Using an Ice Bath to Approximate the Triple Point of Water When Calibrating Secondary Standard Platinum Resistance Thermometers

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Learning Objectives

- Learn about two simplified methods to determine the RTPW value of PRTs using an ice bath instead of a TPW cell.
- Uncertainty analysis of these methods.

Problem Statement

- It is recommended that users monitor the RTPW of reference thermometers to assure proper performance, this is not always practical using TPW cells
  - Limits on size of PRTs – some don't fit!
  - Limits on throughput - inefficient
- TPW cells can be more expensive than alternate methods.
- TPW cells can be more difficult to work with and maintain than alternate methods.

Objective

- Demonstrate that the RTPW of a reference PRT can be determined with adequate uncertainty using non-TPW cell methods.
  - Theoretically explain
  - Experimentally demonstrate
- Compare results for SPRT, Secondary Standard, and Precision Industrial PRTs.

Test Units

- 10 Thermometers were tested
  - 1 metal sheath 25.5 Ω SPRT, 1mK accuracy
  - 1 quartz sheath 25.5 Ω SPRT, 1mK accuracy
  - 4 100 Ω Secondary Standard PRTs, .003925 TCR, 18mK accuracy
  - 4 100 Ω Precision Industrial PRTs, .003851 TCR, 50mK accuracy.

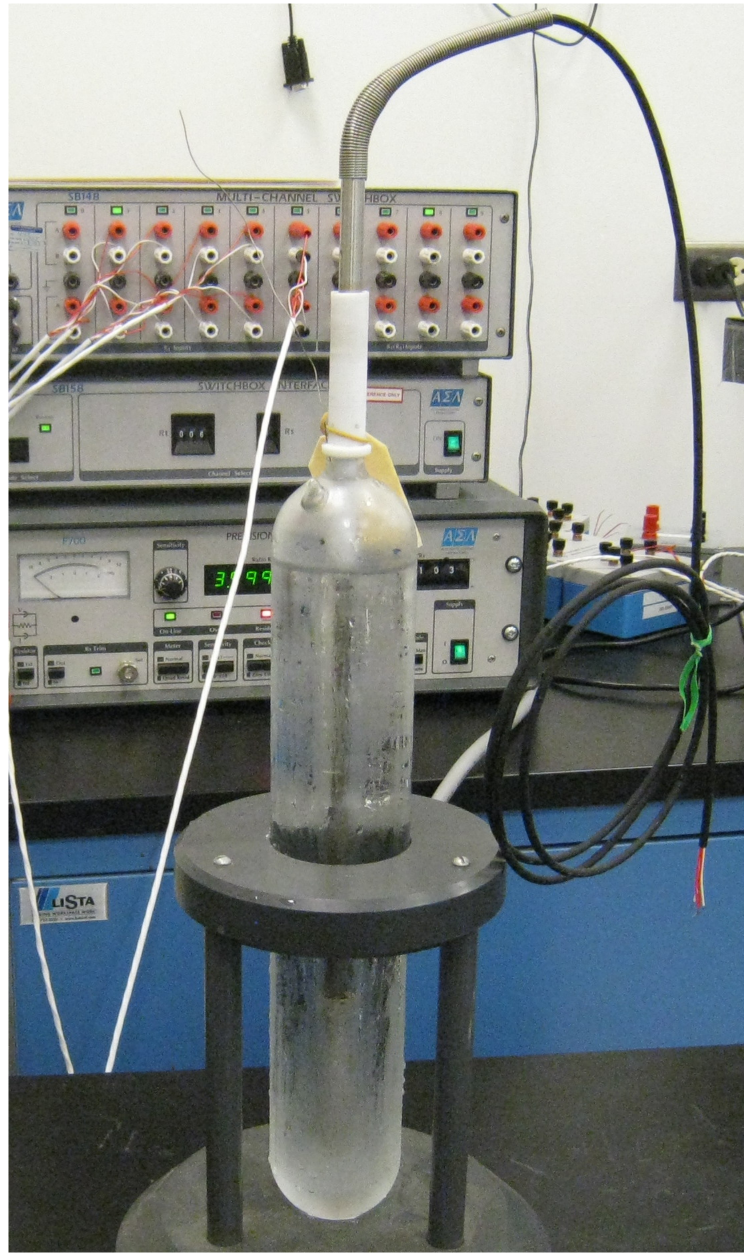
Test Units

- All commercially available and regularly used as reference thermometers.
- Accuracies include short term UUT performance when used over rated range.

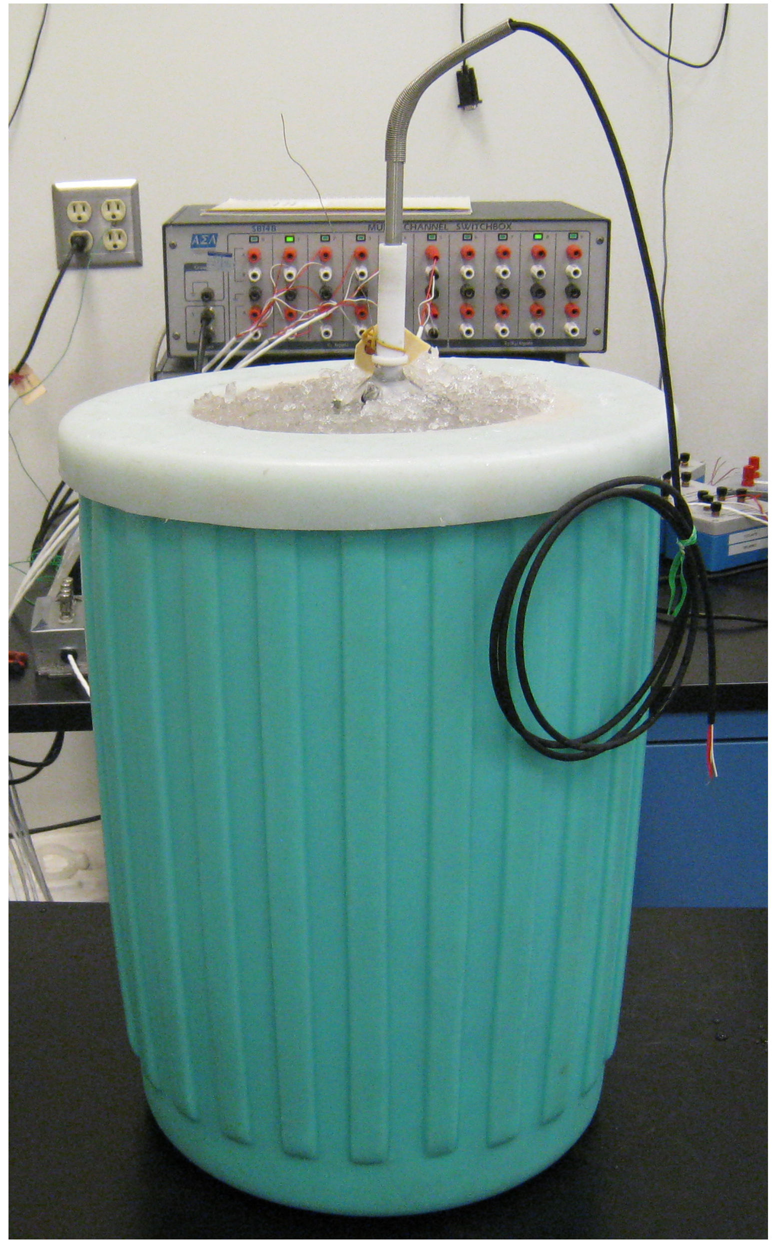
Methods

- Method 1 – TPW cell
  - TPW cell as temperature source
  - Resistance measured using a 1 ppm AC resistance bridge
    - Ratio UUT over 100 Ω standard resistor
    - 1 mA sensing current
  - Ref. ASTM Standard E1750 – *Standard Guide for Use of Water Triple Point Cells*.
  - 3 measurements made on each UUT

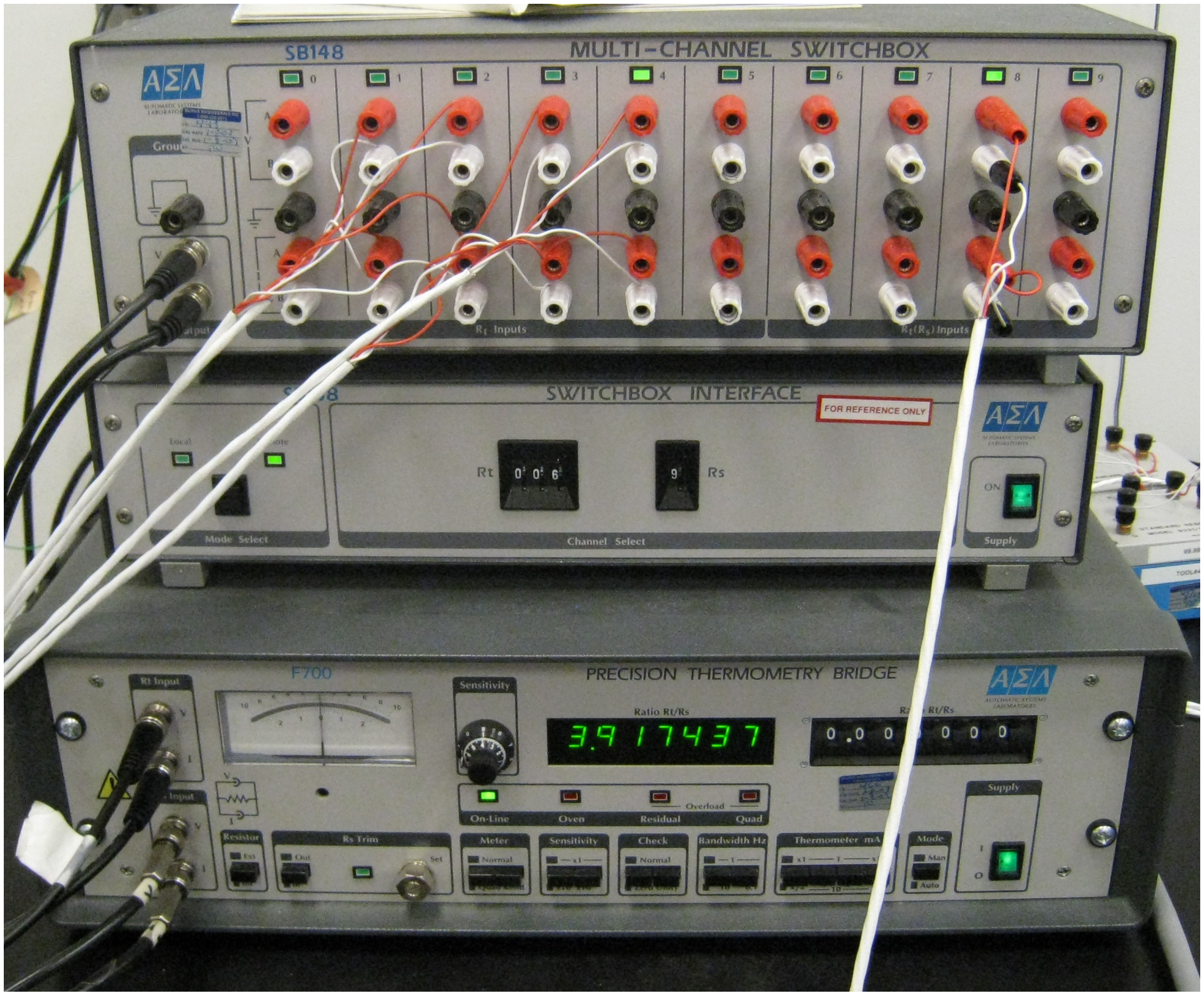
Methods



Methods



Methods


SB148
MULTI-CHANNEL SWITCHBOX
SWITCHBOX INTERFACE
FOR REFERENCE ONLY
Rt
Rs
Mode Select
Channel Select
Supply
F700
PRECISION THERMOMETRY BRIDGE
Ratio Rt/Rs
3.917437
Sensitivity
On-Line
Oven
Residual
Quad
Overload
Resistor
Rs Trim
Meter
Check
Bandwidth Hz
Thermometer mA
Mode

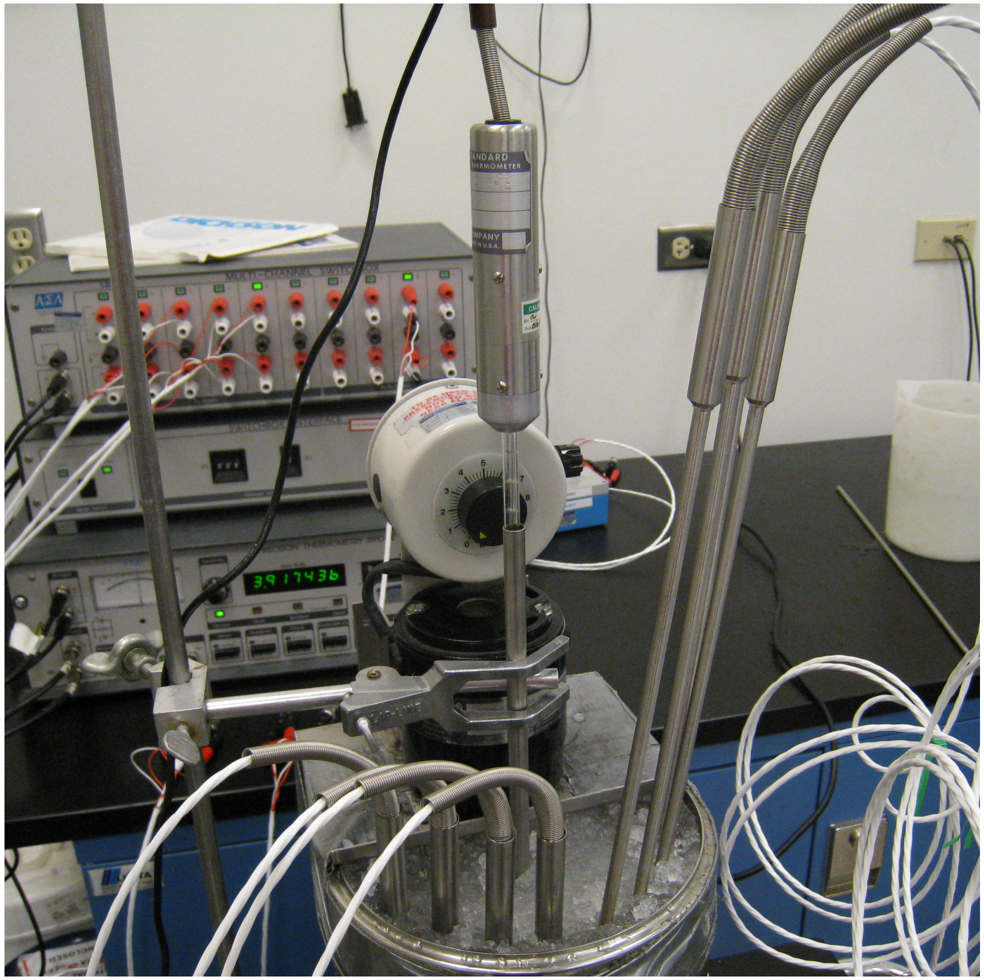
Methods

- Method 1 Advantages
  - Lowest uncertainty of the methods
- Method 1 Disadvantages
  - Requires use of a TPW cell
  - Limits on size of PRTs
  - Limits on throughput

Methods

- Method 2 – Comparison Calibration
  - Ice bath made from distilled water/ice used as temperature source
  - Direct comparison against SPRT
  - Same 1 ppm AC bridge, 1 mA current
    - Ratio UUT over SPRT
    - Multiply ratio by RTPW of SPRT to obtain RTPW of UUT
  - 3 measurements made on each UUT

Methods



Methods

- Method 2 Advantages
  - Does not require a standard resistor or maintenance bath
  - Adaptable to various sensor geometries
  - Improves throughput – multiple sensors in bath
  - Insensitive to purity of ice/water
- Method 2 Disadvantages
  - Requires use of SPRT
  - Larger uncertainty than TPW cell

Methods

- Method 3 – Ice Bath as 0℃ Source
  - Ice bath made from distilled water/ice used as temperature source
  - Same 1 ppm AC bridge, 1 mA current
    - Ratio UUT over 100 Ω standard resistor
    - Nominal ohmic correction added to account for difference between 0℃ ice and 0.01℃ TPW.
  - Ref. ASTM Standard E563 – *Standard Practice for Preparation and Use of an Ice-Point Bath as a Reference Temperature*
  - 3 measurements made on each UUT.

Methods

- Method 3
  - Ohmic Corrections to convert R0 to RTPW

UUT	Nominal RTPW	Ohmic Correction
SPRT	25.5 Ω	0.0010
SSPRT	100 Ω	0.0040
IPRT	100 Ω	0.0039

Methods

- Method 3 Advantages
  - Does not require SPRT or TPW cell
  - Adaptable to various sensor geometries
  - Improves throughput – multiple sensors in bath
- Method 3 Disadvantages
  - Sensitive to purity of ice/water
  - Larger uncertainty than TPW cell

Uncertainty Estimates

- Estimates for each PRT type for each method.
- Identified all significant sources, combined them and expanded to 95%, k=2

Uncertainty Estimates

- TPW cell uncertainty
- TPW cell reproducibility
- Ref SPRT uncertainty
- Ref SPRT drift
- Bath Stability/Uniformity
- Bridge Uncertainty
- Bridge resolution
- Standard Resistor uncertainty
- Standard Resistor drift
- Standard Resistor thermal effects
- Ohmic correction error
- Repeatability & Reproducibility

Uncertainty Estimates

Table A.2B. Uncertainty analysis of a SSPRT by comparison to a SPRT (Method 2).

Source	Source Uncertainty	Type (A/B)	Level of Confidence (%)	k factor	Standard Uncertainty (mK)
Uncertainty of reference SPRT Resistance The standard uncertainty of the RTPW value used for this measurement is 0.000078 ohms, this equates to 0.78 mK. This includes short term drift.	0.78 mK	B	63.1	1	0.78
Drift of reference SPRT Resistance Short term drift is included in value above. Long term drift is eliminated since RTPW is updated daily.	0.00 mK	B	95.45	2	0.00
Bridge Uncertainty Bridge spec is 1 ppm or 1 digit, which ever is larger. For this measurement 1 ppm is larger, 1 ppm equates to 0.25 mK This is assumed as a 95% (k=2) coverage.	0.25 mK	B	95.45	2	.13
Bridge Resolution Bridge spec is 1 ppm, the uncertainty limit is ½ of this which equates to 0.13 mK. This is assumed as a 100% confidence rectangular distribution, (k=1.732).	0.13 mK	B	100	1.732	0.07
Ice Bath Stability and Uniformity Periodic testing of our ice bath shows that it is consistently within 3.0 mK of 0°C. For this analysis stability and uniformity will be considered to be 3.0 mK with a 95% (k=2) coverage.	3.0 mK	B	95.45	2	1.50
Combined Standard Uncertainty for Equipment Only This does not include Repeatability and Reproducibility component which can be heavily influenced by the UUT.					1.70
Repeatability and Reproducibility R&R for this UUT using this method is 0.36 mK	0.36 mK	A	63.2	1	0.36
Standard Uncertainty = RSS Total =					1.73
Expanded Uncertainty, 95% (k=2)					3.5 mK

Uncertainty Estimates

PRT Type	Method 1 TPW Cell	Method 2 Comparison Cal	Method 3 Ice Bath as 0 ℃ Source
SPRT	1.6 mK	3.7 mK	3.5 mK
SSPRT	1.2 mK	3.5 mK	3.3 mK
IPRT	1.9 mK	3.5 mK	3.3 mK

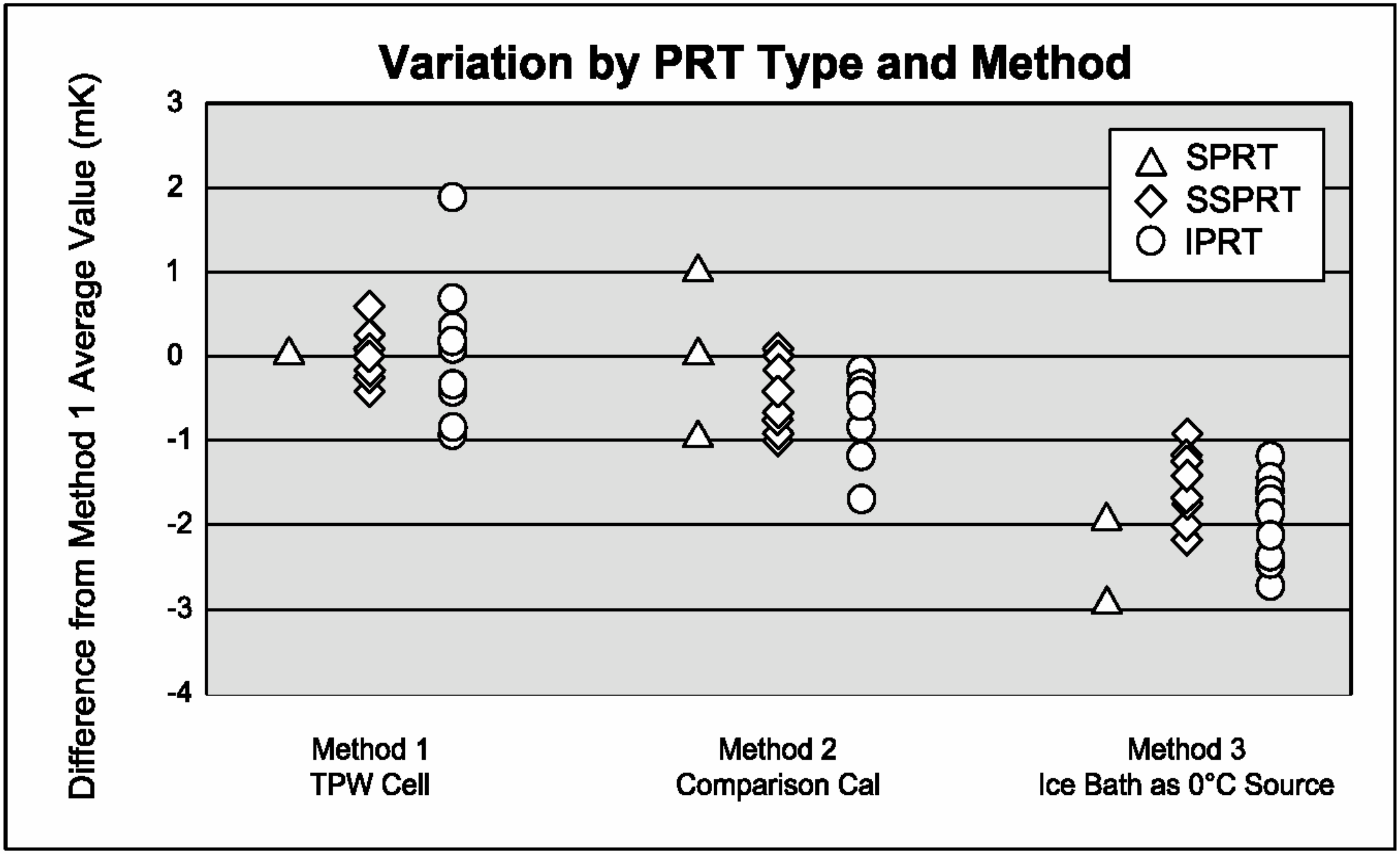
Uncertainty Estimates

- Notes on uncertainty estimates
  - Method 1 had lowest uncertainty
  - Methods 2 and 3 only differ by .2 mK
  - SPRT did not have lowest uncertainty!
    - Bridge uncertainty = 1 digit = 1 mK
    - Bridge resolution = 1 digit = 1 mK
  - Low R&R for all methods because no other thermal exposures, not representative of in service conditions.
    - UUT repeatability/hysteresis would increase uncertainty in SSPRT & IPRT
    - Not a result of method, rather UUT capabilities

Results

- Used average value of 3 resistance measurements from Method 1 as baseline value.
- Determined difference between each measurement and the baseline value
- Converted difference in Ω's to difference in ℃ using nominal sensitivity.

Results



Variation by PRT Type and Method
Difference from Method 1 Average Value (mK)
3
2
1
0
-1
-2
-3
-4
SPRT
SSPRT
IPRT
Method 1
TPW Cell
Method 2
Comparison Cal
Method 3
Ice Bath as 0°C Source

Results

- Method 1 – TPW Cell
  - No variation in SPRT measurements, likely due to resolution of bridge.
  - Variation in SSPRT and IPRT measurements due to UUT short term repeatability and increased sensitivity of bridge.
- Method 2 – Comparison Cal
  - Shows variability in all UUT types, all values grouped within ±2 mK from average TPW cell value

Results

- Method 3 – Ice Bath as 0℃ Source
  - Comparable to method 2 except mean values are biased low 1.5 to 2.5 mK
    - Likely caused by purity of ice/water
  - All measurements within ±3 mK of average TWP cell value

Conclusion

- Using an Ice Bath as a temperature source can be more practical than using a TPW cell when accuracy limitations permit.
- For the SSPRT with 18 mK accuracy, and IPRT with 50 mK accuracy, a 4:1 TUR can be met using any of the 3 methods.
- For the SPRT with 1 mK accuracy, a TPW cell is best method unless full accuracy is not required.

Thank You

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