Instrument Model for Narrow Angle Radiometers

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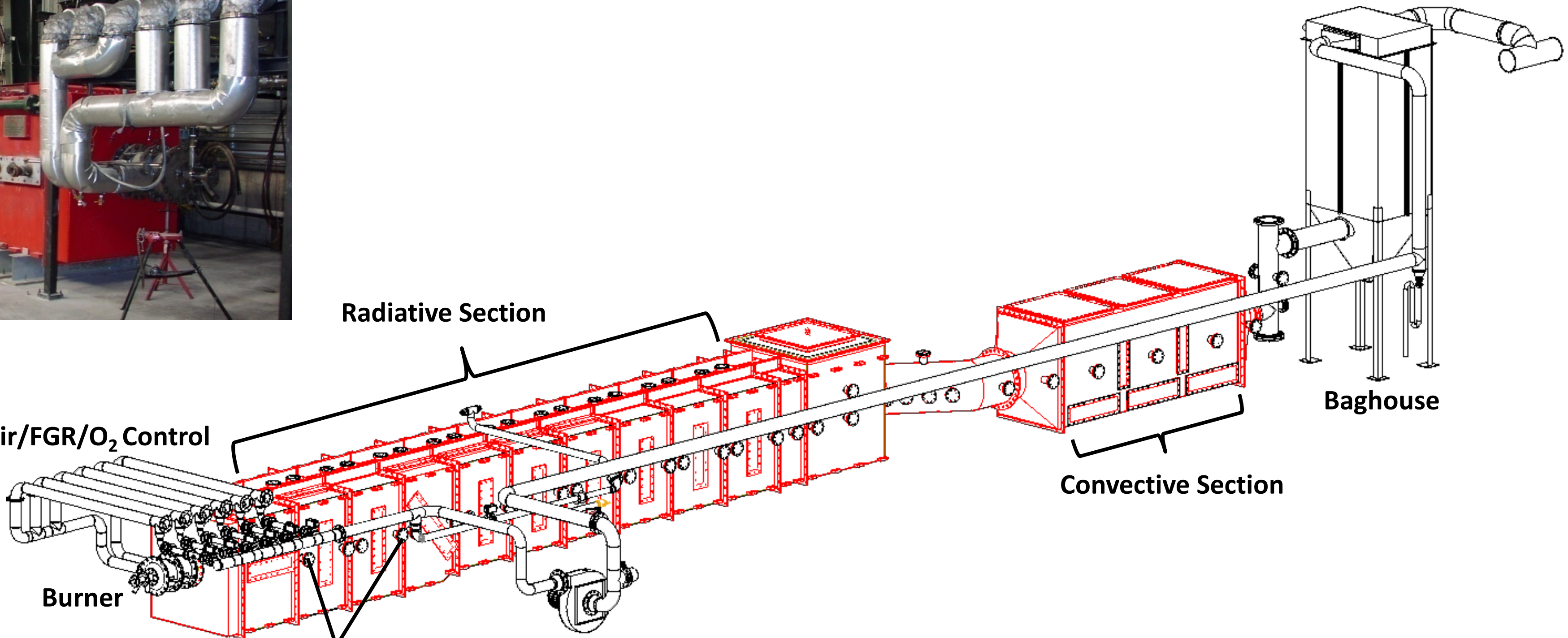
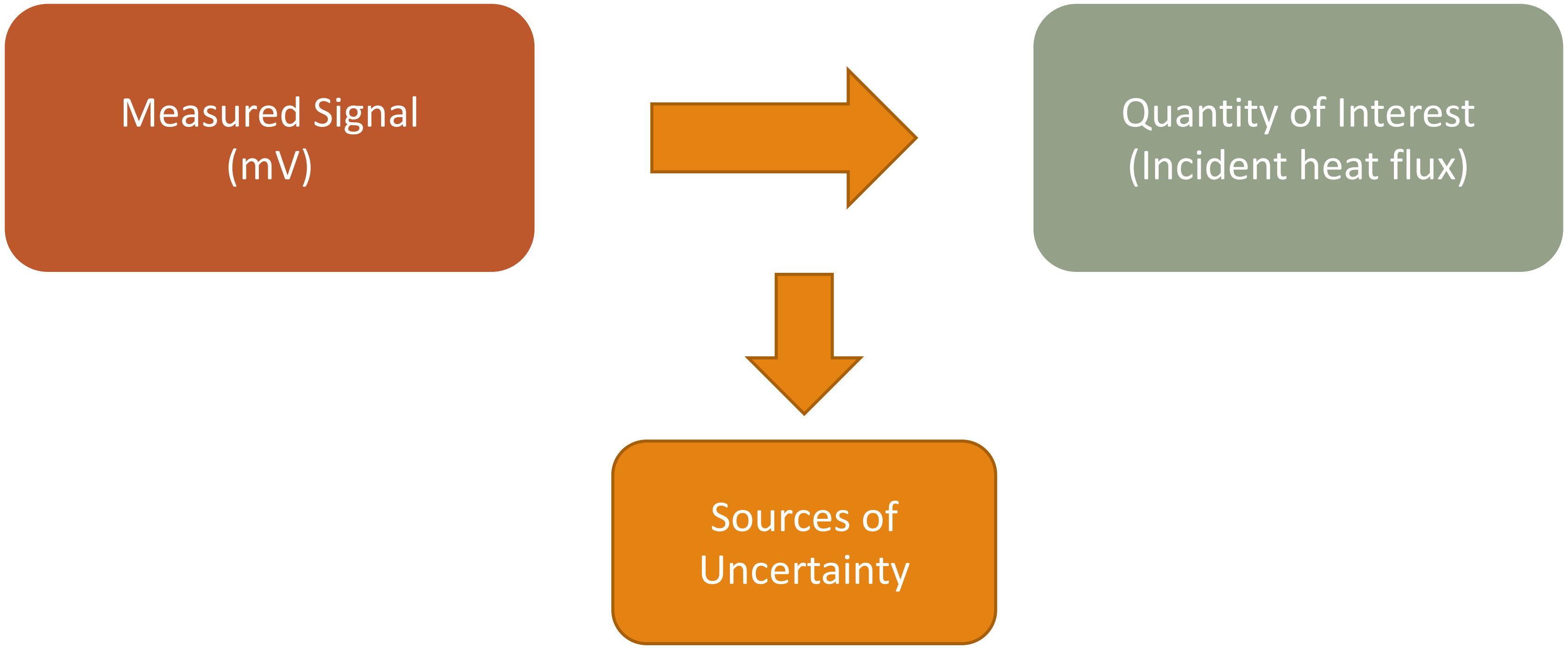
L1500 1.5 MW Furnace

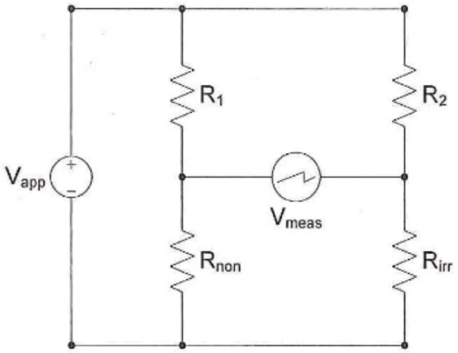


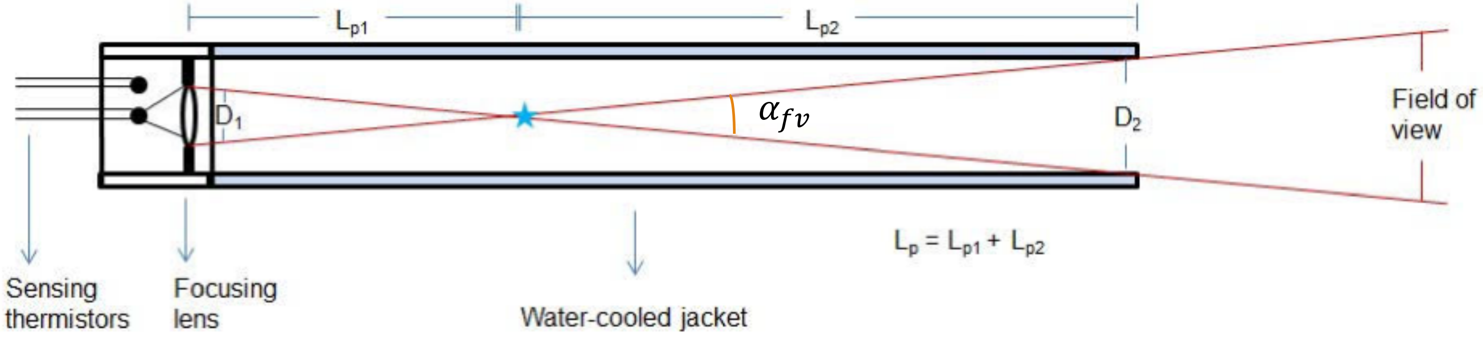
Overview of an Instrument Model



Narrow Angle Radiometer Design

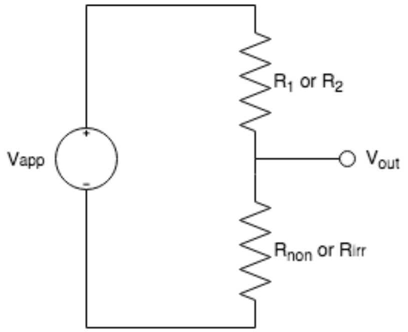
- The change in temperature of the thermistor causes a change in resistance
- Design based on IFRF and used by PRAXAIR
- We have identified uncertainties in construction, operation and calibration



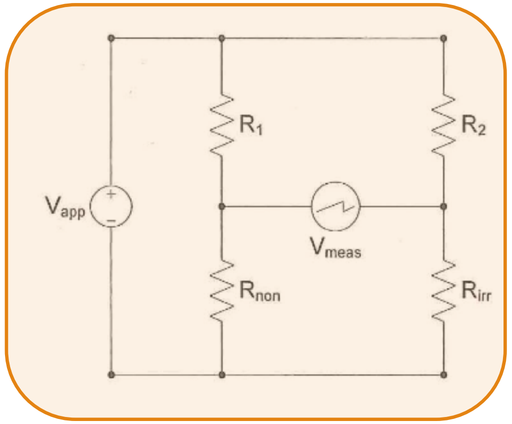


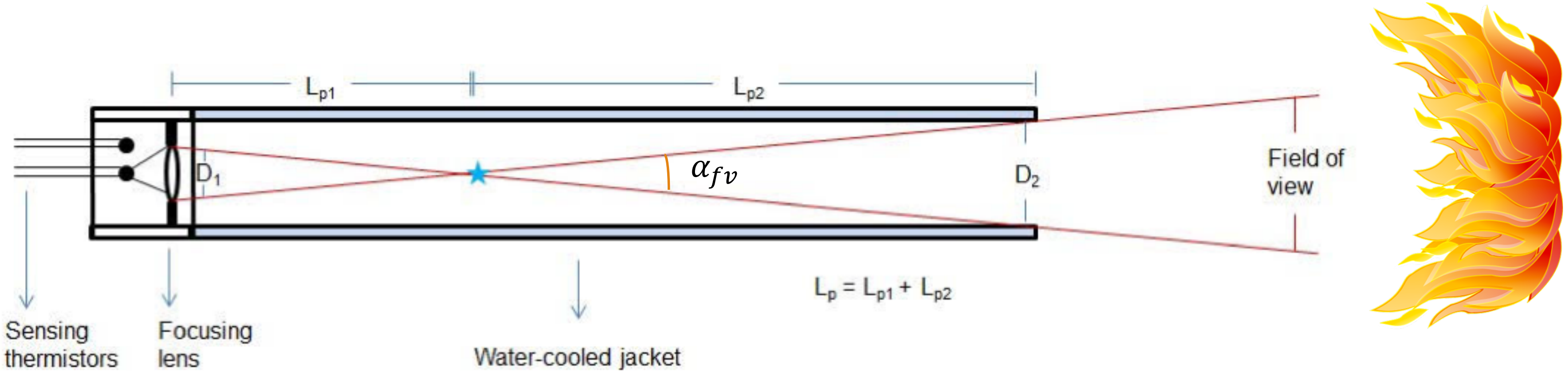
Narrow Angle Radiometer Design: Wheatstone Bridge

$$V_{meas} = V_{app}\left(\frac{R_{non}}{R_{non} + R_1} - \frac{R_{irr}}{R_{irr} + R_2}\right)$$



$$R_{irr} = \frac{V_{out}R_1}{V_{app} - V_{out}}$$

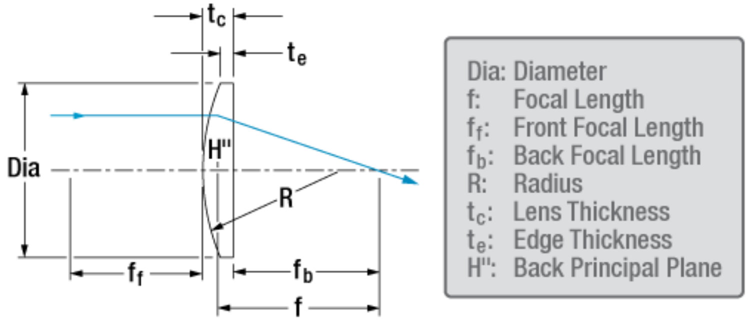


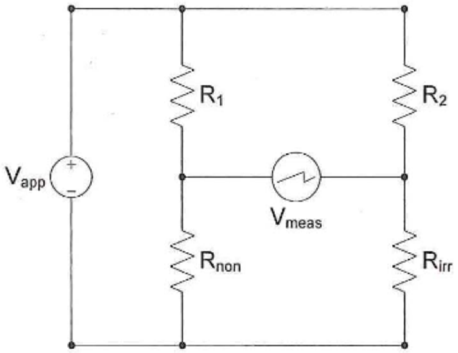


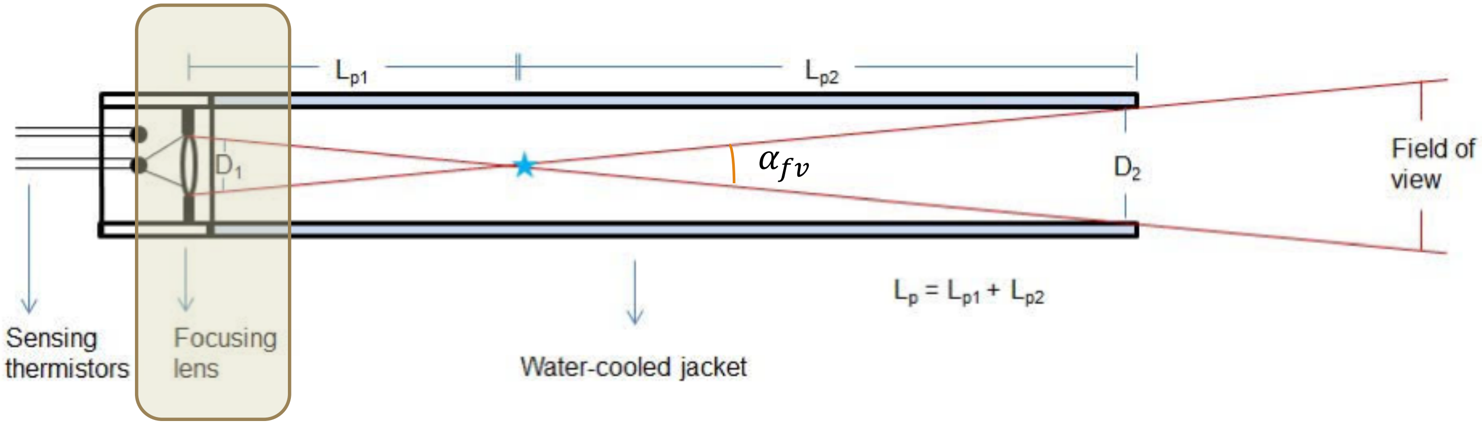
Narrow Angle Radiometer Design: Lens

Focal length (17-25 mm): $f = \frac{R}{n-1}$

Reflectivity (0.022-0.041): $\rho = \left|\frac{n_1 - n_2}{n_1 + n_2}\right|^2$





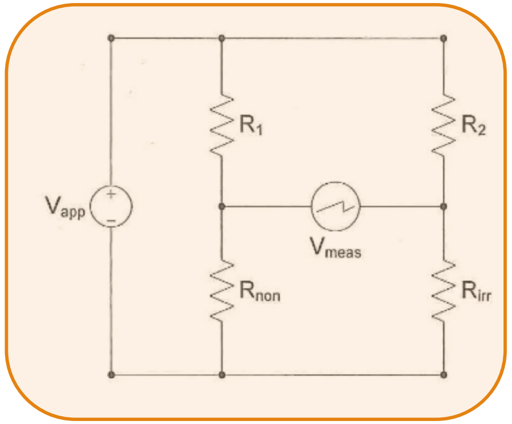


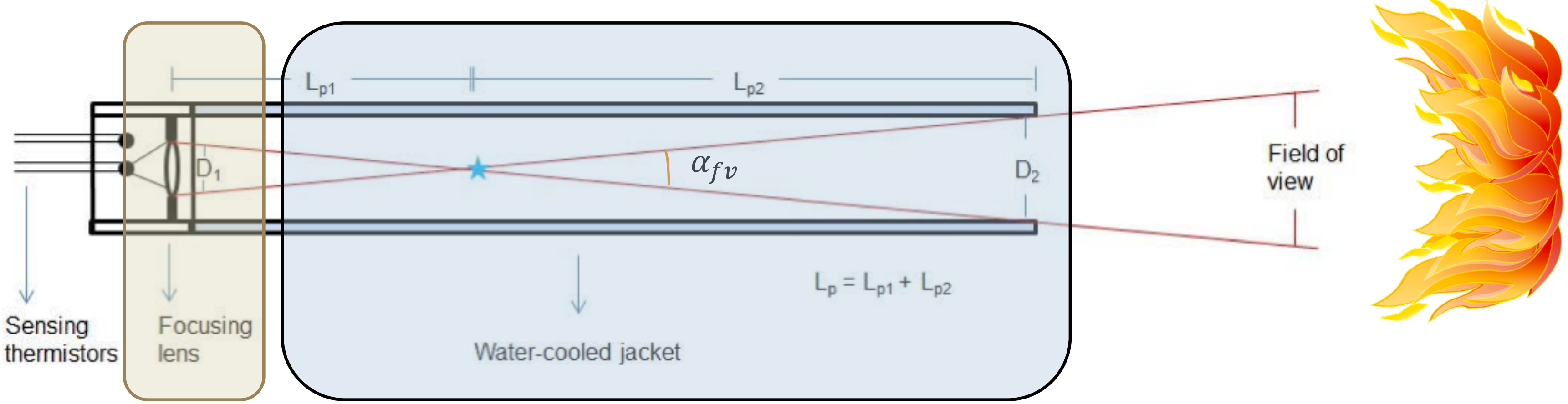
Design Uncertainty

- Transient temperature
- Irradiated thermistor temperature
- Non-irradiated thermistor placement
- Measured voltage

- Refractive index
- Image size
- Focal point
- Lens mounting

- View angle
- Reflectivity





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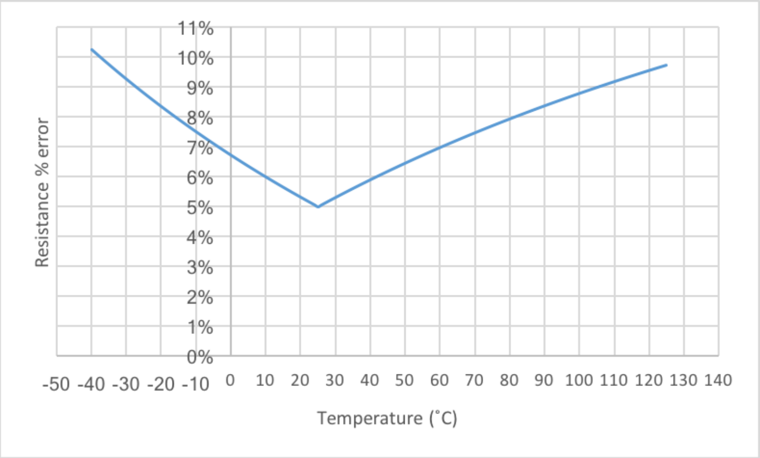
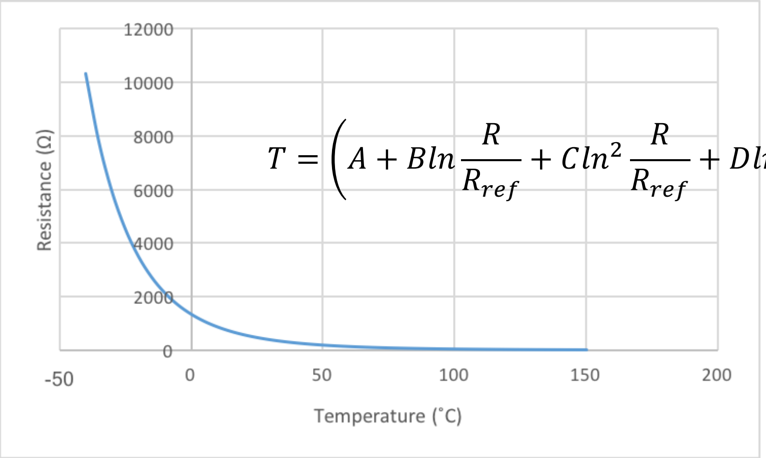
Design Uncertainty: Wheatstone Bridge

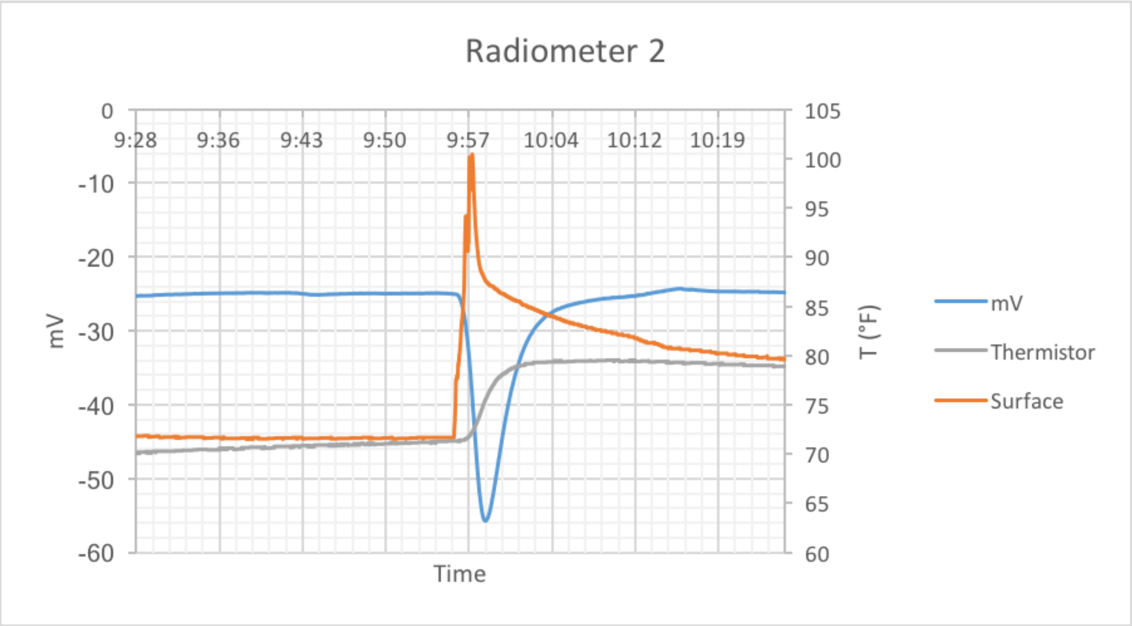
- Resistors
  - Two 250 Ω resistors were used in the Wheatstone bridge
  - Operating temperature range: -55˚C to 150˚C
  - Resistors can drift up to 1% over lifetime
- Thermistors
  - The temperature of the thermistors is related to the resistance
  - The operating temperature range of the thermistors is -40˚C to 125˚C
  - The thermistor resistance can drift up to 1%
  - ±5% uncertainty between thermistors



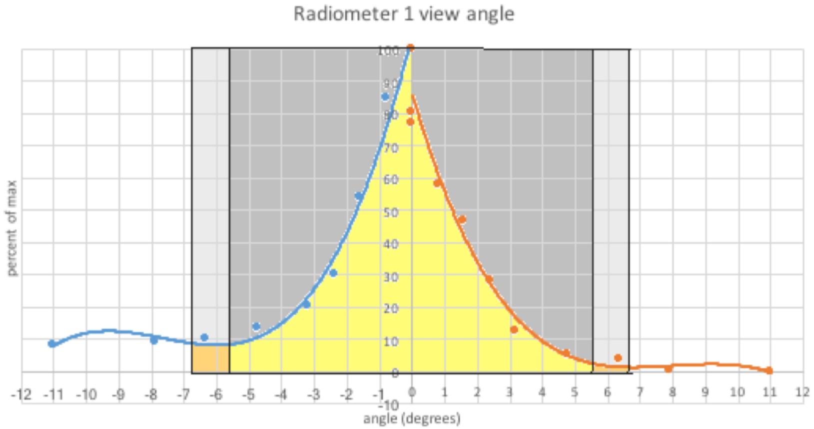


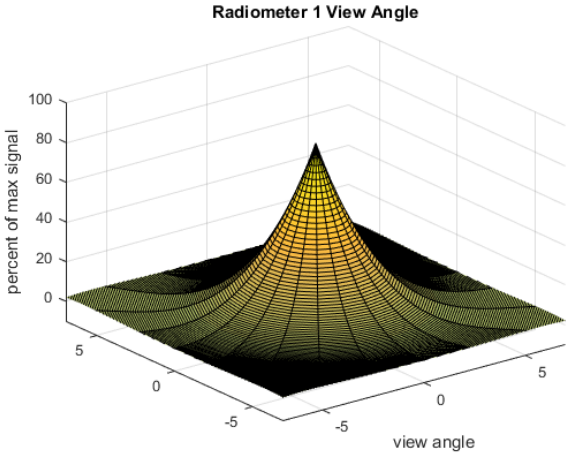
$$T = \left(A + B\ln\frac{R}{R_{ref}} + C\ln^2\frac{R}{R_{ref}} + D\ln^3\frac{R}{R_{ref}}\right)^{-1}$$

Design Uncertainty: Transient Temperature Effects on Wheatstone Bridge



Design Uncertainty: View Angle



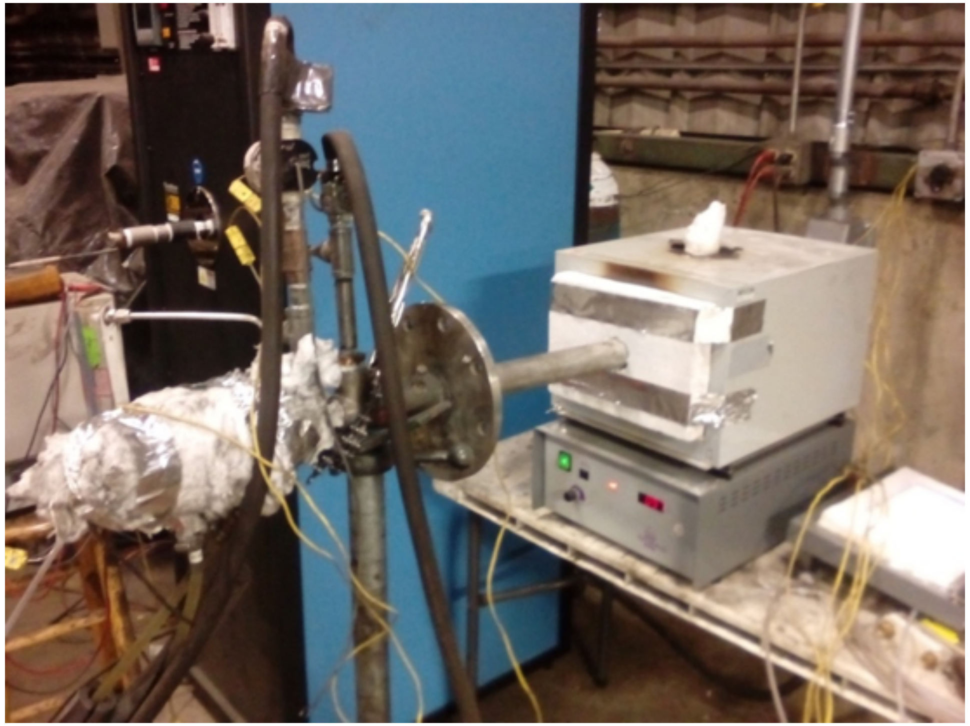


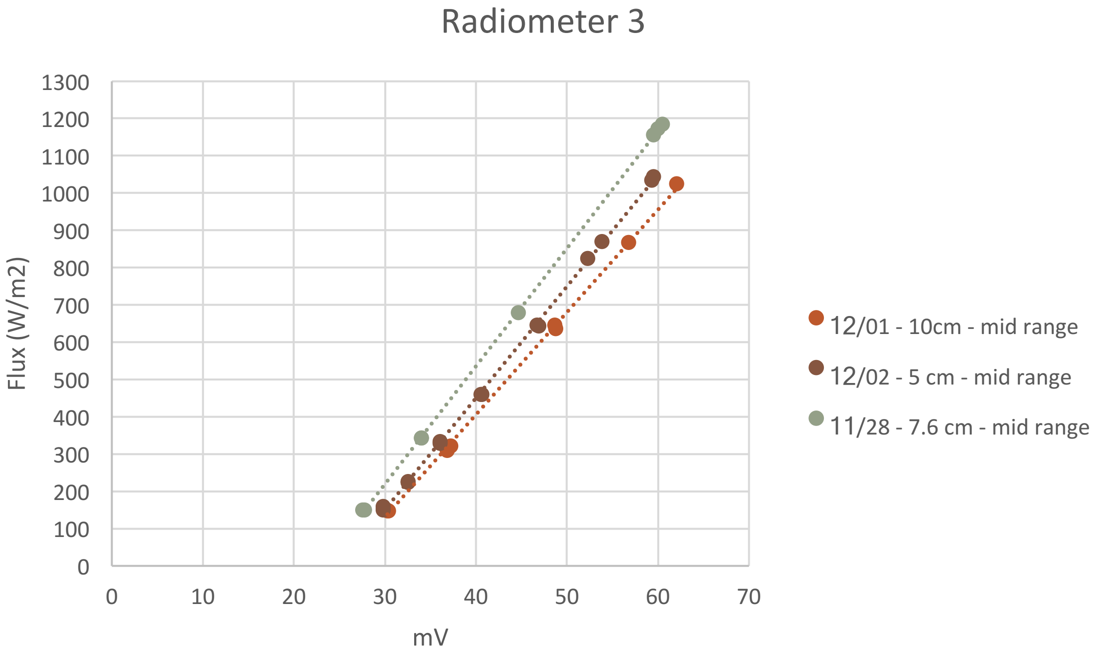
Radiometer	1	1	3	3
Percent of max	2%	0%	2%	0%
View angle	5.67˚	6.7˚	3.7˚	4.16˚
Correction 2D (α)	0.286	0.244	0.356	0.318
Correction 3D (α)	0.303	0.238	0.552	0.474

$$q''_{cal} = q''_i(1-\rho)\alpha$$

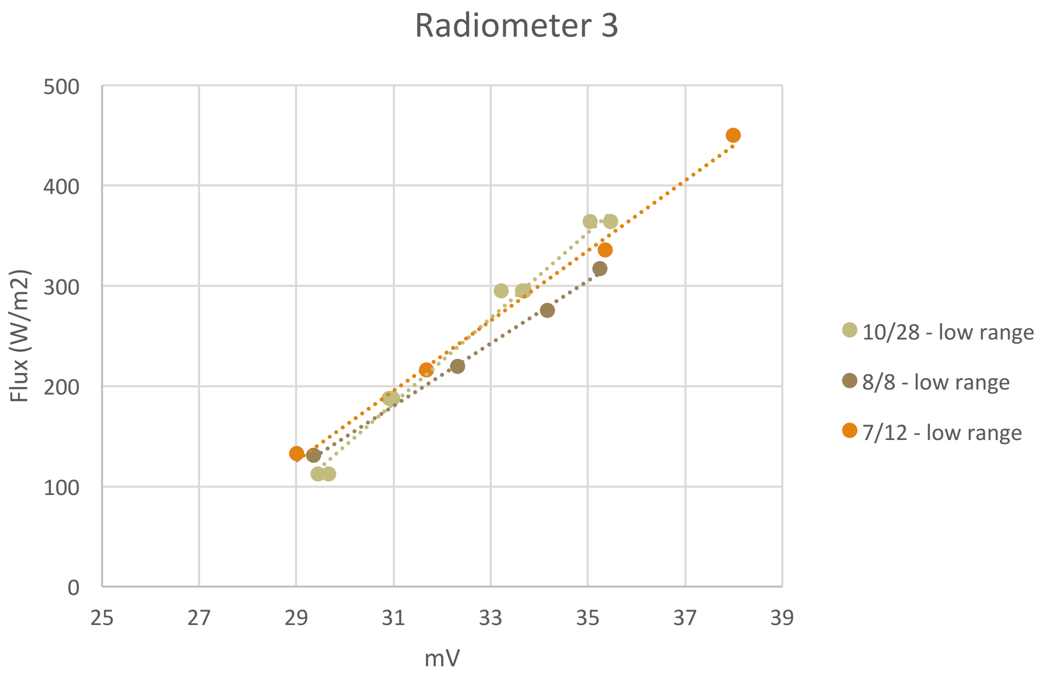
Camperchioli, William. "Narrow Angle Wide Spectral Range Radiometer Design." NASA, 2005.

Calibration: Muffle Furnace





Calibration: Low Range Blackbody

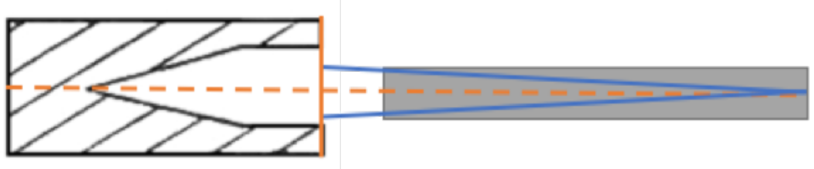


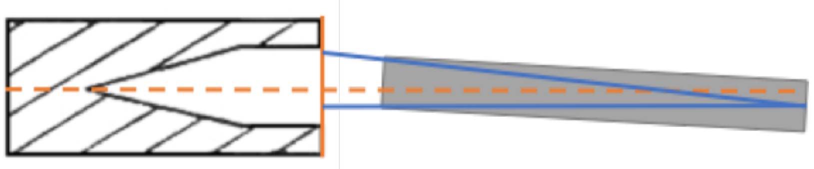
https://www.landinst.com/products/landcal-r1200p-high-temperature-portable

Calibration Uncertainty

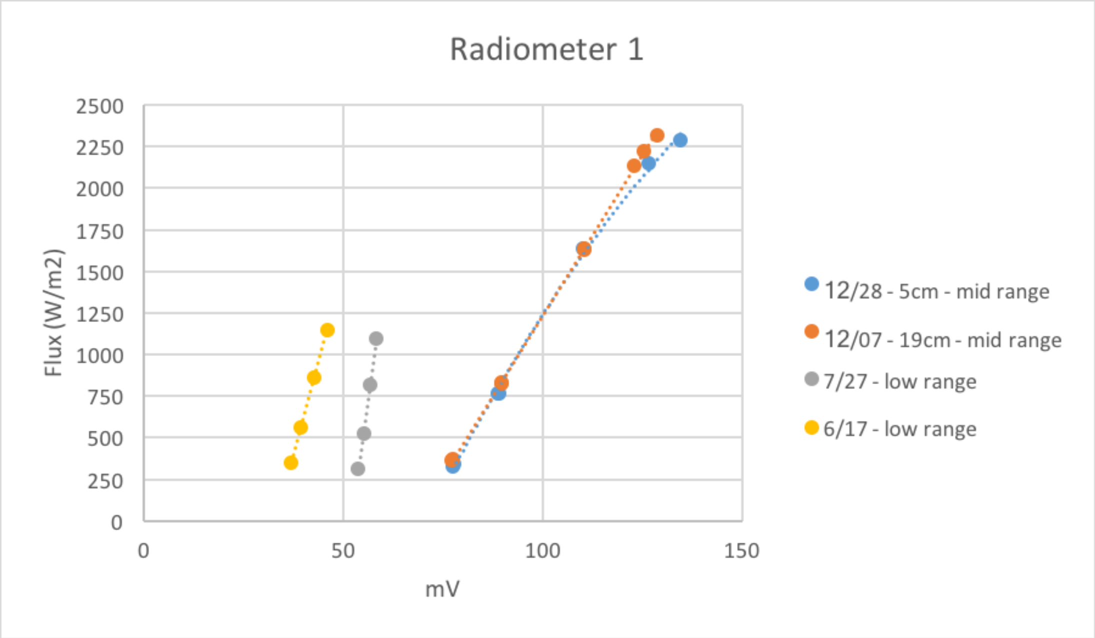
Mid-range uncertainties
- Target temperature
- Graphite sheet
- Non-uniform temperature
- Target size
- Calibration alignment

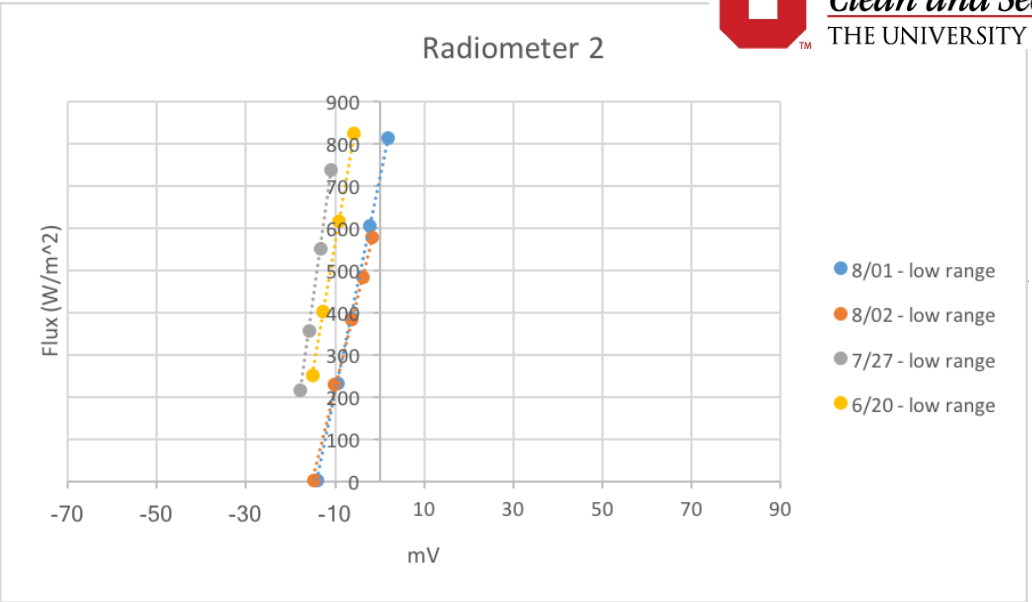
Low-range uncertainties:
- Non-uniform temperature
- Target size
- Target temperature
- Oxide layer formation
- Calibration alignment

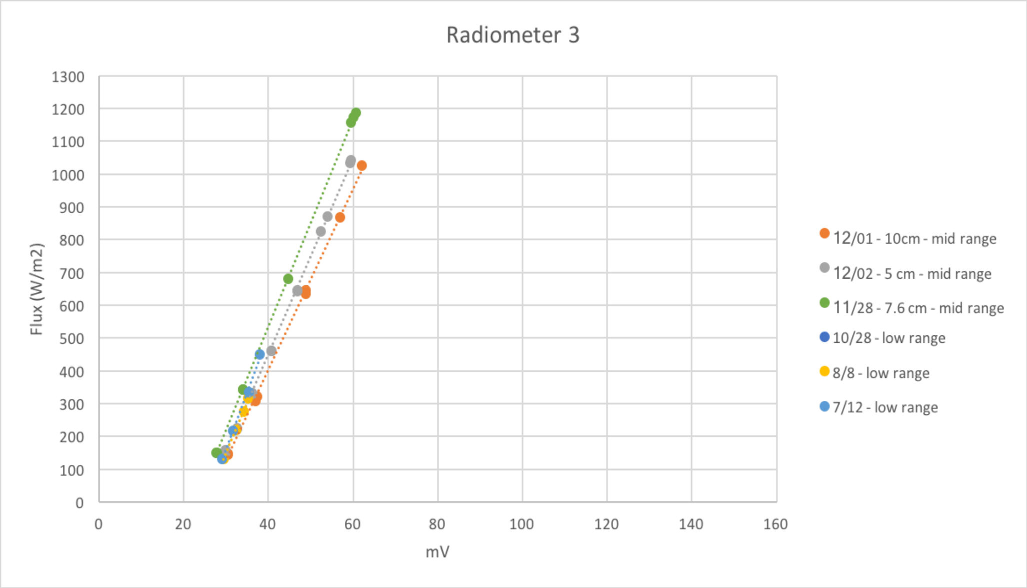




Calibration Results







Instrument Uncertainty: Analysis

WHEATSTONE ANALYSIS

Voltage divider equation:

$$R_{irr} = \frac{V_{out}(R \pm 1\%)}{(V_{app} \pm 3mV) - V_{out}}$$

Wheatstone bridge equation:

$$V_{meas} = (V_{app} \pm 3mV)\left(\frac{R_{non} \pm 1\%}{(R_{non} \pm 1\%) + (R \pm 1\%)} - \frac{R_{irr} \pm 1\%}{(R_{irr} \pm 1\%) + (R \pm 1\%)}\right)$$

HEAT FLUX ANALYSIS

Input parameters	Range
View angle	3.7˚ - 4.16˚
View angle area correction (α)	0.356 – 0.318
Blackbody temperature	±10˚C
Lens refractive index	1.35 – 1.51

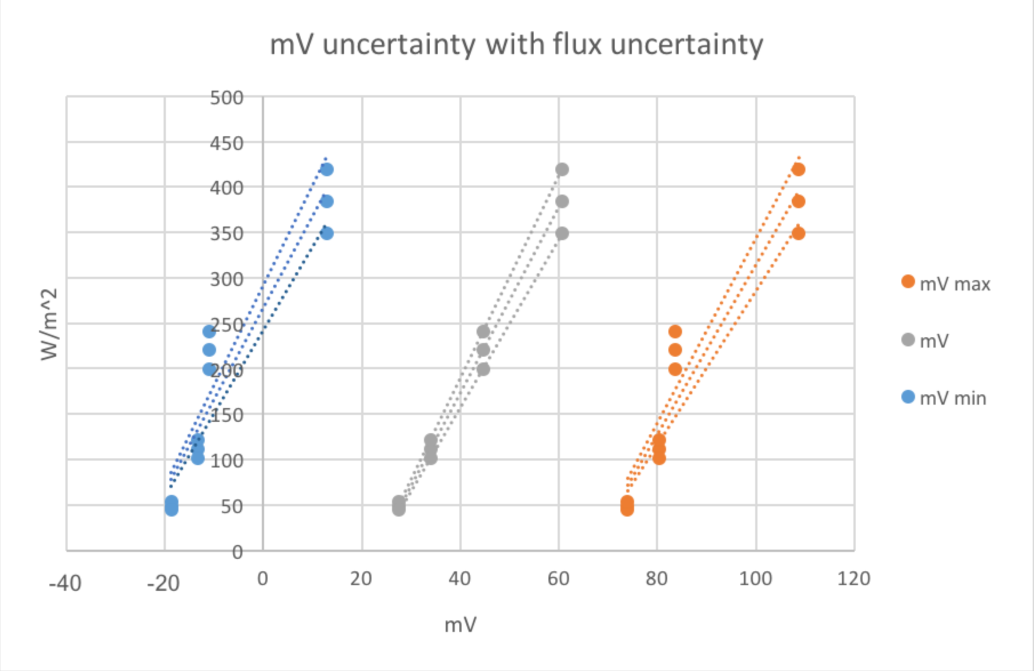
$$q_b'' = \sigma T_b^4$$

$$q_i'' = 2q_b''(1 - cos\theta)$$

$$q_{cal}'' = q_i''(1 - \rho)\alpha$$

Instrument Uncertainty: Results

T_{bb} (˚C)	mV min	mV max	±%
600	-21.591	71.374	186.74%
800	-15.393	78.089	149.10%
1000	-4.570	89.815	110.722%
1200	11.699	107.441	80.361%



Conclusions and Recommendations

Many sources of uncertainty have been identified and accounted for

There are still sources of uncertainty not accounted for as seen in the calibration curves

The largest source of uncertainty comes from the use of the Wheatstone bridge

- $\pm 130\%$ with 1% thermistor uncertainty vs. $\pm 72\%$ with no thermistor uncertainty

We need more accurate heat flux measurements in the future

Recommendations

- Eliminate Wheatstone bridge: use thermopile instead
- Smaller view angle and eliminate reflectivity inside tube
- Higher purge gas flow rate

THANK YOU