Heat Sources

Dry-Wells and Metrology Wells.

Agenda

- Why Calibrate?
- Temperature Calibration Equipment.
- Dry Block Heat Sources.
- Points to Consider.
- A Field Heat Source

Why Calibrate?

As We Like It

As We Don't Like It

Too Much

Too Little

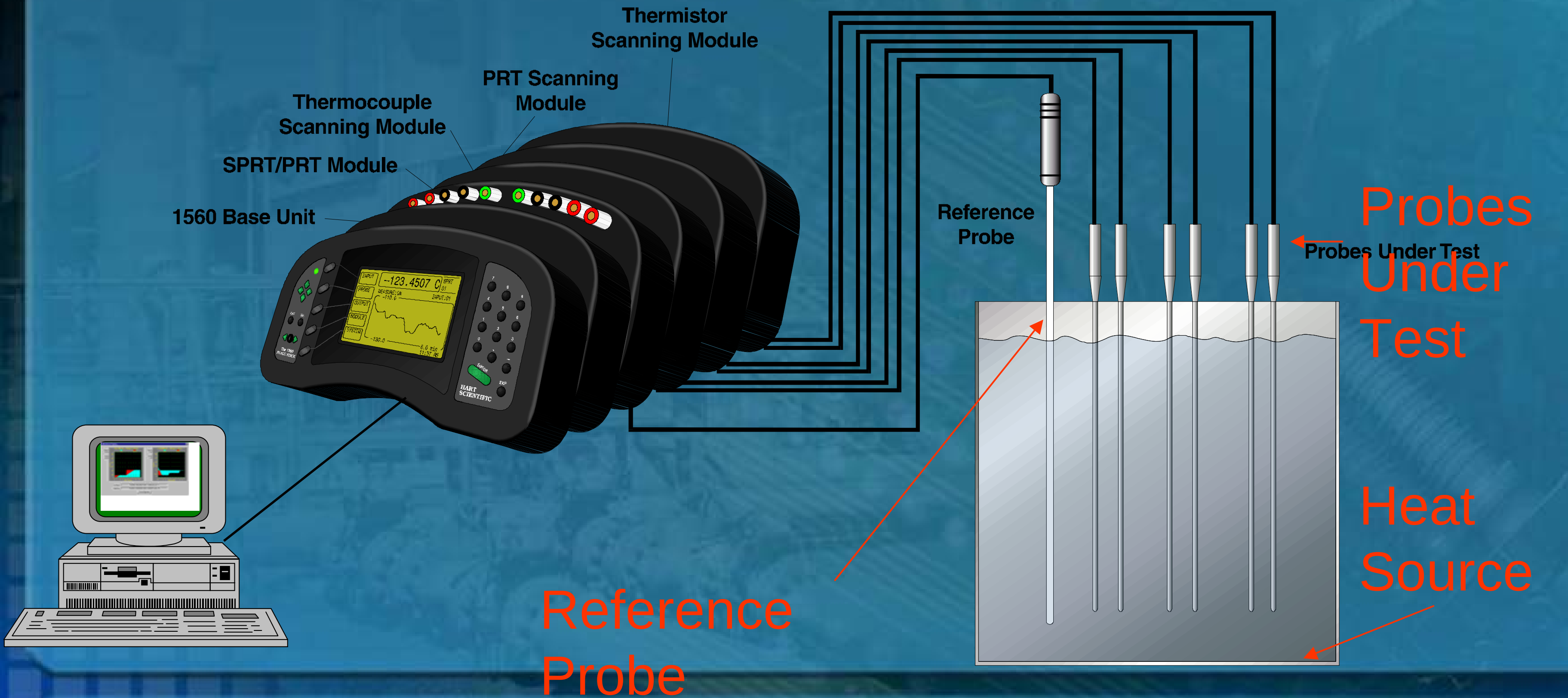
Calibration System includes:

- High stability/uniform baths or drywells
- Reference SPRTs or PRTs
- Readouts for measurement of SPRTs and UUTs
- Software for automated calibration and generation of calibration coefficients and interpolation tables

Procedures - Characterization

FLUKE
Hart Scientific

Thermometer Readout Method



Metrology Temperature Baths

- Range from –100°C to 550°C
- Stability ±0.0007°C best. Typ. a few mK
- Uniformity ±0.003°C best Typ. ± 5 to 10 mK
- High resolution set-point control

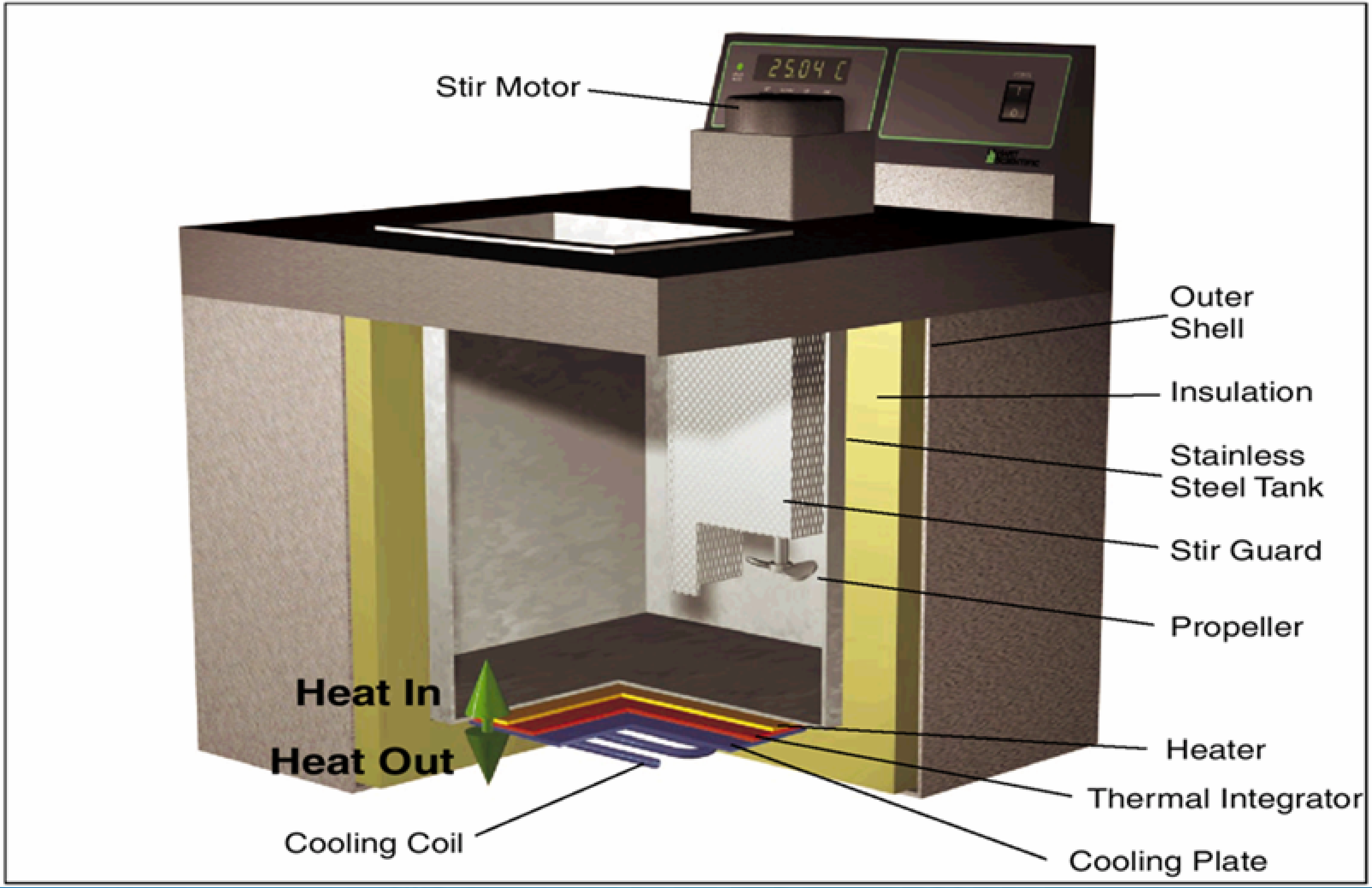
Bath Design

- Controller –high resolution for stability, hybrid analog/digital design
- Automation – RS-232, IEEE-488
- Heat Port Technology

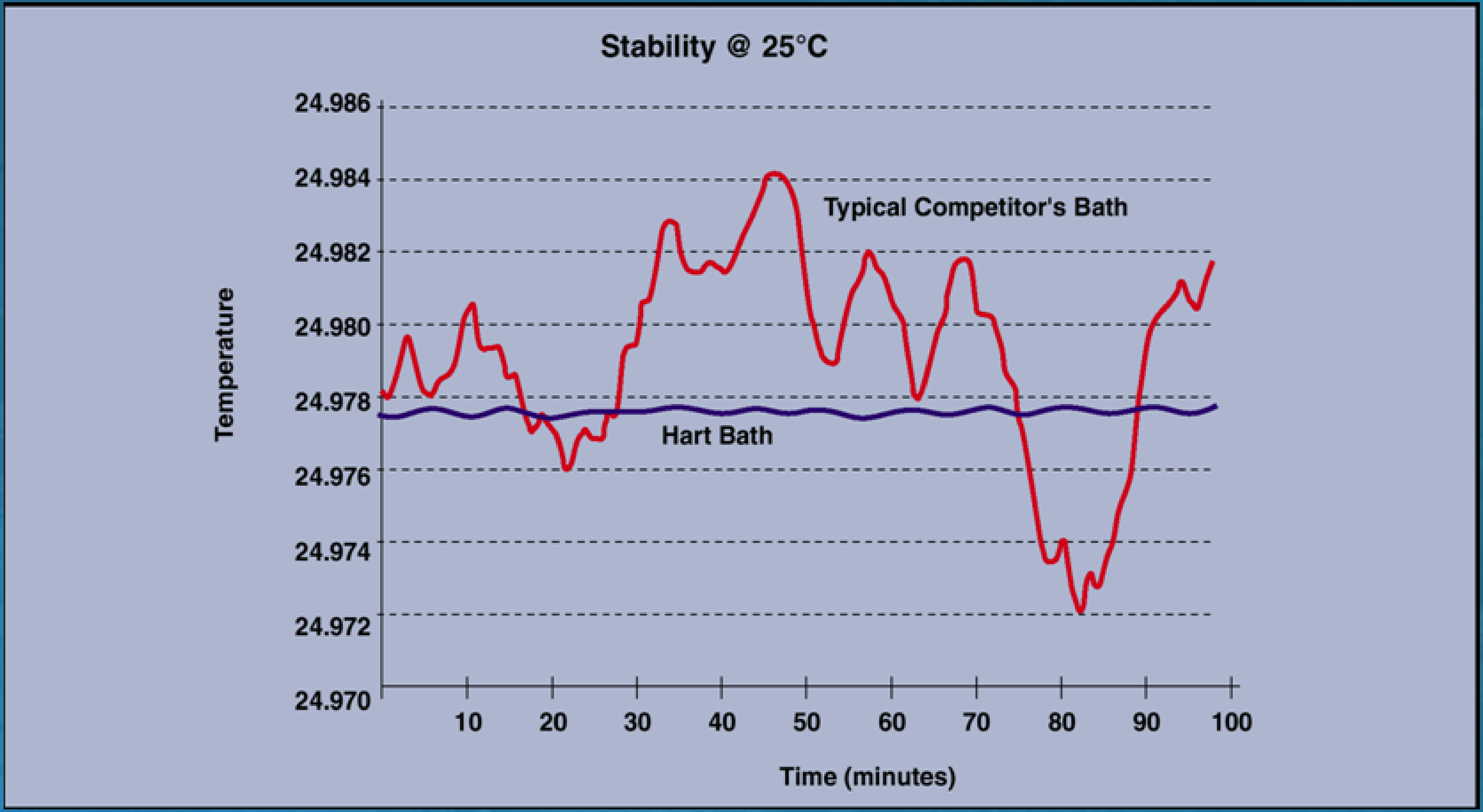
Problems with separate heating and cooling coils directly in the bath reservoir.

Improve bath uniformity and stability by reducing the heat paths from two to one.

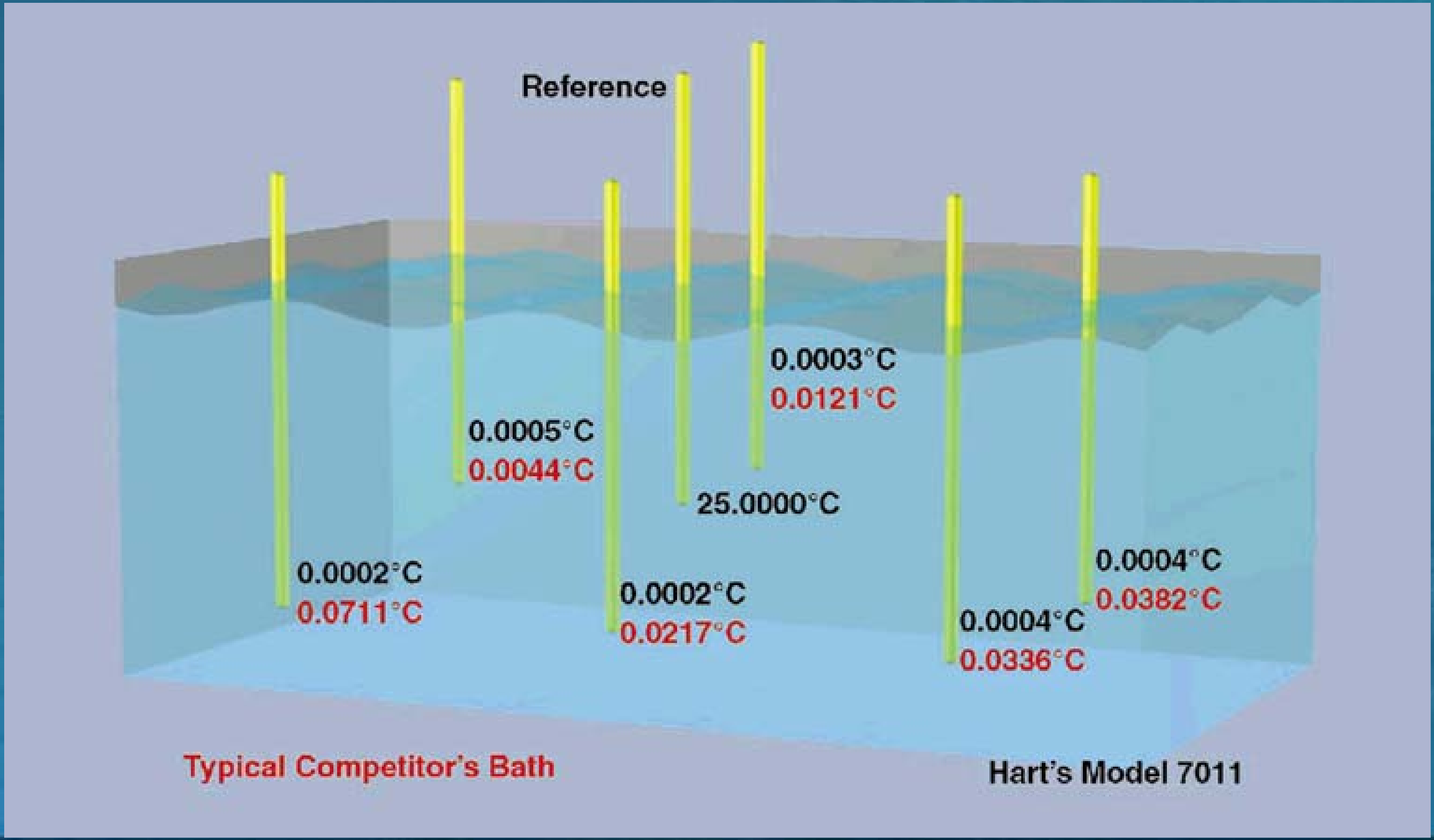
Heat Port Design



Baths - Stability



Baths - Uniformity



The Traditional Dry-Block Calibrator

A Dry-Block Calibrator is an isothermal heat source, which controls a temperature mass intended to provide a stable, uniform environment for temperature calibration.

FLUKE
Hart Scientific

A Different Definition

- An electronic temperature source for heat or cool.
- Controlled by a standard PI loop controller.
- Peltier* cells cool & heat from

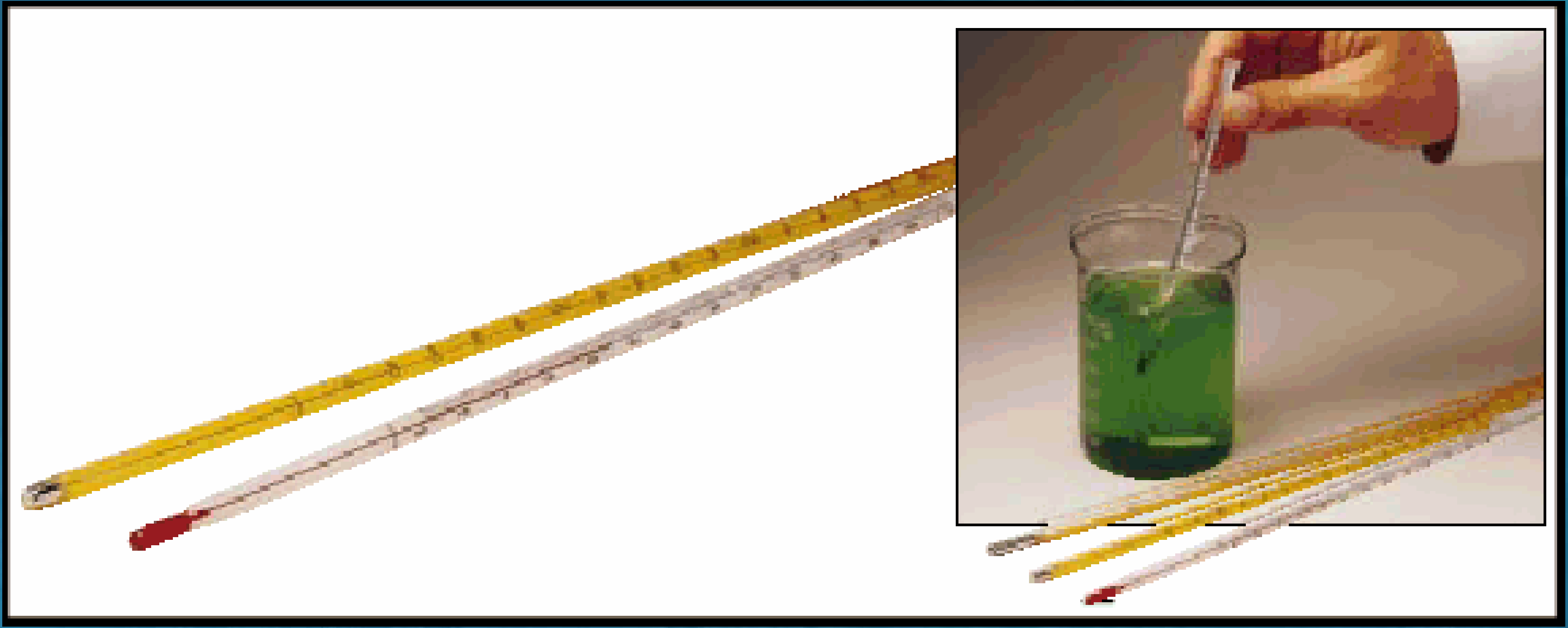
 -45°C to 140°C.

- Heater only units range from T ambient to 700°C.
- Used in the calibration of:
  RTD, Thermocouple, Thermistor, or any other temperature probe mounted in a sheath.

Where it fits…

- Probes.
- Thermocouple's, RTD's & Thermistor's.
- Accuracy within 0.1°C to 0.5 °C.

Where it fits... Yes but!



•Glass Thermometers.

Use a Microbath

- Microbaths are dryblocks with fluid.
- Provide better thermal contact for LIGs.

Where it doesn't fit...

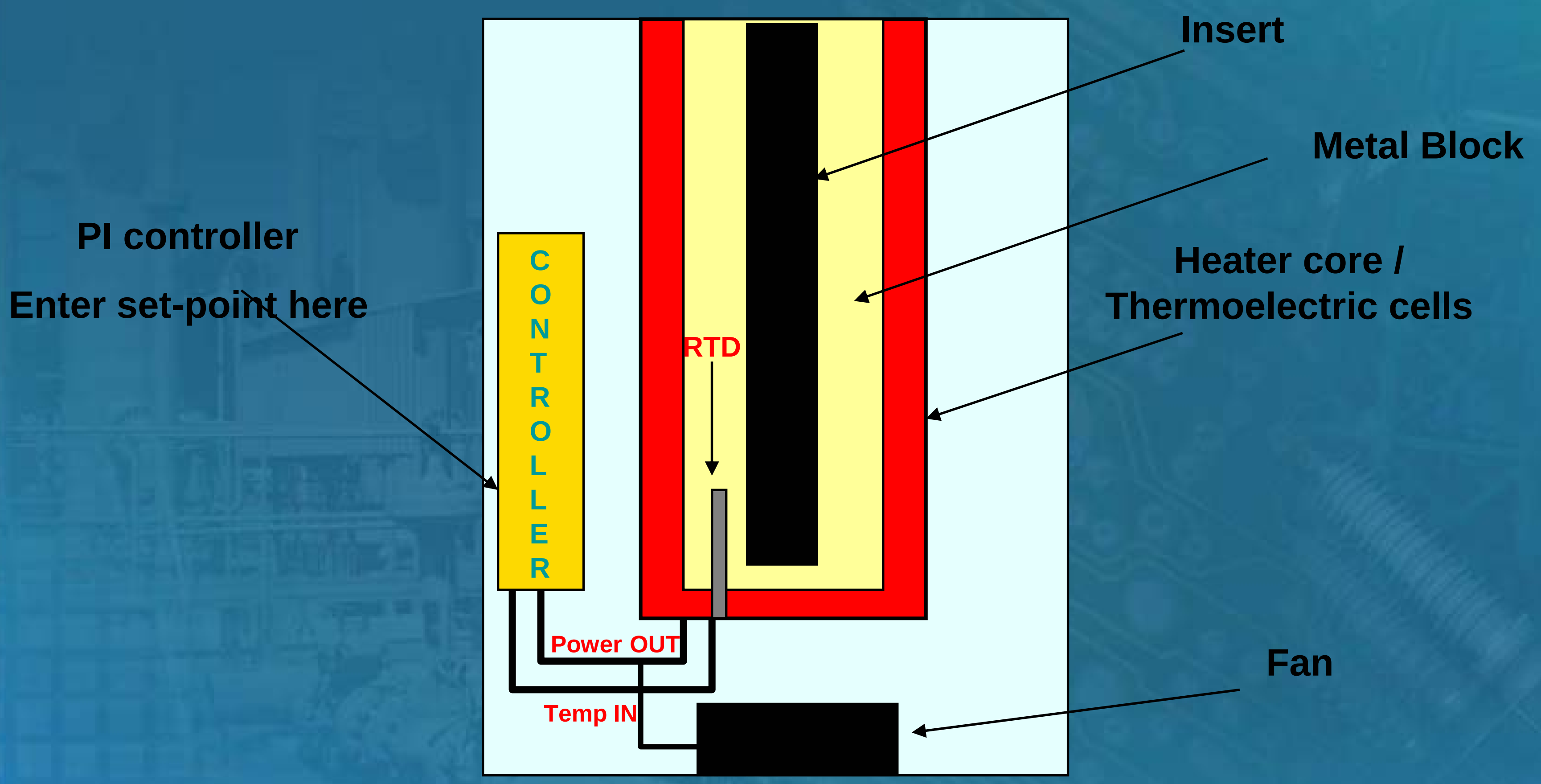
- High Accuracy PRT's/ SPRT's.

FLUKE
Hart Scientific

Where doesn't fit…

- **thermocouple wire.**

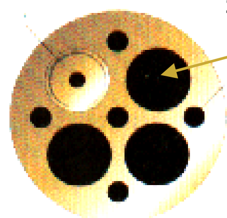
Anatomy of a Dry-Block

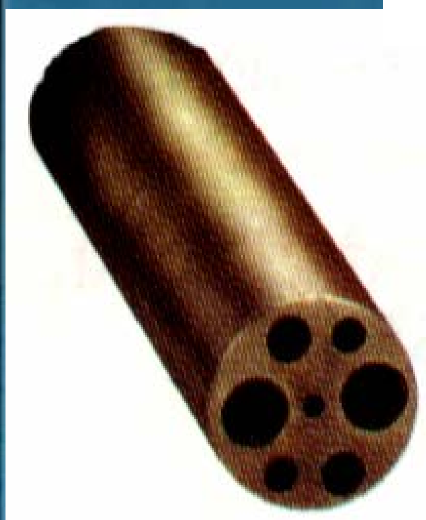


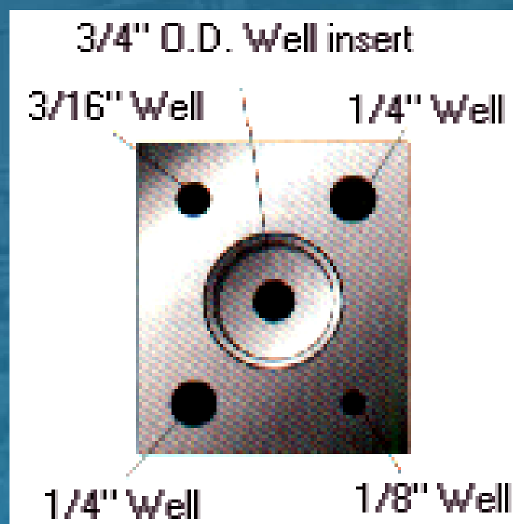
Anatomy of a Dry-Block

¾" O.D. Well Insert

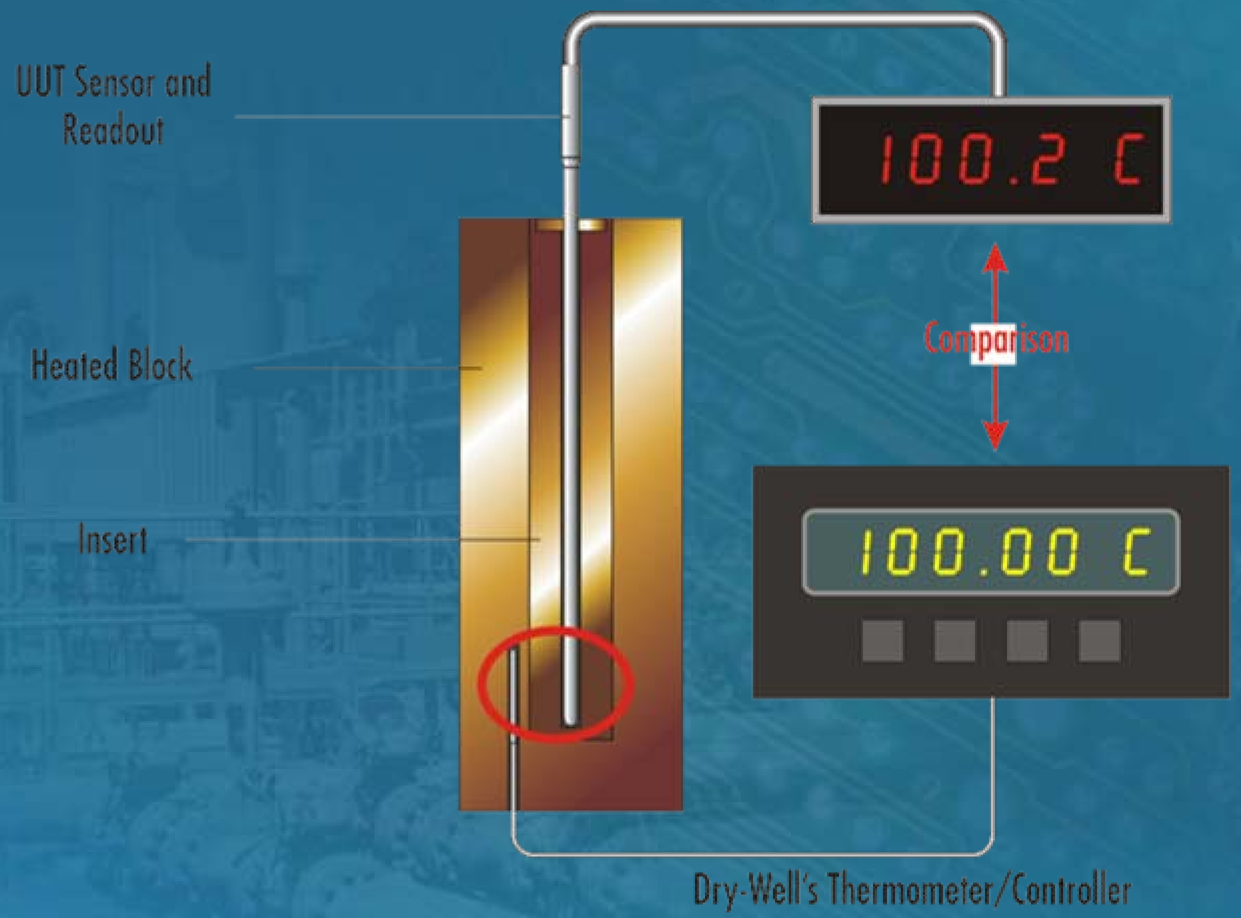
¼" Well



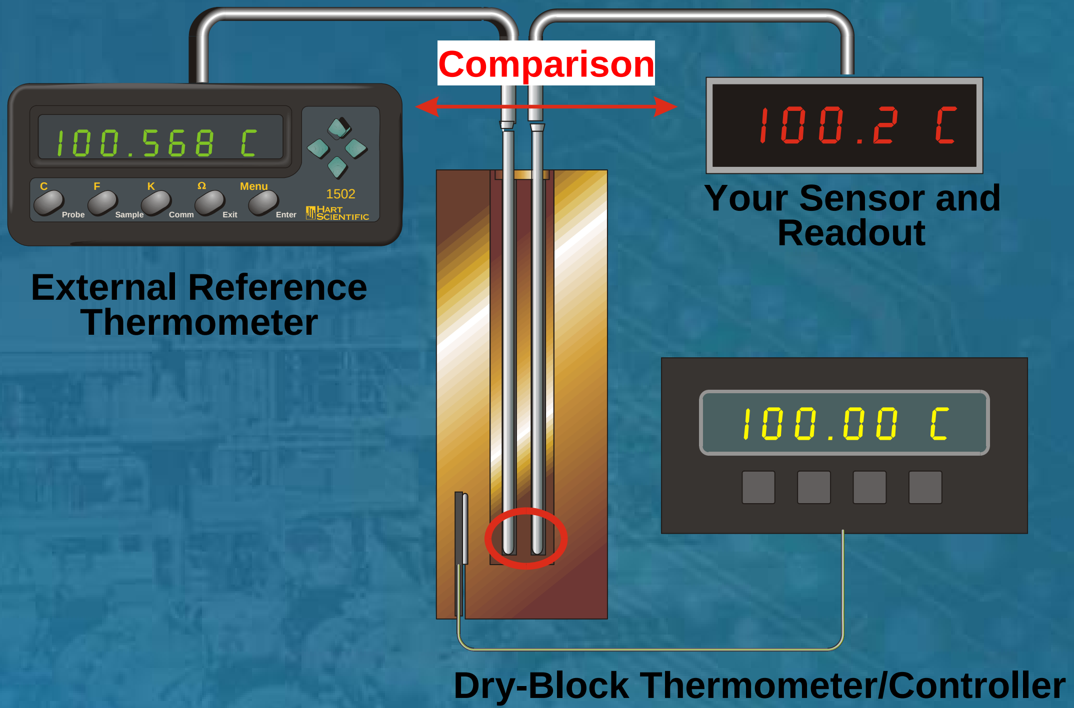




Temperature Reference Standard- *Direct Mode*



Calibration with a Reference Thermometer



Dry Block Comparison

FLUKE
Hart Scientific

Dry Block	Calibration Bath
More Portable.	Usually Stays in Lab.
Reaches Higher Temperatures.	Limited Range of Fluids.
Fast Temperature Response.	Slow to Reach Temperature.
Not as Stable, ±0.02°C Typical.	±0.001°C Stability Attainable.
No Fluid Required.	Fluids Can Be Messy.
Ideal for Industrial Applications.	Made for Lab Performance.
Lower cost.	Best Stability.
Standard probes only.	

Measurement Considerations Dry-Block Calibrators

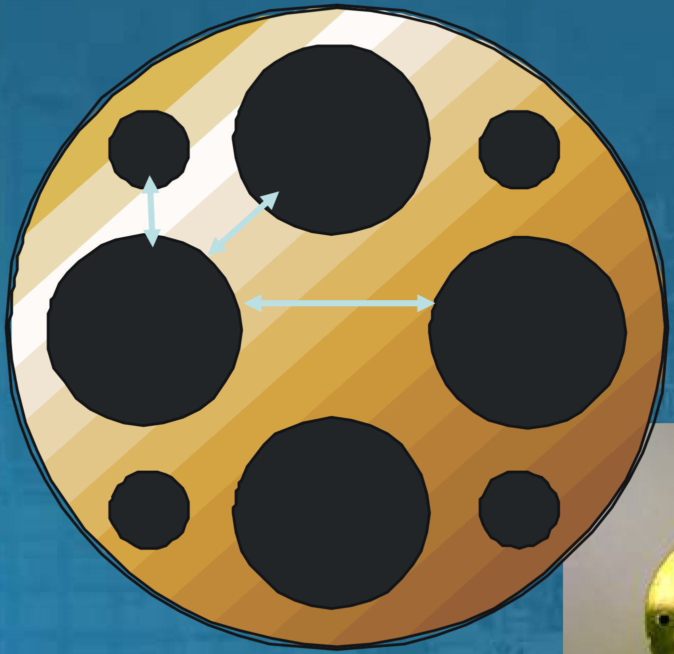
- Stability.
- Uniformity - vertical and horizontal gradients.
- Insertion Depth- its effect on accuracy.
- Stem Effect.
- Well VS Probe diameter - transfer efficiency.

Stability

- Temperature variance of the well caused by applied heating/cooling.
- Poor stability caused by limited resolution controller and controller settings.
- Stability errors add into error budget.
- Typical Dry Block stability: ±0.05°C to ±0.02°C.

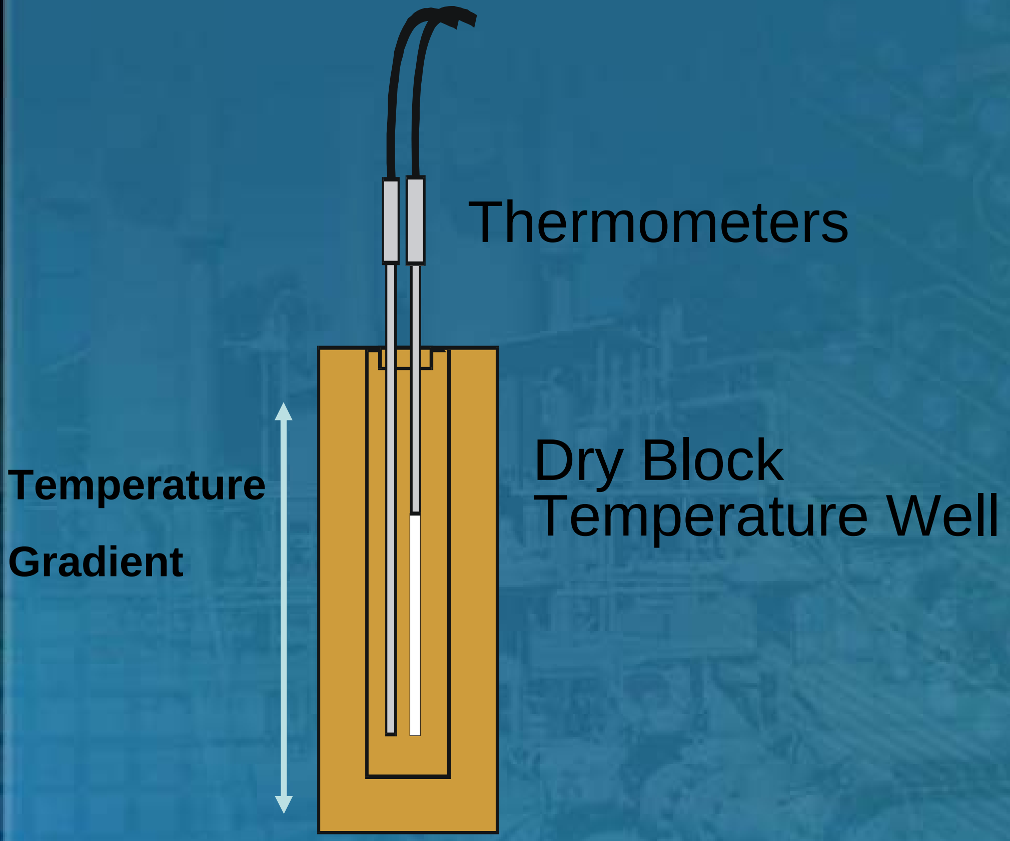
Radial Errors

Radial Uniformity



- Temperature variance between holes.
- Holes should be equi-distant from heaters.
- Reference and test probes should be similar diameter.

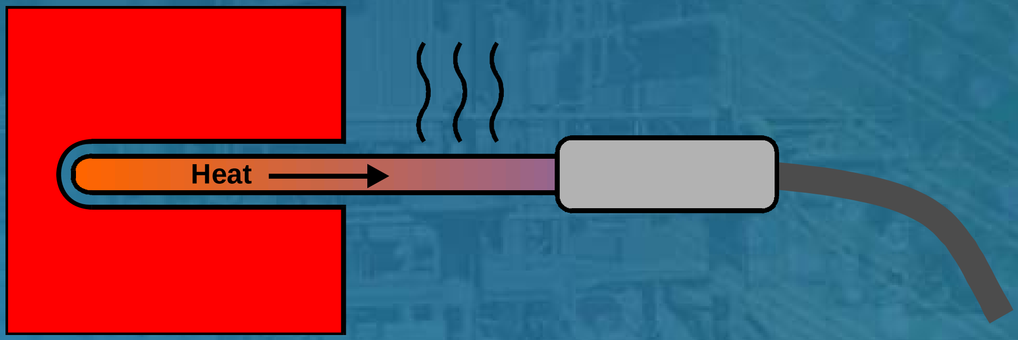
Axial Uniformity



- Temperature variance from top to bottom.
- Probe immersion causes gradient effects.
- Comparison should be made at similar depths.
- Profiling heaters reduces net effect.

Stem Effect

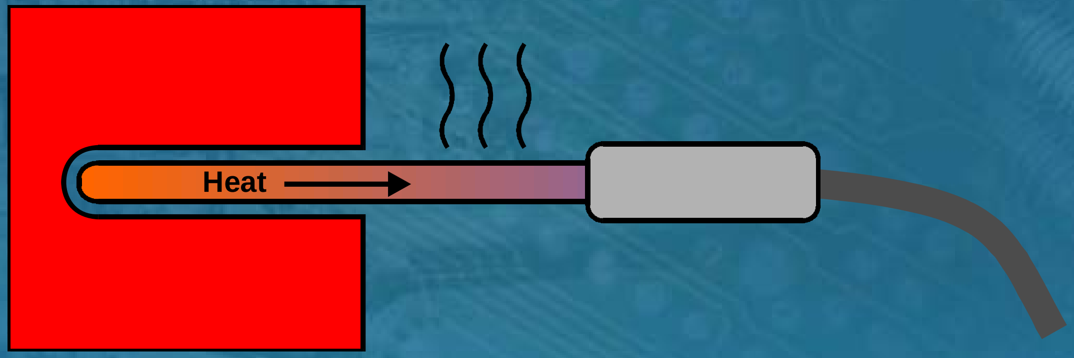
- Temperature measurement error due to heat conducted (loss / gain) along the thermometer stem.



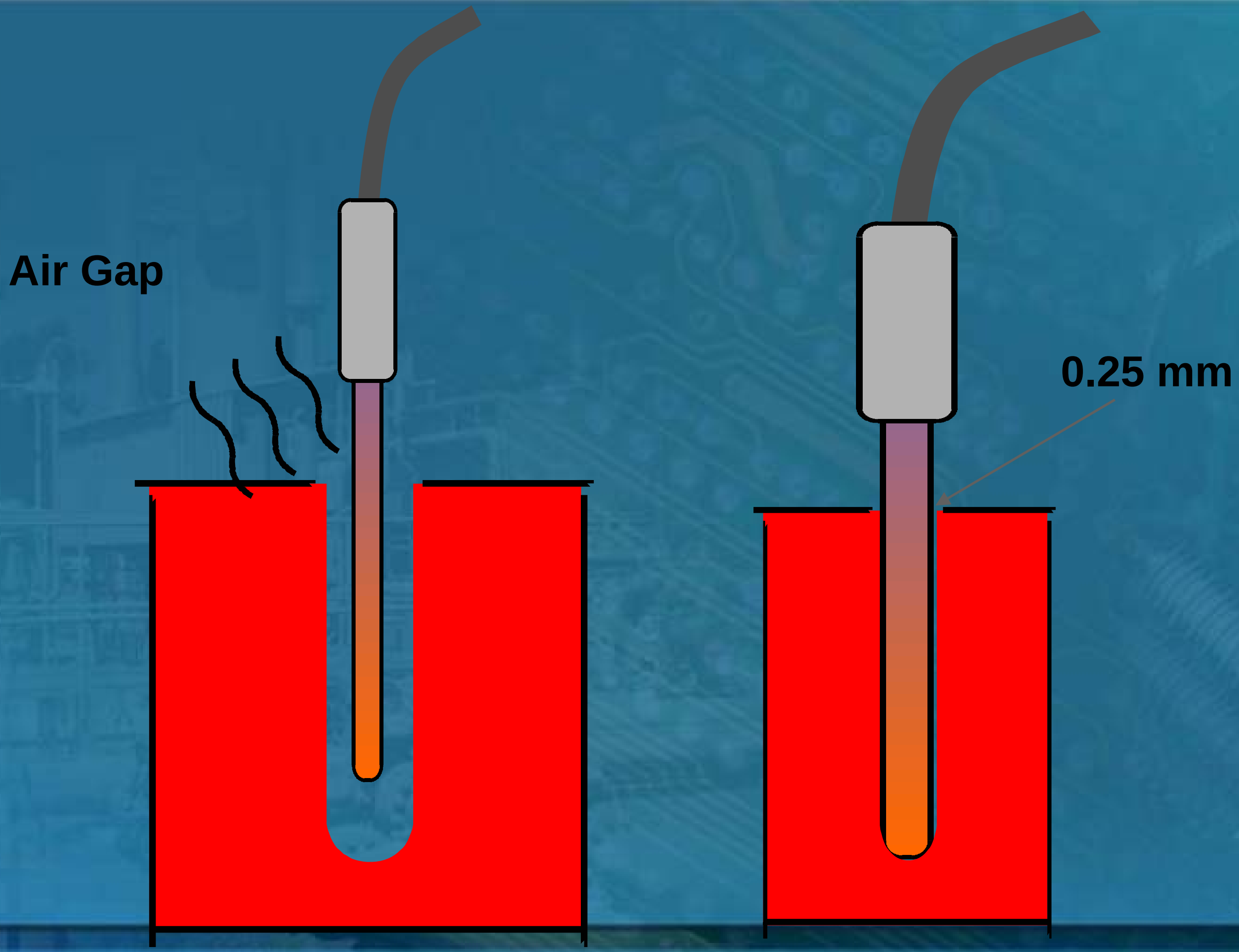
Factors:
- Temperature of block.
- Temperature of room.
- Draught in room.
- Probe Diameter.
- Exposed probe area.
- Probe sheath material.

Insertion Depth

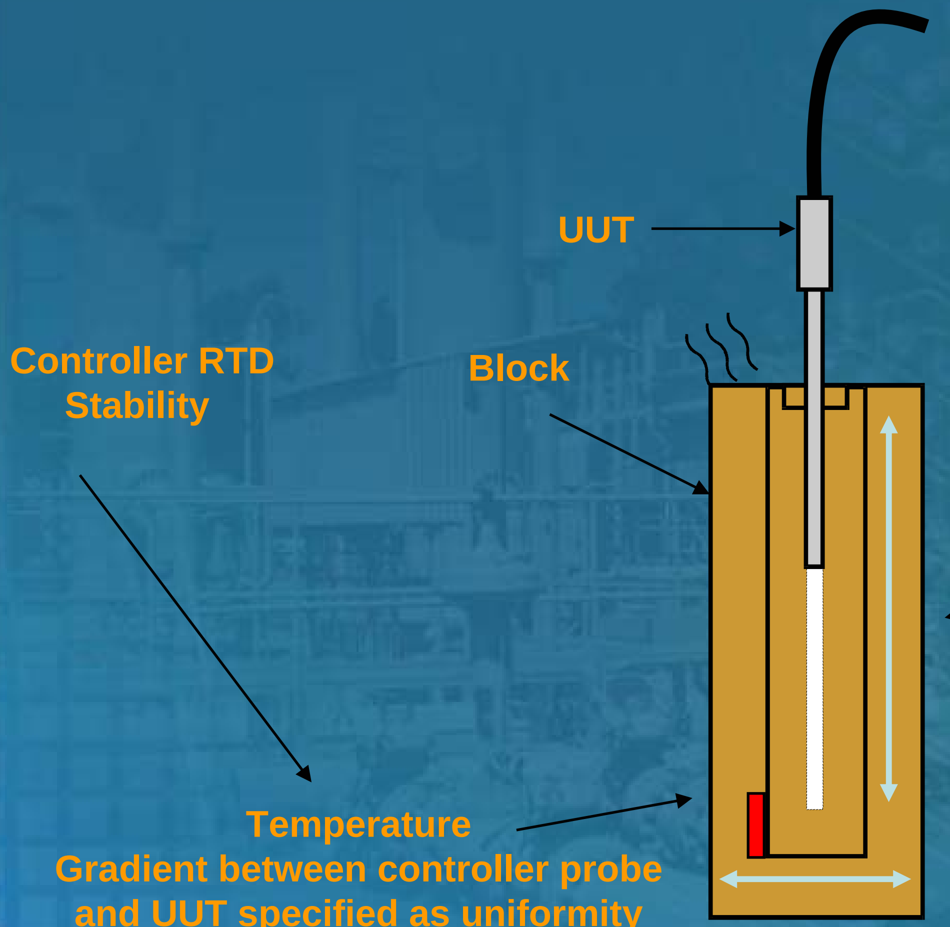
- Insertion Depth.
  - **Standard (PRT) and UUT should be at equal depth.**
    - **Axial gradients.**
    - **Stem effect.**
    - **Probe diameter.**



Thermometer Fit



Sources of Errors - Review



Air space and vertical distance create temperature differences between displayed controller temperature and actual temperature applied to the probe.

Practical solution to this problem is to use a two hole well insert and reference probe inserted to the same depth as the UUT.

Comparison Cal. Tips

- Full Immersion of Probes.
- Reference and UUT at Same Depth.
- Similar Diameters.
- Similar Heat Conduction Characteristics.
- Snug Fit Into Sleeves.
- Allow Ample Time For Stability.

Questions?

?

Evaluating the performance of Metrology Wells

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

EURAMET/cg-13/v.01 latest revision

Metrology Wells

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

Metrology Wells – What are They?

FLUKE
Hart Scientific

- 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?

- 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

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

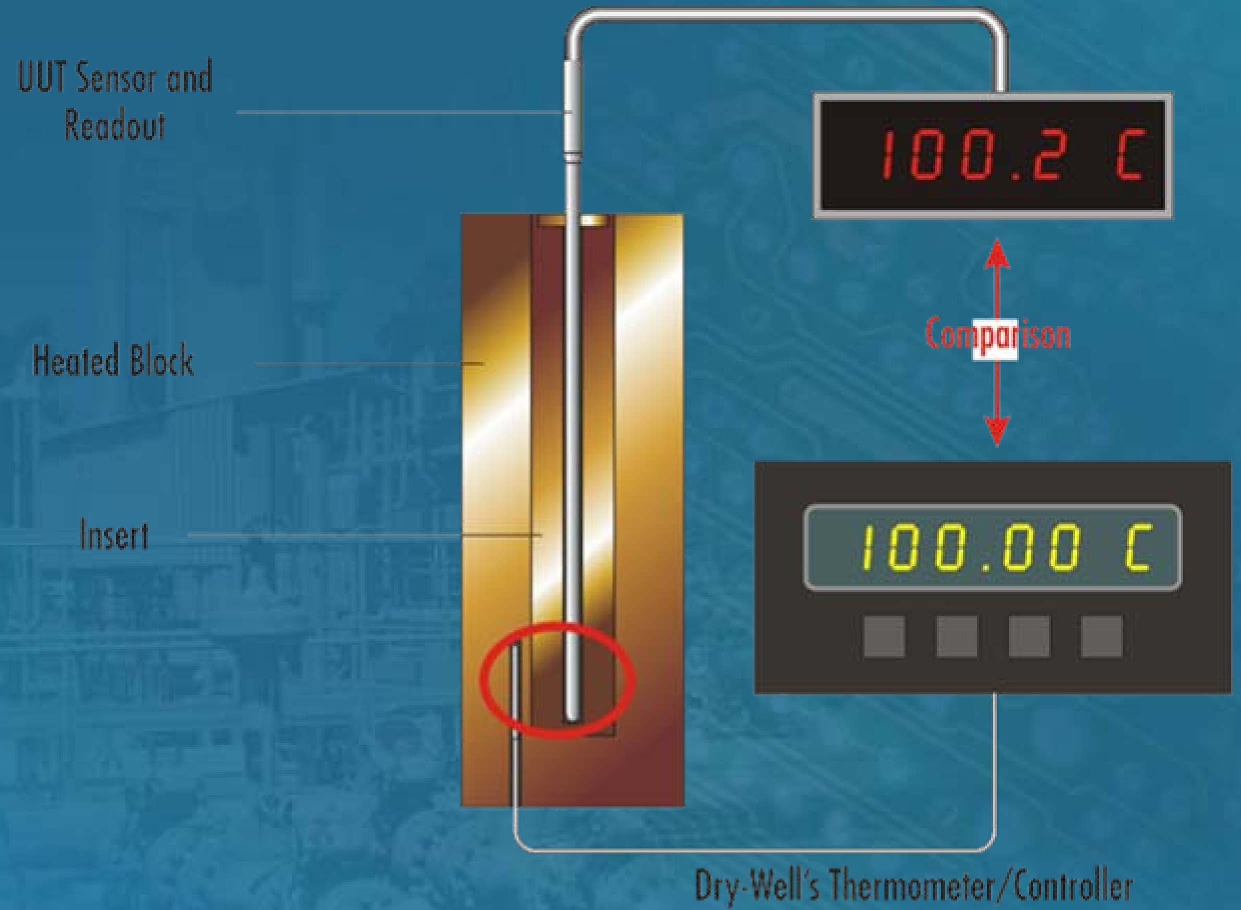
Dry-well Thermal Uncertainties

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

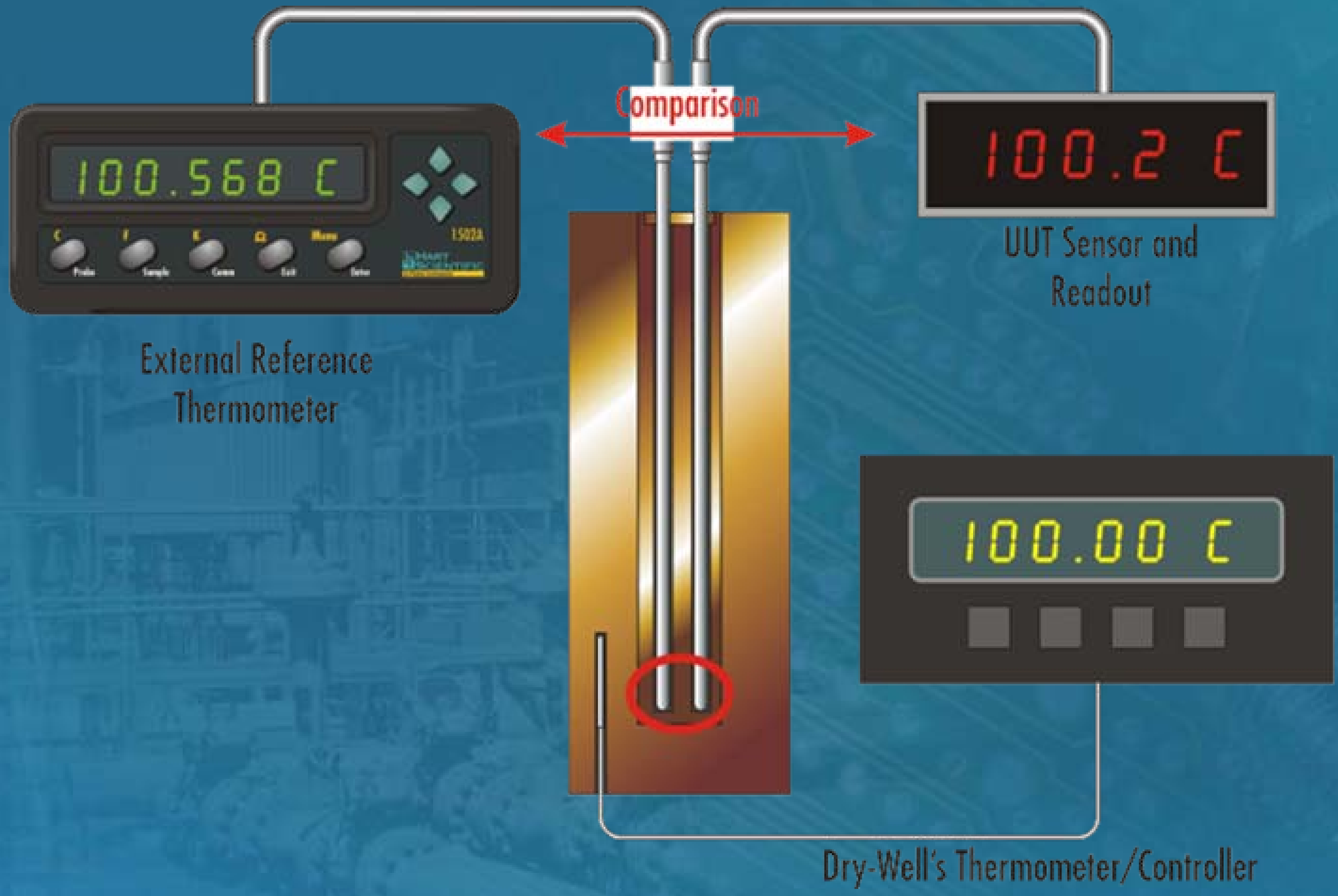
How you use a dry-well greatly affects performance!

- 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

FLUKE
Hart Scientific

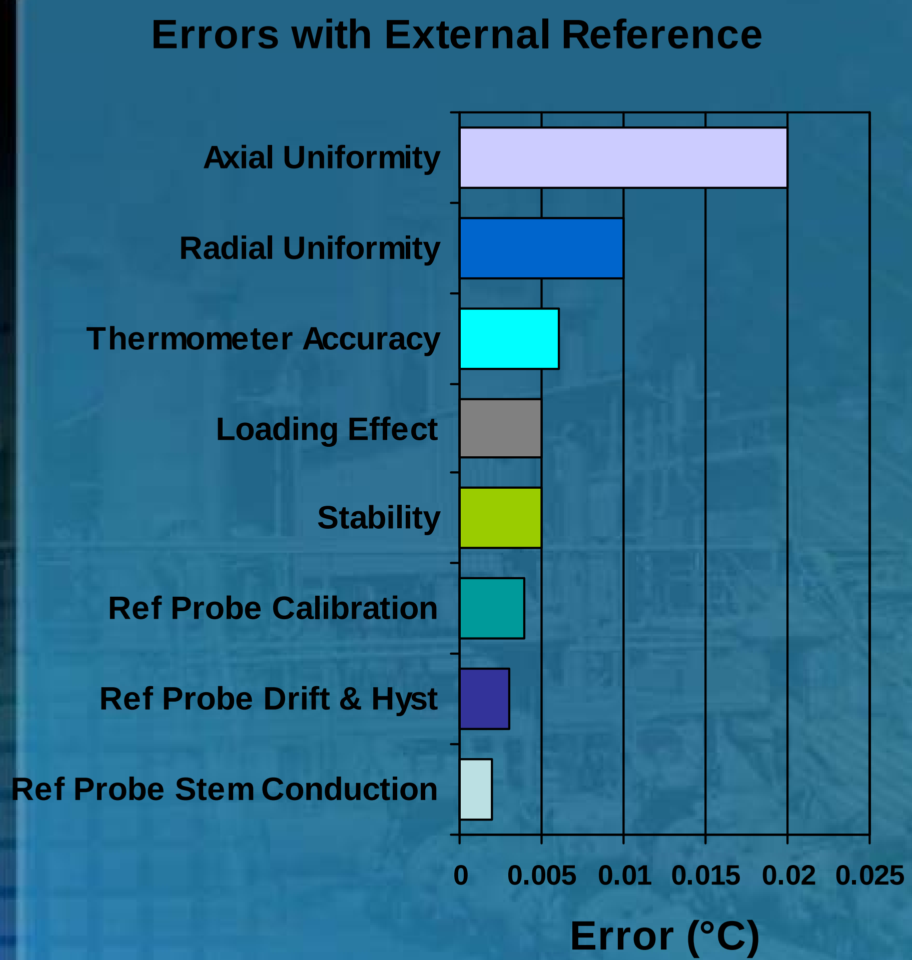
External Reference

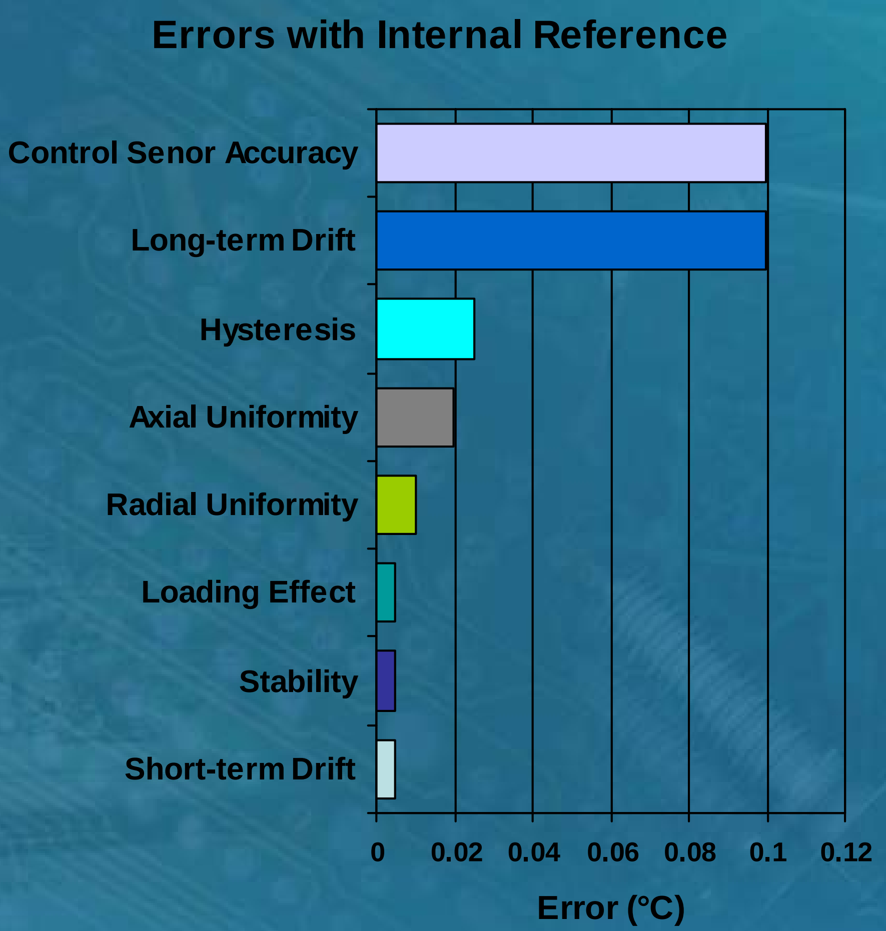
1. Axial Uniformity
2. Radial Uniformity
3. Stem conduction
4. Loading Effect
5. Stability
6. Reference temperature measurement
   - Reference Probe
   - Reference Readout

Internal control sensor and calibrated display

1. Axial Uniformity
2. Radial Uniformity
3. Stem conduction
4. Loading effect
5. Stability
6. Reference temperature measurement
   - Sensor and display drift
   - Hysteresis
   - Sensor Calibration

Estimate of Significance

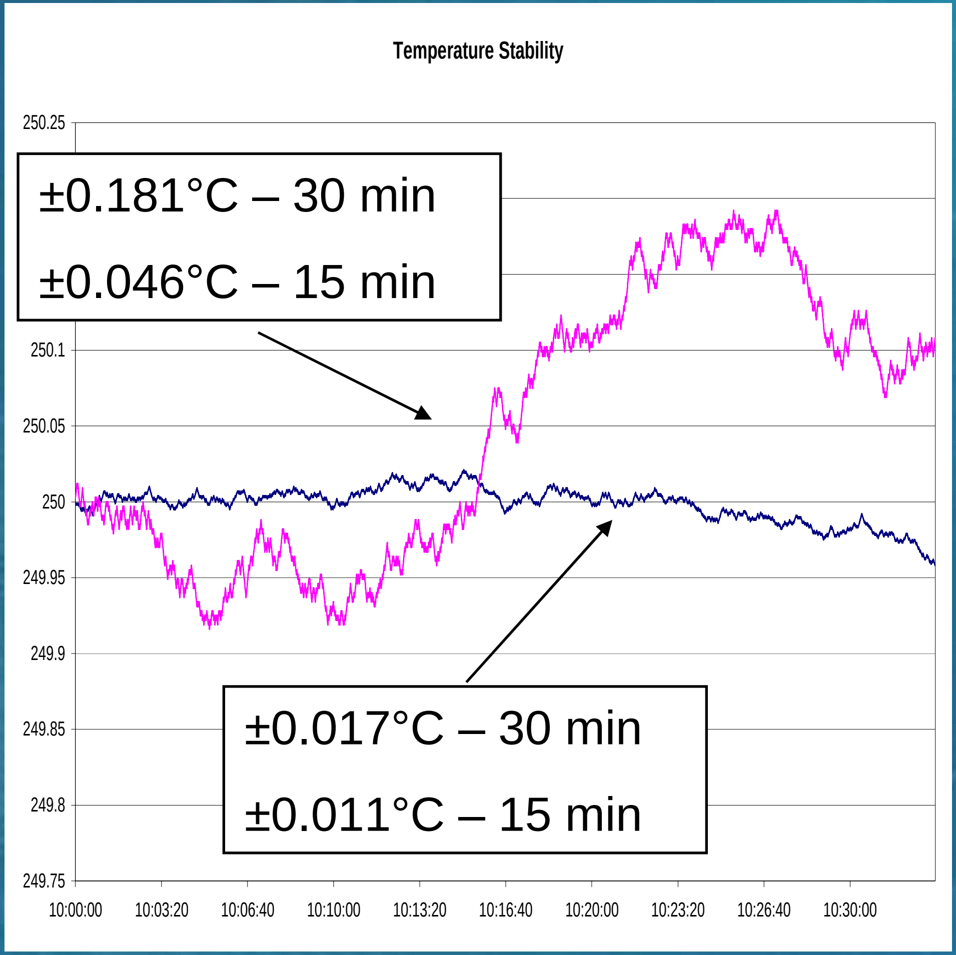




Temperature Stability

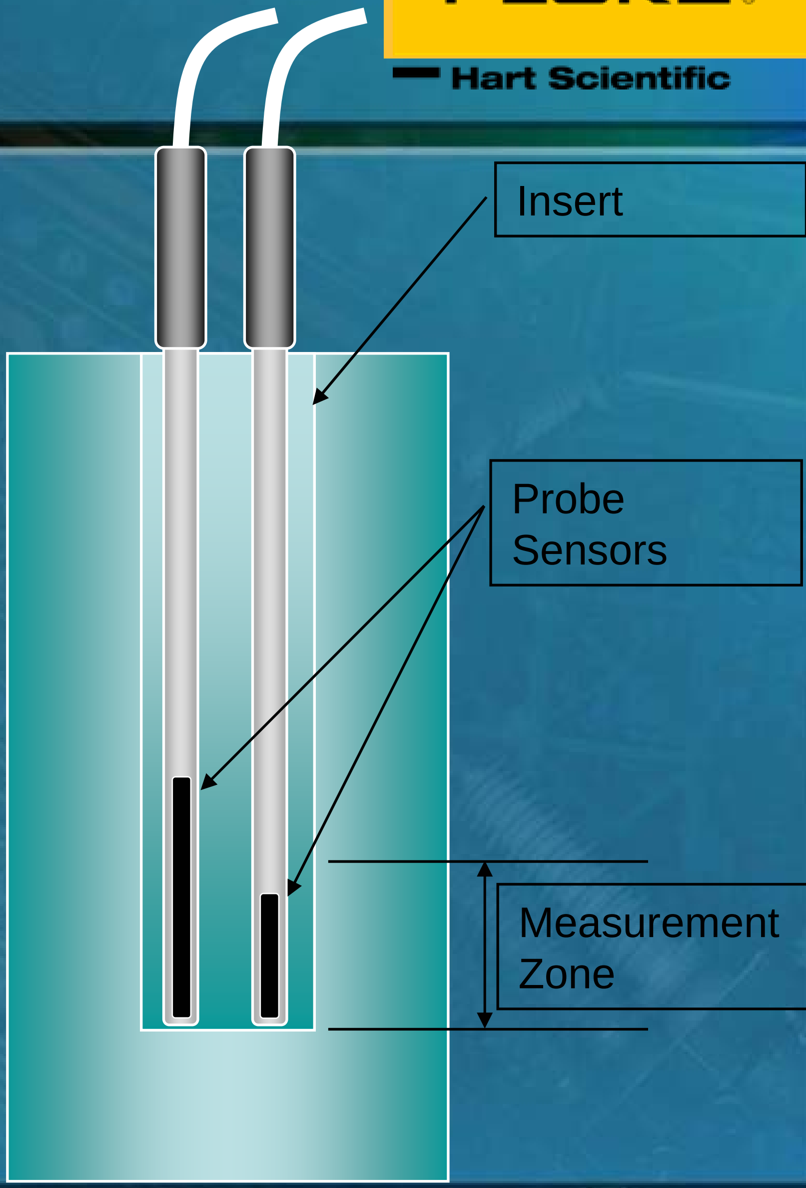
FLUKE
Hart Scientific

- **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



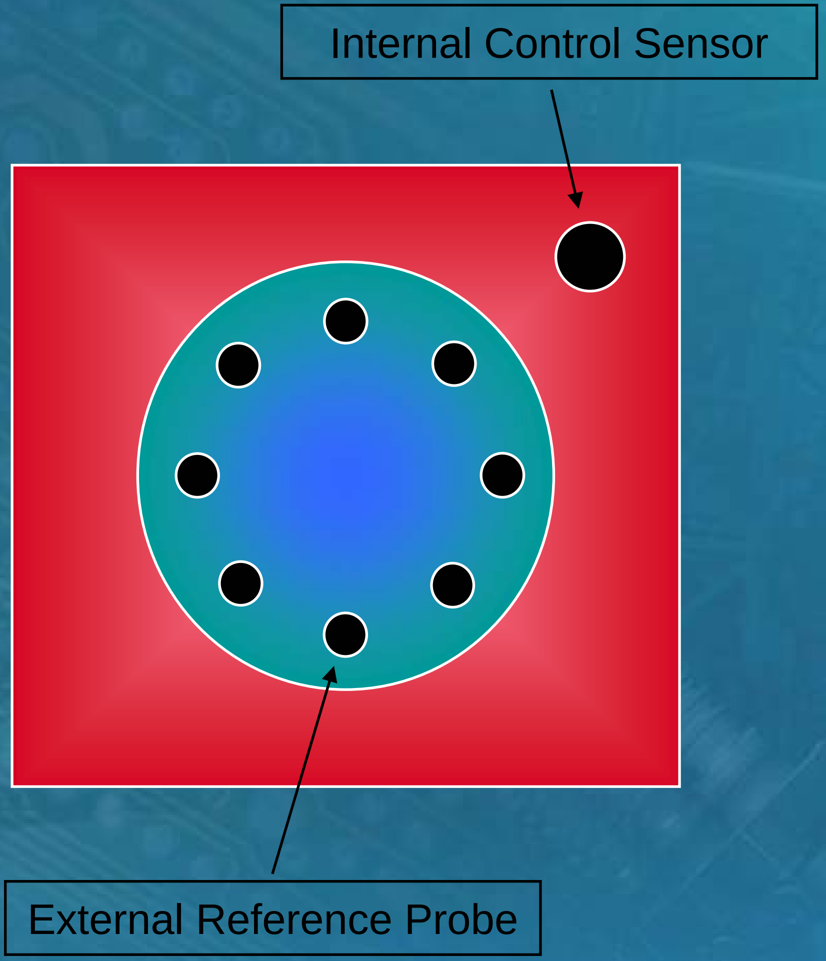
Axial Uniformity

- 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



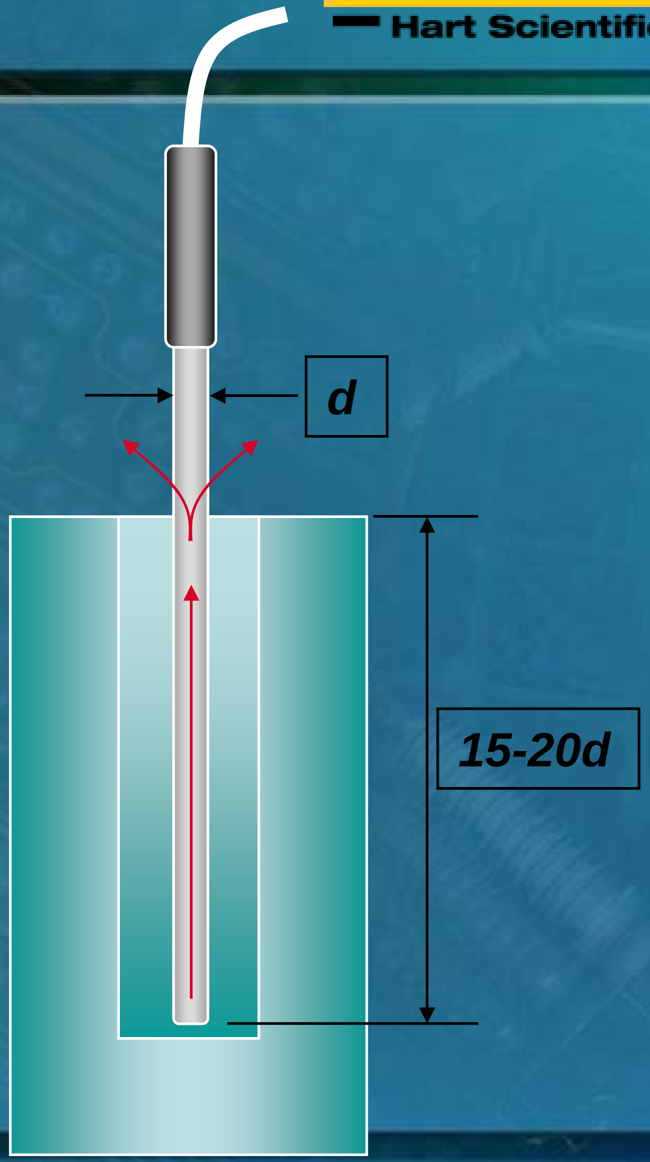
Radial Uniformity

- 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



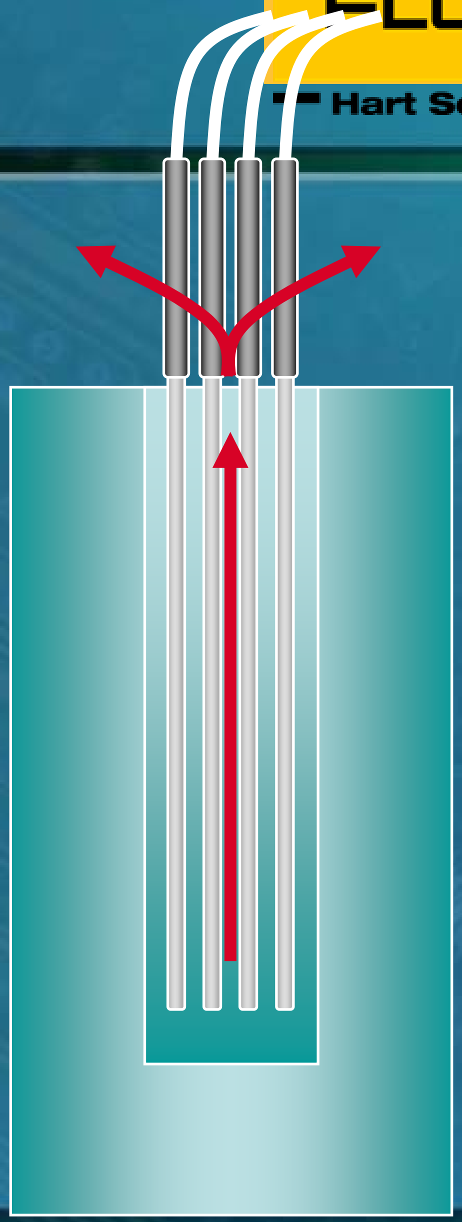
Stem Conduction

- 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



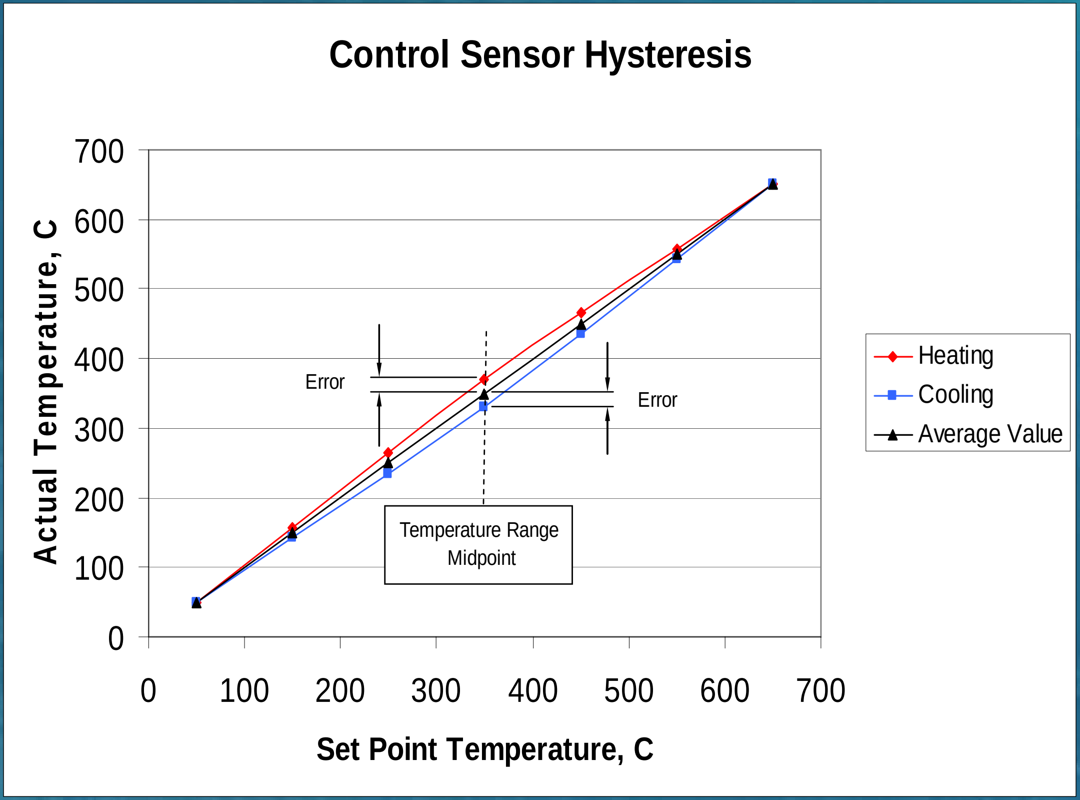
Reference Temperature Measurement

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**.



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

FLUKE
Hart Scientific

- 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

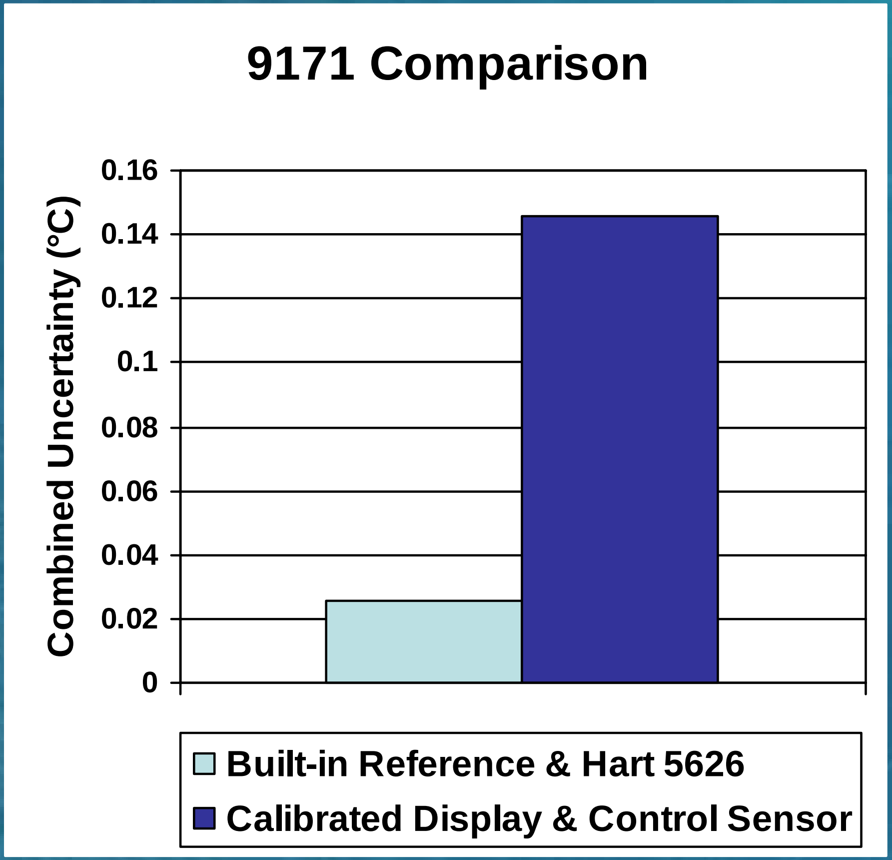
Hart 9171 at 0°C with built in Ref and Hart 5626 Probe			
	Specification (°C)	***Probability Distribution***	***Standard Uncertainty (°C)***
Axial Uniformity	0.020	Normal	0.010
Radial Uniformity	0.010	Rectangular	0.006
Loading Effect	0.005	Rectangular	0.003
Stability	0.005	Normal	0.003
Ref Probe Calibration	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

FLUKE
Hart Scientific

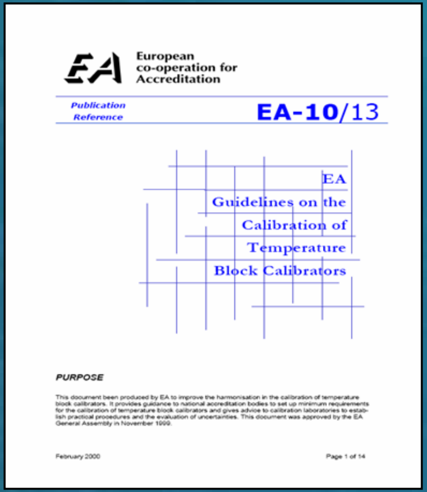
Combined Uncertainty (°C)			
Temperature	***9170 or 9171***	***Competitor 1***	***Competitor 2 (*)***
-45°C (9170)	0.1040	0.207	n/a
-35°C (9170)	0.0433	n/a	0.119
-30°C	0.0433	n/a	0.119
-25°C	0.0433	0.160	0.119
0°C	0.0256	0.160	n/a
50°C	n/a	0.160	0.119
140°C	0.0459	n/a	0.125
155°C (9171)	0.0641	0.161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

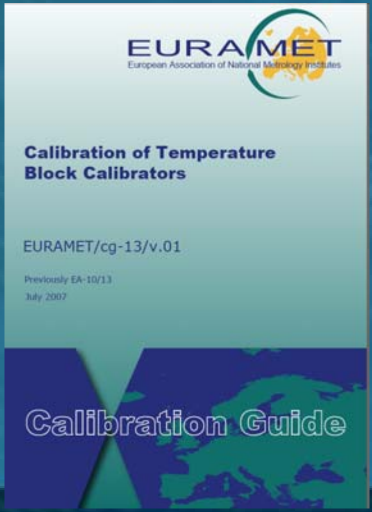
*** Data from evaluation report, not spec sheet**

Guidelines are available to assist in evaluation procedures

FLUKE
Hart Scientific

- EA-10/13 Reference (EURAMET/cg-13/v.01 latest revision)
- 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





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?

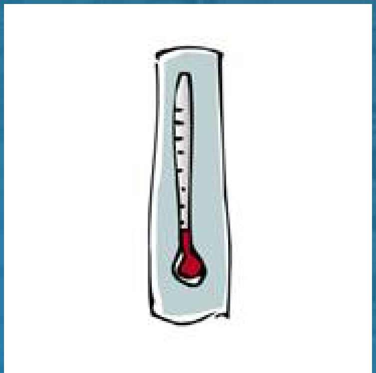
Questions?

?

Temperature Calibration

Optimizing Calibration in the Field

Specific Issue Related to Field Calibration



- Temperature calibration takes time
  - To do a 3 point calibration for as found and as left may take a couple of hours – time is money
  - You may have a tendency to cut corners
- Ambient temperature
  - Your ambient temperature may range from 0°C to 45°C
  - Most test equipment's specifications are only guaranteed at 23°C ± 3°C
- Temperature fluctuations
  - Ambient temperature fluctuations can have a large impact on your measurements
- Portability – size of instruments and # of tools

Specific Issue Related to Field Calibration (Cont.)

FLUKE
Hart Scientific

- Increasing accuracy of industry UUTs
  - Processes are requiring increasing levels of performance even to the level of characterized sensors
- Documentation and automation
  - Need for turnkey solutions without a computer
- Any others?

Introducing a New Solution to Optimize Calibration in the Field

FLUKE
Hart Scientific

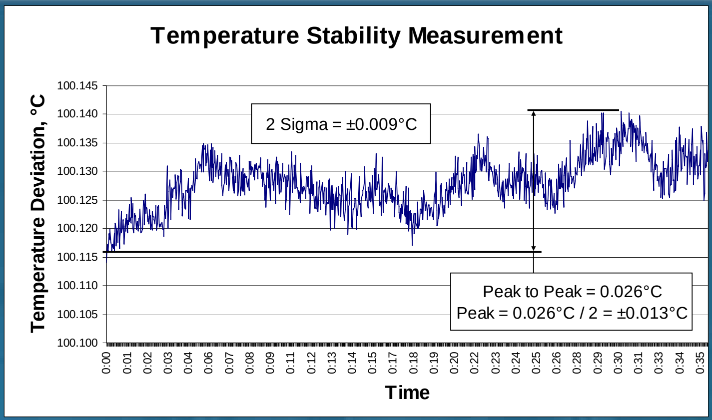
Fluke's 914X Series Field Metrology Wells

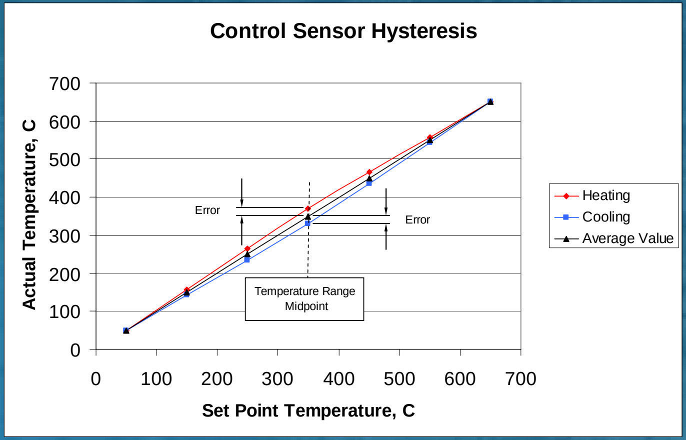
Brief Introduction

- Family of three units
  - 9142: -25°C to 150°C
  - 9143: 33°C to 350°C
  - 9144: 50°C to 660°C
- Optional built in process electronics which
  - Measure a reference PRT
  - Measure UUTs (RTD,TC, and 4-20 mA)
  - Supply of loop power
  - On-board documentation and automation

High Performance – EA 10/13

FLUKE
Hart Scientific

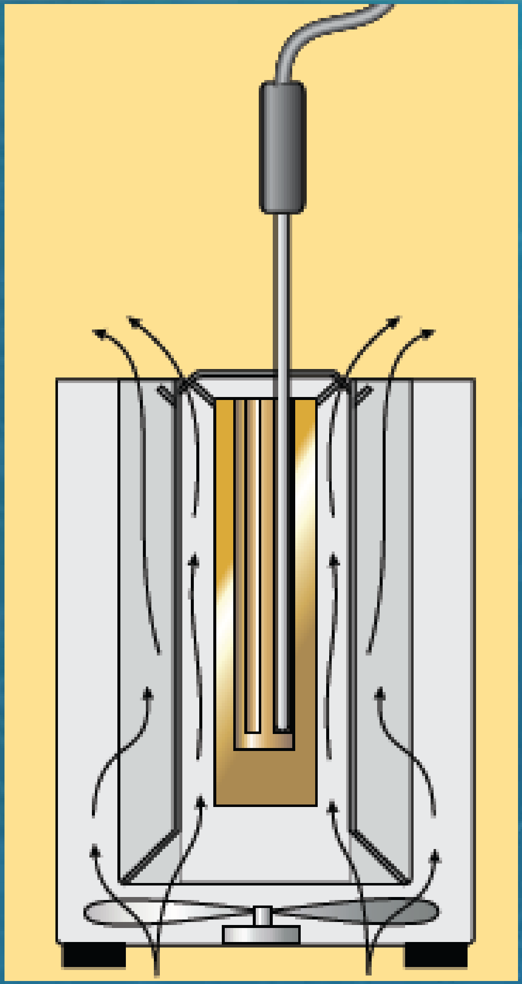




- Dual-zone control
- Stability to ±0.01°C
- Radial uniformity to ±0.01°C
- Axial uniformity to ±0.04°C
- Loading errors to ±0.006°C
- Display accuracy to ±0.2°C
- Reference thermometer accuracy of handheld thermometer (better than model 1521)
  - Din connector input with plug and play technology built-in (new “A” termination for thermometer probes)
- NVLAP-accredited calibration standard
- Immersion depth of 150 mm (6 in)

Fast and Portable!

- Speed:
  - Low temp model will cool to –25°C in 15 min
  - Mid temp model will heat to 350°C in 5 min
  - Hi temp model will heat to 660°C in 15 min
- Portability
  - 7kg to 8 kg (16 lbs to 18 lbs)
  - Heat source, reference thermometer readout, thermocouple, RTD, current readout, 24V loop source, and on-board documentation all in one tool!
  - All inputs on the front of the unit
- Directional air flow (patent pending) keeps sensor handles cool



Field Ready!

- All specifications are guaranteed over the ambient temperature range of 13°C to 33°C
  - Temperature coefficient outside this range is ±0.005% of range per °C
- Operating temperature range from 0°C to 50°C
- Open loop gradient corrections based on ambient temperature changes (patent pending)

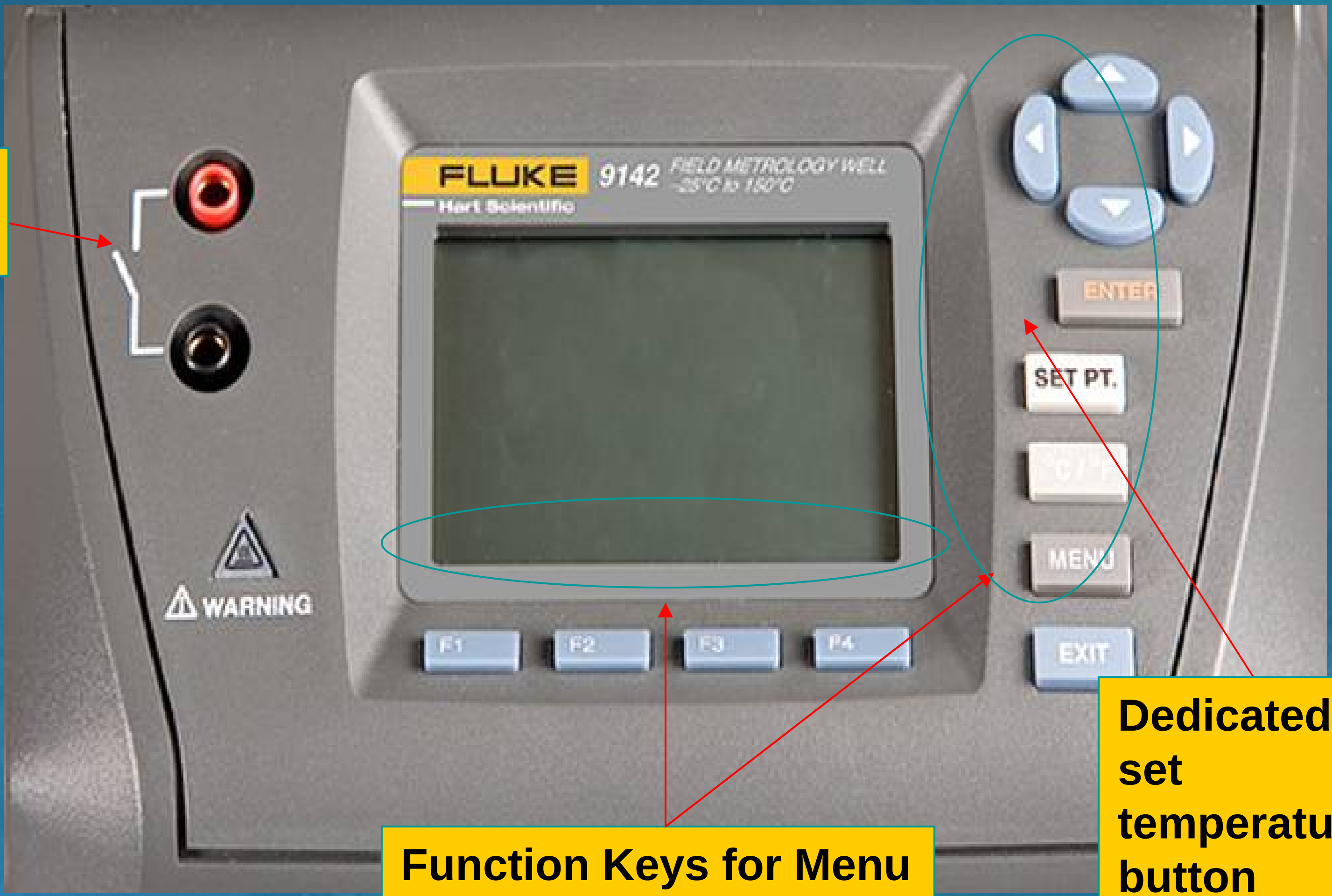
Packed with Functionality!

- Programmable automated tasks
- Automate switch test function
- Stability indicator
- Optional process version:
  - On-board documentation for 20 tests
  - ‘Smart’ reference PRT
  - RTD measurement
  - TC measurement
  - mA current measurement and 24V source
- Directional airflow keeps sensor handles cool
- Multi-language user interface – Chinese, English, French, German, Italian, Japanese, Russian, and Spanish

Easy to use

FLUKE
Hart Scientific

Switch inputs



Function Keys for Menu Navigation

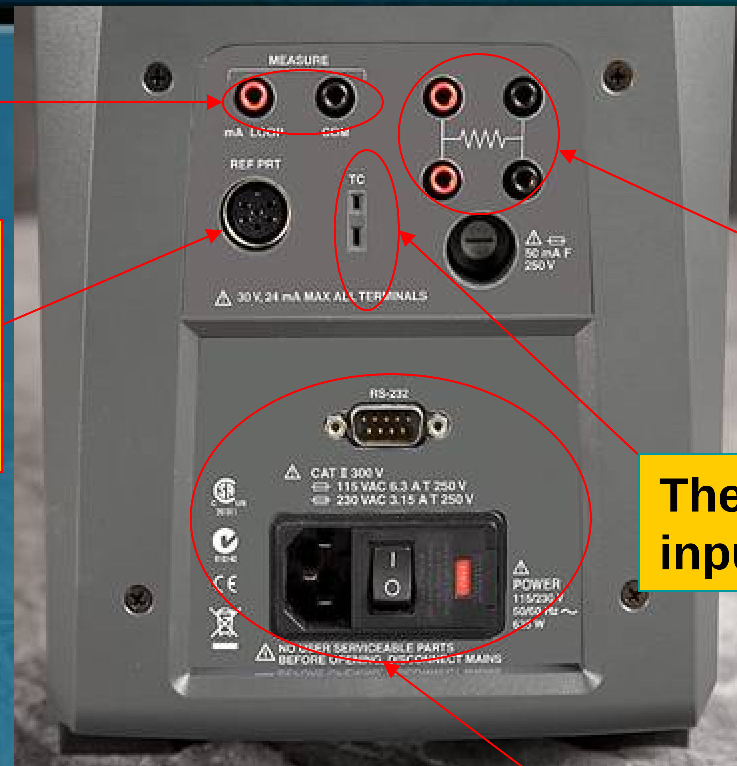
Dedicated set temperature button

Optional Process Version

FLUKE
Hart Scientific

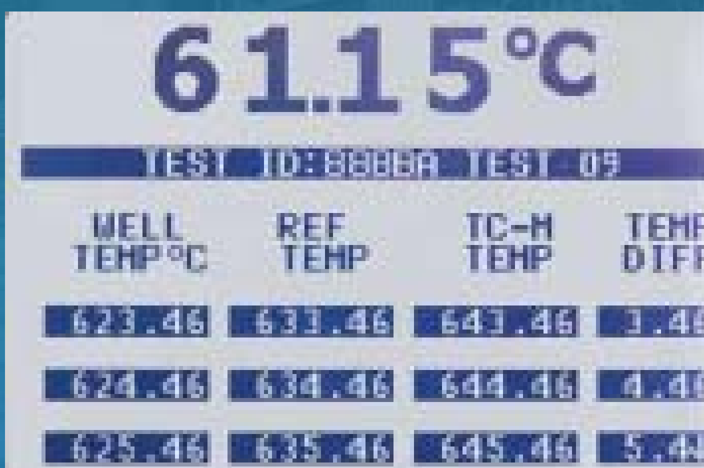
Measurement of mA and loop current

Reference PRT input with smart connector



Ability to ready UUT PRTs or RTDs

Thermocouple input



RS-232 and Power inputs

On-board documentation records set point temp, reference temp, UUT temp, and the difference between the reference and UUT

Questions?

?