EMRP SIB 52 Thermo

Measurement Uncertainty of High-Temperature Guarded Hot Plate Instruments

Uncertainty budget workshop 3

18 month meeting

Stakeholder meeting

NPL, UK

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Overview

- Measurement uncertainty
  - General remarks
  - ISO GUM JCGM 100:2008
- High-Temperature Guarded Hot Plate
  - Ideal model
  - Real model
  - Uncertainty budget
- Summary

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General remarks

- measurement result:

  measured quantity value + measurement uncertainty
- uncertainty assessment:
  - to be able to state the measurement uncertainty
  - to analyse the measuring instrument
    - find weak points
    - improve the measuring instrument

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ISO GUM, JCGM 100:2008

- measurement uncertainty
- mathematical model: $y = f(x_1, x_2, \ldots, x_N)$

  here (GHP), according to Fourier's eq. $\lambda = \frac{\Phi \cdot d}{A \cdot \Delta T}$

- type A evaluation: statistical analysis
- type B evaluation: other means (e.g. estimate)
- combined standard variance:

$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i)$$

- combined standard uncertainty:

$$u_c(y) = \sqrt{u_c^2(y)}$$

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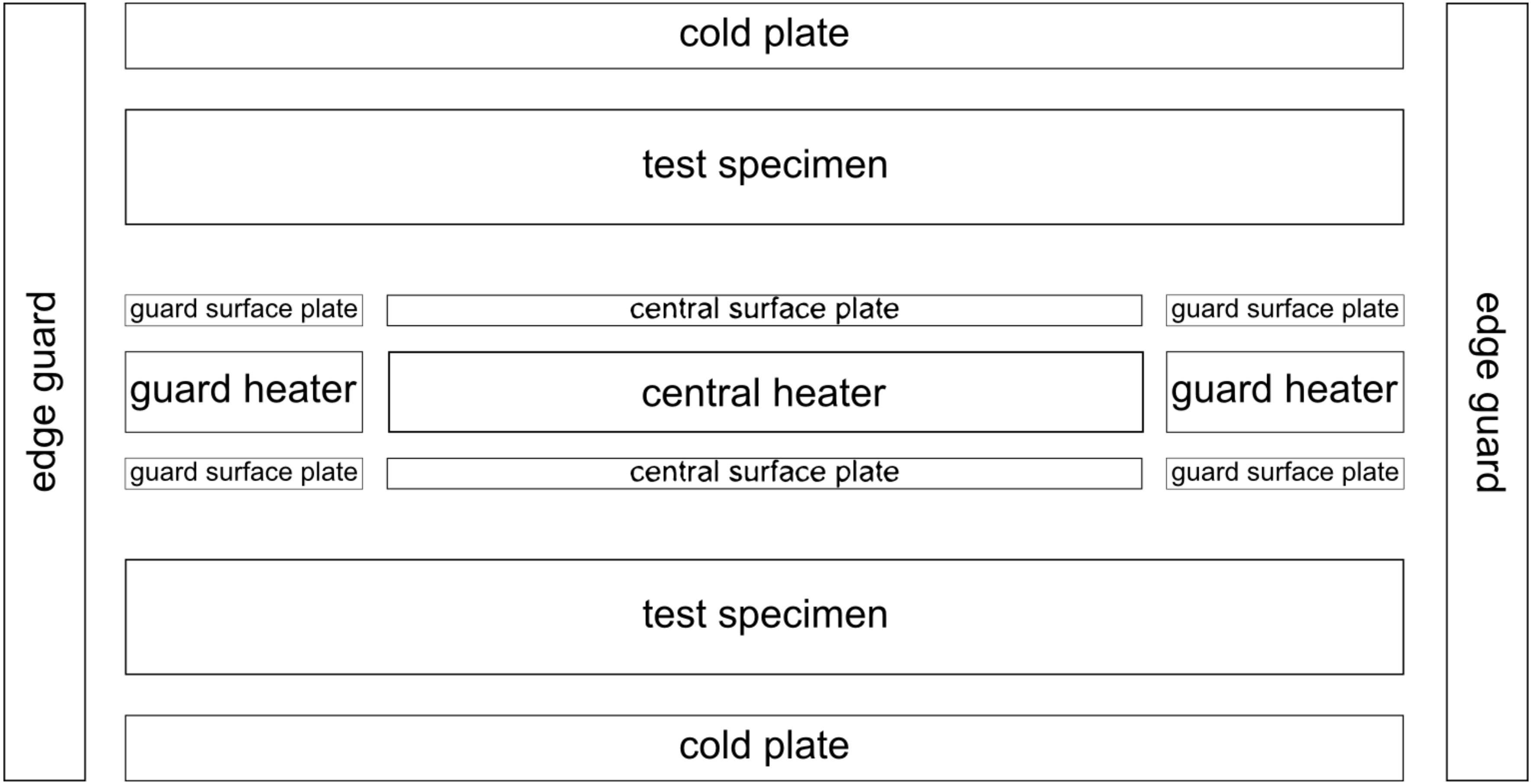
HT Guarded Hot Plate

- two specimens version



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HT Guarded Hot Plate

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- Ideal model

$$\lambda = \frac{\Phi \cdot d}{A \cdot \Delta T}$$

rate of heat flow Φ supplied to the hot plate

specimen thickness d

measuring area A

temperature difference ΔT

- model for a **perfect** GHP

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HT Guarded Hot Plate

- Real model
  - start with ideal model
  - correct systematic measurement errors
    - thickness
    - metering area
    - temperature drop
    - power
    - miscellaneous factors

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Uncertainty budget

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- list of all quantities influencing the measurement uncertainty
  - type A (evaluated by statistical means)
  - type B (evaluated by other means)
- calculation of the standard deviation
- verification
  - certified reference material
    - perform measurements
    - use statistics
      - average and exp. standard deviation of the mean
  - other possibilities to verify measurement uncertainty:
    - intercomparison studies
    - round robin tests

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Thickness measurement

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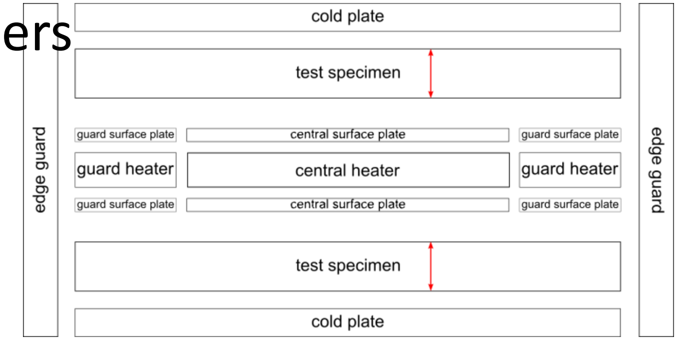
1) thickness measurement outside HTGHP apparatus
    - resolution and calibration of the callipers
    - misalignment
    - operator effect
    - thermal expansion
        - thermal expansion coefficient
        - uncertainty in mean specimen temperature
2) in-situ thickness measurement
    - resolution and calibration of the laser displacement sensor
    - correction for thermal expansion of the specimen stack

- variation in specimen thickness over the measuring area
- calibration of straight edge and feeler gauge
- effect of pressure
- compressible samples: thermal expansion of spacer blocks



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Metering area

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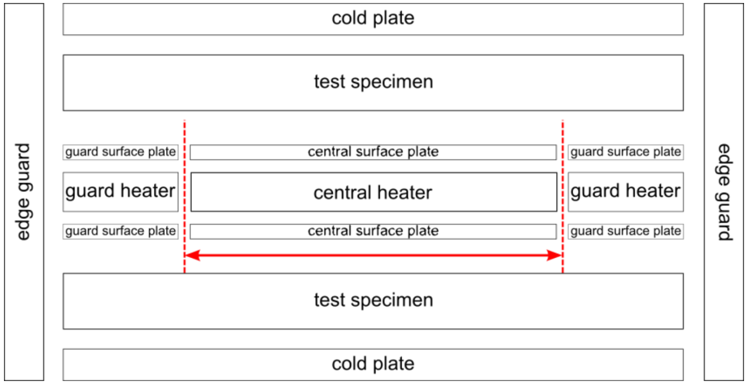
- determination of the metering area:
  - average of the diameter of the hot plate and the diameter of the inner edge of the guard ring
  - correction for thin specimens
- calibration and resolution of the callipers
- misalignment
- operator effect
- thermal expansion
  - thermal expansion coefficient
  - uncertainty in mean hot plate temperature



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Temperature drop

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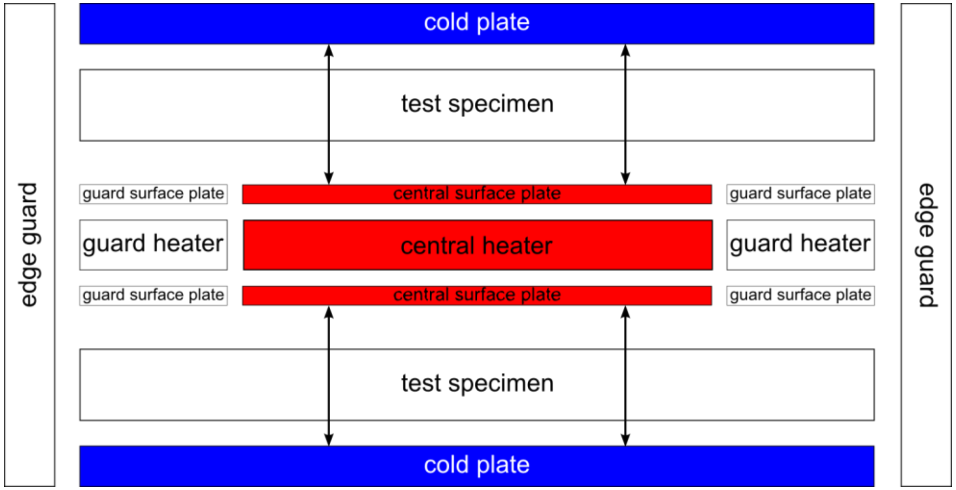
- calibration and resolution of the voltmeter
- calibration of temperature sensors
- stability and batch agreement of temperature sensors
- temperature spread
  - across metering area
  - across cold plate
- parasitic voltages (connections and switches)
- correction for position of thermocouples



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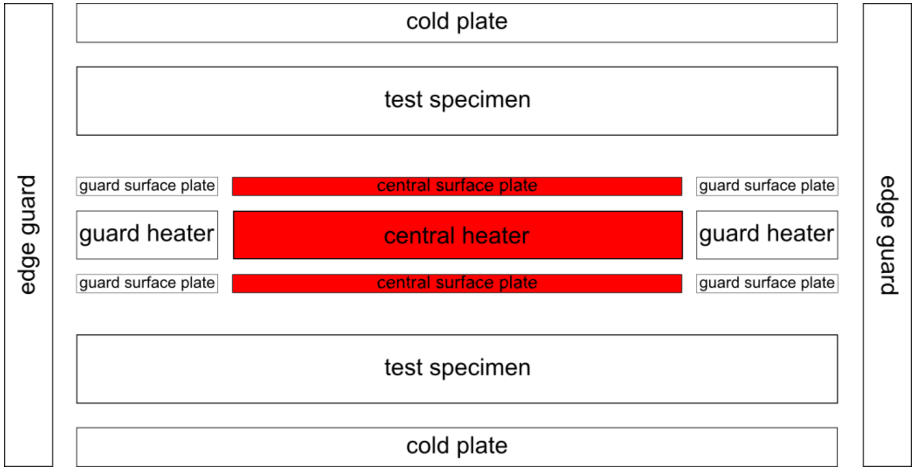
Power measurement

- calibration of the two voltmeters (voltage and current)
- calibration of the standard resistor
- parasitic voltages
- correction for heated length outside the metering area



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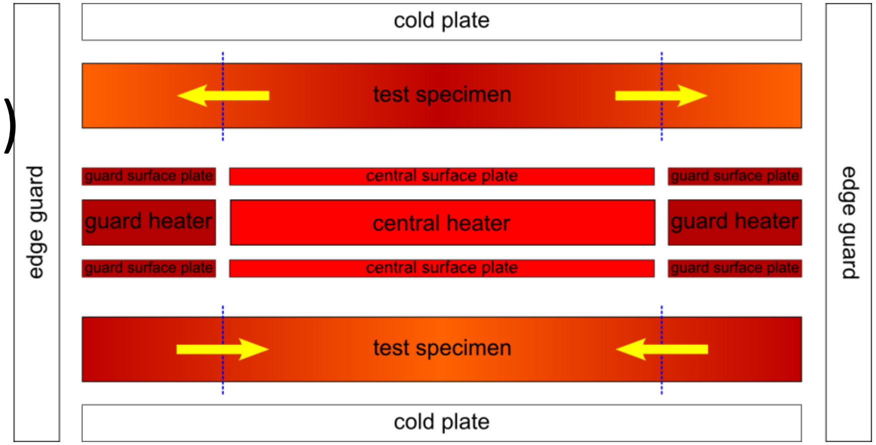
Miscellaneous factors

- temperature imbalance between guard ring and metering area
- temperature imbalance between auxiliary guard and metering area (for single specimen apparatus)
- edge heat loss/gain of the sample
- heat loss/gain between hot plate and auxiliary guard plate (for single specimen apparatus)
- potential deviation from 'true' thermal equilibrium



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Absolute mean temperature
(specimen related)

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- calibration and homogeneity of the temperature sensors
- in-situ temperature sensor calibration:
  - uncertainty of the PRT
  - calibration and resolution of the voltmeter
  - cold junction temperature

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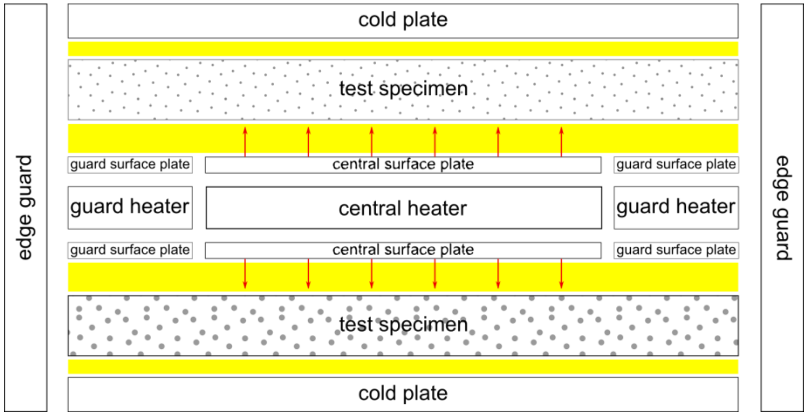
Miscellaneous factors
(specimen related)

- thermal contact resistance between heater plates and sample(s)
- thermal contact resistance between temperature sensors and specimen(s)
- specimen homogeneity
- uncertainty in mean temperature of the sample(s)
- variation of thermal conductivity of the specimen(s) with temperature
- emissivity of the heater plates
- slight difference between the two specimens



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Example uncertainty budget

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Uncertainty budget of PTB's GHP

Quantity X_i	Estimate x_i	Prob. distrib.	sensitivity coeff. c_i	Stand. unc. $u(x_i)$	$u_i(y)$	$[u_i(y)/u_c(y)]^2$
P_0	8.9 W	normal	1.27×10^{-1} m^{-1}·K^{-1}	2.3×10^{-4} W	2.9×10^{-5} W·m^{-1}·K^{-1}	0.007 %
P_x	0 W	normal	-1.27×10^{-1} m^{-1}·K^{-1}	3.9×10^{-4} W^{-1}	-5.0×10^{-5} W·m^{-1}·K^{-1}	0.002 %
P_{V1}	0 W	normal	-1.27×10^{-1} m^{-1}·K^{-1}	9.2×10^{-4} W^{-1}	-1.2×10^{-5} W·m^{-1}·K^{-1}	0.01 %
P_{V2}	0 W	normal	-1.27×10^{-1} m^{-1}·K^{-1}	9.2×10^{-4} W^{-1}	-1.2×10^{-5} W·m^{-1}·K^{-1}	0.01 %
P_{V3}	0 W	normal	-1.27×10^{-1} m^{-1}·K^{-1}	9.2×10^{-4} W^{-1}	-1.2×10^{-5} W·m^{-1}·K^{-1}	0.01 %
A_0	7853.98×10^{-6} m^2	rectangular	-1.44×10^{-3} W·m^{-3}·K^{-1}	7.9×10^{-6} m^2	-1.1×10^{-5} W·m^{-1}·K^{-1}	0.9 %
d_0	10×10^{-3} m	rectangular	1.13×10^{-2} W·m^{-2}·K^{-1}	5.0×10^{-6} m	5.8×10^{-5} W·m^{-1}·K^{-1}	0.3 %
ΔT_0	10 K	normal	-1.13×10^{-1} W·m^{-1}·K^{-2}	5.7×10^{-2} K	-6.4×10^{-5} W·m^{-1}·K^{-1}	32.9 %
ΔT_b	0 K	normal	1.13×10^{-1} W·m^{-1}·K^{-2}	5.7×10^{-2} K	6.4×10^{-5} W·m^{-1}·K^{-1}	32.9 %
ΔT_c	0 K	normal	1.13×10^{-1} W·m^{-1}·K^{-2}	5.7×10^{-2} K	6.4×10^{-5} W·m^{-1}·K^{-1}	32.9 %
λ	**1.13 W·m^{-1}·K^{-1}**				**0.011 W·m^{-1}·K^{-1}**	

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Summary

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- many quantities influence the measurement uncertainty of a HTGHP
- careful uncertainty assessment necessary
  - find weak points
  - improve measurement instrument
  - state measurement uncertainty

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