Evaluating the performance of Metrology Wells

Using the Guidelines of EA-10/13:- 'Guidelines on the Calibration of Temperature Block Calibrators'

Metrology Wells

Ultra-stable heat source with optional built-in reference thermometer readout for calibration of temperature sensors

Metrology Wells – What are They?

- Stable heat sources that have:
  - Bath-level stability
  - Bath-level axial and radial uniformity
  - Legitimate reference thermometry
  - Dry-Well functionality

- A new product category that surpasses "dry-wells" in performance—it's not a dry-well, it's a Metrology Well!

Metrology Wells – How is this accomplished?

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- Bath-level performance
  - Metrology Well performance is accomplished through dual-zone control technology
  - Our new 2400 controller (patent pending)—fine resolution digital control
  - 25 years of control technology experience
- Legitimate reference thermometry
  - Use of existing “Tweener” (Model 1502A) circuitry
  - Current-reversal techniques cancel common thermal EMF errors
- Dry-Well functionality
  - Portable package allows for calibrations in “lab” or “field” environments

The Basics

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- Temperature heat source primarily used for calibration of various temperature sensors, with an optional built-in reference indicator:
  - User Interface – large LCD display and numeric keypad
  - Multi-hole insert to accommodate various different sized probes
- High-accuracy, traceable reference standard when the calibrated display or calibrated built-in reference thermometer readout (accredited calibration on readout only) is used

How do you determine dry-well accuracy?

To answer this question you need to know:

- How the dry-well will be used
- Important sources of error
- How dry-well manufacturers' specifications are written and applied

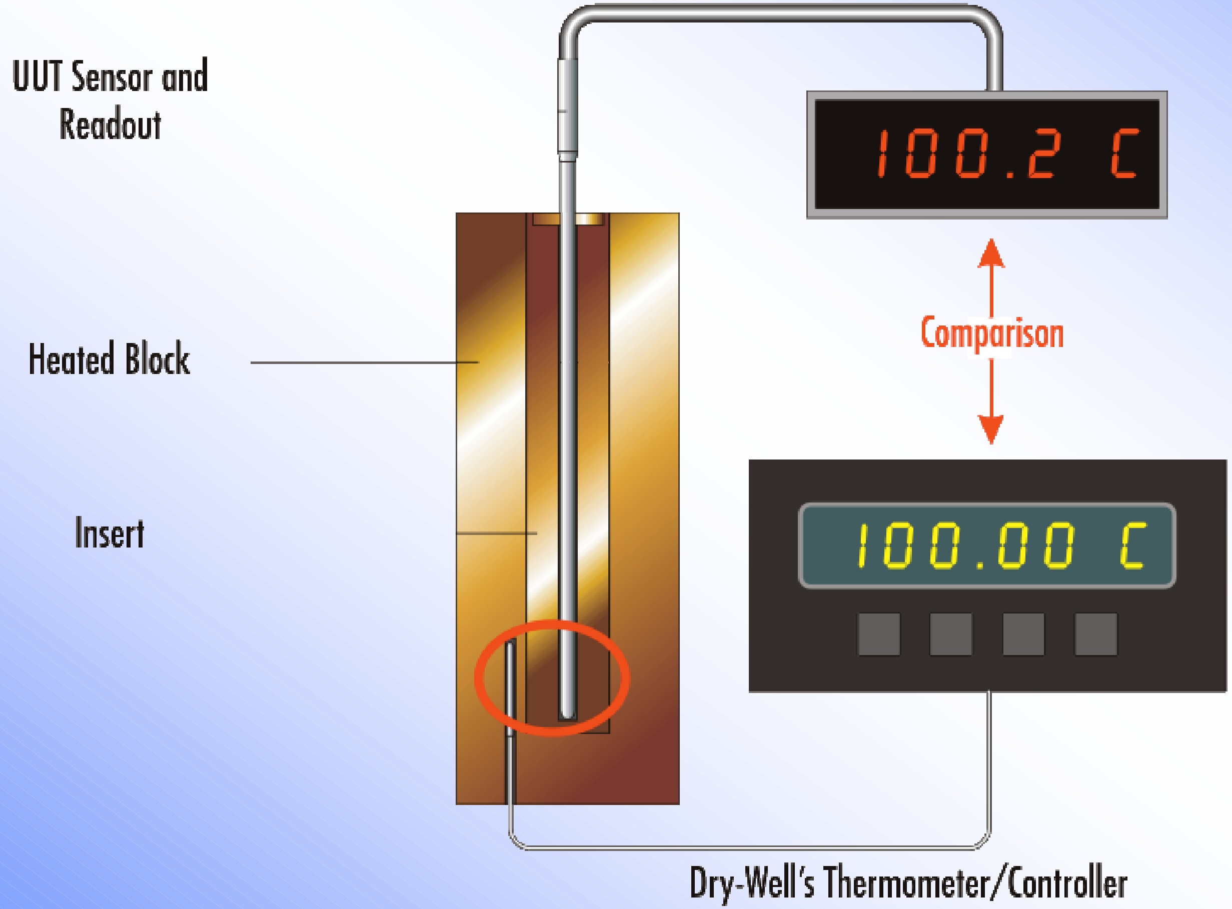
Dry-well Thermal Uncertainties

- Temperature Stability
- Temperature Uniformity
  - Axial
  - Radial
- Block Loading
- Hysteresis of the Control Sensor
- Immersion Effects (Stem Conduction)

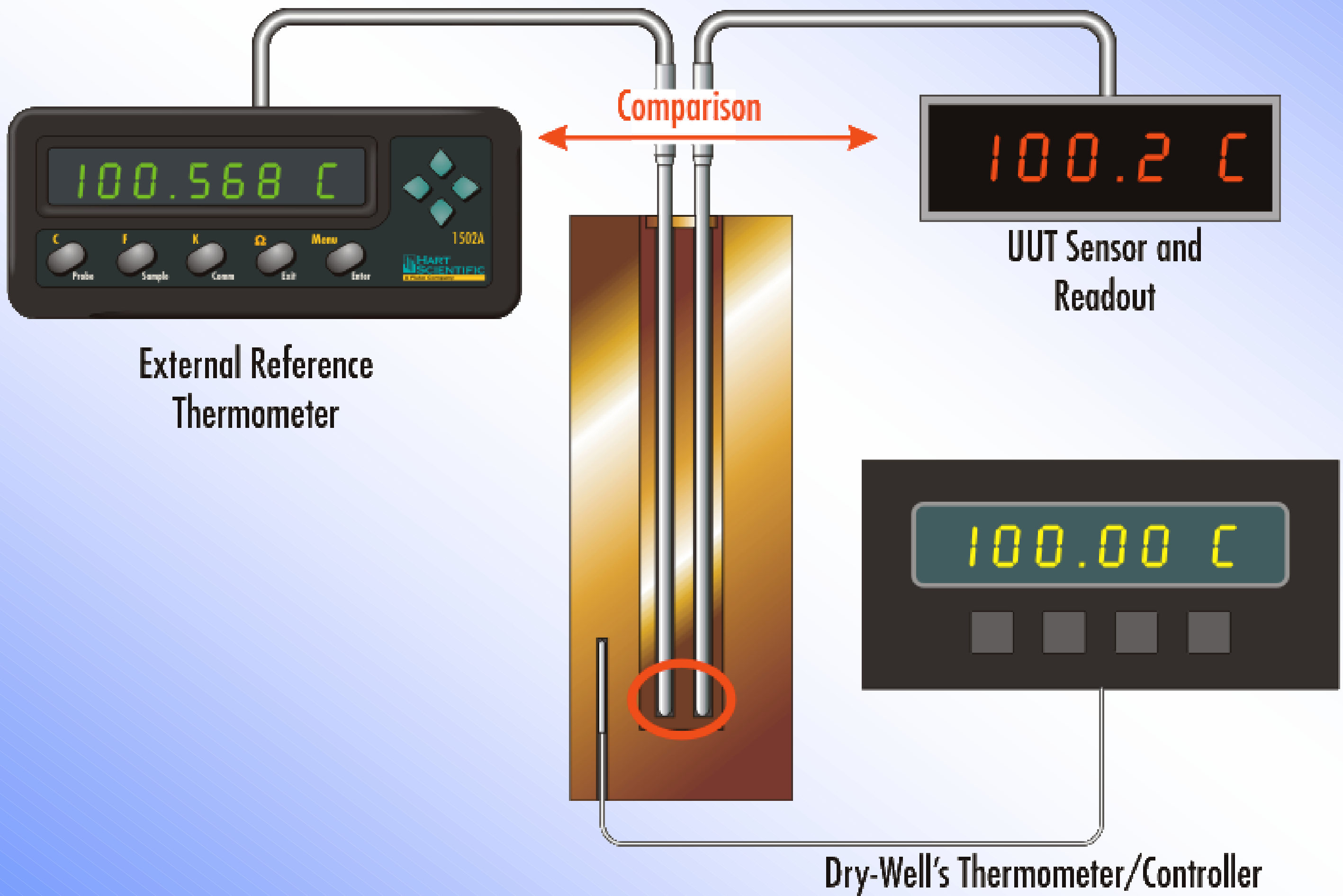
How you use a dry-well greatly affects performance!

- Temperature range
  - Generally errors are greater the further away from ambient temperature
- Will dry-well temperature be measured using an external reference or the internal control sensor and display?
  - Each method is valid, but an external reference will generally provide better uncertainties

Temperature Reference Standard- *Direct Mode*



Temperature Reference Standard- *Indirect Mode*



What errors are significant?

- Metrology Wells and Dry-Wells are used for comparison calibrations
- Comparison calibrations require thermal equilibrium and consistency
  - Without thermal equilibrium no comparison can be made
    - * Equilibrium requires stability
    - * Comparisons require uniformity (low thermal gradients)
  - Consistency allows the comparisons to have meaning over time and between different tests
    - * Good consistency requires similar loading, low drift, good handling practices and verification

Errors depend upon mode of use

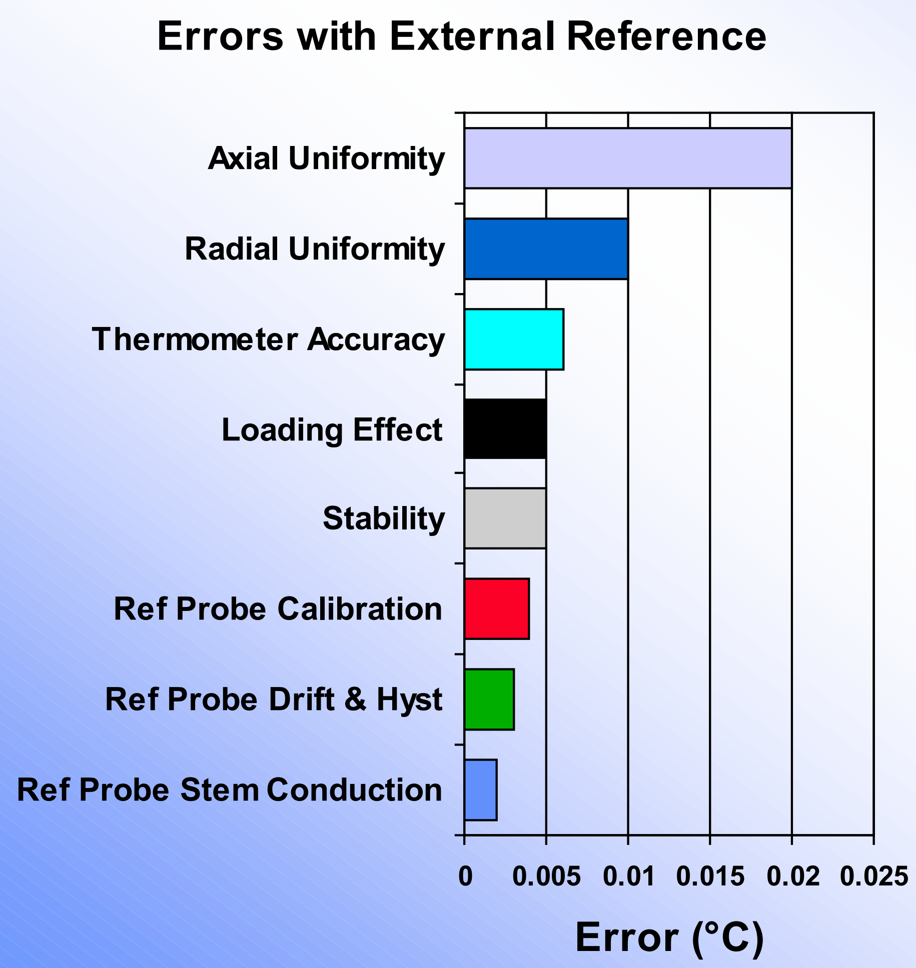
External Reference

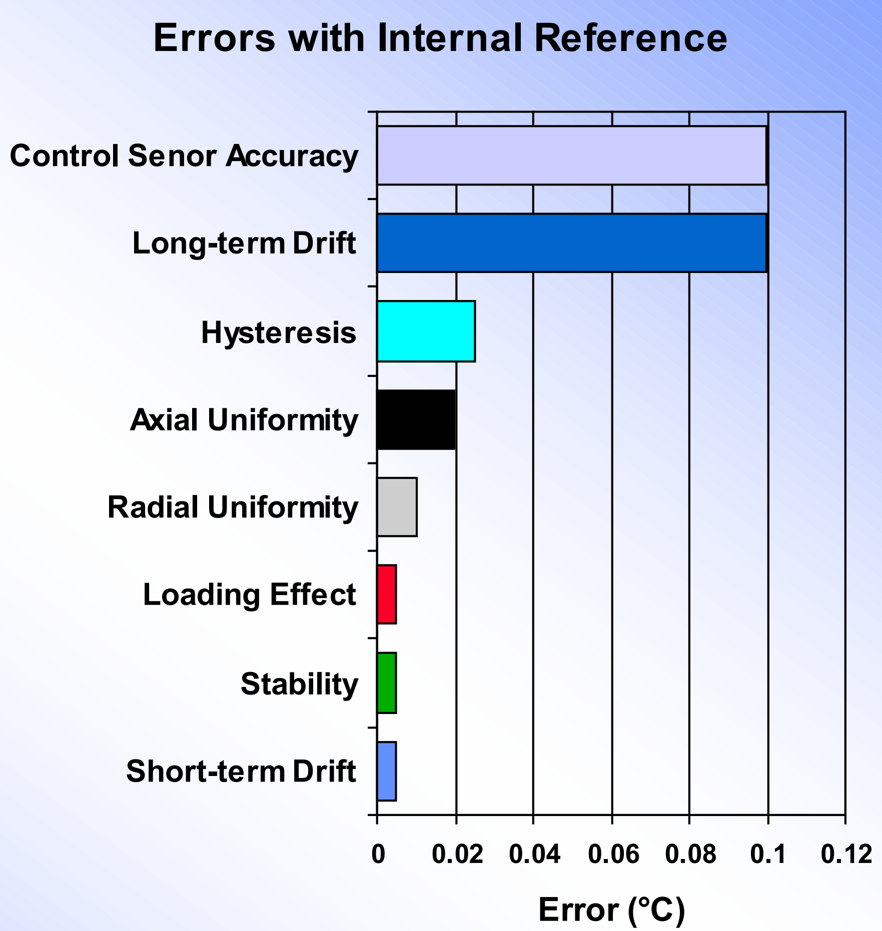
- Axial Uniformity
- Radial Uniformity
- Stem conduction
- Loading Effect
- Stability
- Reference temperature measurement
  - Reference Probe
  - Reference Readout

Internal control sensor and calibrated display

- Axial Uniformity
- Radial Uniformity
- Stem conduction
- Loading effect
- Stability
- Reference temperature measurement
  - Sensor and display drift
  - Hysteresis
  - Sensor Calibration

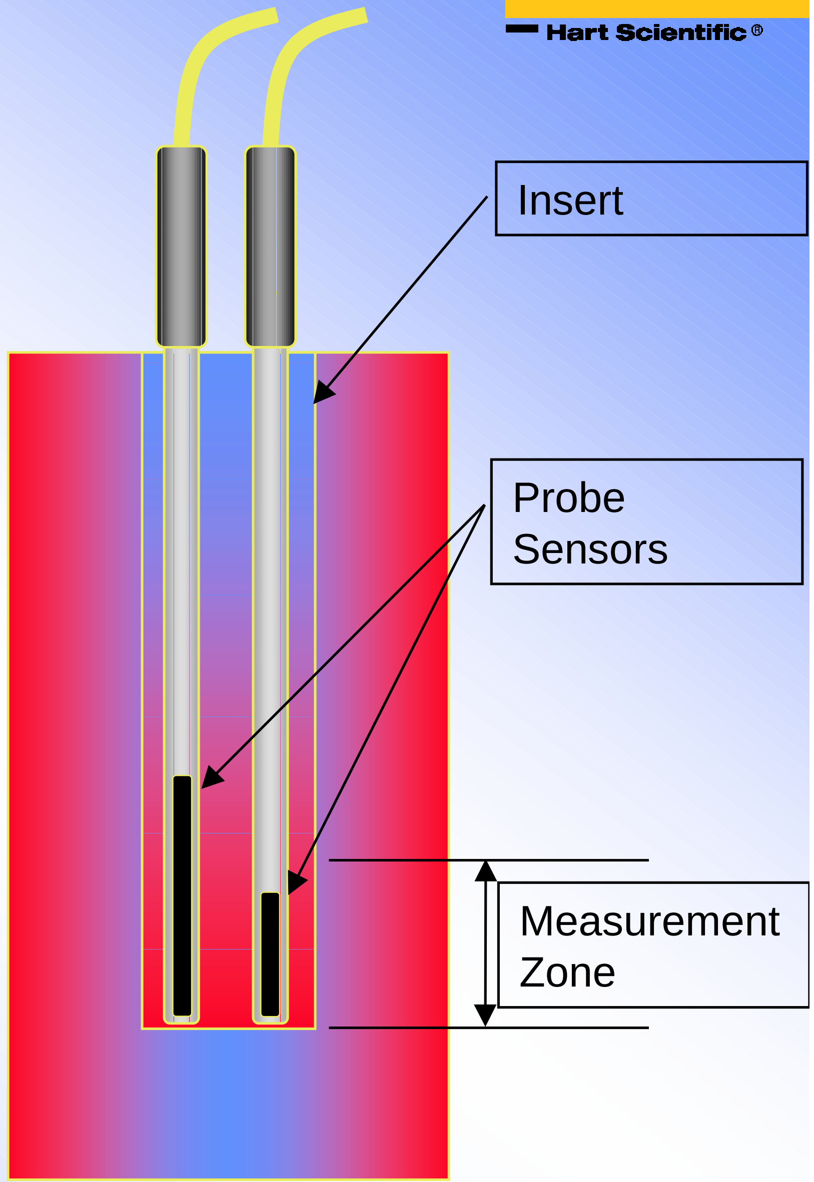
Estimate of Significance





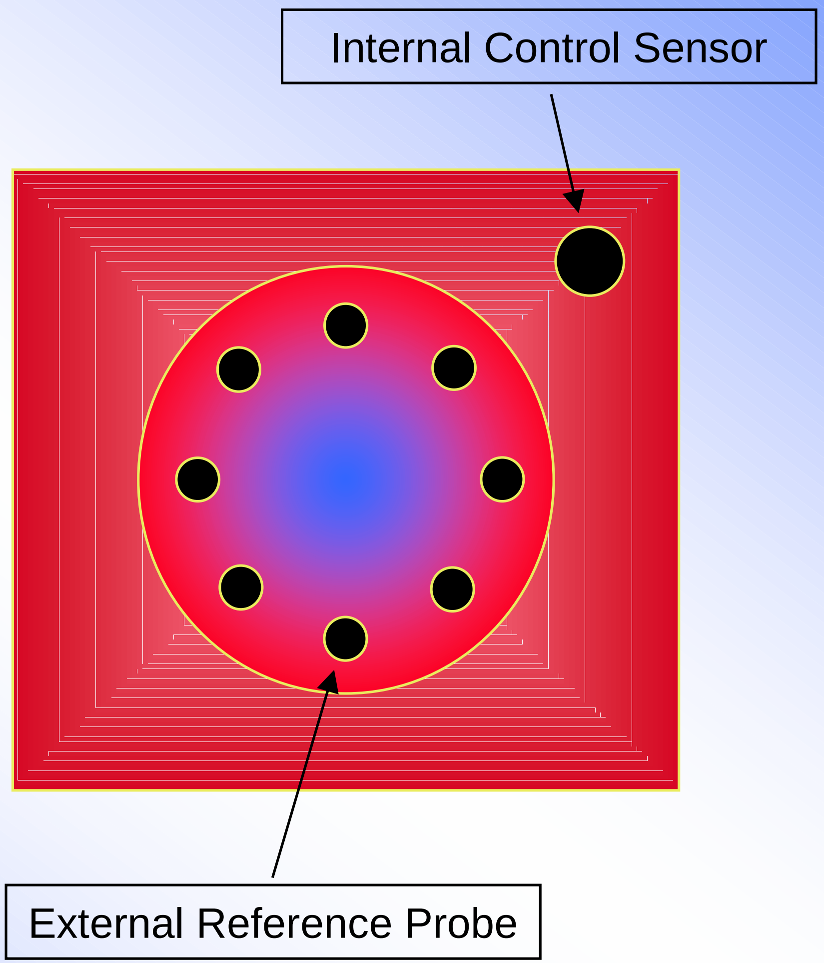
Axial Uniformity

- The temperature difference between the top and bottom of the well
- Measurement zone is where Axial Uniformity is smallest
  - EA-10/13 requires 40mm (1.5 inches)
  - Hart recommends 60mm (2.25 inches)
- Axial Uniformity in the measurement zone needs to be known to determine uncertainty
  - Hart has a special probes designed to measure this error
- Axial Uniformity error is minimized by
  - Dual-zone control
  - Ensuring probe sensor fits in Measurement Zone
  - Aligning the centers of the sensing elements in the reference and UUT



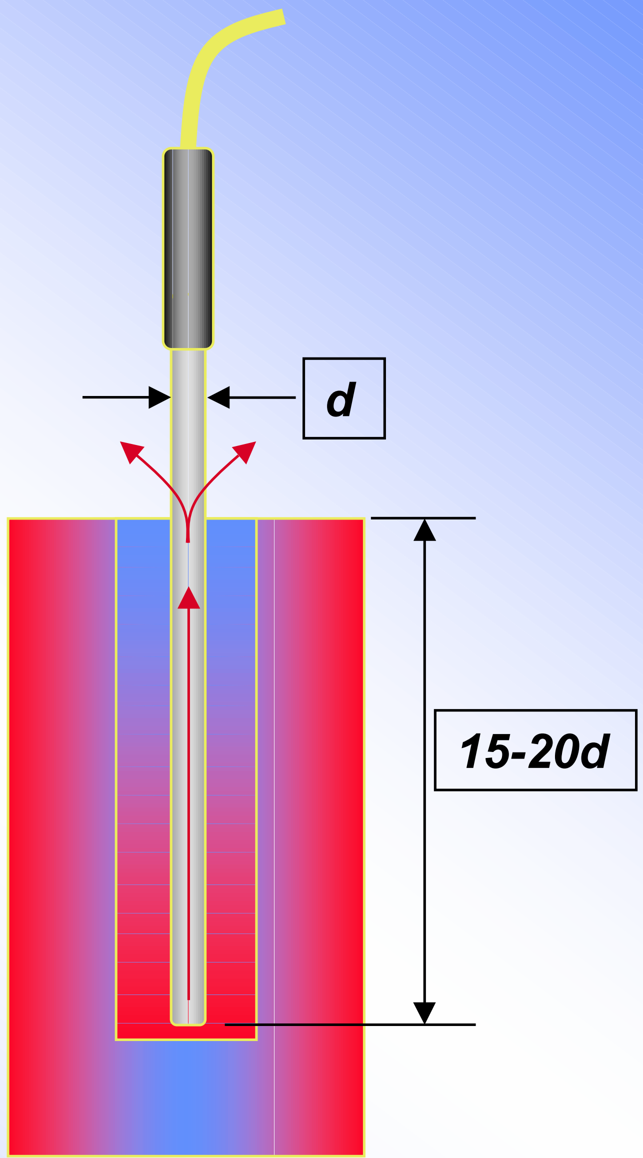
Radial Uniformity

- Radial Uniformity is the temperature difference between holes and the reference at the same depth
  - Primarily a function of distance and type of material
  - External References can be closer to the tested probes
- Radial Uniformity also needs to be known to determine uncertainty
- Radial Uniformity is minimized by placing the reference sensor close to the UUT



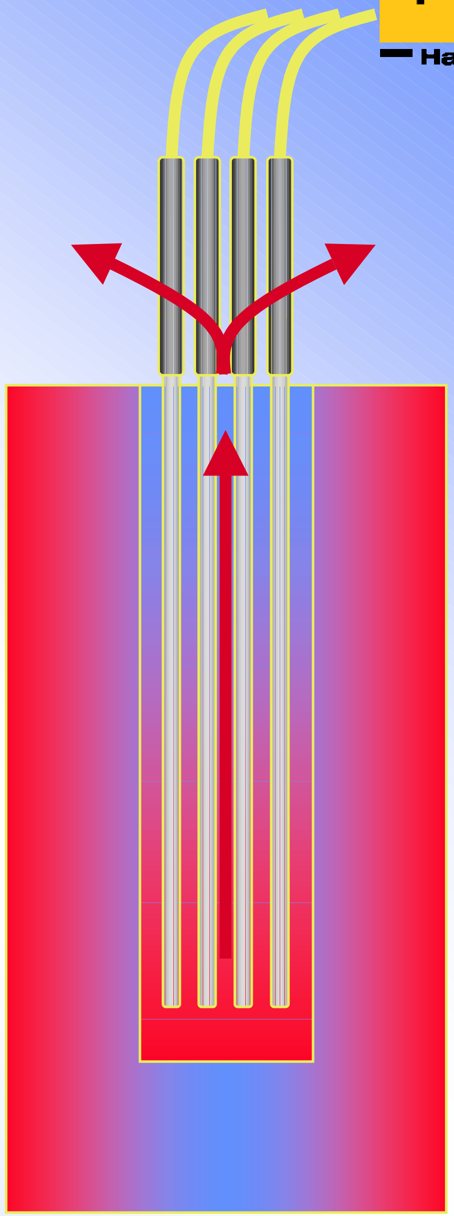
Stem Conduction

- Heat conducted up the sheath of the probe
  - Causes the sensor to not be at equilibrium with the source
- This is a function of the size and type of material
  - Large diameter probes conduct more heat
  - Alumina conducts more than Inconel
- This error is minimized by deeper immersion
  - Hart suggests 15 to 20 times the diameter of the probe
    - * A 8mm probe should have 120mm to 160mm of depth
    - * Metrology Wells have the extra depth needed to minimize this error



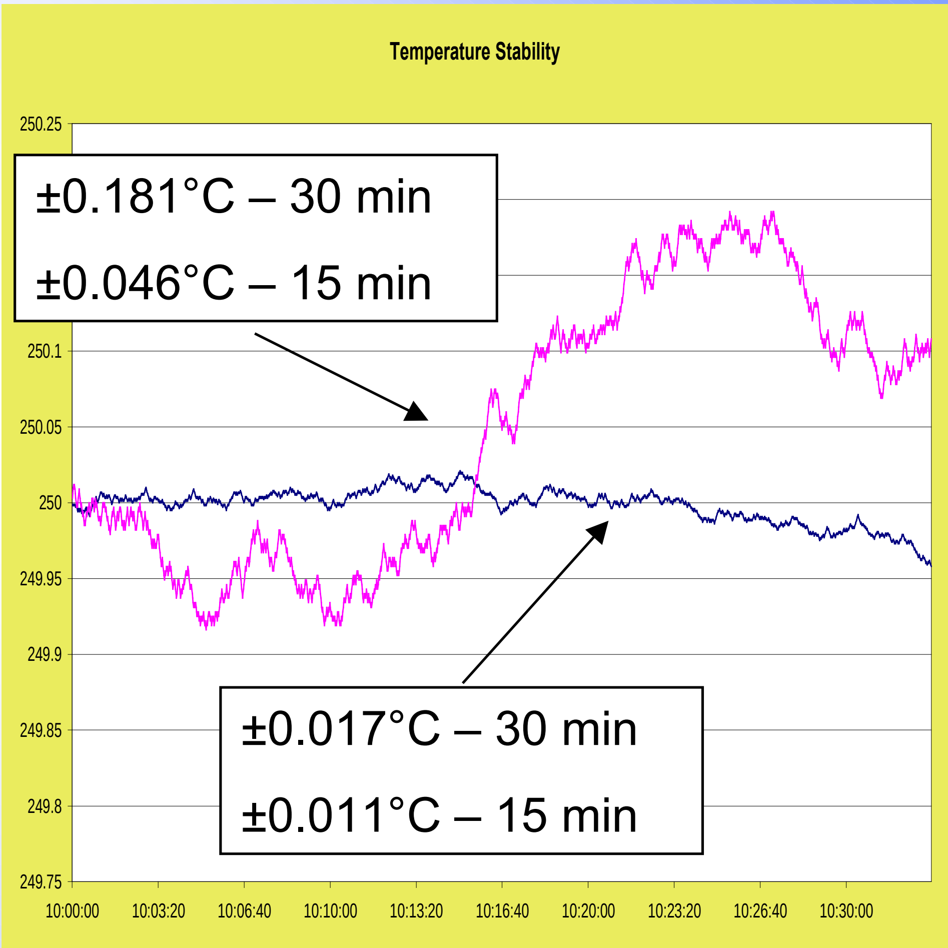
Loading Effect

- The number of probes will impact the amount of heat drawn from or into the well
  - Internal control sensor will not completely see this effect
- Loading Effect is minimized by well design
  - Deeper immersion
  - Dual-zone control



Temperature Stability

- **Stability is the temperature variation over time**
  - To be meaningful the time frame needs to be specified
    - * EA-10/13 guidelines suggest 30 minutes
    - * This should be stated with high confidence
      - "Typical" should be avoided!
- **Stability is required to reach thermal equilibrium**
  - Probes need time to reach equilibrium with their surroundings
  - Multiple measurements are rarely instantaneous
- **Temperature stability error is minimized by design**
  - Accurate control with good resolution
    - * Off the shelf temperature controllers don't provide exceptional stability



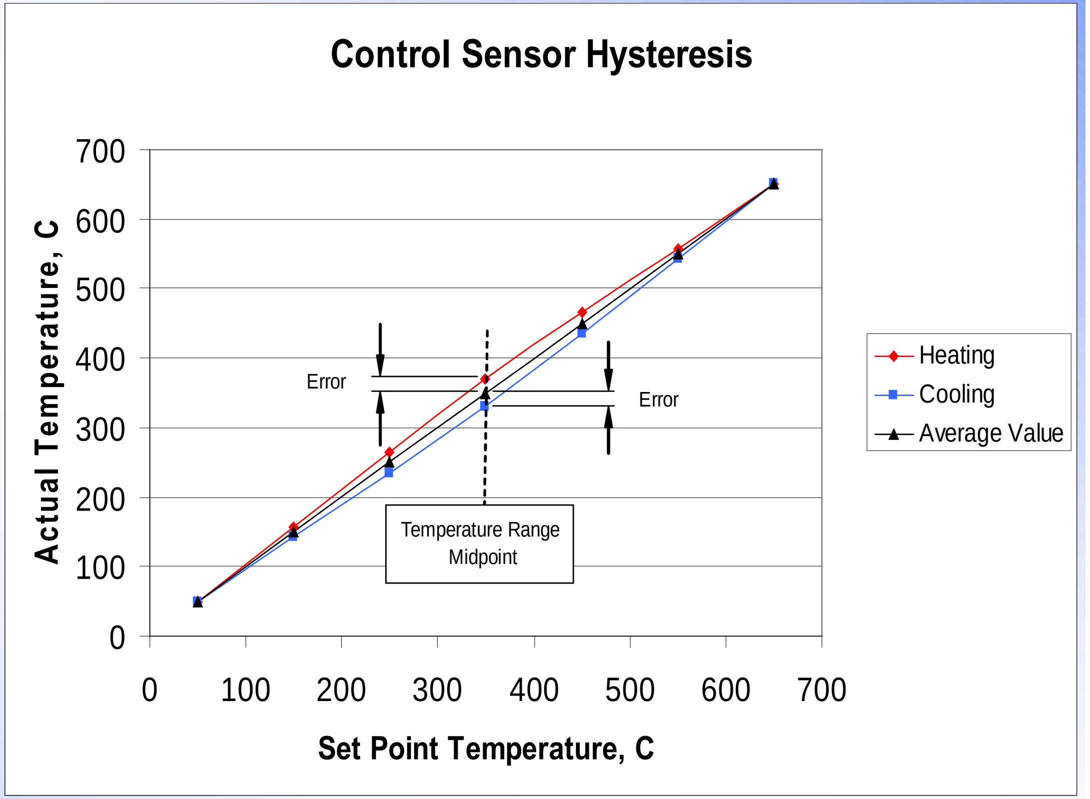
Reference Temperature Measurement

Sources of Error to Consider

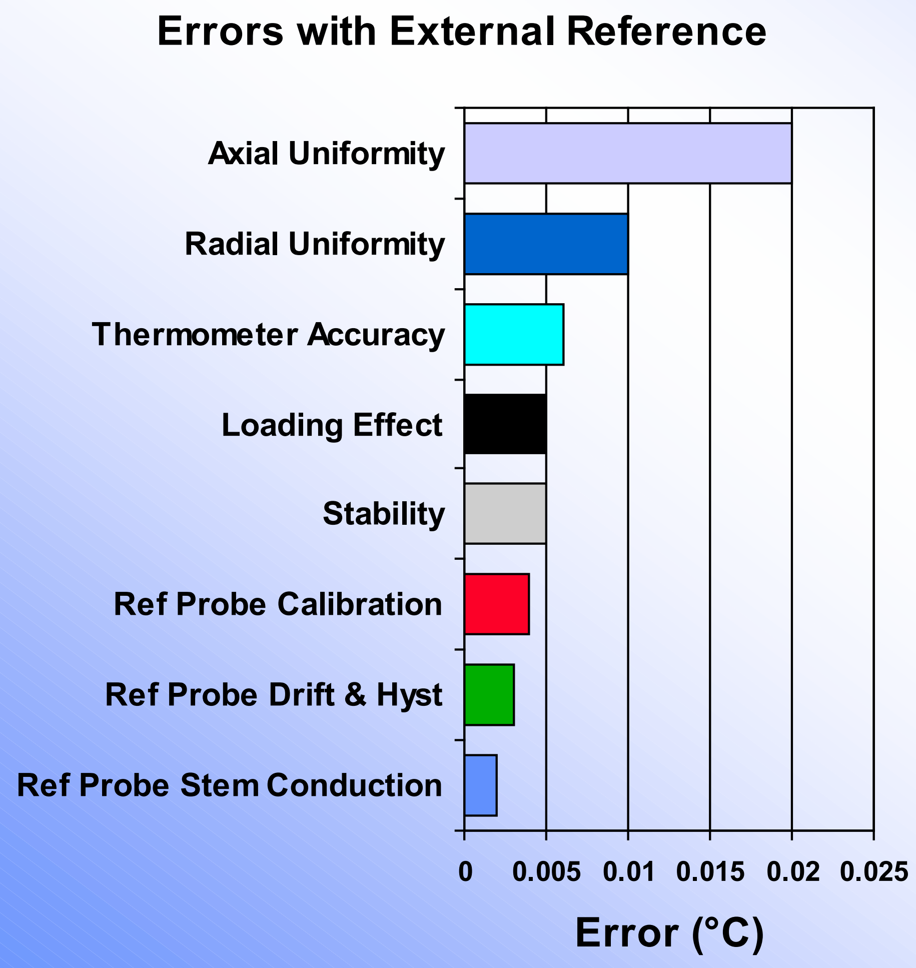
- External Reference
  - Probe calibration uncertainty
  - Probe handling
  - Probe characteristics
  - Readout calibration uncertainty
  - Readout resolution
  - Measurement technique
- Internal control sensor and display
  - Well calibration uncertainty and procedure
  - Hysteresis
  - Probe drift
  - Control electronics calibration
  - Control electronics resolution
  - Control measurement technique

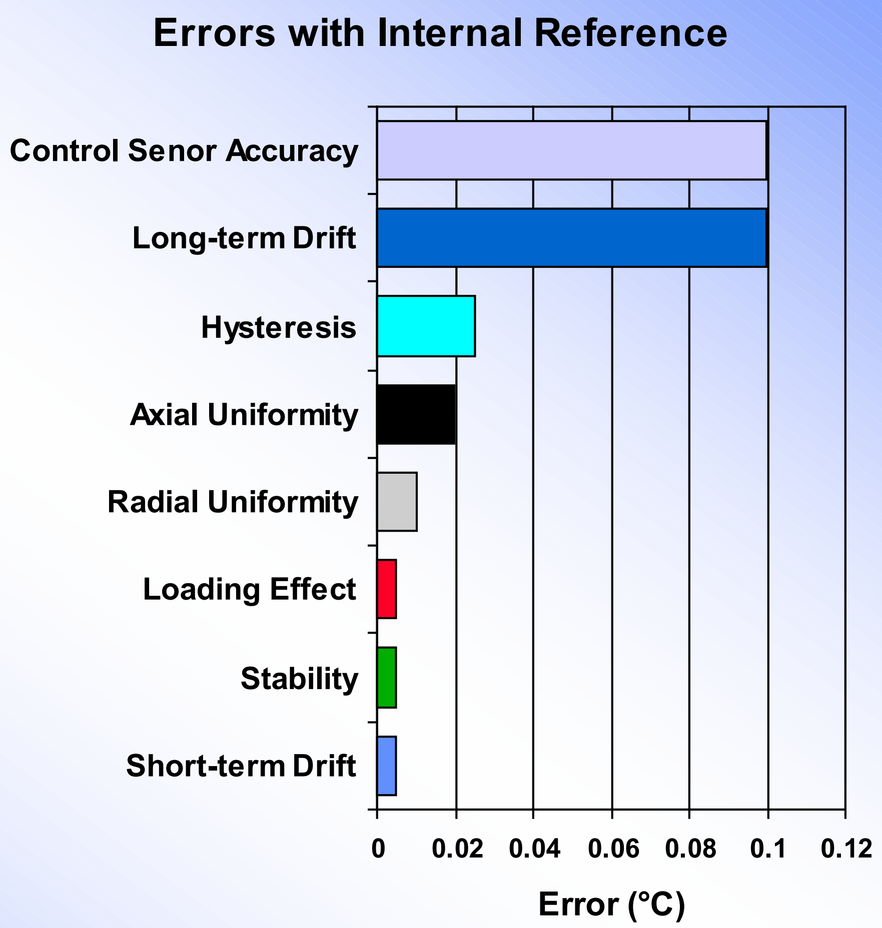
Control Sensor Hysteresis

- **Hysteresis is the result of:**
  - Varying strain on a sensing element as it moves through a range of temperature
  - The effect of its immediate thermal history.
- **The effect is typically largest at the midpoint of the range.**
- **The hysteresis is reasonably repeatable**.



Estimate of Significance (Re-Cap)





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How do you know if a Dry-Well is any good?

- There are dozens of manufacturers
- Hundreds of different models
  - Handheld, portable, bench, vertical, horizontal, combo-units

Hart Metrology Wells are designed to reduce errors seen in typical Dry-Wells!

Total uncertainty with external reference probe

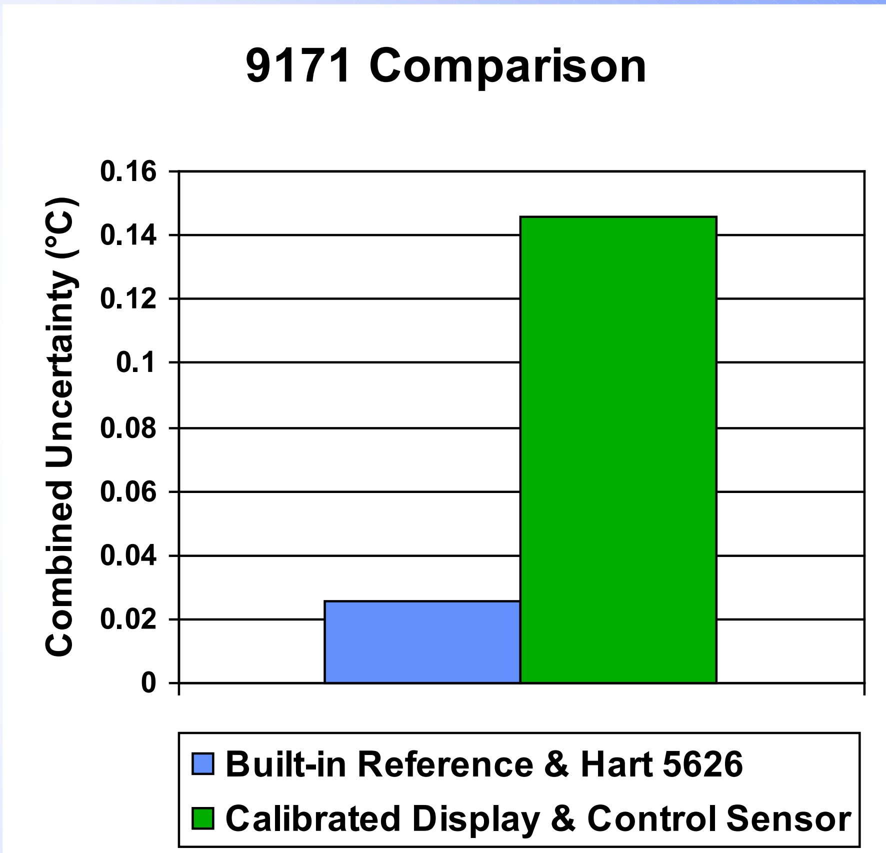
Hart 9171 at 0°C with built in Ref and Hart 5626 Probe			
	Specification (°C)	***Probability Distribution***	***Standard Uncertainty (°C)***
Axial Uniformity	0.020	Normal	0.010
Radial Uniformity	0.010	Rectangular	0.006
Loading Effect	0.005	Rectangular	0.003
Stability	0.005	Normal	0.003
Ref Probe Calibration	0.004	Normal	0.002
Ref Probe Drift & Hyst	0.003	Normal	0.002
Ref Probe Stem Conduction	0.002	Normal	0.001
Thermometer Accuracy	0.006	Rectangular	0.003
	Total Uncertainty (k=2)		**0.026**

Total uncertainty with internal reference

Hart 9171 at 0°C with internal reference and Display			
	Specification (°C)	***Probability Distribution***	***Standard Uncertainty (°C)***
Axial Uniformity	0.020	Normal	0.010
Radial Uniformity	0.010	Rectangular	0.006
Loading Effect	0.005	Rectangular	0.003
Stability	0.005	Normal	0.003
Short-term Drift	0.005	Normal	0.003
Hysteresis	0.025	Normal	0.013
Control Sensor Accuracy	0.100	Normal	0.050
Long-term Drift	0.100	Normal	0.050
	Total Uncertainty (k=2)		**0.146**

Comparison of modes of use

- All Metrology Wells can be ordered with an internal reference readout
- When a calibrated probe is connected unmatched performance can be achieved!



Cold Metrology Wells compared to Dry-Wells

Combined Uncertainty (°C)			
Temperature	*9170 or 9171*	*Competitor 1*	*Competitor 2 (*)*
-45°C (9170)	0.1040	0.207	n/a
-35°C (9170)	0.0433	n/a	0.119
-30°C	0.0433	n/a	0.119
-25°C	0.0433	0.160	0.119
0°C	0.0256	0.160	n/a
50°C	n/a	0.160	0.119
140°C	0.0459	n/a	0.125
155°C (9171)	0.0641	0.161	n/a

*** Data from evaluation report, not spec sheet**

Mid-Temp Metrology Well compared to Dry-Wells

Combined Uncertainty (°C)			
Temperature	**9172**	**Competitor 1**	**Competitor 2 (*)**
35°C	0.055	n/a	0.119
50°C	0.055	0.188	n/a
100°C	0.055	n/a	n/a
125°C	0.105	n/a	n/a
155°C	0.105	0.235	0.337
225°C	0.105	n/a	n/a
250°C	0.204	n/a	0.376
320°C	0.204	0.309	n/a
425°C	0.204	n/a	n/a

*** Data from evaluation report, not spec sheet**

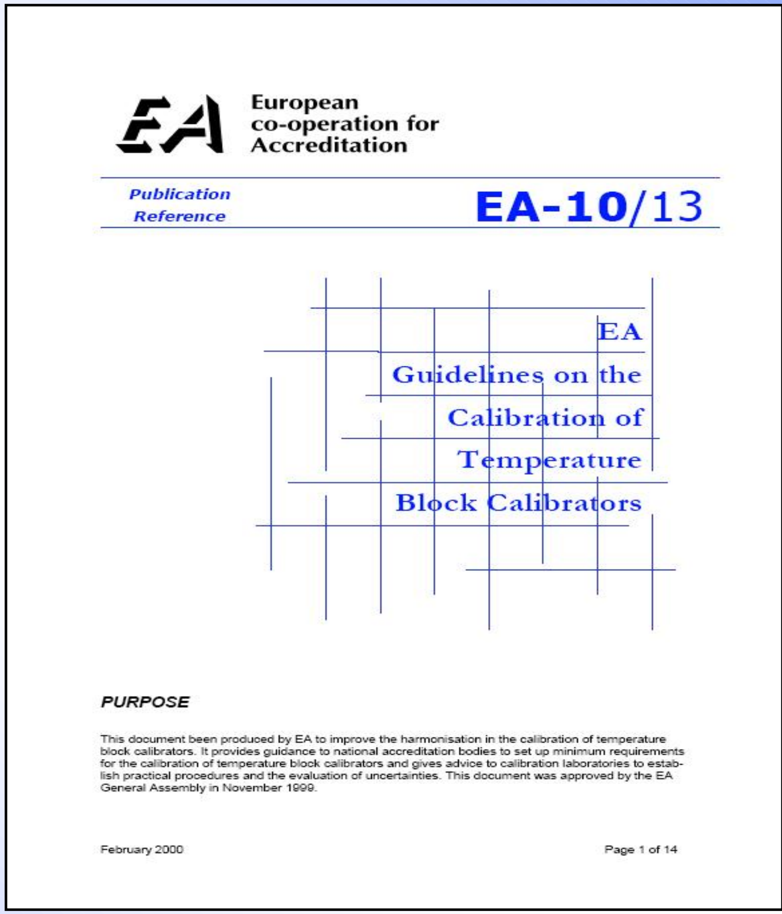
High-Temp Metrology Well compared to Dry-Wells

Combined Uncertainty (°C)				
Temperature	**9173**	**Competitor 1**	**Competitor 2 (*)**	**Competitor 3 (*)**
35°C	n/a	n/a	0.127	0.133
50°C	0.104	0.214	n/a	n/a
275°C	n/a	n/a	0.182	0.176
320°C	0.257	0.630	n/a	n/a
425°C	0.257	n/a	n/a	n/a
550°C	0.408	n/a	0.844	0.349
650°C	0.408	1.019	n/a	n/a

*** Data from evaluation report, not spec sheet**

Guidelines are available to assist in evaluation procedures

- EA-10/13 Reference Publication
  - Guidelines on the Calibration of Temperature Block Calibrators
- ASTM Guidelines being written
  - Hart's Tom Wiandt is on this committee
- Several NMI's have published or are currently revising their guidelines


European co-operation for Accreditation

Publication Reference EA-10/13

EA Guidelines on the Calibration of Temperature Block Calibrators

PURPOSE

This document been produced by EA to improve the harmonisation in the calibration of temperature block calibrators. It provides guidance to national accreditation bodies to set up minimum requirements for the calibration of temperature block calibrators and gives advice to calibration laboratories to establish practical procedures and the evaluation of uncertainties. This document was approved by the EA General Assembly in November 1999.

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EA-10/13 is one of the first guidelines available

- Approved by EA General Assembly in 2000
  - Document can be obtained free of charge from:

  www.european-accreditation.org

- Provides technical and procedural guidelines and a suggested method for calculating Uncertainty

EA-10/13 is not a standard it is a suggested guide to auditors and laboratories seeking European Accreditation

Accuracy isn't the only criteria to use in choosing a temperature calibrator!

- Understand what you need!
  - Where will you use it?
  - What temperature range is needed?
  - What kind of probes will be tested?
    - * Size, dimension
    - * TC, RTD, Thermistor
    - * Accuracy
  - Do you need speed or do you need to calibrate many probes at the same time?


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