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# **Comparison of Measured Temperature and Heat Flux in Fire Resistance Test Furnaces Controlled by Six Temperature measuring Devices**

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National Research  
Council Canada

Conseil national  
de recherches Canada

Canada

# Outline

- Introduction
- Parameters investigated
- Test Facility/Experiments
- Results and Discussion
- Summary

# Introduction

## Why this research is needed?

- Performance-based fire safety design
  - Lack of engineering data from standard test E119
- NIST Report on WTC (recommendations)
- FPRF Report (recommendations)
  - Furnace instrumentation (plate thermometer)
  - Furnace operation (calibration test to quantify thermal exposure)
- Development of a new E05 standard
  - Heat flux measurement
- Laboratories use different type of temperature sensor in controlling fire resistance furnace temperature

## Parameters Investigated

- Compare temperature heat flux responses for fire resistance floor furnace controlled by
  - ASTM E119 shielded thermocouples
  - ISO 834 plate thermometers
  - Directional flame thermometers
  - Bare bead thermocouples
  - Sheathed grounded thermocouples
  - Sheathed non-grounded thermocouples
- Time response for shielded, PT and DFT

# NRC Test Facility Floor/Ceiling Furnace



# Experimental Measurements: Temp. & Incident Heat Flux

- Test 1, Furnace controlled by ASTM E119 shielded thermocouples
  - PT, DFT, BBT, Sheathed T-grounded Sheathed T non-grounded
- Test 2, Furnace controlled by ISO 834 plate thermometers
  - Shielded T, DFT, Sheathed T-grounded Sheathed T non-grounded and BBT
- Test 3, Furnace controlled by directional flame thermometers
  - Shielded T, BBT, PT, Sheathed T-grounded Sheathed T non-grounded



# Experimental Measurements: Temp. & Incident Heat Flux

- Test 4, Furnace controlled by bare bead thermocouples (BBT)
  - PT, DFT, Shielded T, Sheathed T-grounded and Sheathed T non-grounded
- Test 5, Furnace controlled by Sheathed Thermocouples-grounded
  - Shielded T, PT, DFT, BBT and Sheathed T grounded
- Test 6, Furnace controlled by Sheathed non-grounded
  - Shielded T and PT, DFT, BBT and Sheathed T-grounded



# Temp and Heat Flux Devices

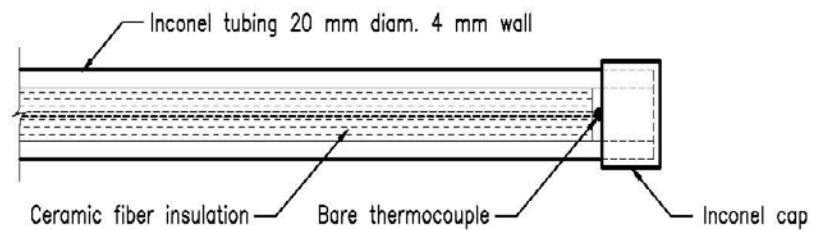


- Heat Flux Meter
- DFT
- PT (ISO 834)
- BBT
- Sheathed Un-G
- Sheathed G
- Shielded  
(ASTM E119)

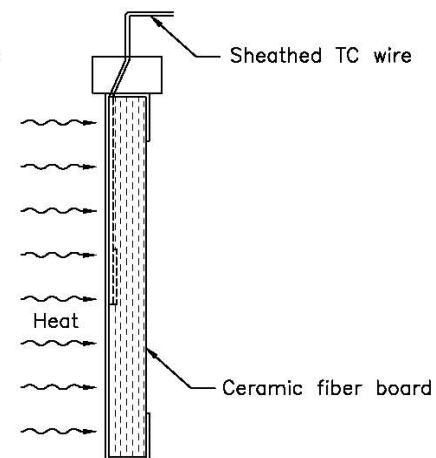
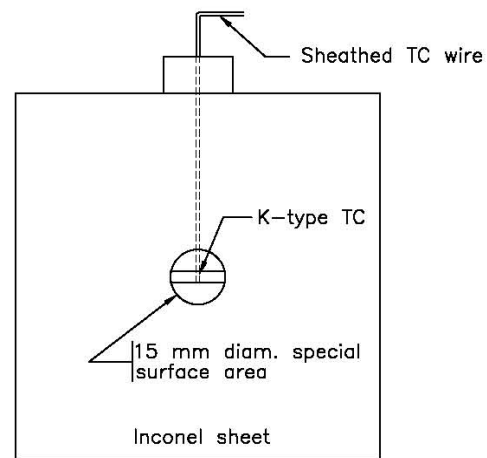
# Temp and Heat Flux Devices



# Shielded Thermocouple

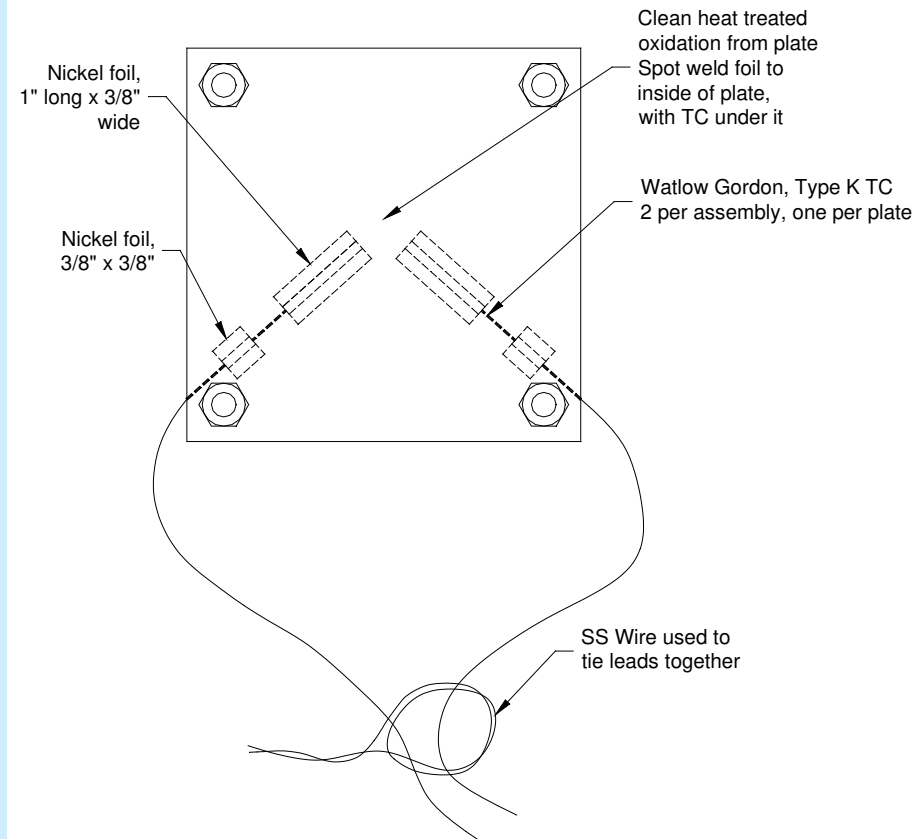
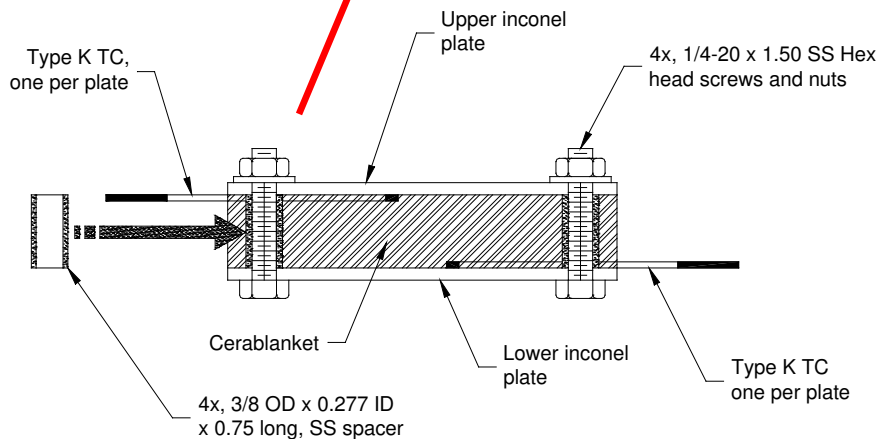


# Plate Thermometer





# Directional Flame Thermometer



# Sheathed Thermocouple



# Grounded and Ungrounded Sheathed Thermocouple

## Sheathed Grounded Thermocouple

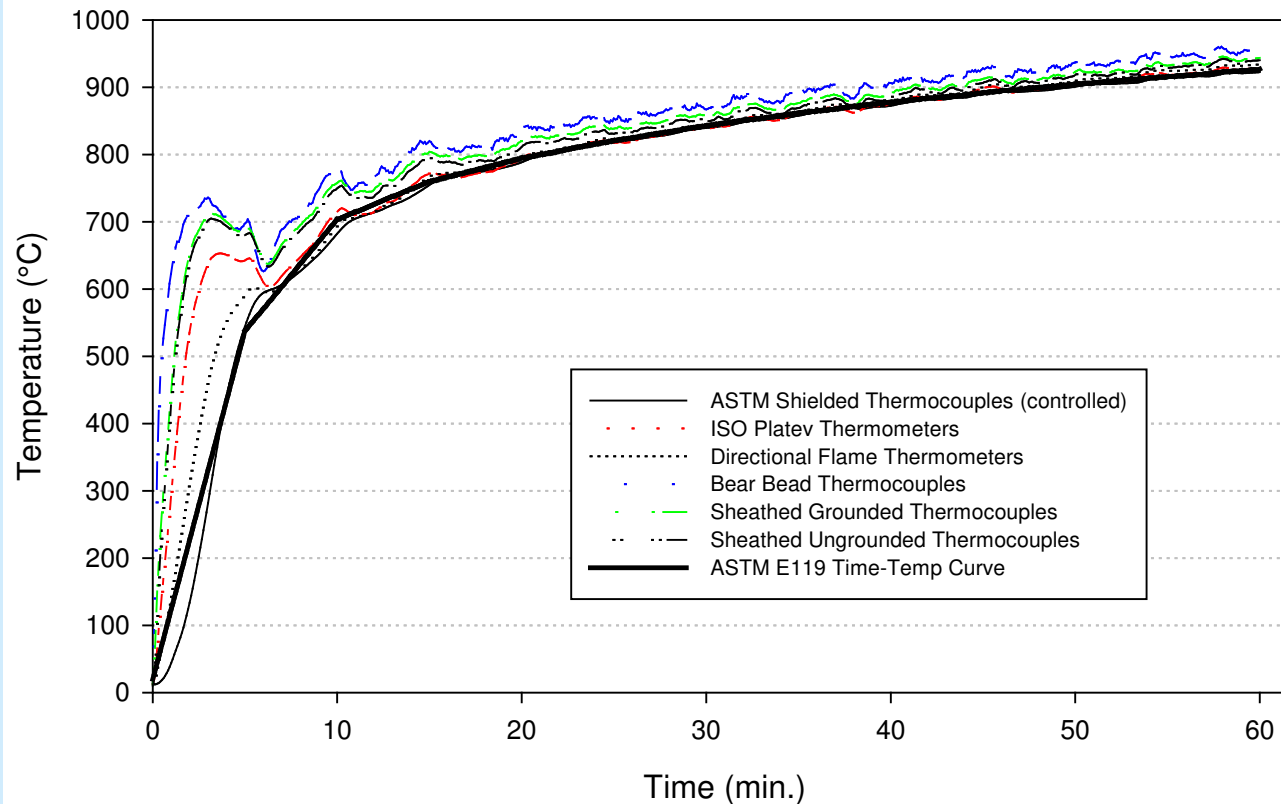
The thermocouple bead is  
attached to the inside of the probe  
wall

## Sheathed Ungrounded Thermocouple

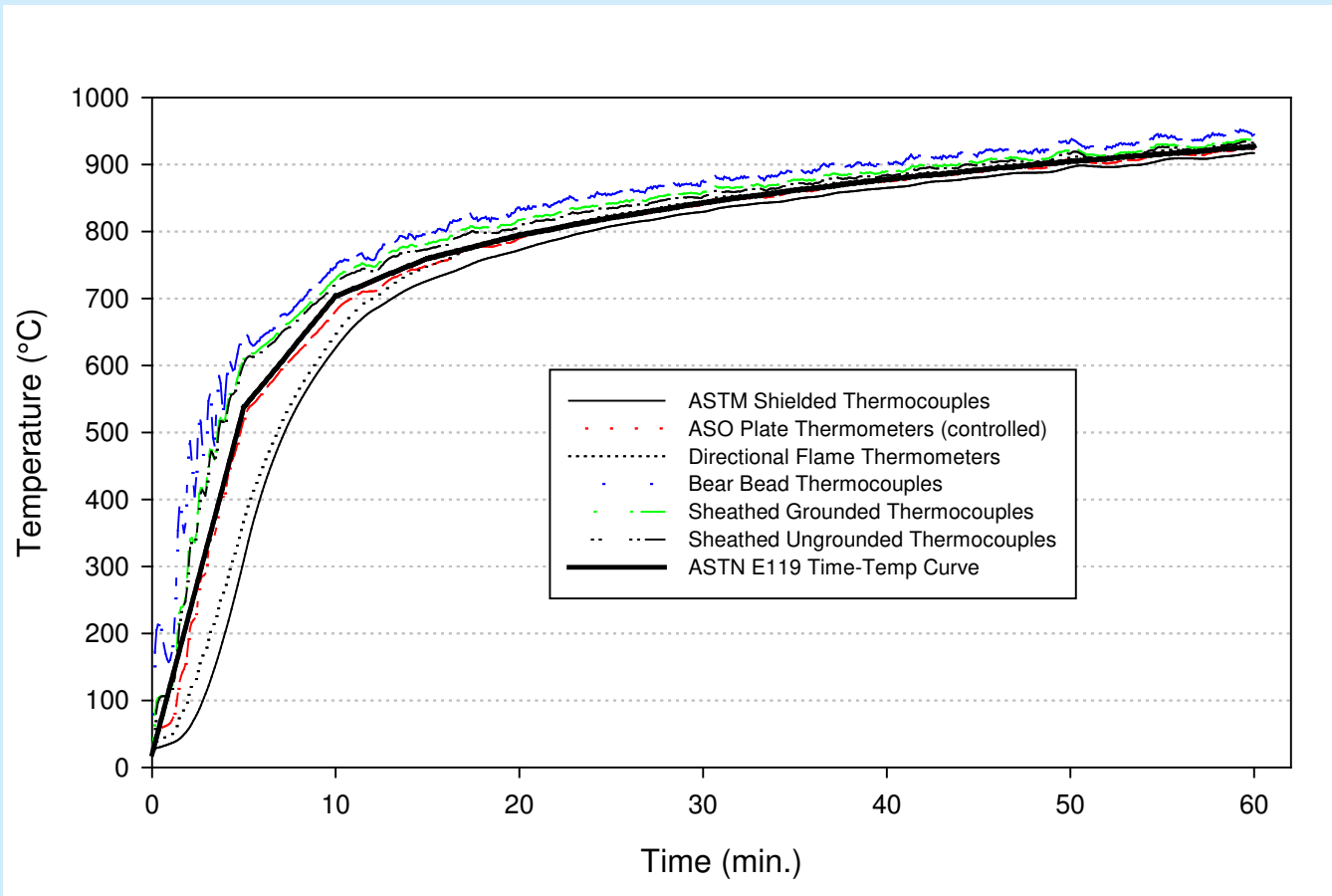
The Thermocouple bead is  
detached from the inside of the  
probe wall



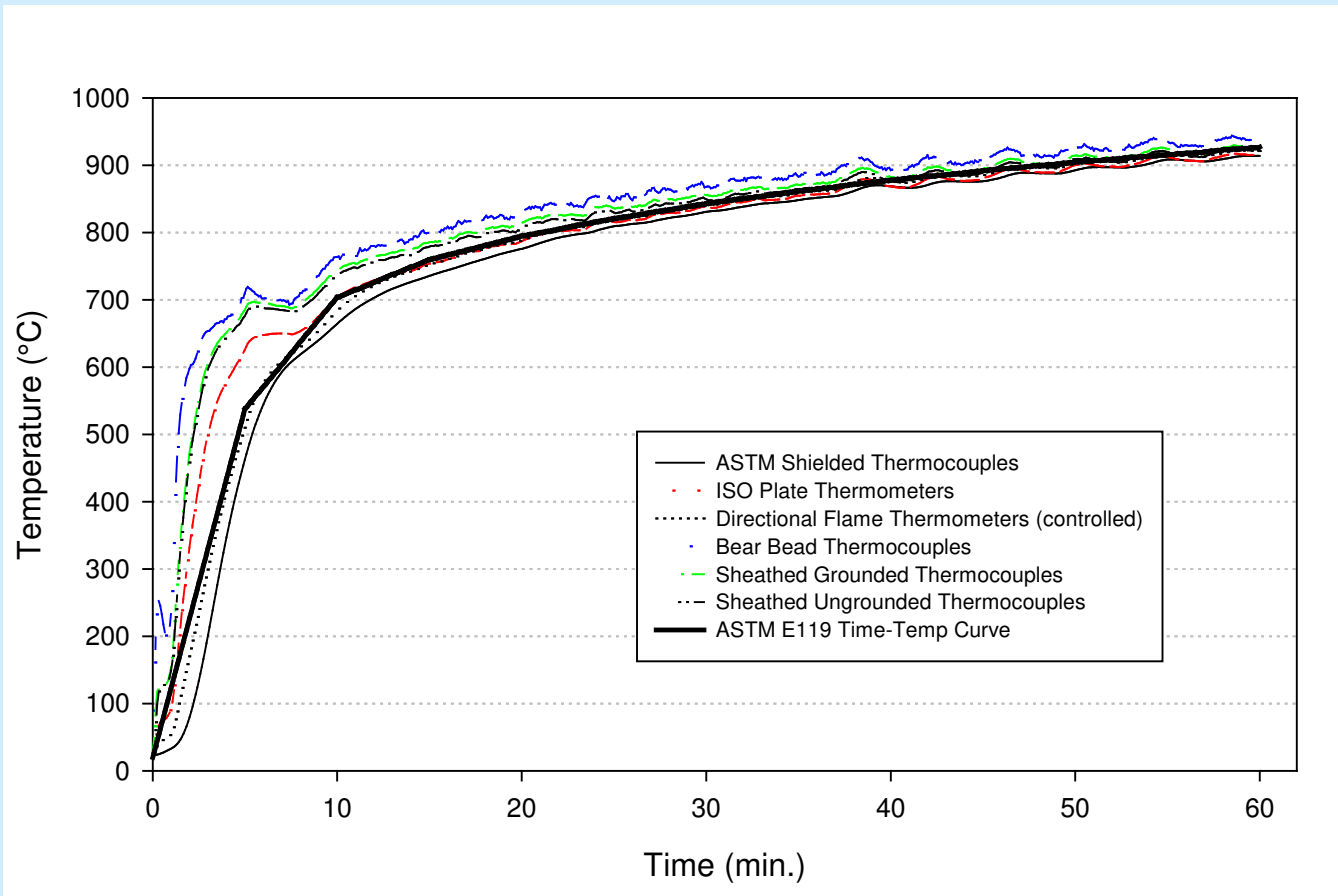
# Furnace Controlled by ASTM Shielded Thermocouples



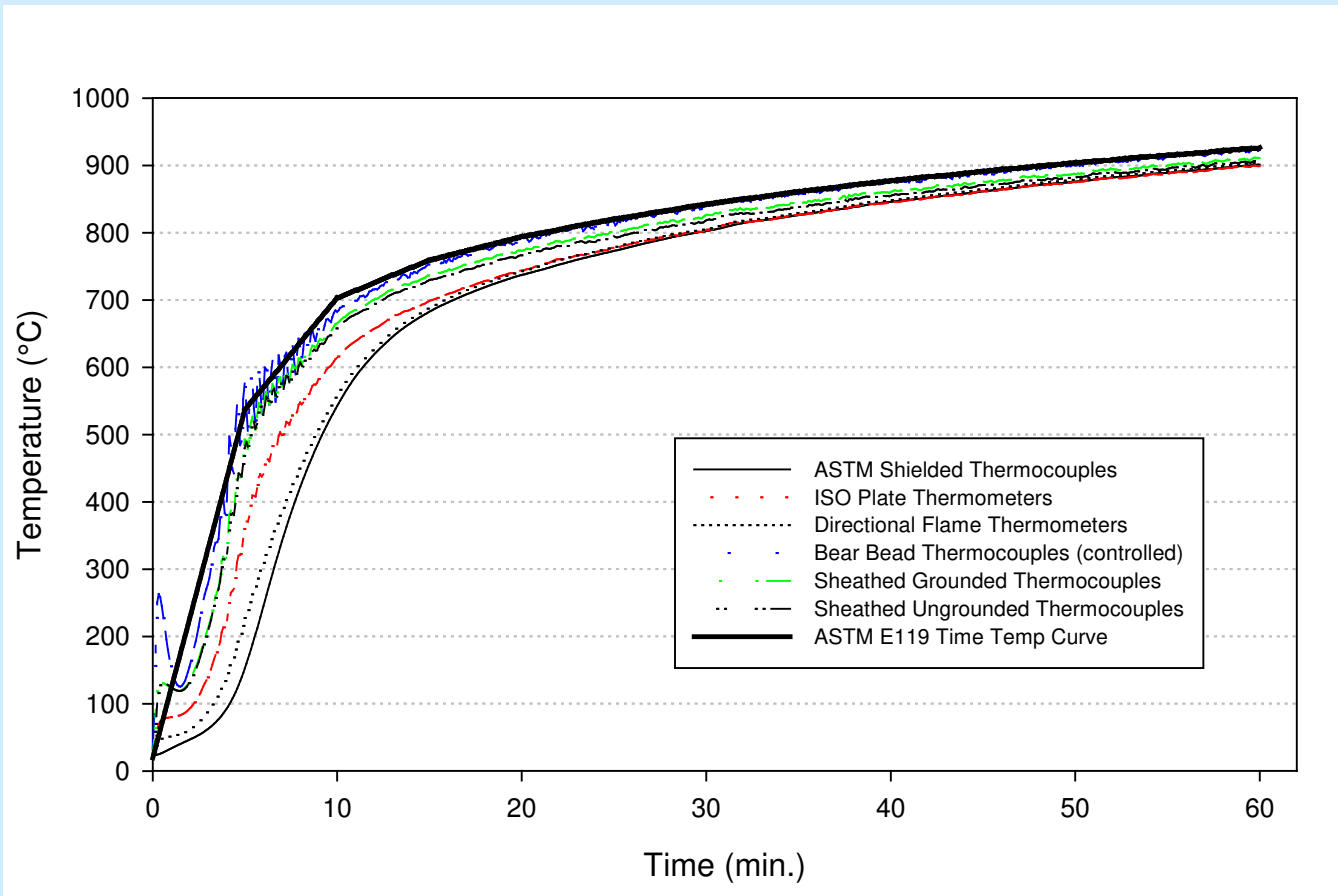
# Furnace Controlled by ISO Plate Thermometers



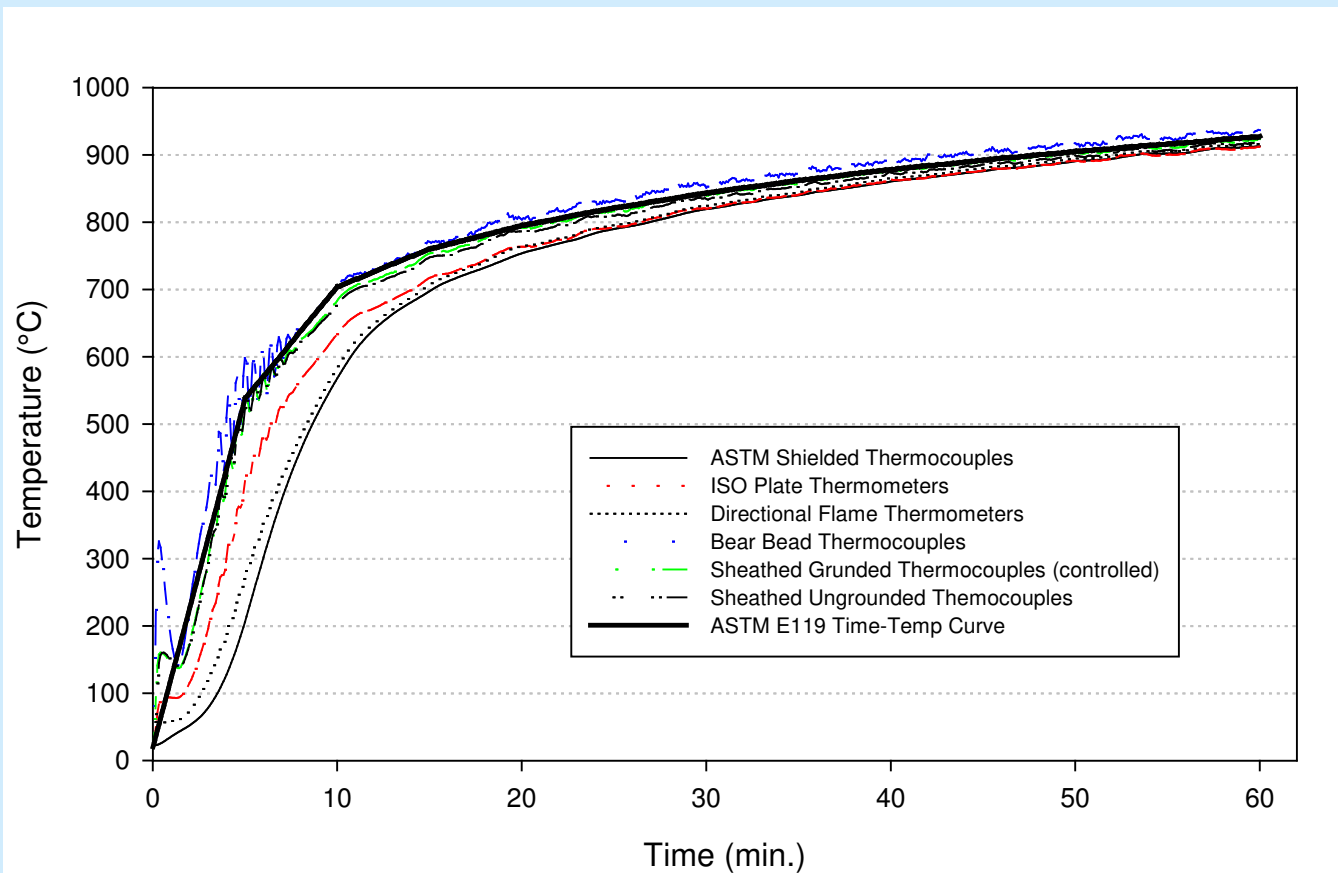
# Furnace Controlled by Directional Flame Thermometers



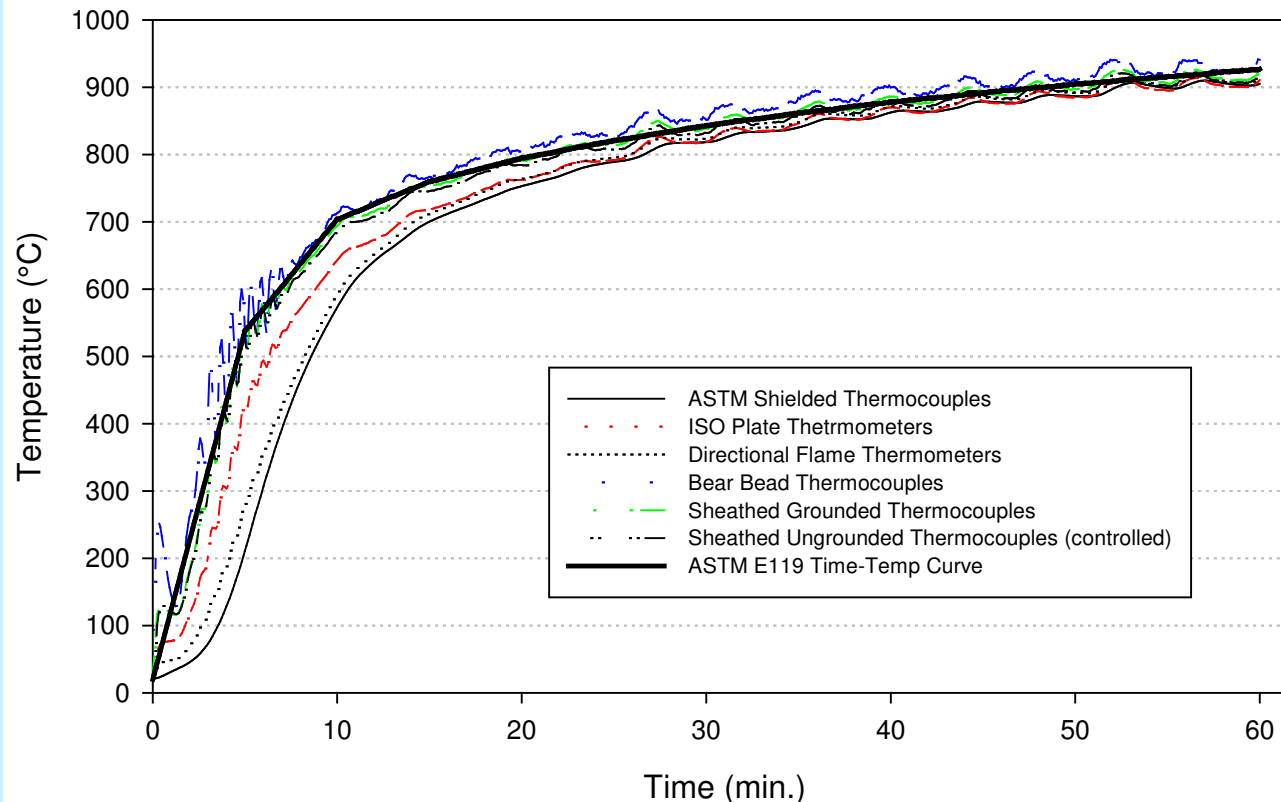
# Furnace Controlled by Bare Bead Thermocouples



# Furnace Controlled by Sheathed Grounded Thermocouple



# Furnace Controlled by Sheathed Ungrounded Thermocouple

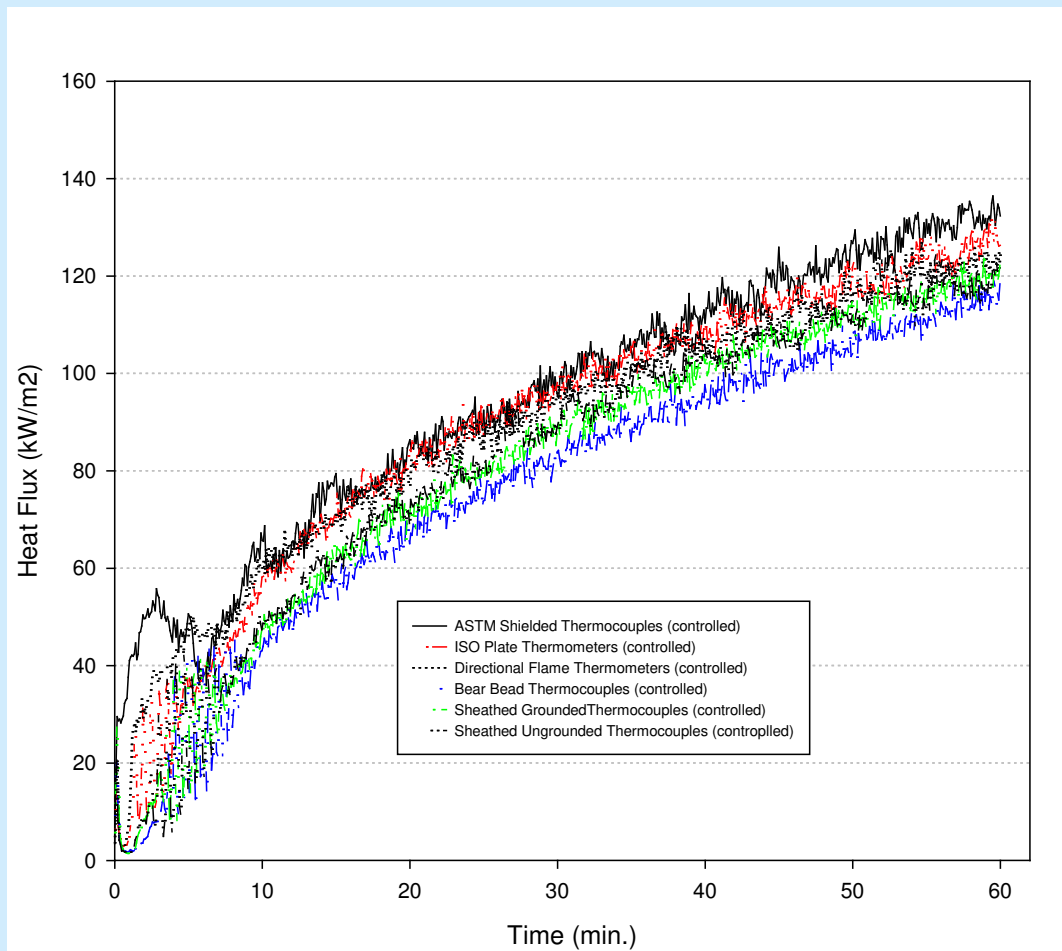


# Gardon Gauge Heat Flux Sensor





# Incident Heat Flux



## Total heat transfer to fire exposed surface

$$\begin{aligned} Q_{\text{total}} &= \text{Radiation} + \text{Convection} \\ &= \varepsilon \sigma (T_{\text{AST}}^4 - T_s^4) + h_c (T_{\text{AST}} - T_s) \end{aligned}$$

Where:

$T_{\text{AST}}$  Plate Thermometer temperature measurement  
(Adiabatic Surface Temperature)

$T_s$  Surface temperature (target surface)

$h_c$  Convective heat transfer coefficient

# Incident Heat Radiation

$Q_{inc} = \sigma T_f^4$  (assuming convective heat is small) Predicted

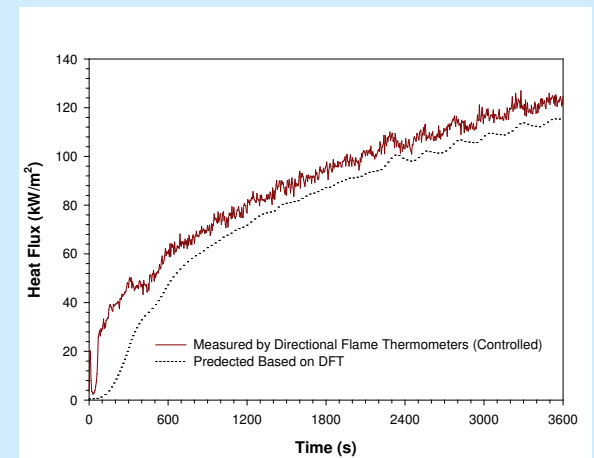
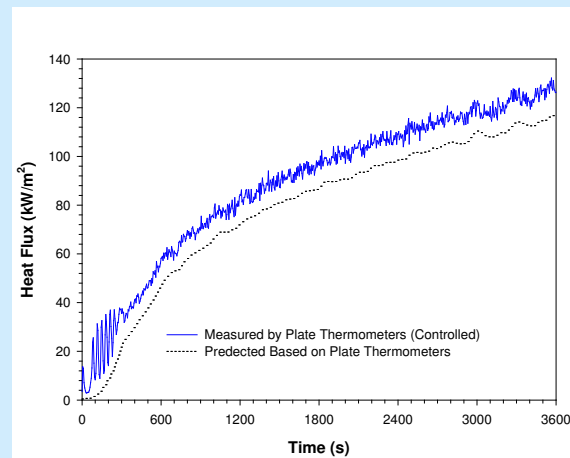
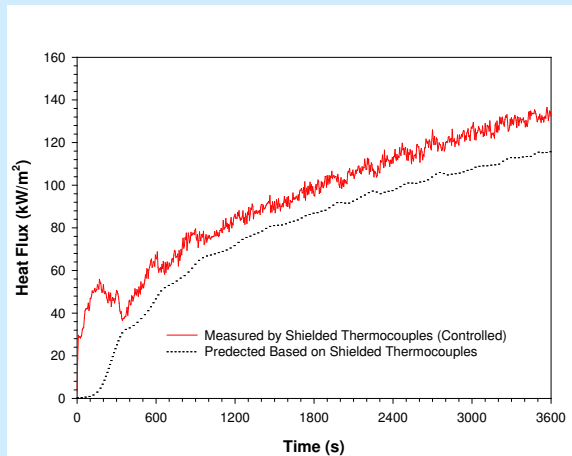
$Q_{inc}$  measured by Gardon gauge heat flux meter

Furnace Controlled by

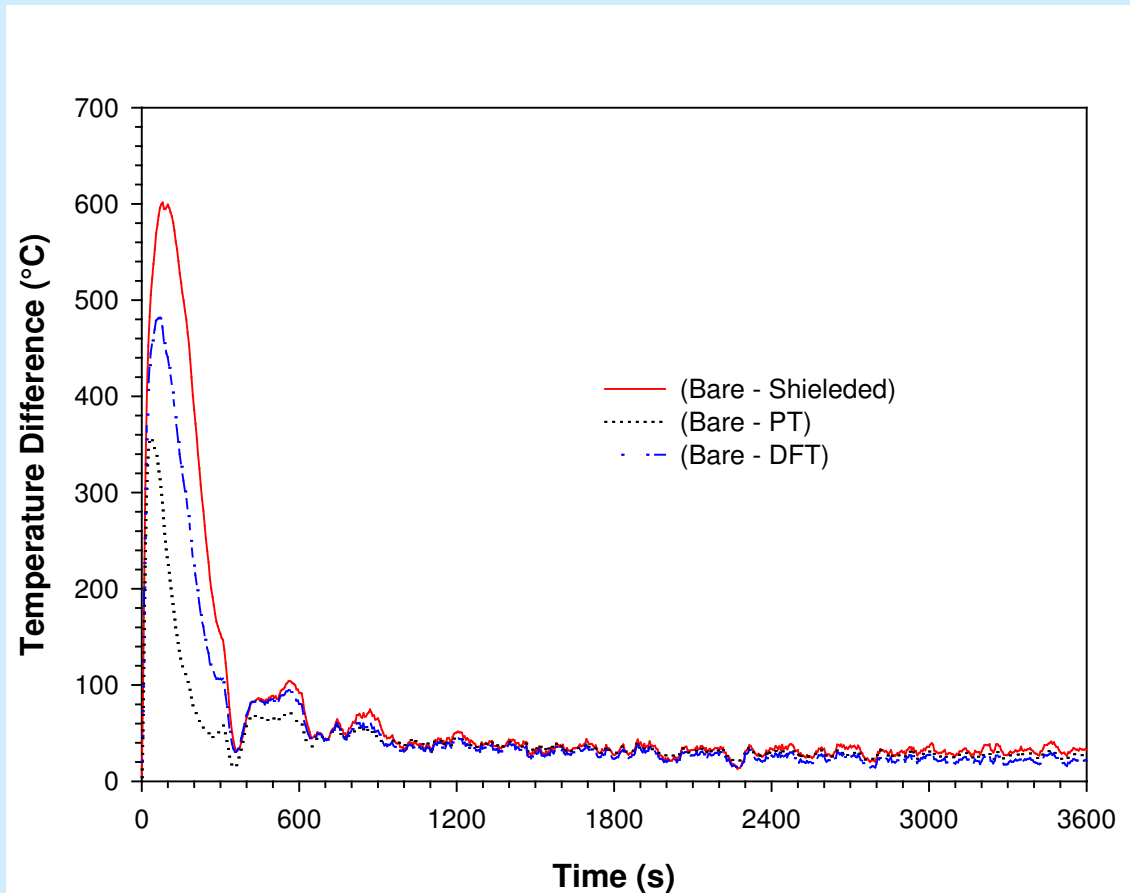
Shielded Thermocouples

Plate Thermometers

Directional Flame Thermometers

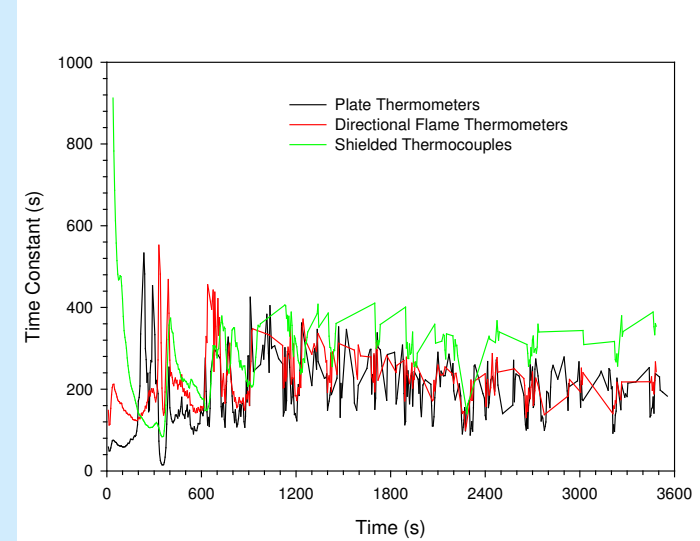
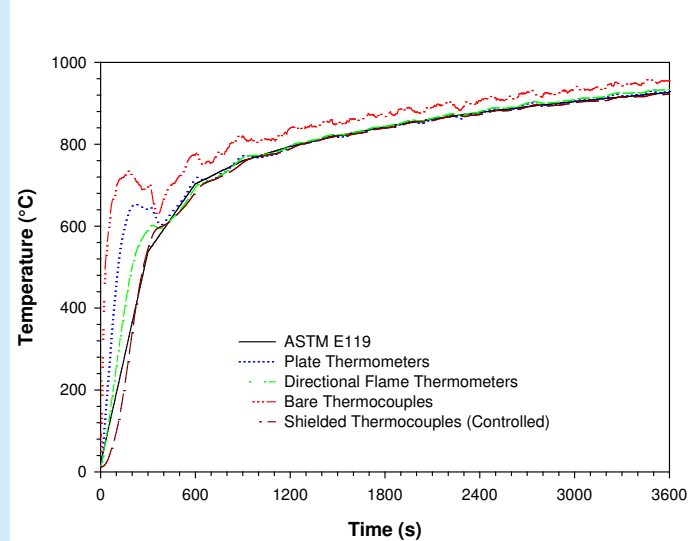


# Temperature Lag with Respect to a Bare Bead Thermocouple



# Time Constant

Time Constant  $\tau(t) = (T_f - T_t) / (\Delta T_t / \Delta t)$   
 $T_f$  bare bead thermocouple



# Summary

- In first 8-10 min, the effect of furnace control method on furnace temperature is significant, however, after 8-10 min, difference is insignificant.
- In first 8-10 min, the effect of furnace control temperature on heat flux is significant, however, after 8-10 min, difference is insignificant for the plate and directional flame thermometers and significant for bead and sheathed thermocouples.

# Summary

- Furnace temperature and incident heat flux are comparable for furnaces controlled by bear bead and sheathed thermocouples.
- In first 8-10, time constant for DFT, PT and Shielded are different, however, after 8-10 min, difference is insignificant.



# Summary

- The predicted incident heat flux is approximately 10-15% less than of the measured value.
- For a short duration fire resistance test (i.e. 15 min test), the type of the thermocouple used to control the furnace is important.



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# Questions



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