Proper Platinum Resistance Thermometer Calibration Uncertainty Analysis

Introduction

- Uncertainty quantification is a primary task of the metrologist
- The uncertainty analysis must reflect our best understanding of the measurement and the instrument being calibrated
- If a calibration process is not fully understood, the uncertainty analysis is almost certainly flawed
- If the uncertainties do not reflect some aspects of UUT behavior, it will not reflect the UUT in use

Introduction

- Incomplete uncertainty analysis
  - Thorough uncertainty analysis is often more complex than it appears
  - Ignorance is bliss - the less we know, the better our numbers look
  - Although our assessors are very good, some do not possess sufficient *current* understanding to notice omissions in the uncertainty analysis
- Philosophical viewpoint
  - Should the calibration be considered as an isolated experiment or as part of a process?
  - Should the uncertainty analysis include only those components present at the time of calibration?
  - Should the uncertainty analysis include additional components to reflect UUT short term behavior?
  - Should the uncertainty analysis include additional components to reflect UUT long term behavior?

Introduction

- Consequently, it is easy to underestimate the real measurement uncertainty
  - Some omissions are insignificant to the final result and amount to a minor embarrassment or controversy when discovered
  - Other omissions may result in a noticeable, substantive underestimation of the final uncertainty

Categorization

- Often categorization helps us see things more clearly
- Platinum resistance thermometer calibration uncertainties can be categorized into two areas:
- Uncertainties in temperature
- Uncertainties in resistance measurement

Categorization

FLUKE ®
Hart Scientific ®

- Thermal uncertainties
  - Temperature stability
  - Temperature uniformity
  - Determination of the temperature
  - Temperature equilibrium
  - Self heating caused by excitation current*

- Resistance measurement uncertainties
  - Readout accuracy
  - Readout linearity
  - Electrical noise
  - Electrical interference
  - Self heating caused by excitation current*

*Evaluate only once (avoid double counting)

Uncertainty Budget

Uncertainty Evaluation

Type A Evaluation	**Category**	**LN2 mK**	**tn100 mK**	**Hg mK**	**TPW mK**	**FPIn mK**	**FPSn mK**	**FPZn mK**	**t500 mK**
Readout Noise (1σ)	E	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Total A	**A**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**
Type B Evaluation									
SPRT accuracy (calibration and drift)	T	1.50	1.50	1.25	0.80	1.45	1.50	1.75	2.50
Bath uniformity	T	1.15	0.58	0.58	0.58	0.87	1.15	1.44	1.73
Thermometer readout (6 ppm, SPRT)	E	0.20	0.21	0.22	0.22	0.36	0.44	0.64	0.75
Thermometer readout (6 ppm, UUT)	E	0.03	0.08	0.11	0.84	0.24	0.29	0.42	0.54
Total B	**B**	**1.91**	**1.63**	**1.42**	**1.45**	**1.79**	**2.03**	**2.50**	**3.31**
Total Standard Uncertainty	U	1.92	1.65	1.43	1.46	1.80	2.04	2.51	3.31
Total Expanded Uncertainty (*k* =2)	**U'**	**3.84**	**3.29**	**2.87**	**2.93**	**3.60**	**4.08**	**5.02**	**6.62**

Additional Components

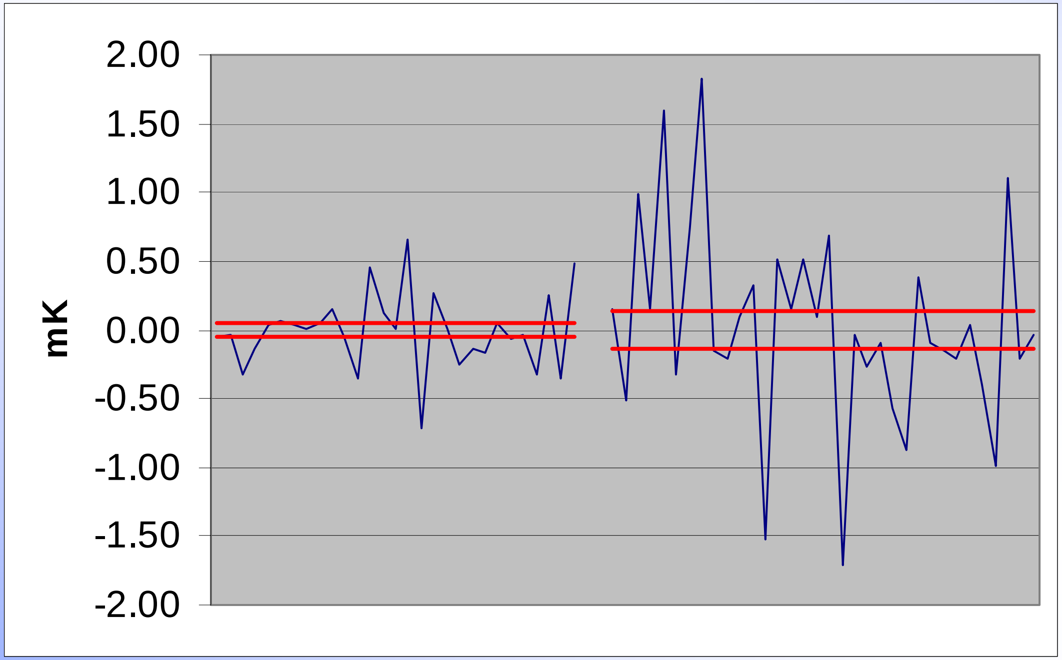
- Some components are missing
  - Reference SPRT R_{TPW} propagation
  - Reference SPRT self heating correction
  - **Reference SPRT immersion error**
  - **UUT noise contribution**
  - UUT short term repeatability
  - UUT immersion error
  - UUT insulation resistance
  - **Mathematical model uncertainties**
  - Process repeatability

SPRT Uncertainties

- SPRT R_{TPW} measurement (or ambiguity allowance) during use propagates to uncertainty in determination of W_{T90}
  - Example, R_{TPW} uncertainty of 0.5 mK becomes 1.4 mK at 500 °C
- SPRT self heating is different in different thermal environments
  - Fixed point cells (SPRT cal) and comparison baths (use)
- SPRT has immersion requirements which may or may not be satisfied in the application
  - For example, calibration of short sensors

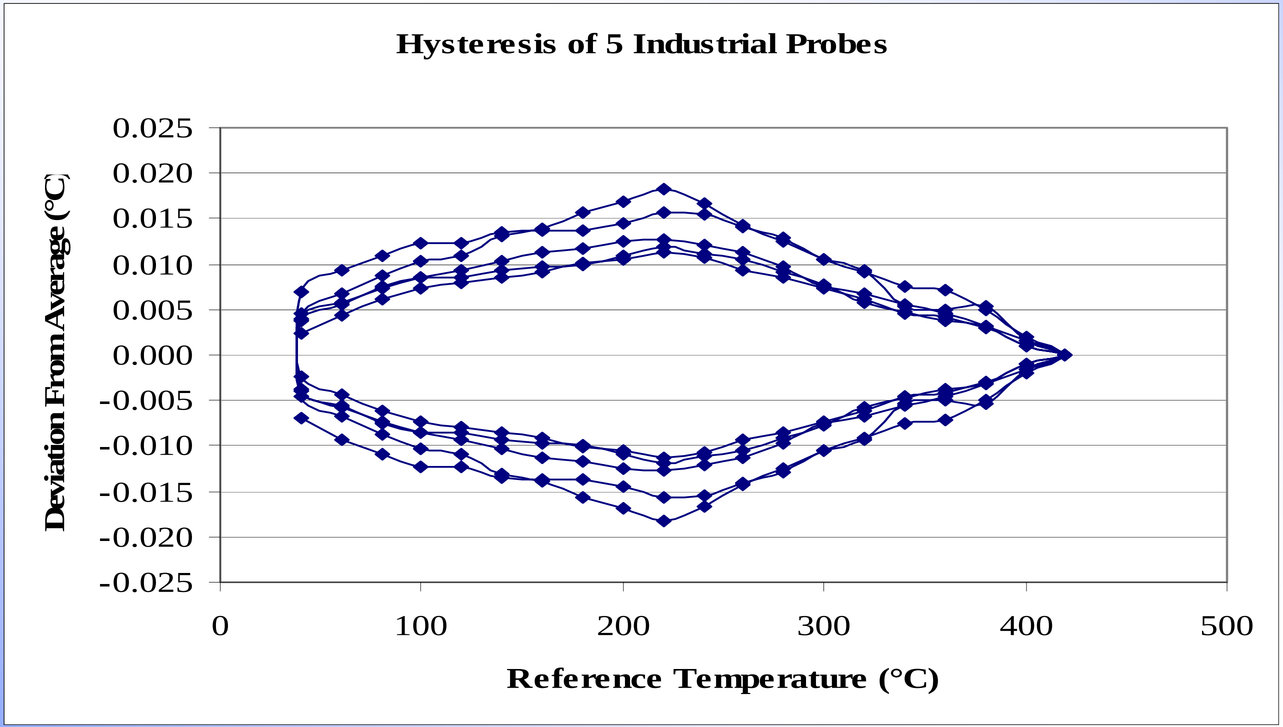
UUT Uncertainties

- UUT noise allowance
  - The noise influences the precision of the average obtained during the calibration



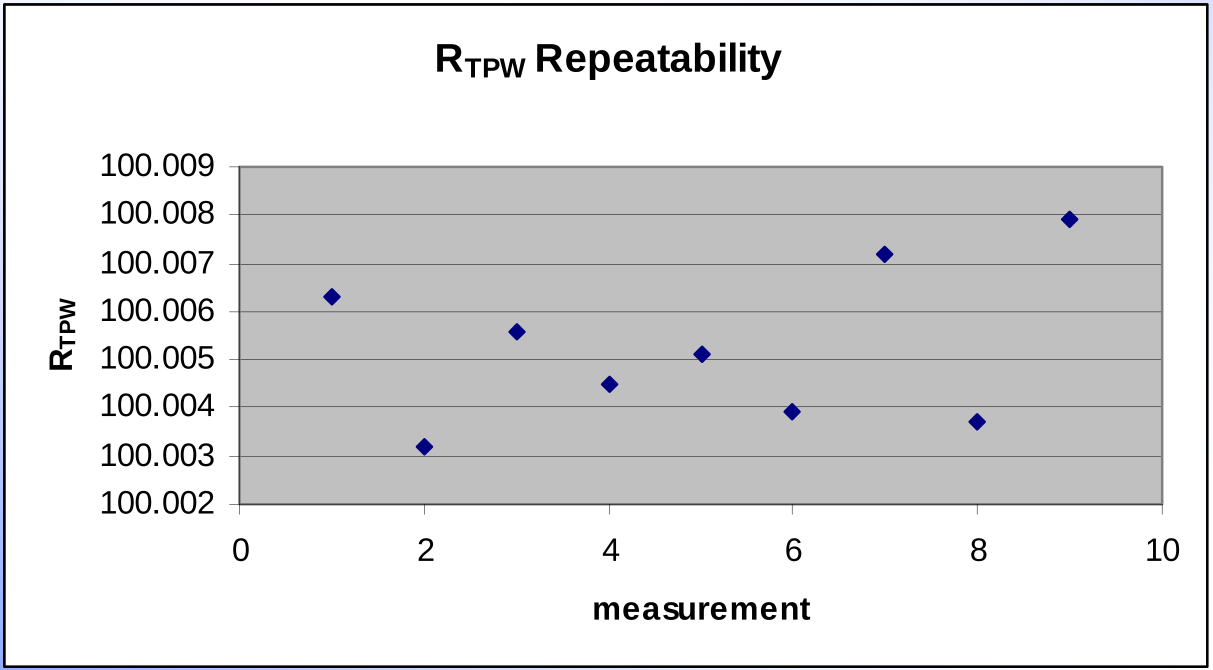
UUT Uncertainties

- UUT short term repeatability
  - Hysteresis



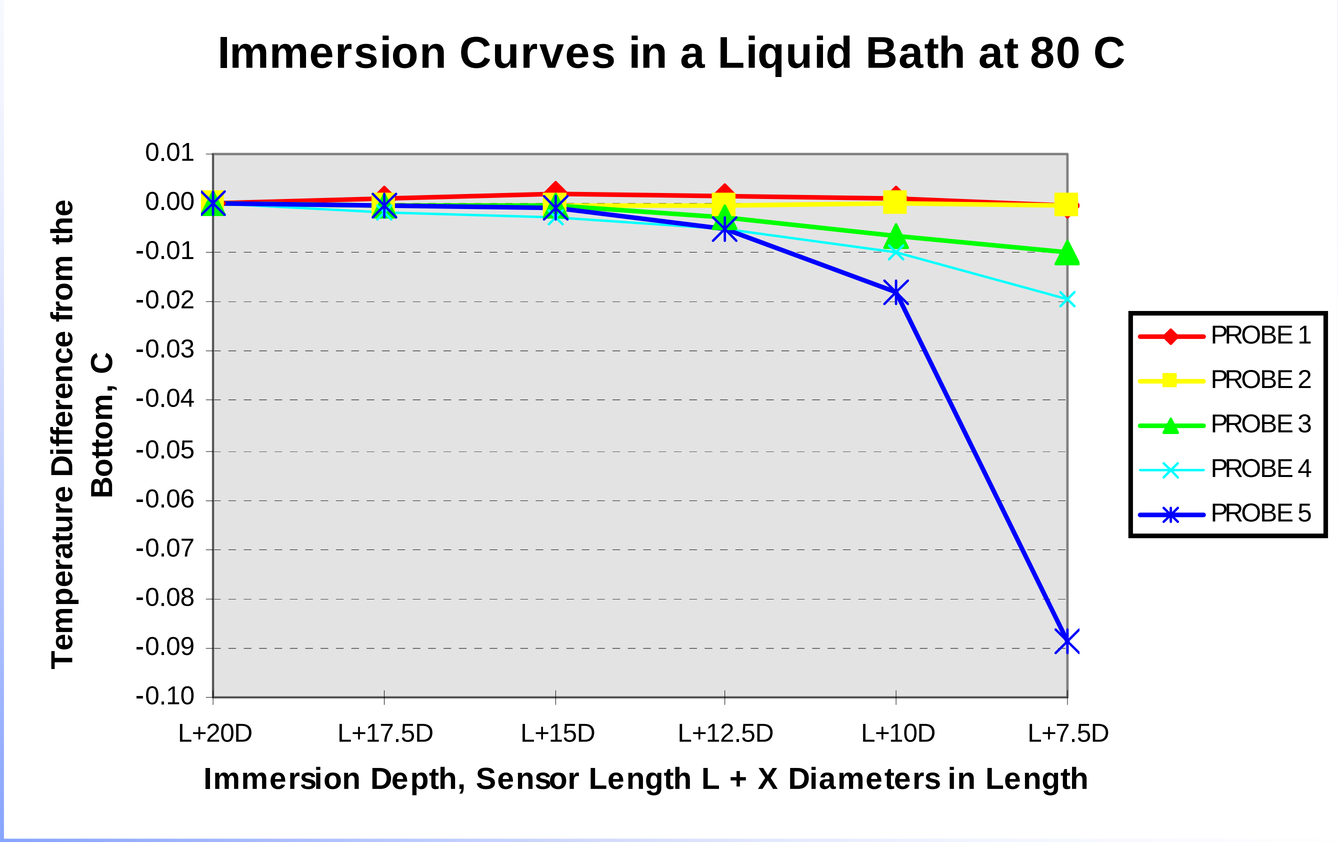
UUT Uncertainties

- UUT short term repeatability
  - R_{TPW} repeatability (average = 100.0053, spread = 0.012 °C)



UUT Uncertainties

- UUT immersion error



UUT Uncertainties

- UUT insulation resistance effects (worst case)

$$1)\quad R_{total}(\Omega) = \frac{1}{\frac{1}{R_1}+\frac{1}{R_1}+\dots\frac{1}{R_n}} = \frac{1}{\frac{1}{256\Omega}+\frac{1}{10M\Omega}}$$

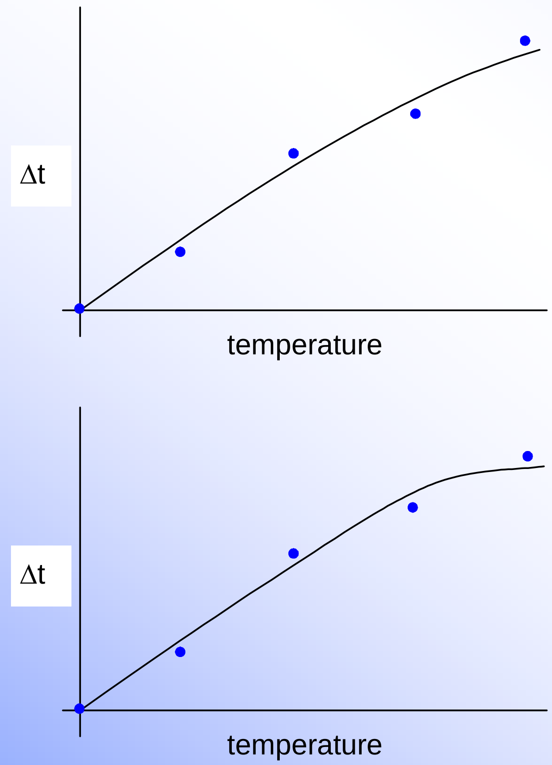
$$2)\quad R_{total}(\Omega) = 255.993447\ \Omega$$

$$3)\quad \Delta R = 256\Omega - 255.993447\ \Omega \approx 6.55\times10^{-3}\Omega$$

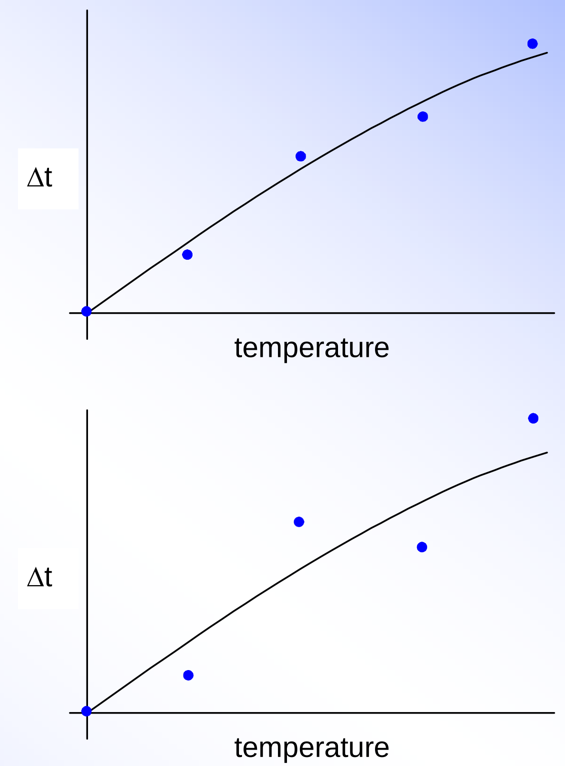
$$4)\quad 6.55\times10^{-3}\Omega \Big/ 0.36\,{}^{\Omega}\!/_{\circ C} = 1.82\times10^{-3}\,{}^{\circ}C = 18.2mK$$

$$5)\quad 18.2mK \Big/ \sqrt{3} = 10.5mK$$

Mathematical Model U

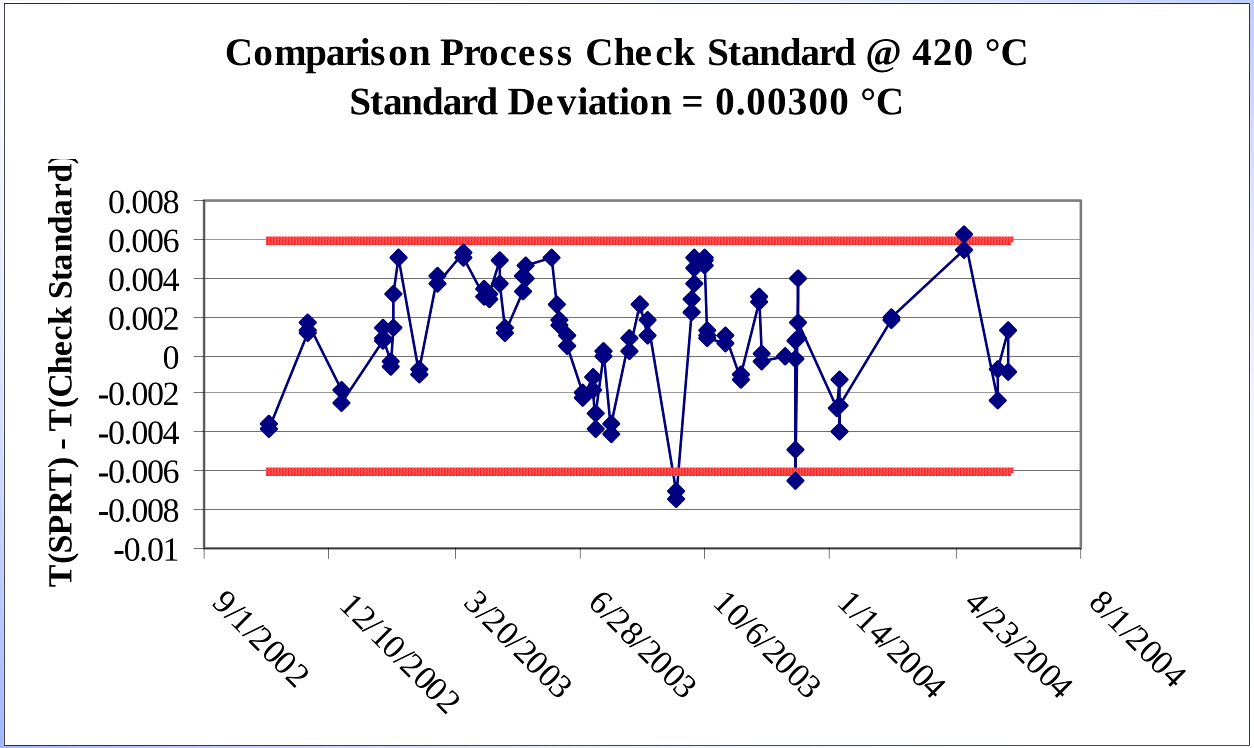


Curve Fit



Magnitude of Residuals

Process Repeatability



Revised Uncertainty Budget

Uncertainty Evaluation

Type A Evaluation	**Category**	**LN2 mK**	**tn100 mK**	**Hg mK**	**TPW mK**	**FPIn mK**	**FPSn mK**	**FPZn mK**	**t500 mK**
Process variability	P	0.90	1.80	1.30	1.00	1.99	2.60	3.20	3.70
Precision of UUT measurement	T&E	2.22	1.67	1.67	1.11	1.67	1.67	2.22	2.78
Propagated repeatability of R_{TPW} (UUT)	UUT	0.42	1.36	1.94	2.31	3.72	4.36	5.91	6.47
Total A	**A**	**2.43**	**2.81**	**2.87**	**2.75**	**4.53**	**5.35**	**7.08**	**7.95**
Type B Evaluation									
SPRT accuracy (calibration and drift)	T	1.50	1.50	1.25	0.80	1.45	1.50	1.75	2.50
SPRT R_{TPW} propagation	T	0.05	0.17	0.24	0.29	0.55	0.55	0.74	0.81
SPRT self heating correction	T	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
Insulation resistance (UUT)		0.01	0.09	0.20	0.29	0.75	1.03	2.10	2.61
Bath uniformity	T	1.15	0.58	0.58	0.58	0.87	1.15	1.44	1.73
Thermometer readout (6 ppm, SPRT)	E	0.20	0.21	0.22	0.22	0.36	0.44	0.64	0.75
Thermometer readout (6 ppm, UUT)	E	0.03	0.08	0.11	0.84	0.24	0.29	0.42	0.54
Total B	**B**	**1.99**	**1.74**	**1.56**	**1.61**	**2.10**	**2.41**	**3.40**	**4.32**
Total Standard Uncertainty	U	3.15	3.30	3.27	3.19	5.00	5.86	7.85	9.05
Total Expanded Uncertainty (*k* =2)	**U'**	**6.29**	**6.61**	**6.54**	**6.38**	**9.99**	**11.73**	**15.71**	**18.10**

Difference

Original Uncertainty Evaluation	**U'**	**3.84**	**3.29**	**2.87**	**2.93**	**3.60**	**4.08**	**5.02**	**6.62**
Revised Uncertainty Evaluation	**U'**	**6.29**	**6.61**	**6.54**	**6.38**	**9.99**	**11.73**	**15.71**	**18.10**
Difference	**Absolute**	**2.46**	**3.31**	**3.67**	**3.45**	**6.39**	**7.65**	**10.69**	**11.48**
	%	**64.0**	**100.6**	**128.1**	**117.7**	**177.4**	**187.7**	**213.1**	**173.3**

Conclusions

- Uncertainty evaluation involves variables that may not be readily apparent
- Some variables are difficult to quantify and may vary from UUT to UUT
- Underestimating the uncertainties in this manner may lead to significant errors
- Incomplete uncertainty analyses are very common among both unaccredited and accredited laboratories