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

High-Temperature Guarded Hot Plate Apparatus – Control of Edge Heat Loss

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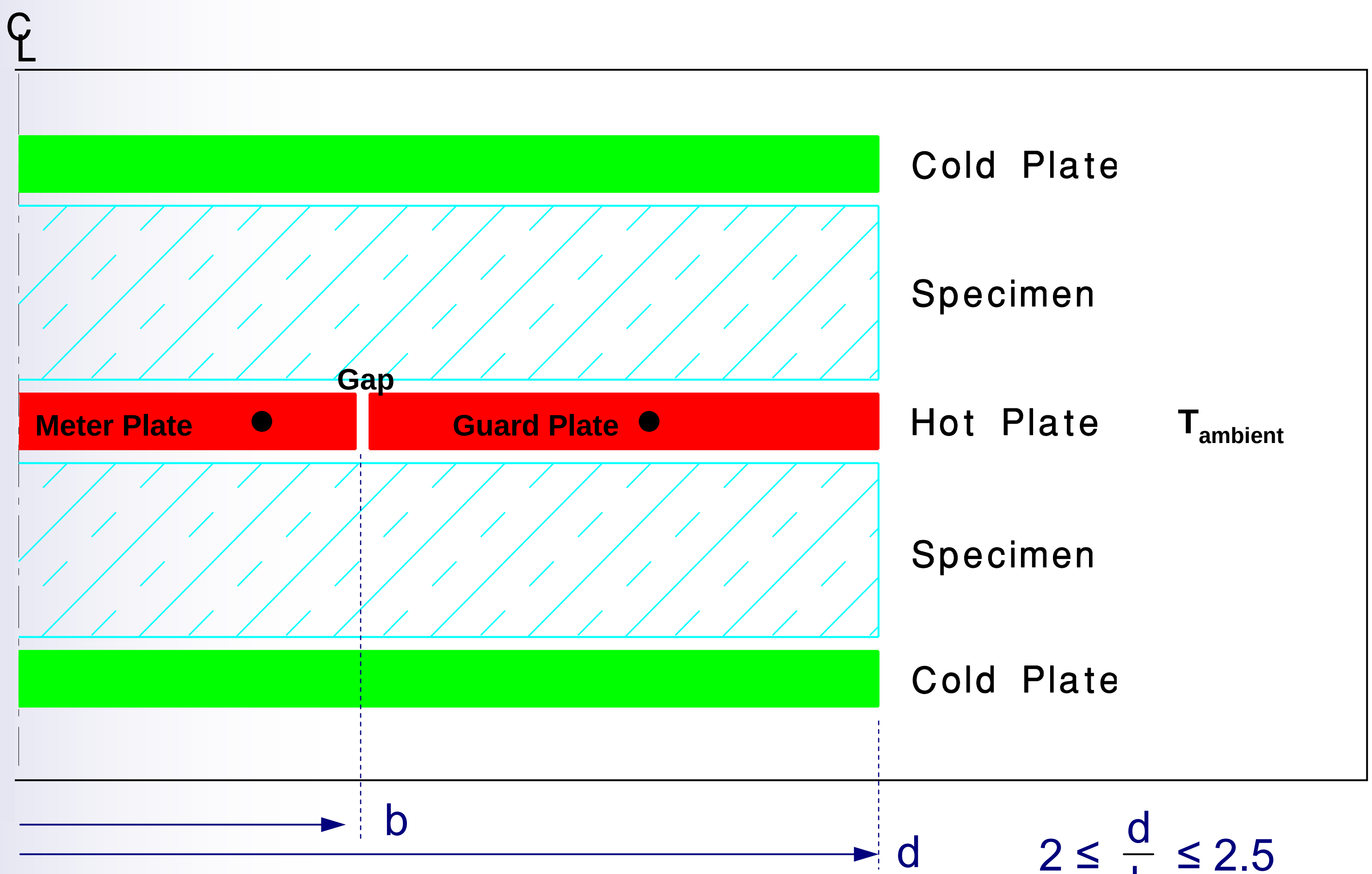
ITCC 28/ ITES 16

June 28, 2005

Outline

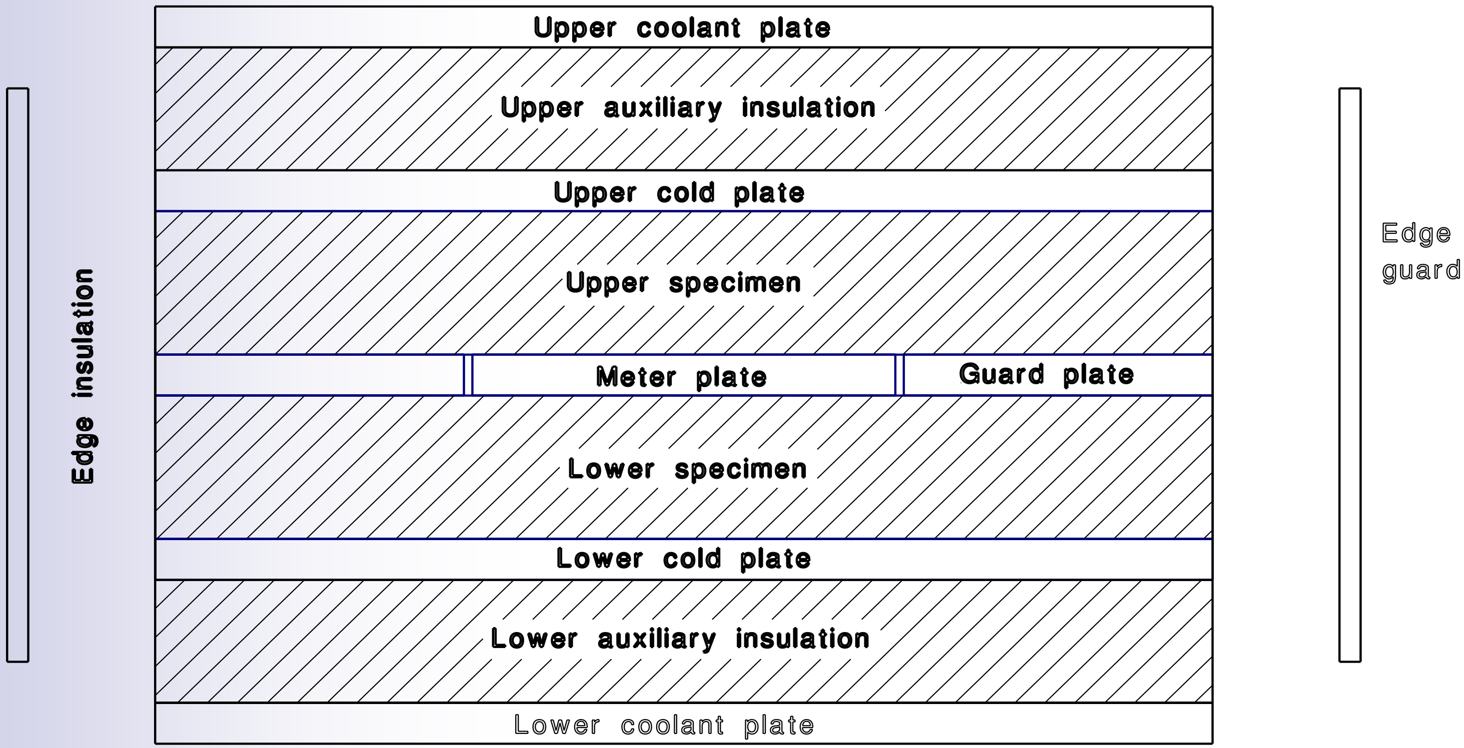
- Description of Typical Guarded Hot Plates
  - For Use at Moderate Temperatures
  - For Use at High or Very Low Temperatures
- Prior Analyses of Edge Heat Loss with Neumann (Convective) Boundary Condition at Edge
- Approximate Analytical Solution for Thermal Shunting in Edge Insulation
- Results of Analytical Computations
- Finite Element Analyses
- Conclusions

Typical Guarded Hot Plate Apparatus for Measurements on Building Insulation



$$2 \leq \frac{d}{b} \leq 2.5$$

Typical Guarded Hot Plate Apparatus for Use at High or Very Low Temperatures



Prior Analysis Based upon Neumann (Convective) Boundary Condition at Edge

- The error due to edge heat loss or gain is given by:

$$\varepsilon = A + BX \ , \qquad \text{where} \qquad X = \frac{2(T_m - T_a)}{T_h - T_c} \ ,$$

  in which T_h is the hot plate temperature, T_c is the cold plate temperature, the mean temperature is $T_m = (T_h + T_c)/2$, and T_a is the ambient temperature with which heat is exchanged at the edge of the specimen.

- Above analysis based on work of Bode (PTB in Germany) and Peavy and Rennex (NBS, now NIST)

Prior Analysis Based upon Neumann Boundary Condition at Edge (Cont'd)

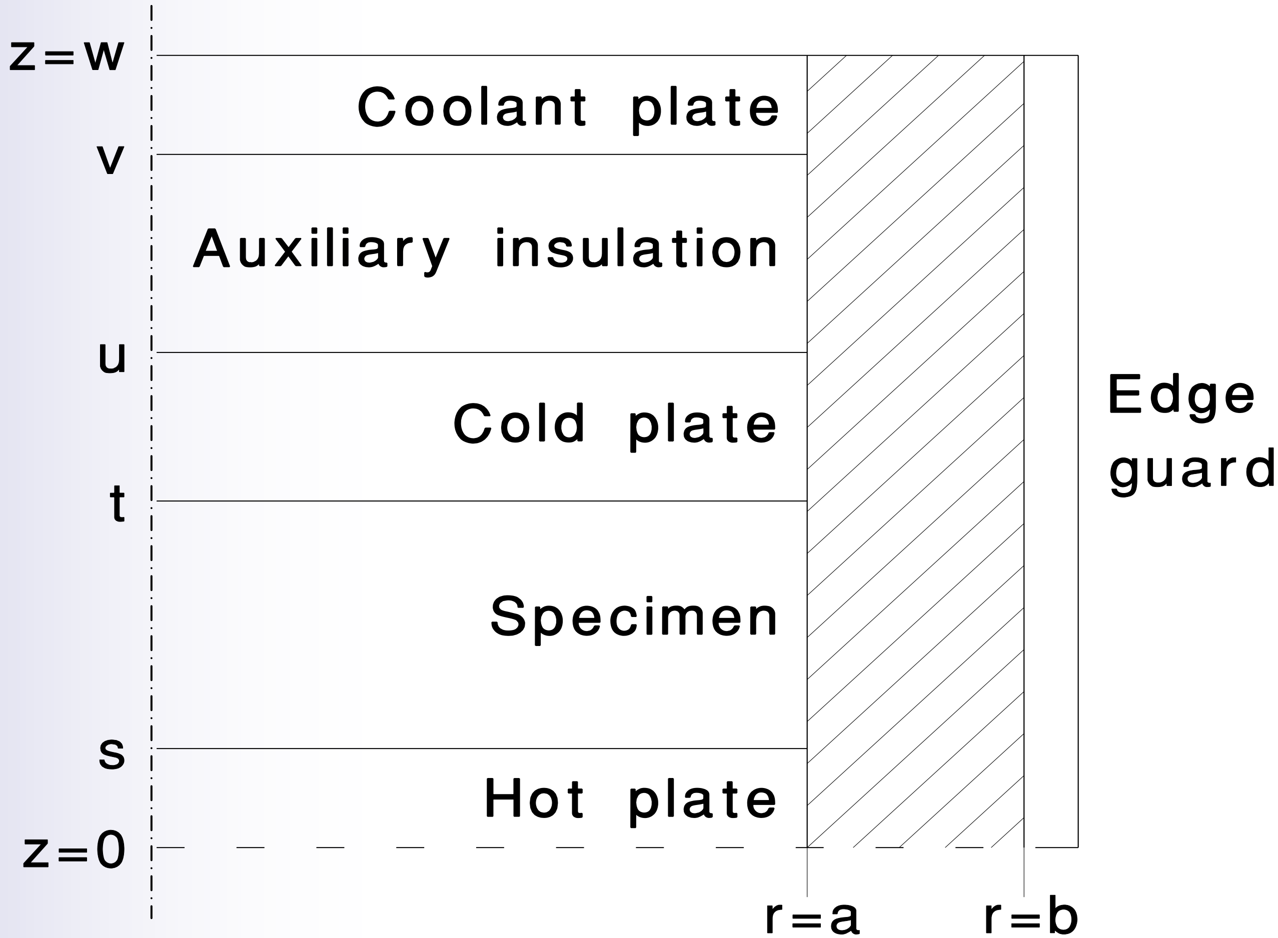
- In the equation $\varepsilon = A + BX$,
  for a circular geometry, the constants *A* and *B* depend upon the dimensionless quantities

$$\frac{\gamma \ell}{b}, \quad \frac{\gamma \ell}{d}, \quad \text{and} \quad \frac{h \ell}{\lambda},$$

  where:

  b is the meter plate radius;
  d is the outer guard plate radius;
  ℓ is the specimen thickness;
  h is the effective heat transfer coefficient at the edge;
  λ is the geometrical mean of the axial and radial thermal conductivities of the specimen; and,
  γ is a measure of the specimen anisotropy.

Approximate Analysis of Thermal Shunting in Edge Insulation



Approximate Analysis of Thermal Shunting in Edge Insulation (Cont'd)

- Analysis of Annular Edge Insulation
- First, Temperature Distribution Along the Stack is Assumed to be the Same as if There were No Heat Loss
- Edge Guard is Assumed Isothermal (but analysis could easily handle a known temperature distribution)
- Potential Transformation Allows for Thermal Conductivity of Edge Insulation to Vary with Temperature
- Heat Flux from Stack into Edge Insulation is Computed
- Heat Flux from Specimen into the Edge Insulation is Used as the Boundary Condition for the Temperature Distribution and the Heat Flows inside the Specimen

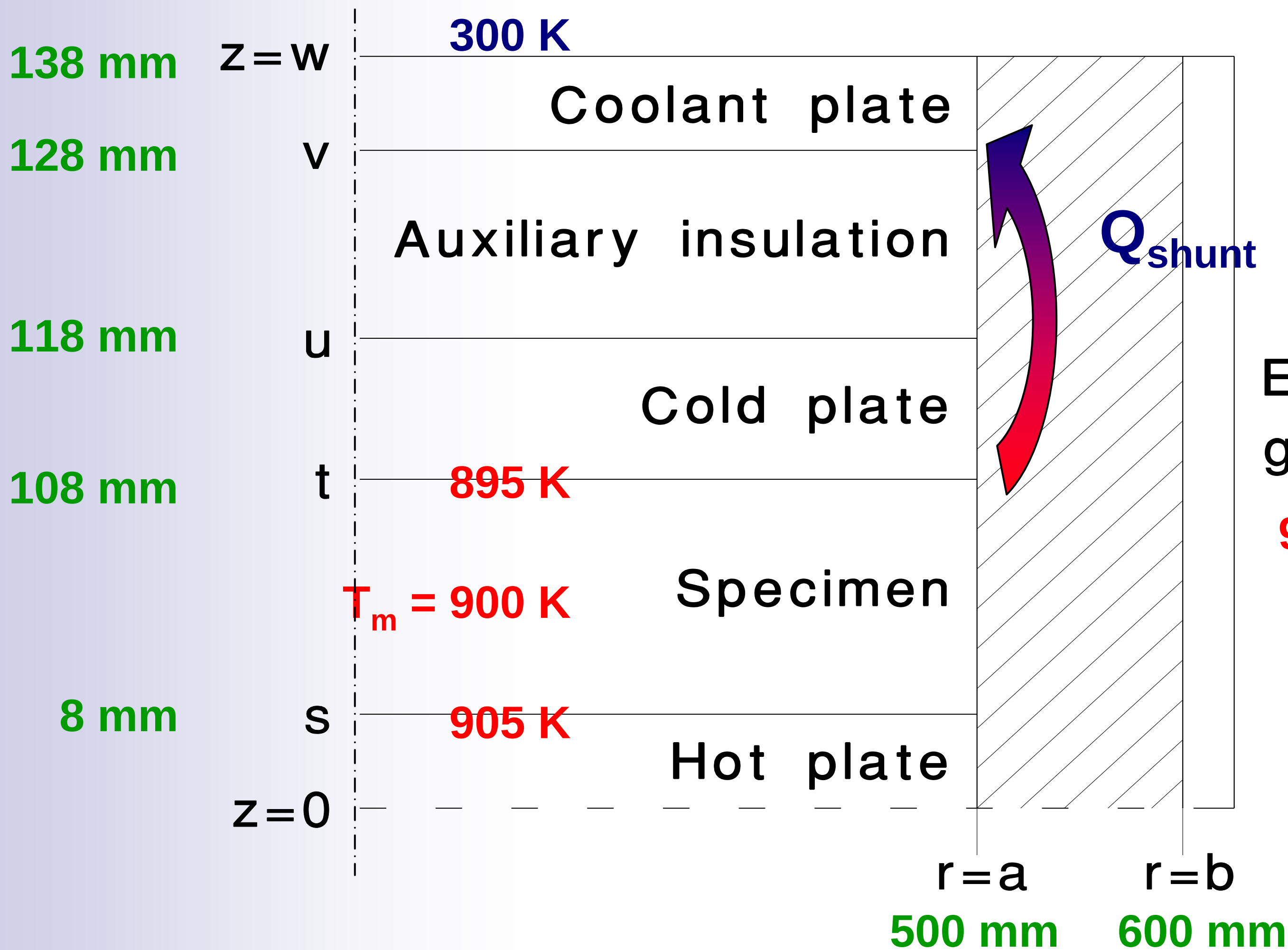
Approximate Analysis of Thermal Shunting in Edge Insulation (Cont'd)

- The Detailed Mathematics of the Analysis are Included in the Written Paper
- While the Analysis is Approximate in that One should Iterate to Get Agreement between the Temperature Distribution and the Heat Fluxes in the Stack and in the Edge Insulation, this Approximate Analysis is quite Adequate to Indicate Whether or Not the Edge Conditions need to be Modified to Avoid Significant Shunting Errors

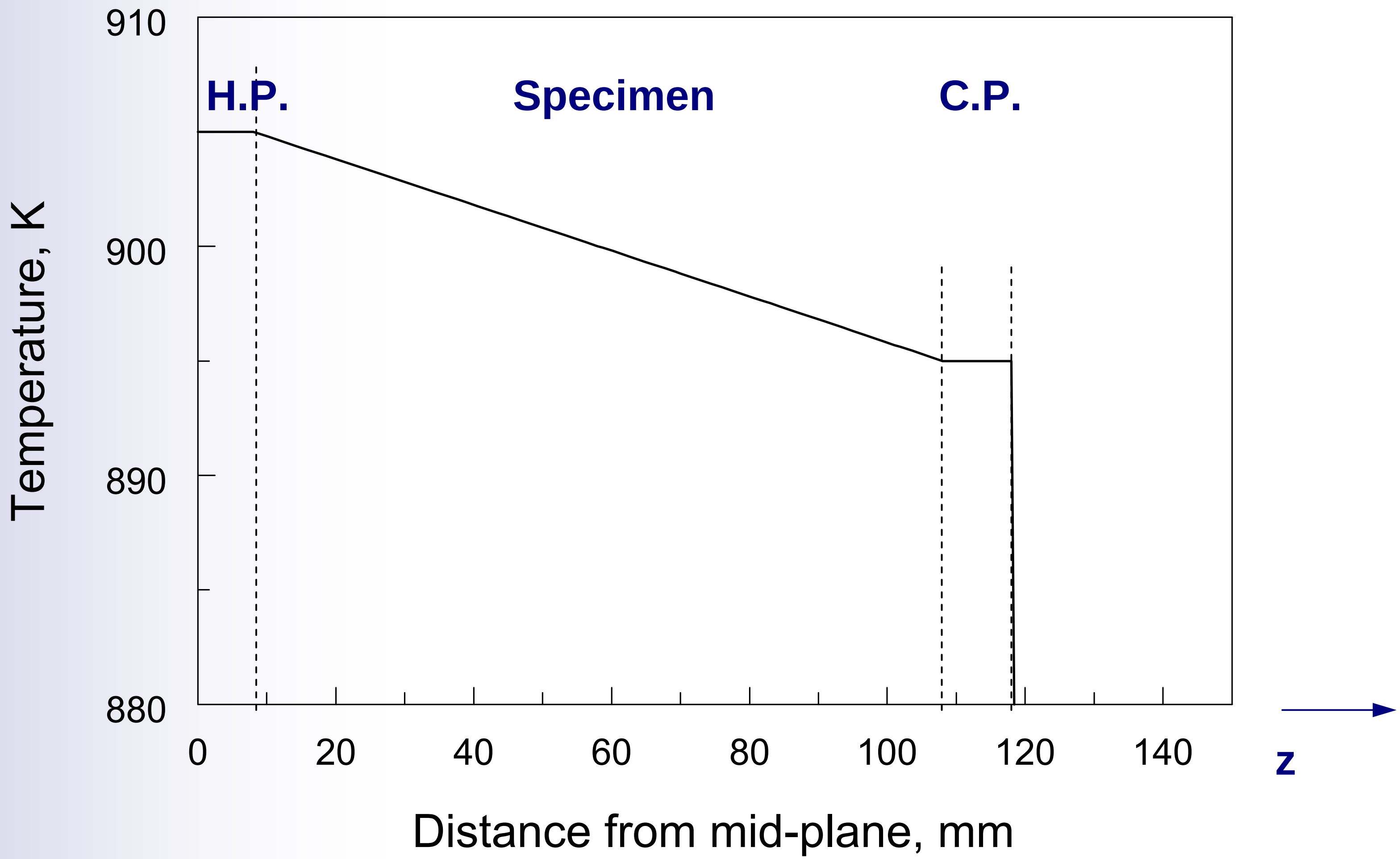
Results of Analytical Computations

- Computations Carried out for a “Worst-Case Scenario”
  - 500 mm Diameter Stack
  - 600 mm Inside-Diameter Edge Guard
  - Thus, a 50 mm Wide Annulus of Edge Insulation
  - 16 mm Thick Hot Plate
  - 10 mm Thick Cold Plate, Auxiliary Insulation, & Coolant Plate
  - 100 mm Thick Specimen
  - Mean Specimen Temperature of 900 K
  - Isothermal Edge Guard Temperature of 900 K
  - Coolant Plate Temperature of 300 K
  - Only 10 K Temperature Difference Across Specimen

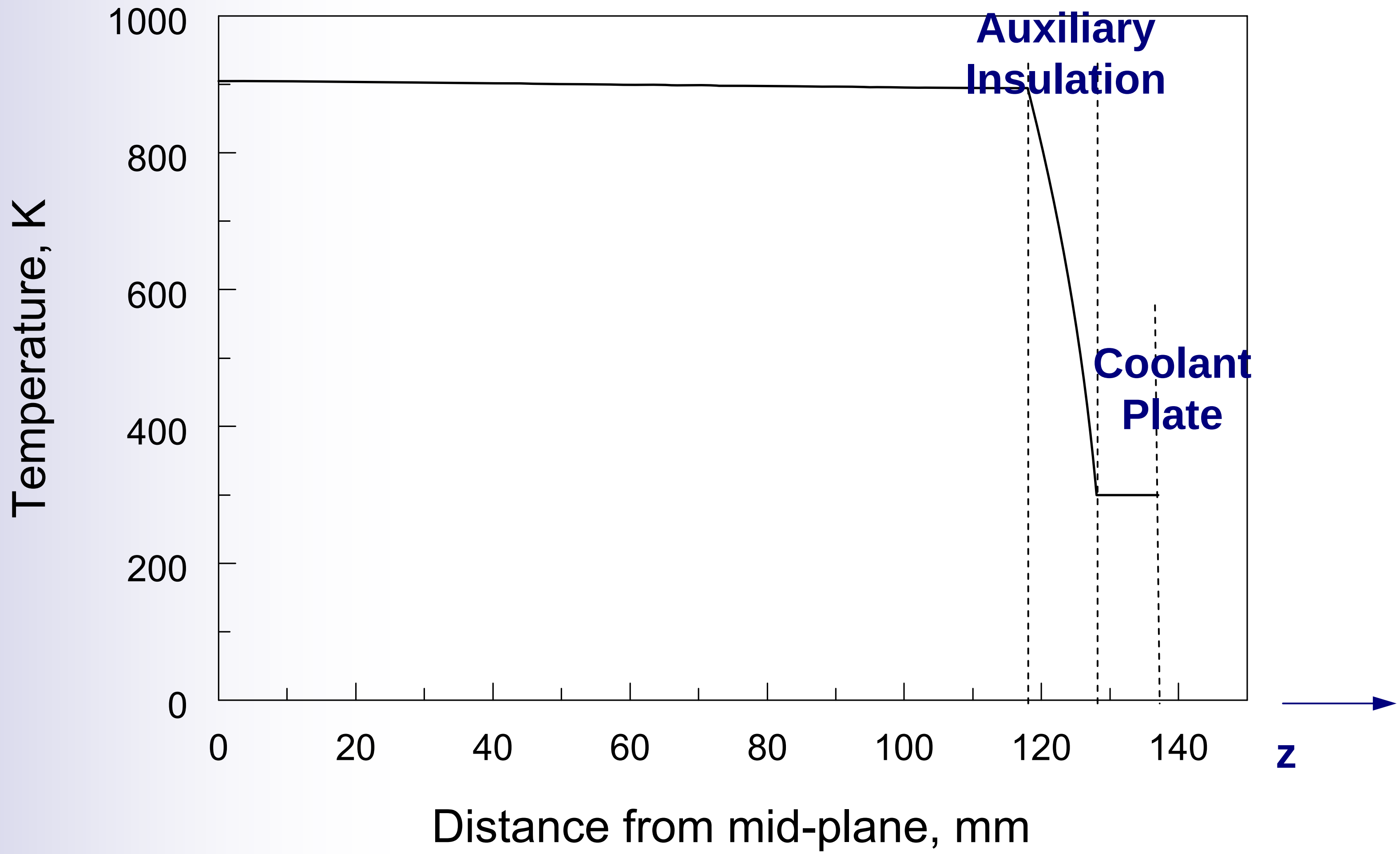
Approximate Analysis of Thermal Shunting in Edge Insulation – Example



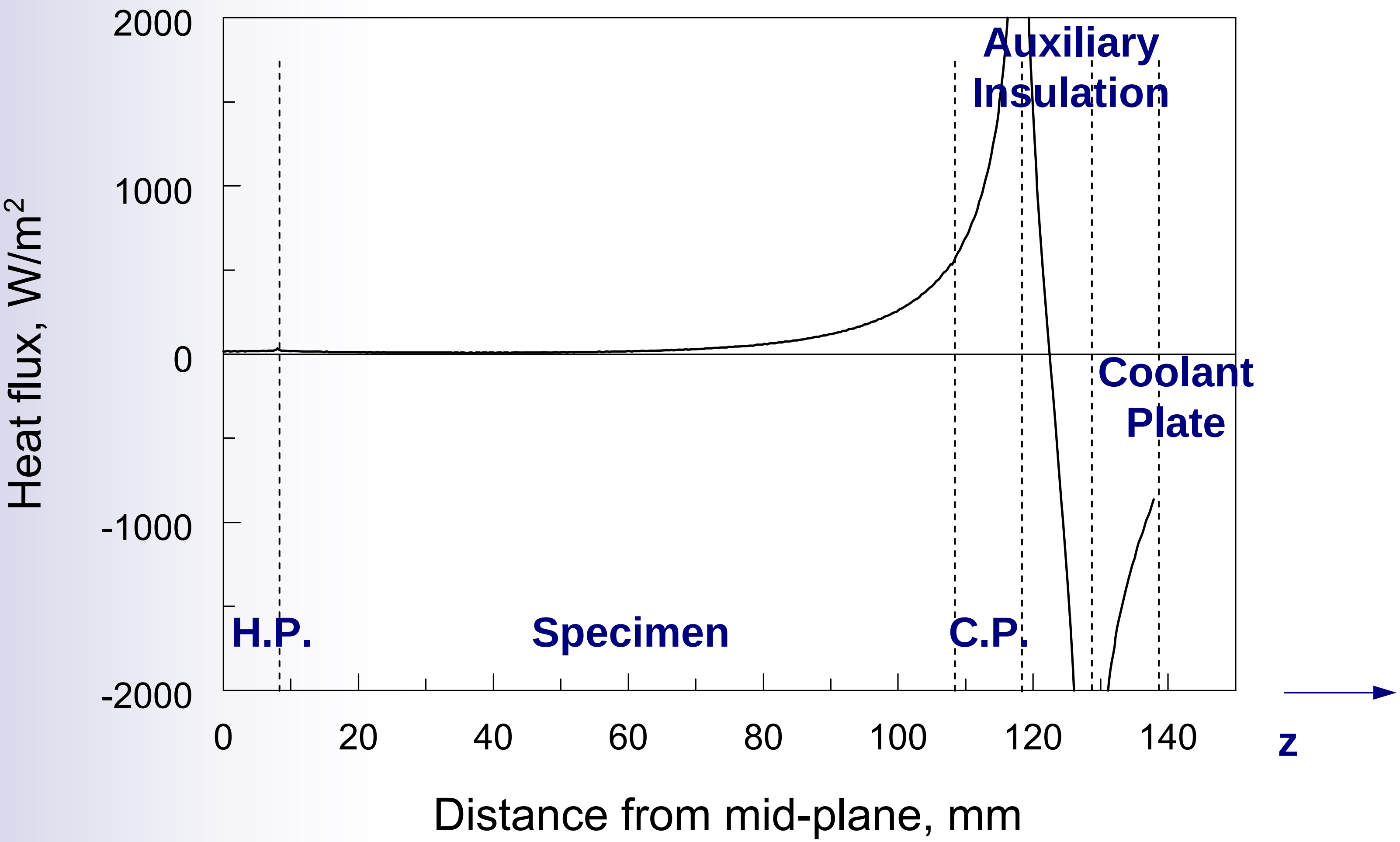
Temperature Distribution along Stack



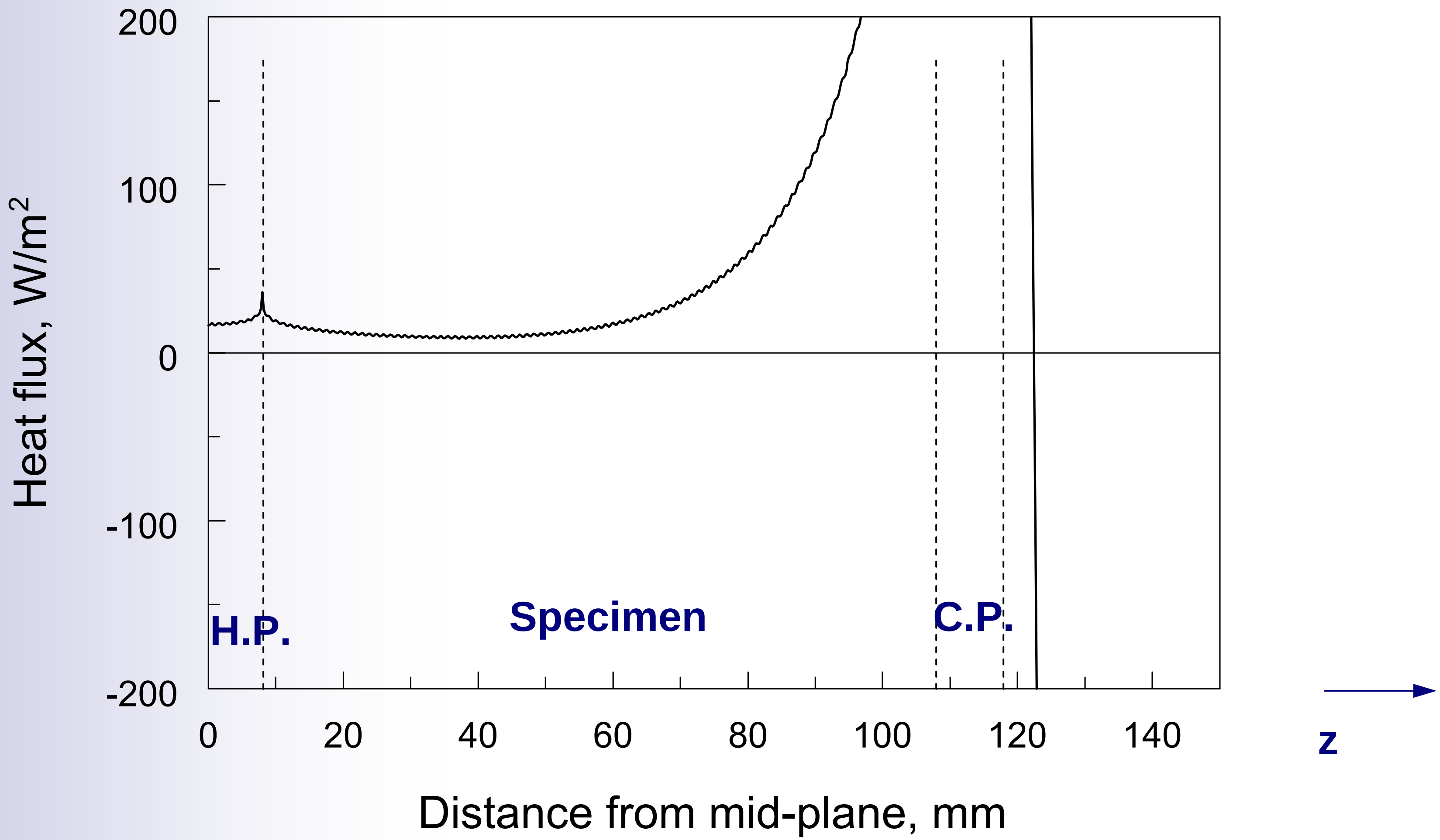
Temperature Distribution along Stack



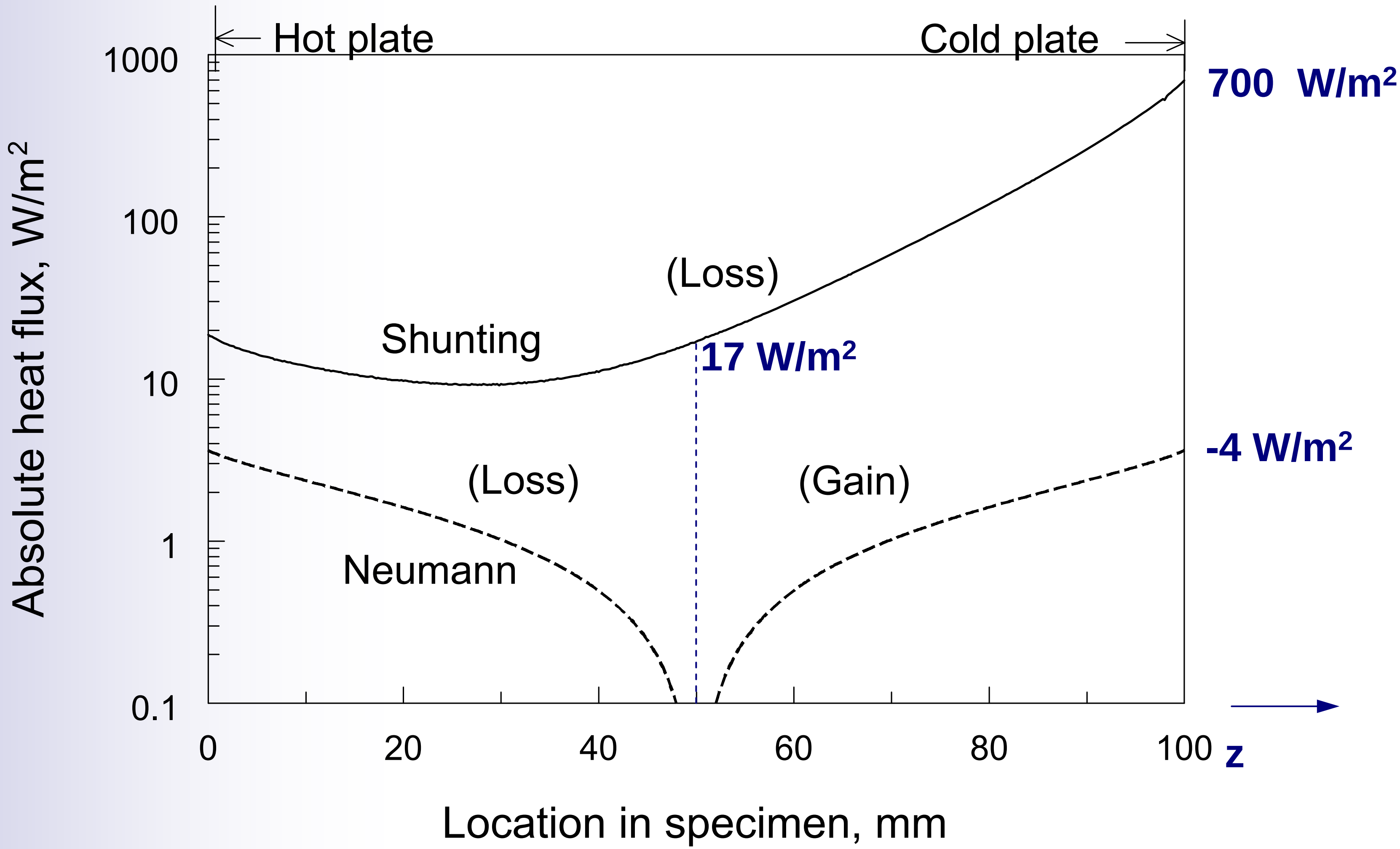
Heat Flux Distribution along Stack



Heat Flux Distribution along Stack

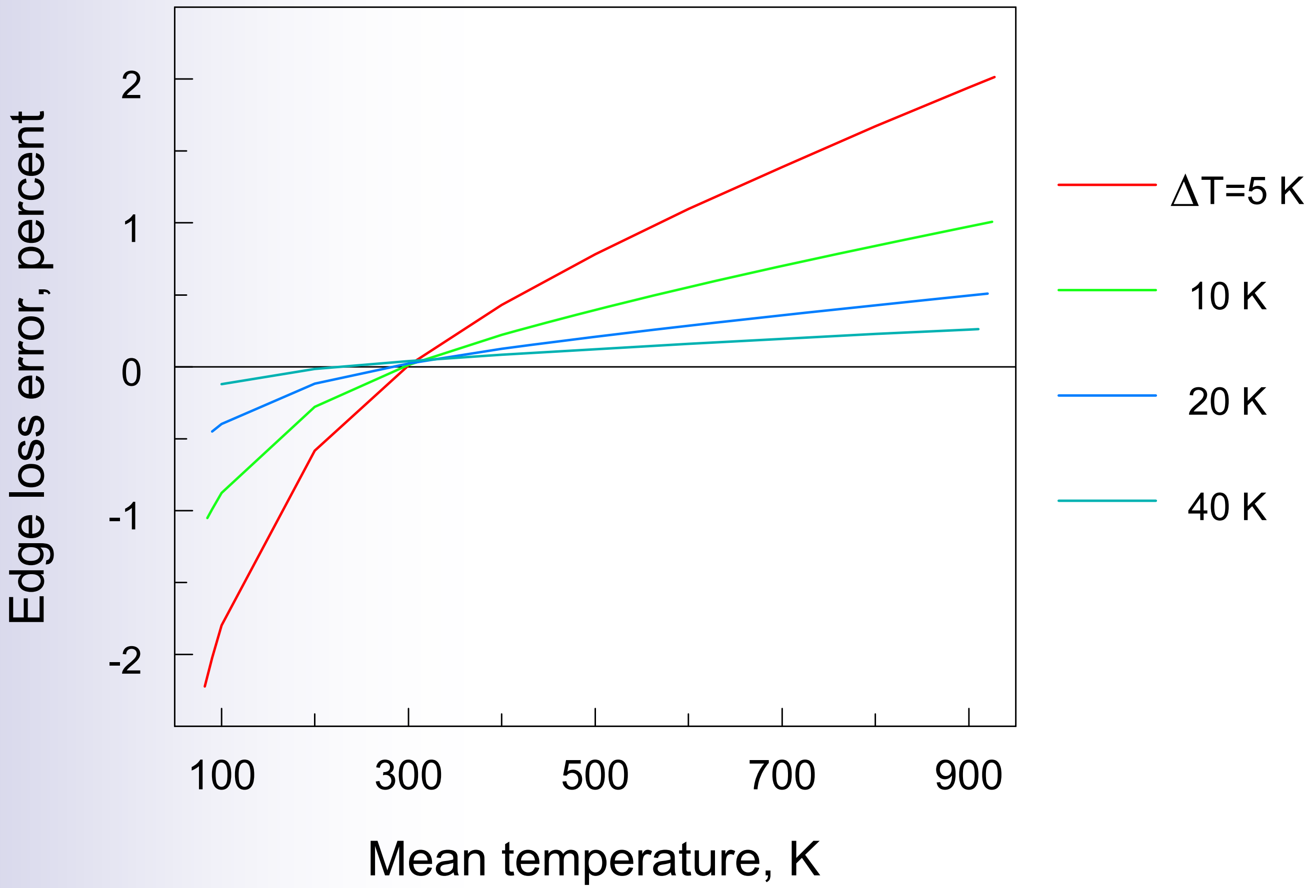


Comparison of the Two Analytical Results

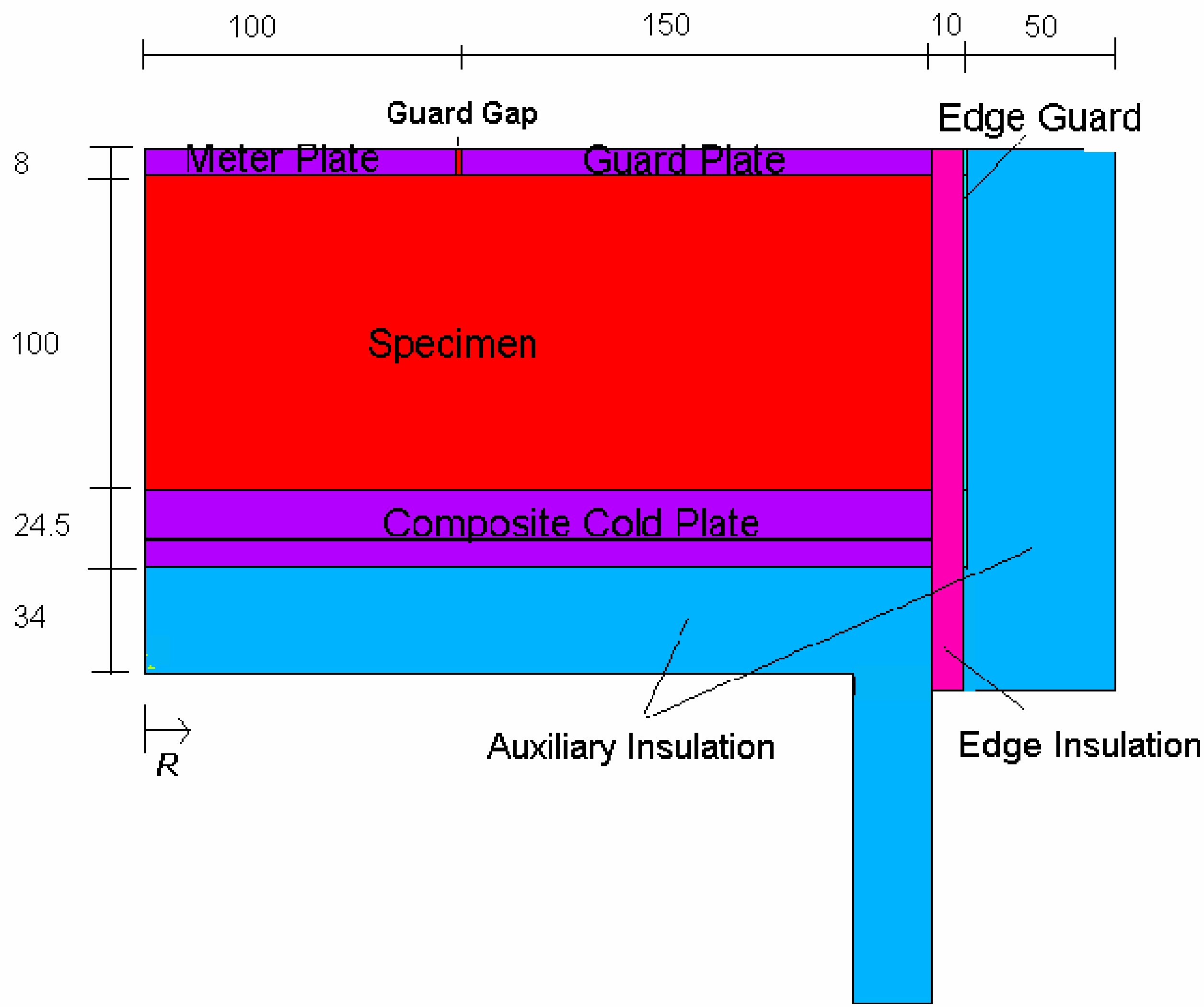


Edge Heat Loss Errors versus Temperature

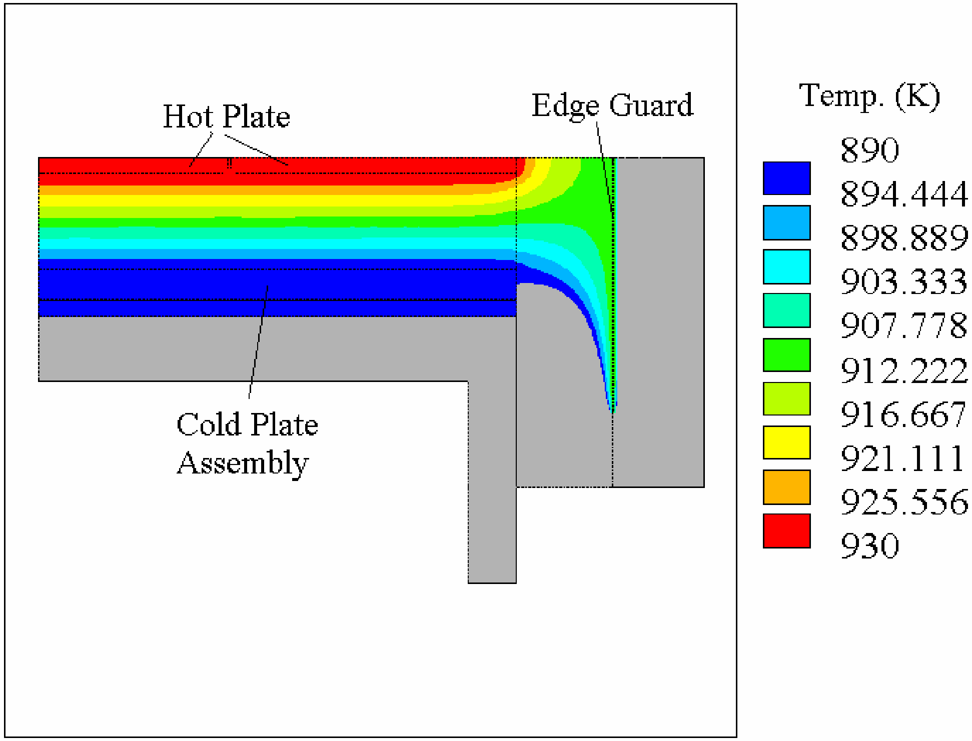
- 25 mm Thickness for Auxiliary Insulation and Cold Plates

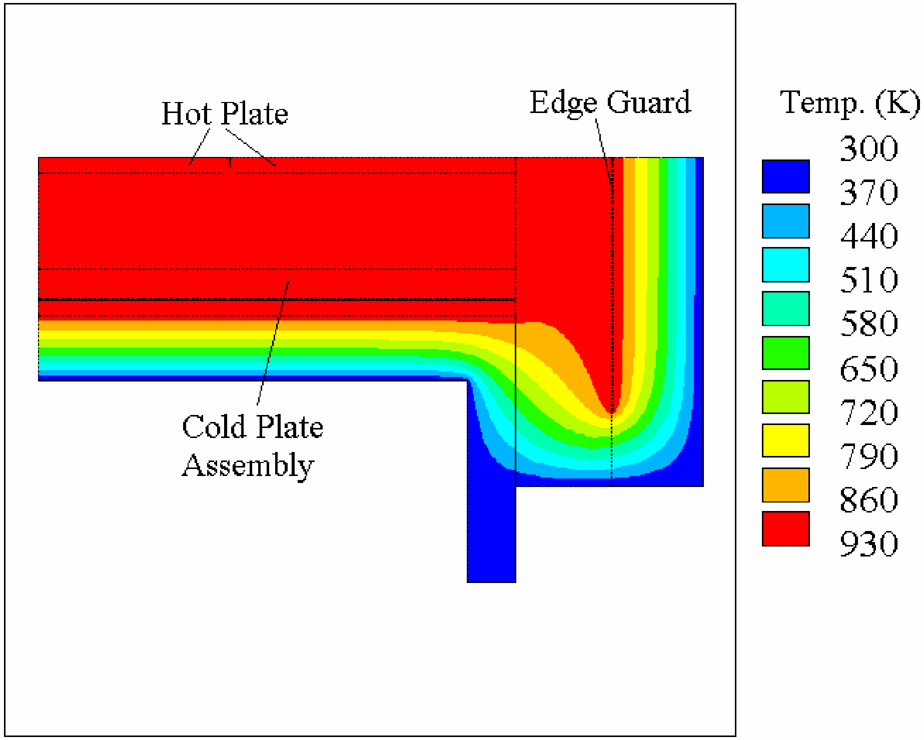


Geometrical Configuration of NIST 500 mm Guarded Hot Plate Apparatus

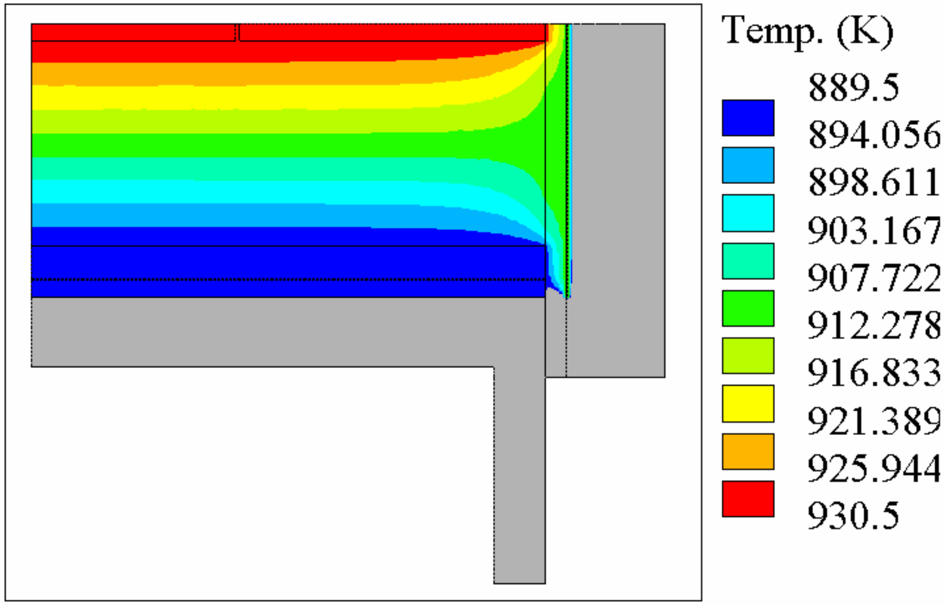


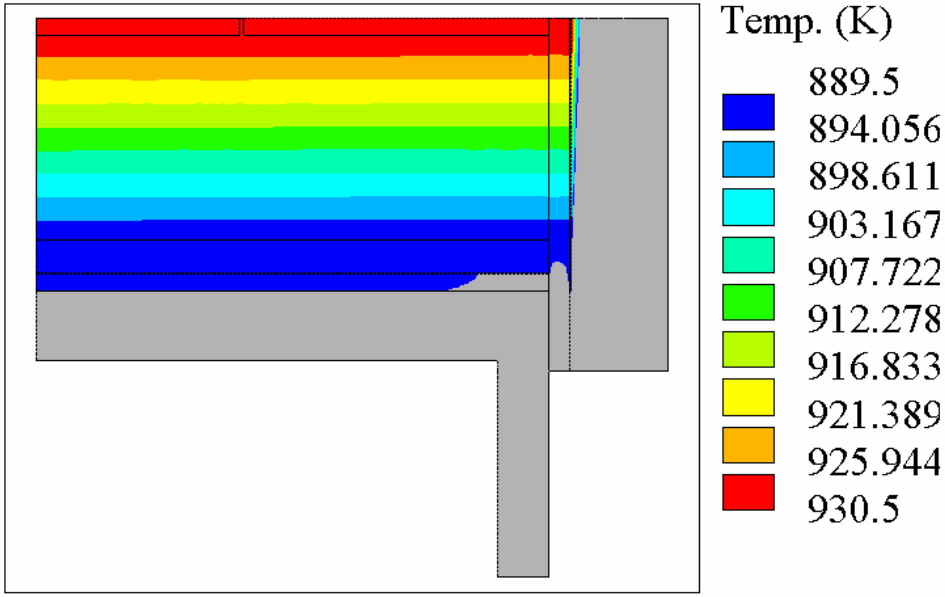
Finite Element Analysis – 50 mm Annulus





Finite Element Analysis – 10 mm Annulus





Isothermal guard

Linear guard

Conclusions

- Neumann (Convective) Boundary Condition is Okay for Estimating Edge Heat Flow Effects for Guarded Hot Plates at Moderate Temperatures if there is no Nearby Heat Sink or Source at a Temperature Quite Different from that of the Specimens
- Approximate Analytical Solutions are Given in the Written Paper for Heat Flow in the Edge Insulation when there is a Coolant Plate at a Temperature Quite Different from That of the Cold Plates and Specimens

Conclusions (Cont'd)

- If the Edge Insulation is too Thin, there may be Excessive Heat Exchange between the Edge Guard and the Hot Plate, Specimens, and Cold Plates
- If the Edge Insulation is too Thick, there may be Excessive Shunting Heat Flows from the Specimen into the Edge Insulation
- Computations Made Using the Approximate Analytical Solutions Indicate that such Shunting Heat Flows can be Drastically Larger than would be Expected from the Conventional Analysis with a Convective Boundary Condition

Conclusions (Cont'd)

- The Magnitude of the Errors due to Shunting Heat Flows were Confirmed by Finite Element Analyses for the Geometry of the New NIST 500 mm Guarded Hot Plate Apparatus
- In the Design of Future Guarded Hot Plate Apparatus, it is Important to Analyze the Possible Effects of Extraneous Heat Flows
- The Presence of Significant Shunting Heat Flows May be Confirmed by Running Tests at the Same Mean Temperature but with Very Different Temperature Differences across the Specimens

The End

Questions and comments: Daniel.Flynn@nist.gov