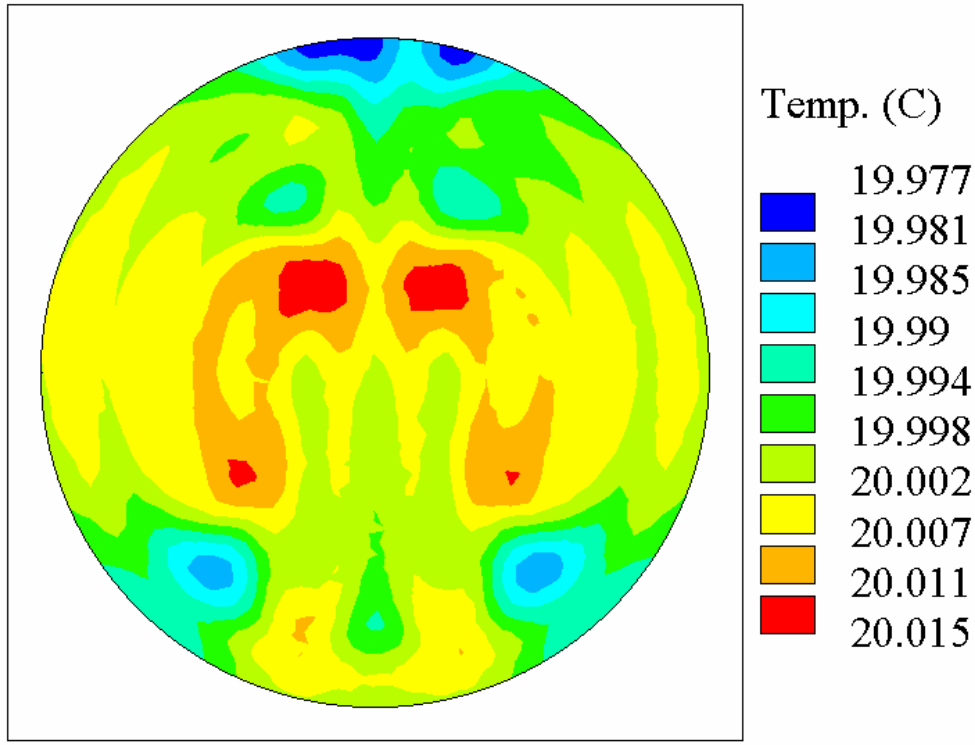
Continuous Heater Layout Suitable for Use with Small Temperature Sensors

Continuous Heater Layout Used with Standard Platinum Resistance Thermometer



Computed Temperature Contours on Surface of Meter Plate





<u>Simulation Parameters:</u>

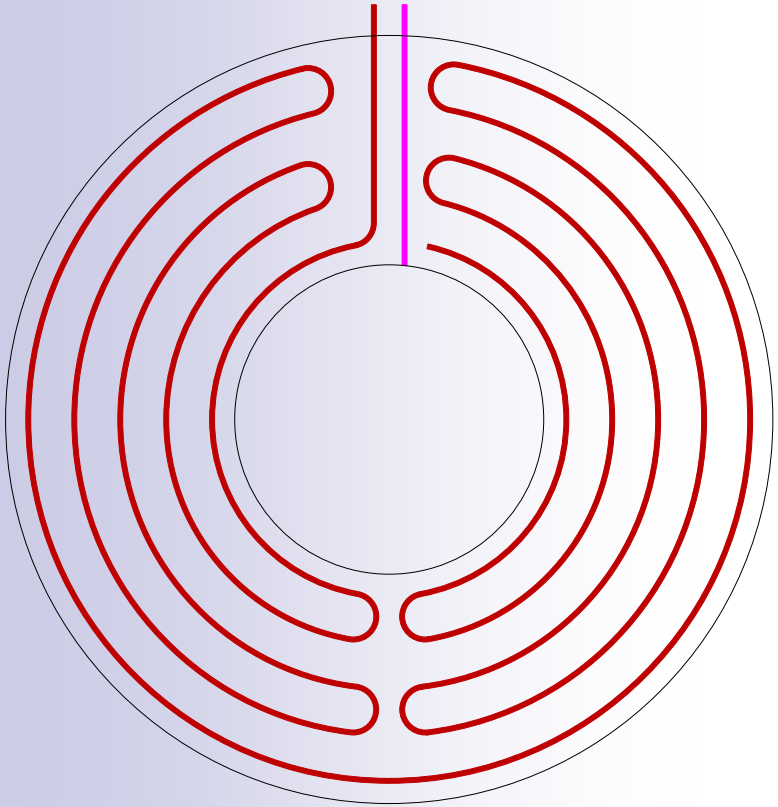
Plate material: **Nickel**

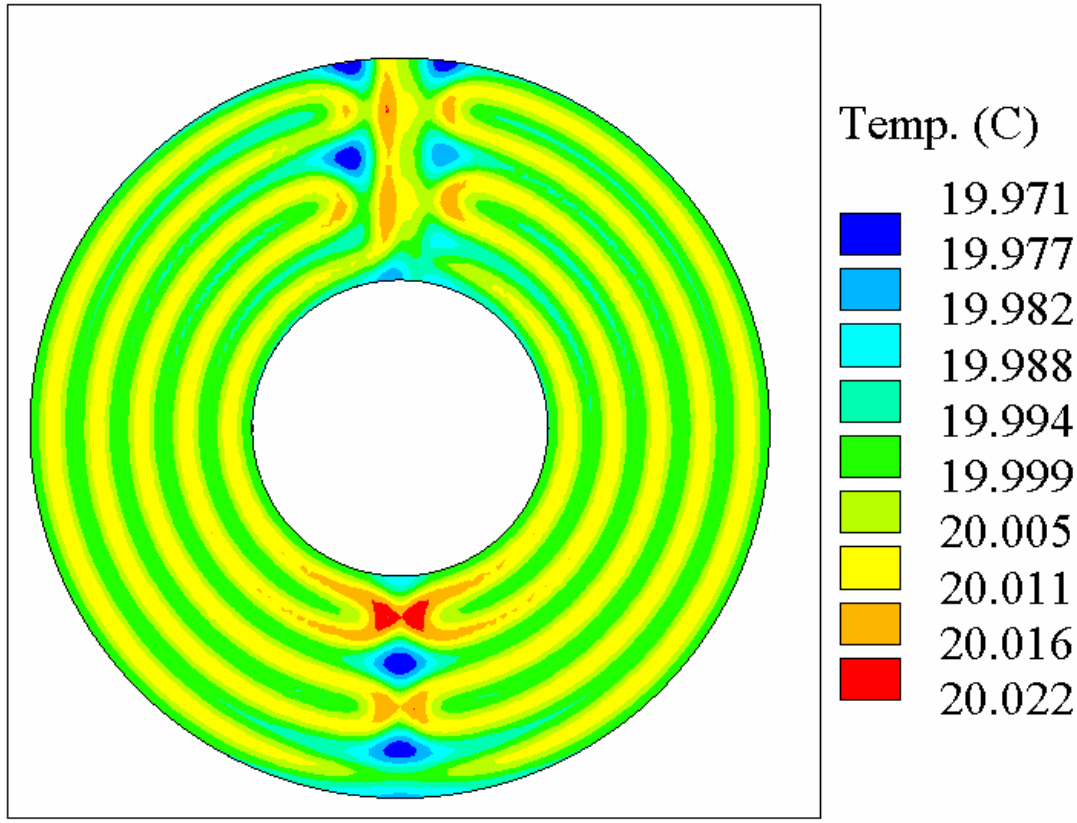
Specimen R-value = **0.125 m²·K/W**

Cold Plate T = **0 °C**

Heater Power = **5 W**

Continuous Guard Plate Heater Layout for New NIST 500 mm Guarded Hot Plate





Simulation Parameters:

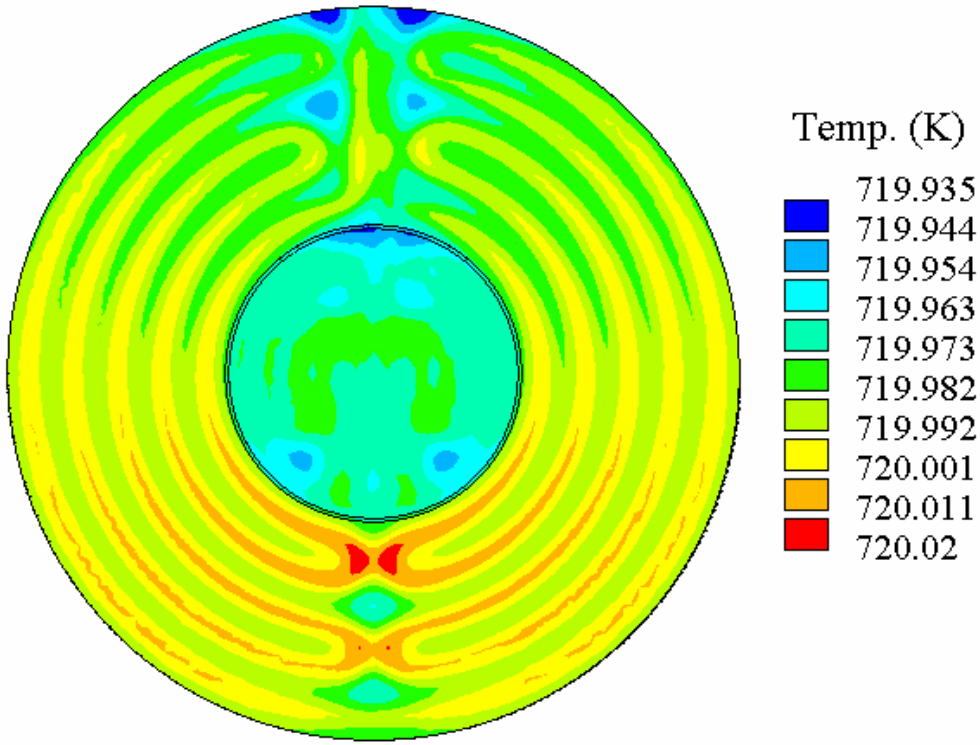
Plate material: **Nickel**

Cold Plate T = **0 °C**

Specimen R-value = **0.125 m²·K/W**

Heater Power = **5 W**

Overall Hot Plate Heater Layout for New NIST 500 mm Guarded Hot Plate



Simulation Parameters:

Plate material: **Nickel**

Specimen R-value = **0.125 m²·K/W**

Cold Plate T = **700 K**

Heater Power = **5 W**

Conclusions

- Formulae and Tables are Given in Paper for Locations of Multiple Circular Heaters
- Analytical and Finite-Element Analyses Show that Meter and Guard Plates can be Made Very Isothermal
- Multiple-Heater Designs Can be “Morphed” into a Single Continuous Heater Layout
- Meter-Plate Heater Designs can be Further Morphed to Accommodate Standard Platinum Resistance Thermometer

The End

Questions and comments: Daniel.Flynn@nist.gov