A Better Understanding of Temperature Sensors

Seminar Objective

A Better Understanding of Temperature Sensors – a very high payback exercise

Seminar Outline

A Quick (Short) and Easy Trip Back to the Class Room

Rules of the Game

History - Galileo to Today

Today's Heroes

Calibration

Unsung Heroes

Tomorrow's Heroes Today

Squeeze all the Juice from the Lemon

It all starts with

Heat

Heat is Energy (the ability to do work) in transit.

Heat (Thermal) Energy transfer takes place as a consequence of temperature differences only and is usually measured in calories or BTUs.

Heat Energy is associated with the motion of atoms or molecules.

Heat Energy is transferred by conduction, convection and radiation.

Cold is the Absence of Heat (Absolute Zero, 0 Kelvin)

Heat is Good

Importance to us is in <u>Activation of Materials</u>

- Chemicals React
  - Combine (Polymers, Combustion)
  - Split apart (Pyrolsis)
- Separations (Distillations)
- Solids Flow (Forming, Heat treating)

Temperature

<u>Common Definition:</u>

…is the degree of hotness or coldness of a particular body.

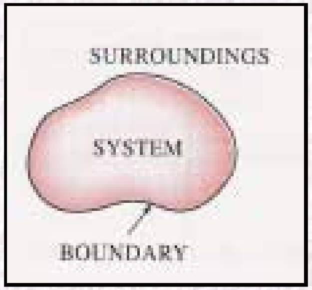
<u>Thermodynamics Definition:</u>

… a specific degree of hotness or coldness on a standard scale; a scalar quantity that is independent of the size of the system and determines the heat flow between two systems in thermal contact.

Temperature Scales

	Fahrenheit	Celsius	Kelvin
Boiling Point of Water	**212º**	**100º**	**373**
Body Temperature	**98.6º**	**37º**	**310**
Freezing Point of Water	**32º**	**0º**	**273**
Coincidence point	**-40º**	**-40º**	**233**
Absolute Zero	**-460º**	**-273.16º**	**0**

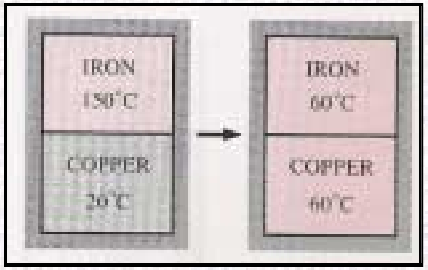
Rules of the Road



First Law of Thermodynamics:

"The total energy of any system and it's surroundings is conserved"

When in thermal contact, heat will flow from a hotter system to a cooler system until equilibrium is achieved.



Zeroth Law:

"Two systems in equilibrium with a third are in equilibrium with each other"

This is the basis for Calibration

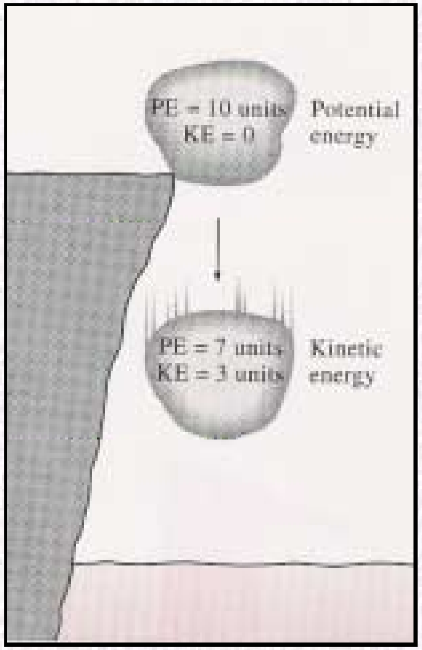
More Rules of the Road

2nd Law of Thermodynamics (Quality of Energy):

"All spontaneous processes are to some extent irreversible and are accompanied by a degradation of energy"

3rd Law of Thermodynamics (Zero Energy):

"At absolute zero the Entropy of any pure crystalline substance free of all random arrangement is zero."



Entropy is simply a property that represents the total energy of any system based away from zero.

ENTROPY ON THE WILD SIDE

"At the heart of thermodynamics lies the second law. Which forbids heat to flow spontaneously from cold to hot bodies, while allowing it to flow from hot to cold. This law is therefore not reversible: it imprints upon the universe an arrow of time, pointing the way of unidirectional change. Scientists are quick to draw the conclusion that the universe is engaged in a one-way slide toward a state of thermodynamic equilibrium, this tendency toward uniformity, wherein temperatures even out and the universe settles into a stable state, to become known as the 'heat death.' It represents a state of maximum molecular disorder, or entropy."

A Hillbilly’s View of

The Laws of Thermodynamics

The laws of thermodynamics

1. You can't win, you can only break even.
2. You can only break even at absolute zero.
3. You can never reach absolute zero.

Absolute Zero must be cool.

Entropy has nothing to do with sour mash distallation.

History - Evolution of Temperature Measurement

1600 - Galileo – Glass bulb thermometer (Thermoscope)
1710 - Fahrenheit – Sealed Mercury Thermometer
Later – Bimetallic Strip
1820 – Seebeck – Thermocouple
- •Seebeck voltage created by temperature difference
- •Combining any 2 dissimilar metals –> voltage
- •Standard metal pairs (Types T,J,K,S, etc.)

1870 – Siemans – Resistance Temperature Detectors
- •Resistance of a metal proportional to Temperature
  - •Platinum RTD
- •More recent Resistance Temp Devices
  - •Thermister
  - •IC Temperature Sensors

1980's - Radiation Devices – Optical Pyrometers
1998 – Self Validating / Self Diagnosing Temperature Loop

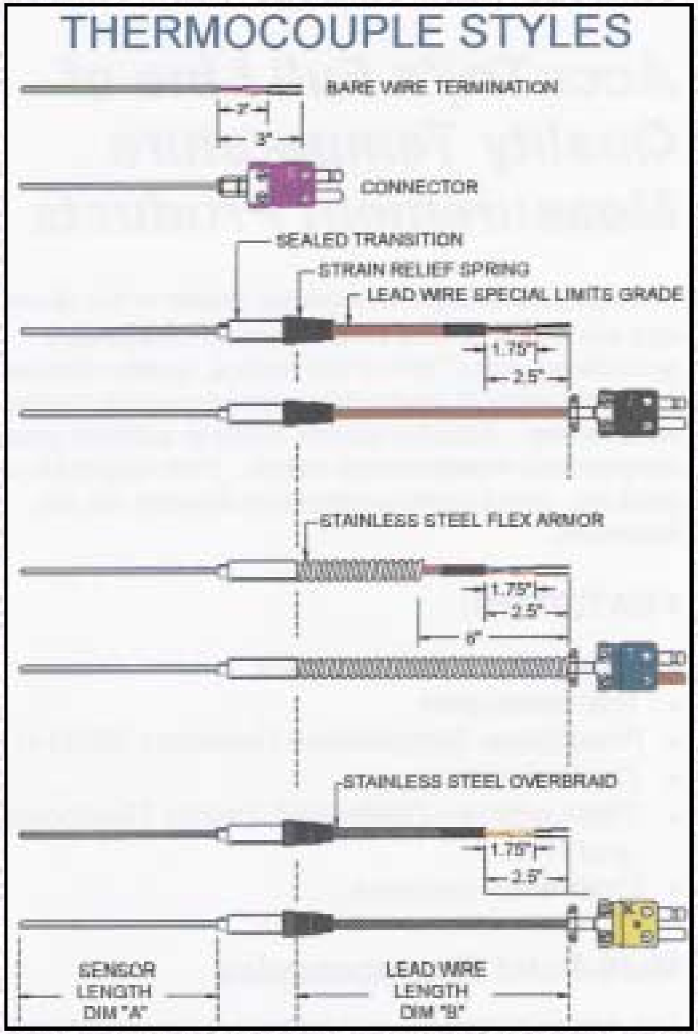
Today's Heroes

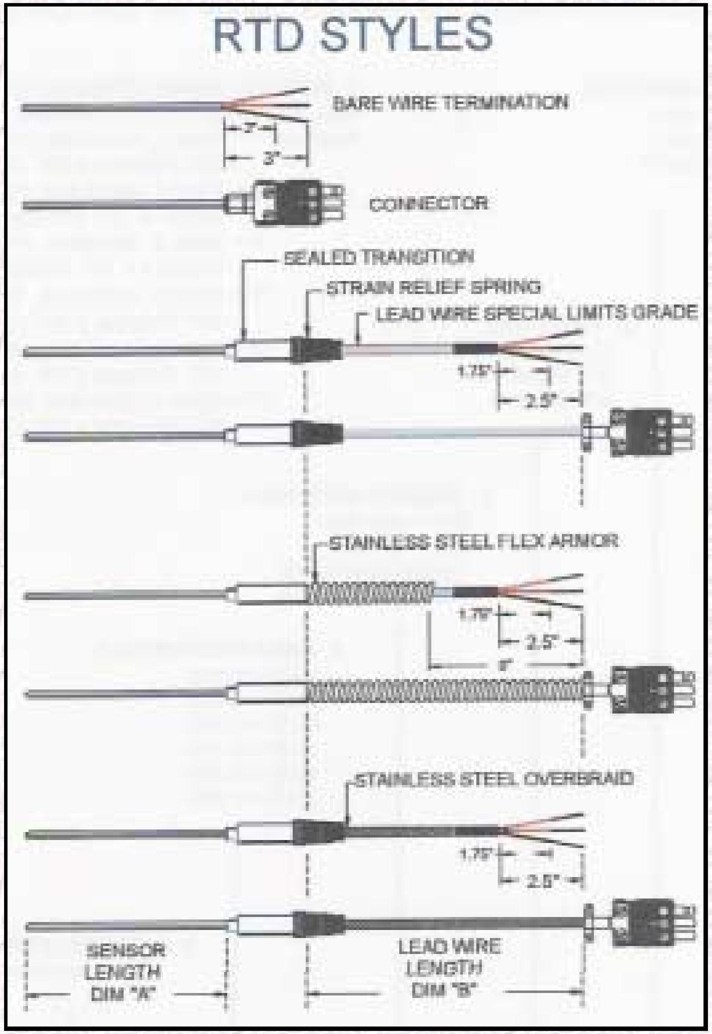
In Rugged Industrial Application, Nine Times out of Ten (or more) Applications will Require:

Thermocouples

or RTDs

Thermocouples and RTDs



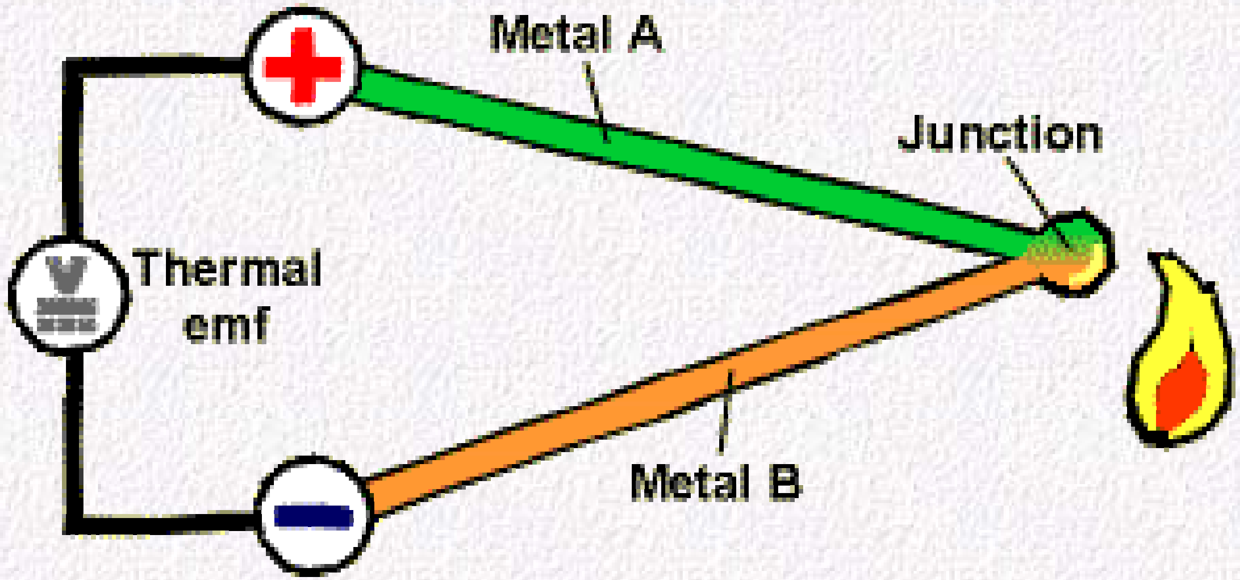


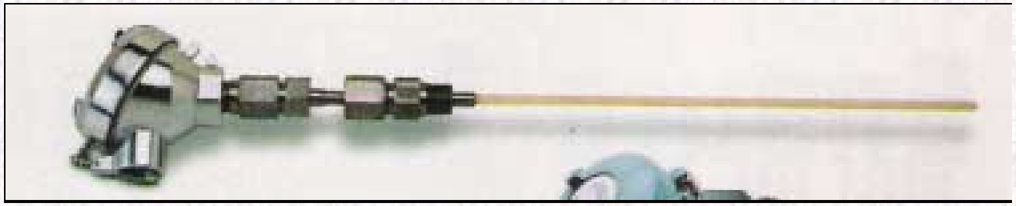
The

Thermocouple

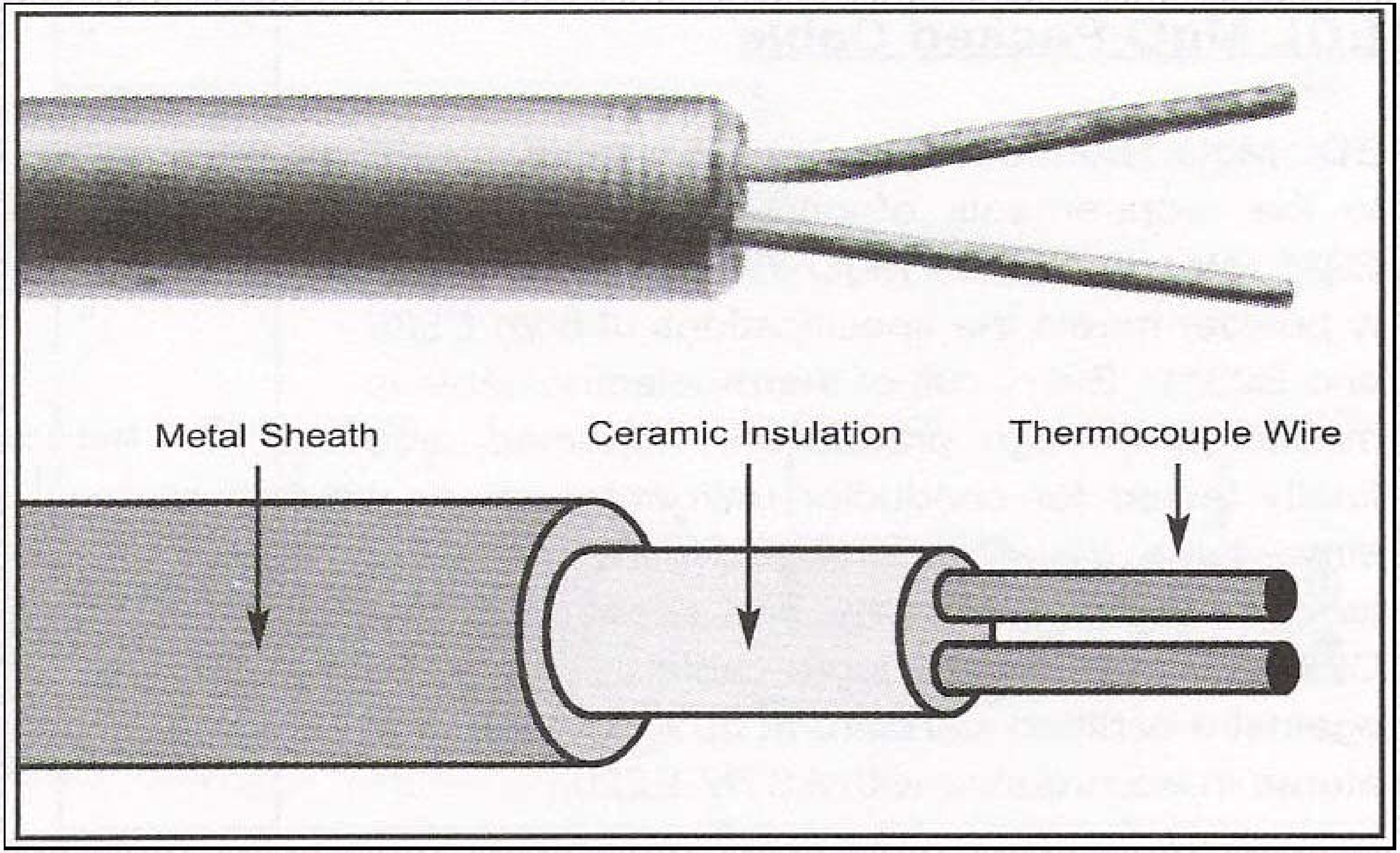
Story

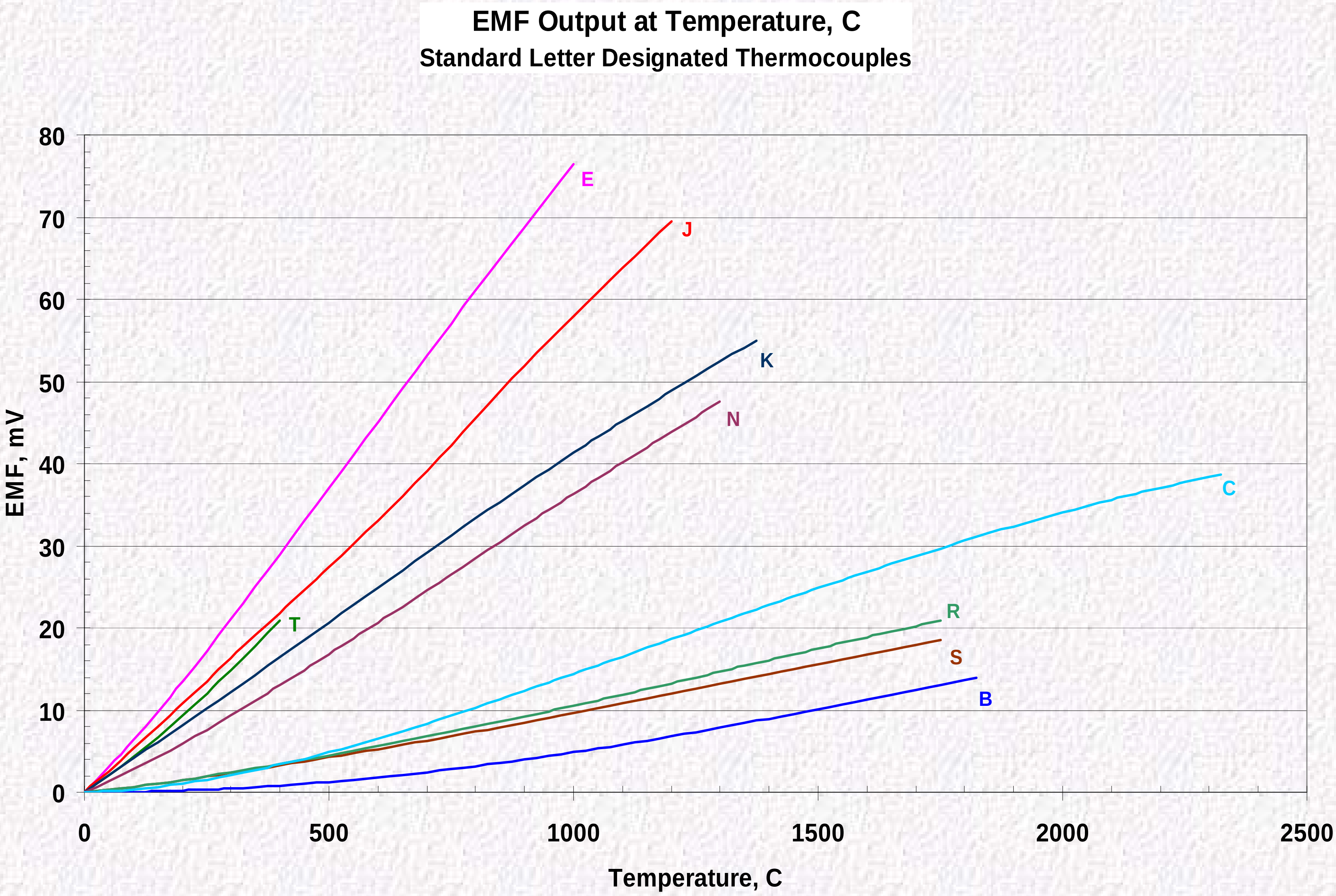
Thermocouple





Thermocouple Construction




EMF Output at Temperature, C
Standard Letter Designated Thermocouples
80
70
60
50
40
30
20
10
0
EMF, mV
0
500
1000
1500
2000
2500
Temperature, C
E
J
K
N
C
R
S
B
T

Standard Temperature Scale

Thermometry Fixed Points

THERMOELECTRIC FIXED POINT	MELTING POINTS FROM THE PRACTICAL INTERNATIONAL TEMPERATURE SCALE IPTS-68	
Boiling point of oxygen	−183.0 °C	−297.3 °F
Sublimation point of carbon dioxide	− 78.5	−109.2
Freezing point of mercury	− 38.9	− 38
Ice Point	0	32
Triple point of water	0.01	32
Boiling point of water	100.0	212
Triple point of benzoic acid	122.4	252.3
Boiling point of naphthalene	218	424.4
Freezing point of tin	231.9	449.4
Boiling point of benzophenone	305.9	582.6
Freezing point of cadmium	321.1	610
Freezing point of lead	327.5	621.5
Freezing point of zinc	419.6	787.2
Boiling point of sulfur	444.7	832.4
Freezing point of antimony	630.7	1167.3
Freezing point of aluminum	660.4	1220.7
Freezing point of silver	961.9	1763.5
Freezing point of gold	1064.4	1948
Freezing point of copper	1084.5	1984.1
Freezing point of palladium	1554	2829
Freezing point of platinum	1772	3222

Characteristics Table

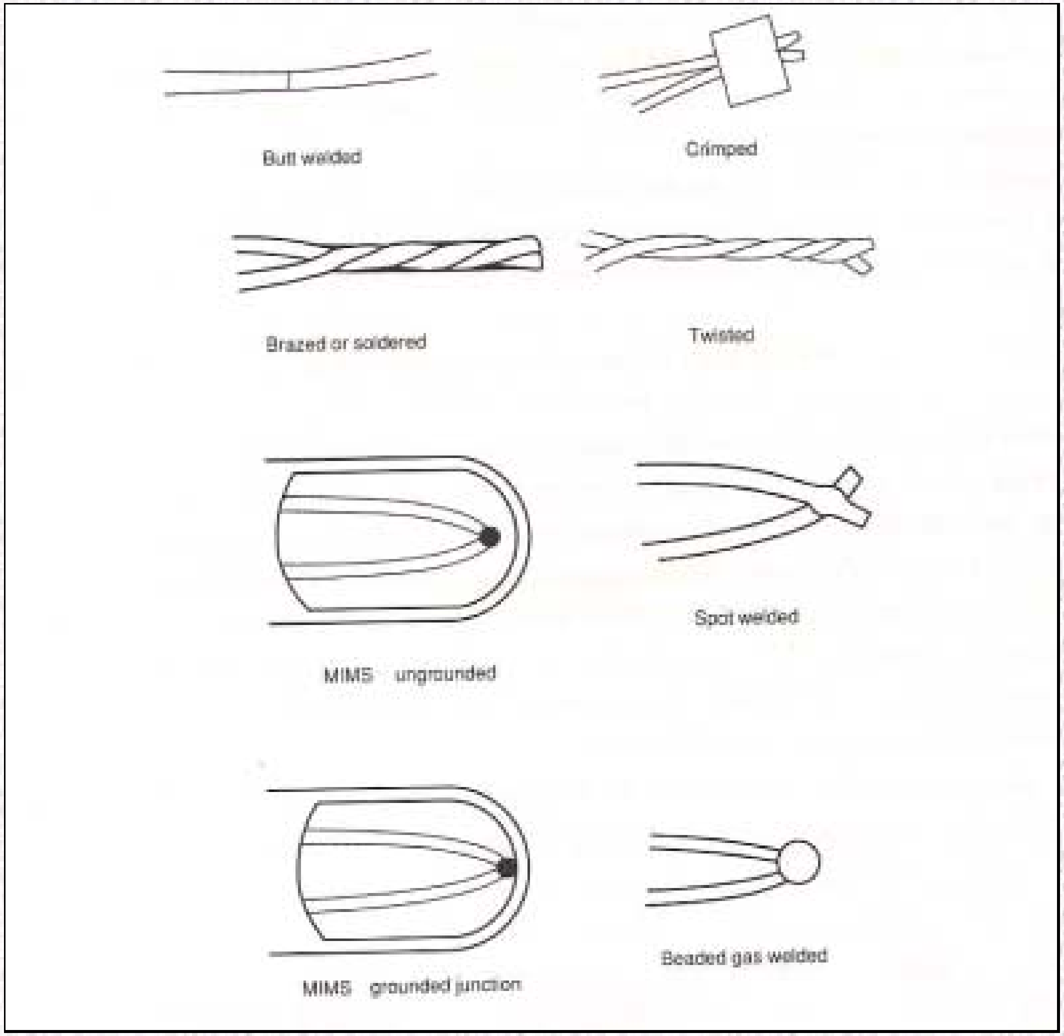
ANSI Calibration Type	C°			F°			Positive Leg (+) Color Code	Negative Leg (-) Color Code	Positive Leg (+) Alloy	Negative Leg (-) Alloy	Jacket Color Code	
	Temperature Range	Tolerance on Installation		Temperature Range	Tolerance on Installation						TC Grade	Extension Grade
		Standard Limits	Special Limits		Standard Limits	Special Limits						
W/5 C	0 to 2320	4.5° to 425C° 1% over 425	N/A	32 to 4208	4.5° to 425C° 1% over 425	N/A	White (+)	Red (-)	Tungsten/5% Rhenium	Tungsten/26% Rhenium	Extension Grade Only	
W/3 D	0 to 2320	4.5° to 425C° 1% over 425	N/A	32 to 4208	4.5° to 425C° 1% over 425	N/A	White (+)	Red (-)	Tungsten/3% Rehenium	Tungsten/25% Rhenium	Extension Grade Only	
W/R G	0 to 2320	4.5° to 425C° 1% over 425	N/A	32 to 4208	4.5° to 425C° 1% over 425	N/A	White (+)	Red (-)	Tungsten	Tungsten/26% Rhenium	Extension Grade Only	
B	870 - 1700	0.5%	0.25%	1600 to 3100	0.5%	0.25%	Grey (+)	Red (-)	Platinum/30% Rhodium	Platinum/6% Rhodium	Extension Grade Only	
S	600 to 1480 0 to 600	.025% 1.5°	0.1% 0.6°	1112 to 2642 32 to 1112	.025% 2.7°	0.1% 1.08°	Black (+)	Red (-)	Platinum/10% Rhodium	Platinum	Extension Grade Only	
R	600 to 1480 0 to 600	0.25% 1.5°	0.1% 0.6°	1112 to 2642 32 to 1112	.025% 2.7°	0.1% 1.08°			Platinum/13% Rhodium	Platinum	Extension Grade Only	
N	285 to 1260 0 to 285	0.75% 2.2°	0.4% 1.1°	545 to 2300 32 to 545	0.75% 4.0°	0.4% 2.0°	Orange (+)	Red (-)	Nicrosil	Nisil	Type N	Type N
K	285 to 1260 0 to 285 -110 to 0 -200 to -110	0.75% 2.2° 2.2° 2%	0.4% 1.1° n/a n/a	545 to 2300 32to 545 -165 to 32 -328 to -165	0.75% 4.0° 4.0° 2.0%	.04% 2.0° n/a n/a	Yellow (+)	Red (-)	Nickel-Chromium	Nickel-Aluminum	Type K	Type K
E	340 to 870 250 to 340 0 to 250 -170 to 0 -200 to -170	0.5% 1.7° 1.7° 1.7° 1%	0.4% 0.4% 1° 1° 1°	640 to 1600 480 to 640 32 to 480 -270 to 32 -328 to -270	0.5% 3.0° 3.0° 3.0° 1.0%	0.4% 0.4% 1.8° 1.8° 1.8°	Purple (+)	Red (-)	Nickel-Chromium	Constantan	Type E	Type E
J	285 to 760 0 to 285	0.5% 2.2°	0.4% 1.1°	545 to 1400 32 to 545	0.75% 4.0°	0.4% 2.0°	White (+)	Red (-)	Iron	Constantan	Type J	Type J
T	130 to 370 0 to 130 -65 to 0 -200 to -65	0.75% 1° 1° 1.5%	0.4% 0.5° 0.5° 0.8%	270 to 700 32 to 270 -85 to 32 -328 to -85	0.75% 1.8° 1.8° 1.5%	0.4% 0.9° 0.9° 0.8%	Blue (+)	Red (-)	Copper	Constantan	Type T	Type T
SVS™	SVS™ TOLERANCES SHOWN FOR LIFE OF SENSOR						SVS™ ADVANTAGES OVER CONVENTIONAL THERMOCOUPLES					
SVS/3212	0 to 1750	1.1°	0.4%	32 to 3182	3.0°	0.4%	*Real Time Drift Detection*			*Longer Life*		
SVS/2311	0 to 1260	1.1°	0.4%	32 to 2300	3.0°	0.4%	*Active Drift Correction*			*Self-Diagnostic*		
SVS/411	-200 to 400	1.1°	0.4%	-328 to 752	3.0°	0.4%	*Proactive warning system*			*Superior tolerance for life*		

* All ***AccuTru*** sensors are constructed using special limits of wire only.

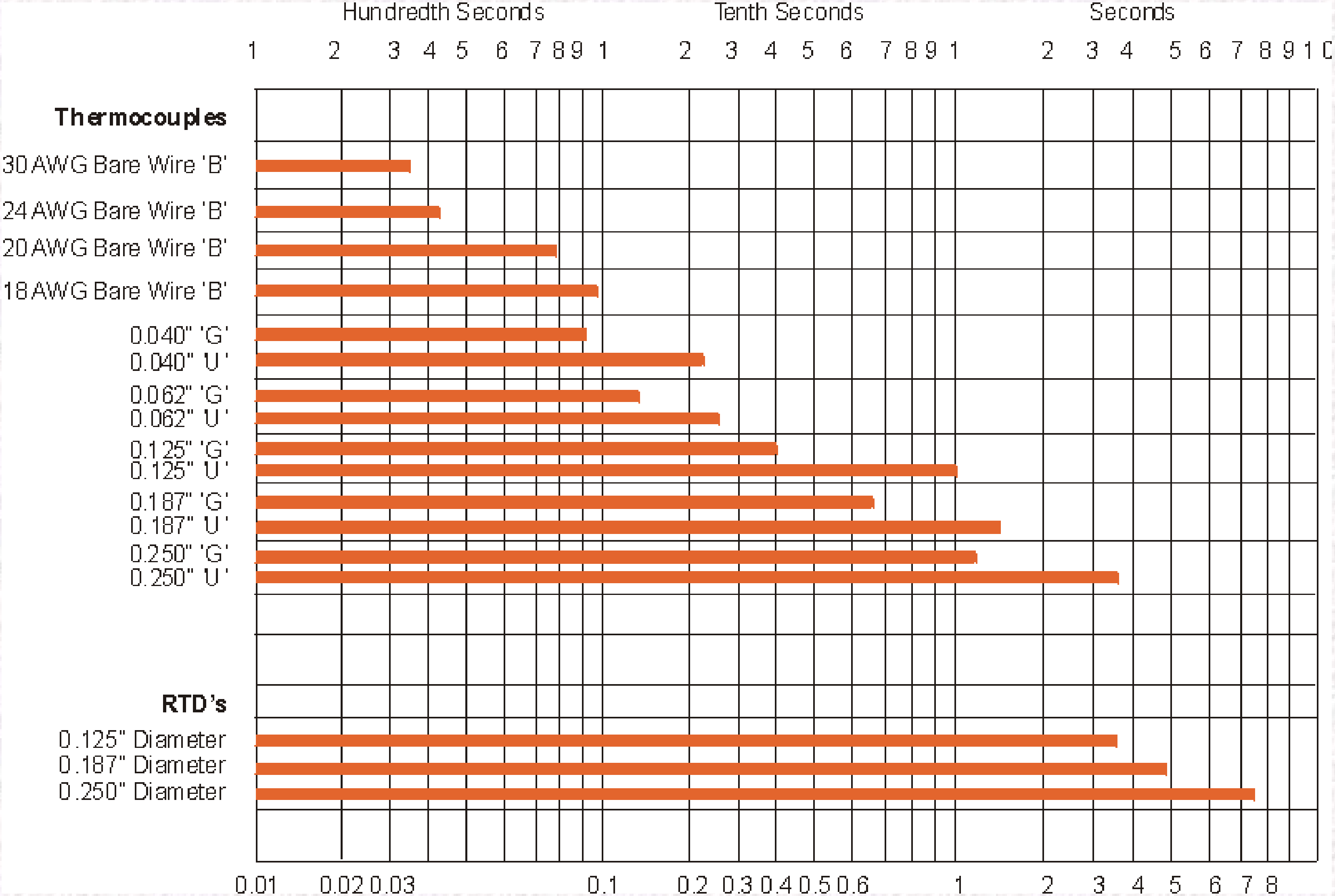
**Fahrenheit tolerance is 1.8 times greater than the "C tolerance at the equivalent C temperature

***Maximum temperatures based on the following thermocouple wire sizes: B,R,S, 24 Awg, All others 14 Awg

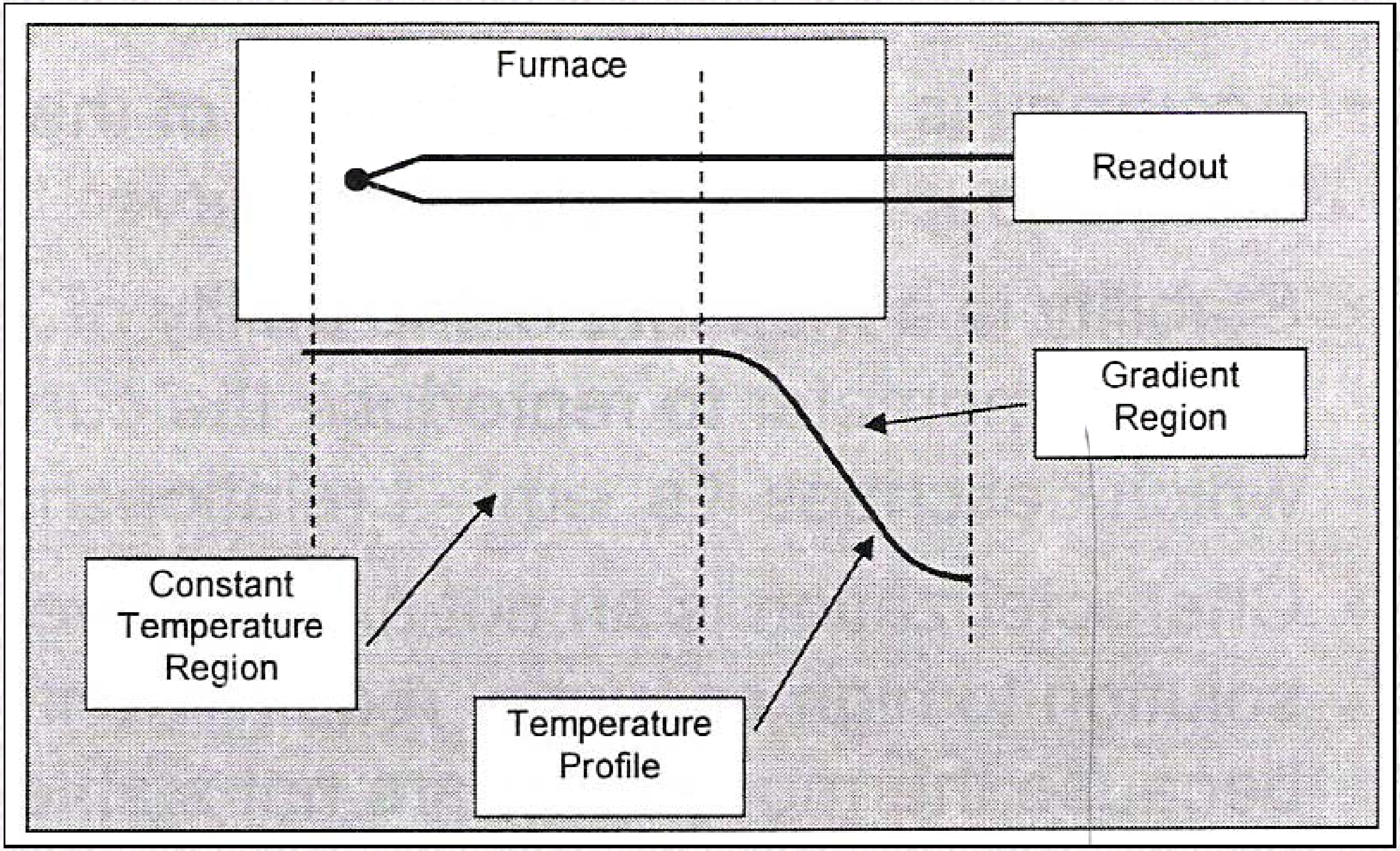
Thermocouple Measuring Junctions



Response Time



Thermocouple voltage



The Voltage is generated in the Gradient Region!

Thermocouples

Advantages:
- Self-powered
- Simple
- Rugged
- Inexpensive
- Wide variety
- Wide temperature range

Disadvantages:
- Non-linear
- Low voltage
- Reference required
- Less stable than RTDs
- Drift and fail unpredictably

Primary Sources of Errors in Thermocouples

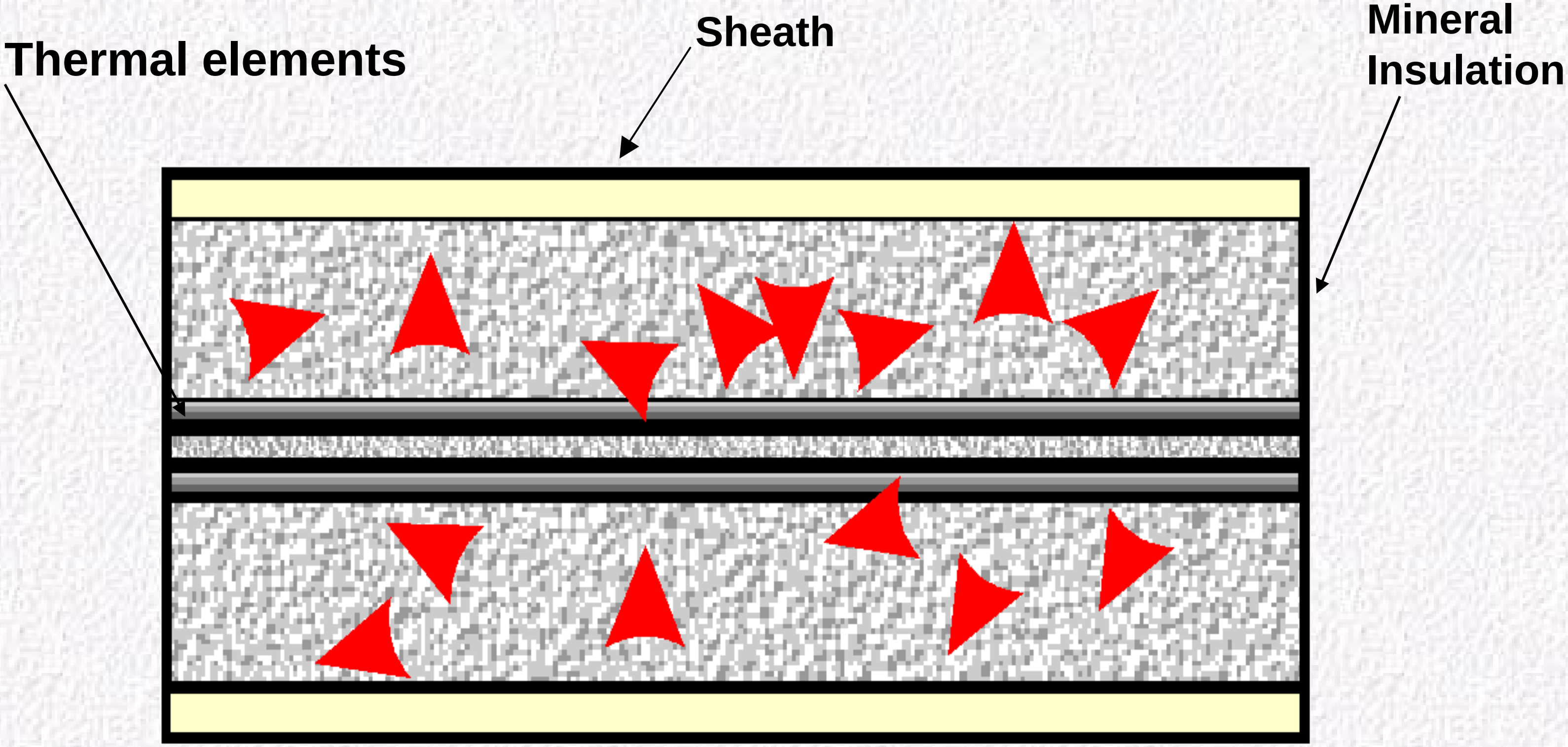
1. Inhomogeneity
2. Thermal errors due to
   - Immersion depth
   - Thermal lag
   - Thermal capacity
3. Radiation
4. Noise and leakage currents
5. Thermal shunting (Virtual Junction Error)
6. Incorrect thermocouples or thermowell specifications

Inhomogeneity – Things that cause Decalibration

(mechanical and chemical)

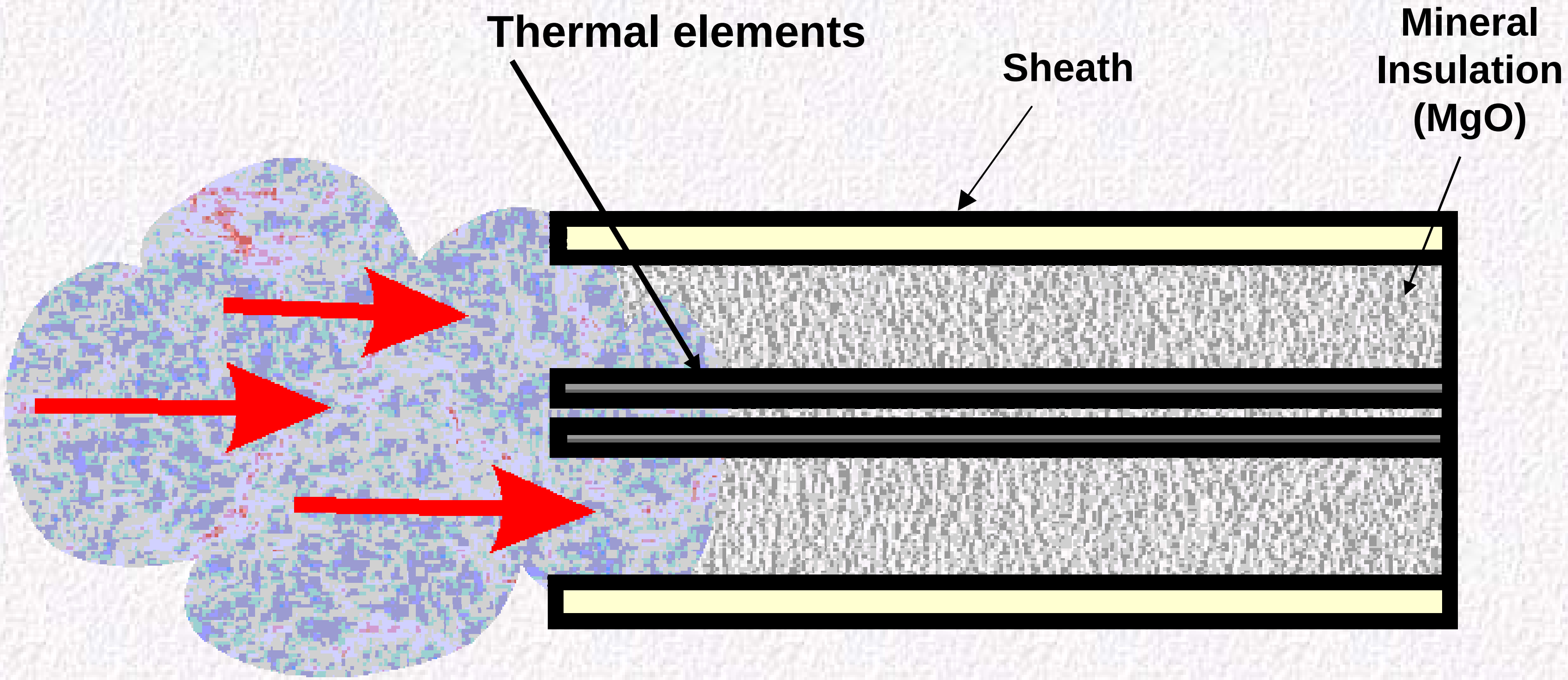
- *Thermocouple wire manufacture*
- *Cable fabrication – drawing and annealing*
- *Fabrication of thermocouple junction*
- *Atmospheric particle diffusion*
- *Cold working*
- *Inadvertent high temperature annealing of a section*
- *Alteration of thermocouple wire composition*

Failure Mechanisms in Thermocouple & RTD MI Cable



In service, contaminants migrate to thermal elements causing de-calibration

Failure Mechanisms in Thermocouple & RTD MI Cable



Moisture accelerates failure mechanisms!

Thermocouple Drift

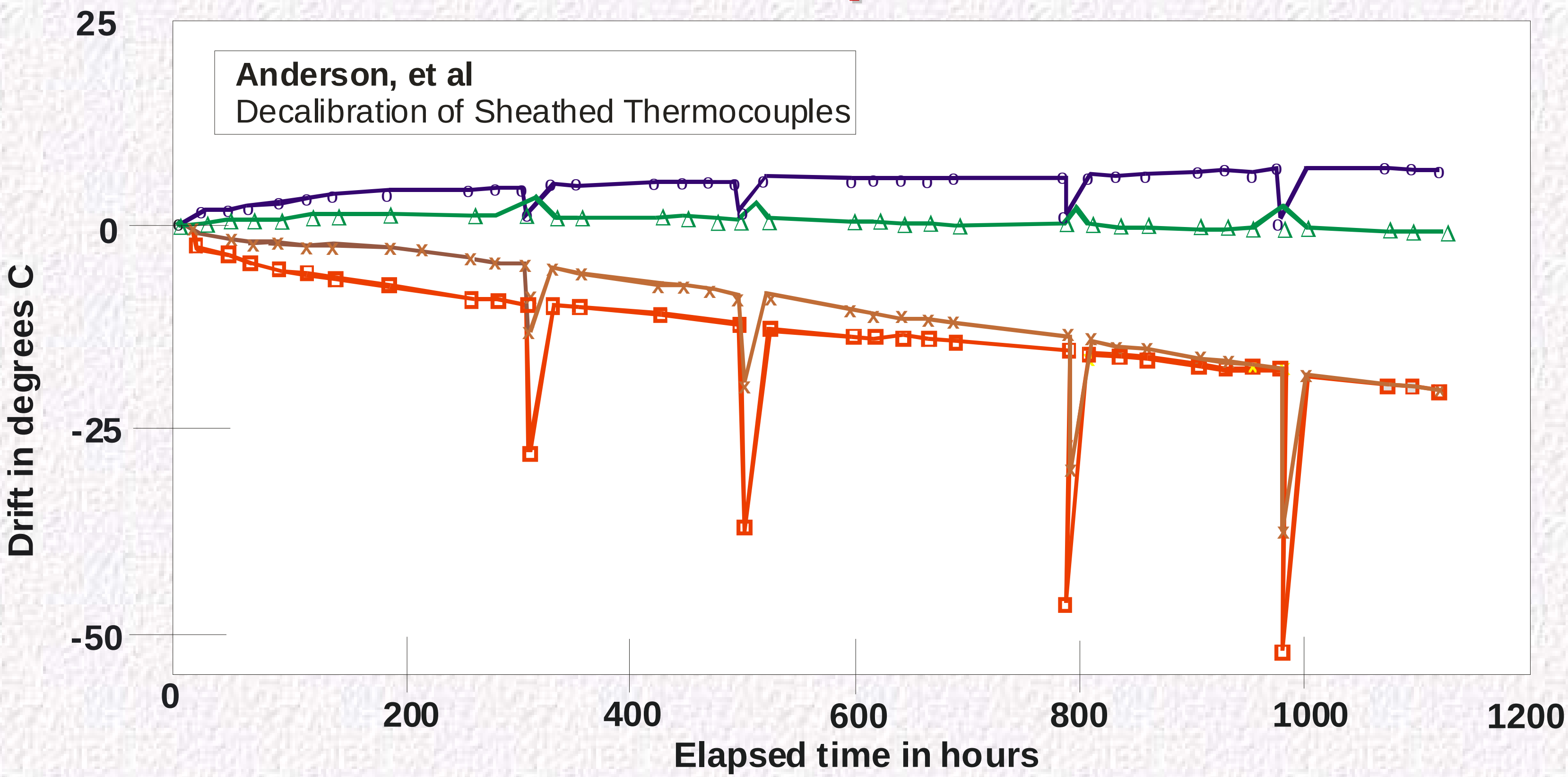


Fig. 30. Drift of 3-mm-diameter stainless steel-sheathed and Inconel 600-sheathed type K and Nicrosil versus Nisil thermocoupes at 1200 C in vacuum. The dips in the drift curve are the result of the "in-place inhomogeneity test" where the samples were extracted from the furnace by 5 cm. The symbols used for the various samples are: type K in Inconel - circles; Nicrosil versus Nisil in Inconel - triangles; Nicrosil versus Nisil in stainless steel - crosses; and type K in stainless steel - squares.

Thermocouple Drift (or Decalibration)

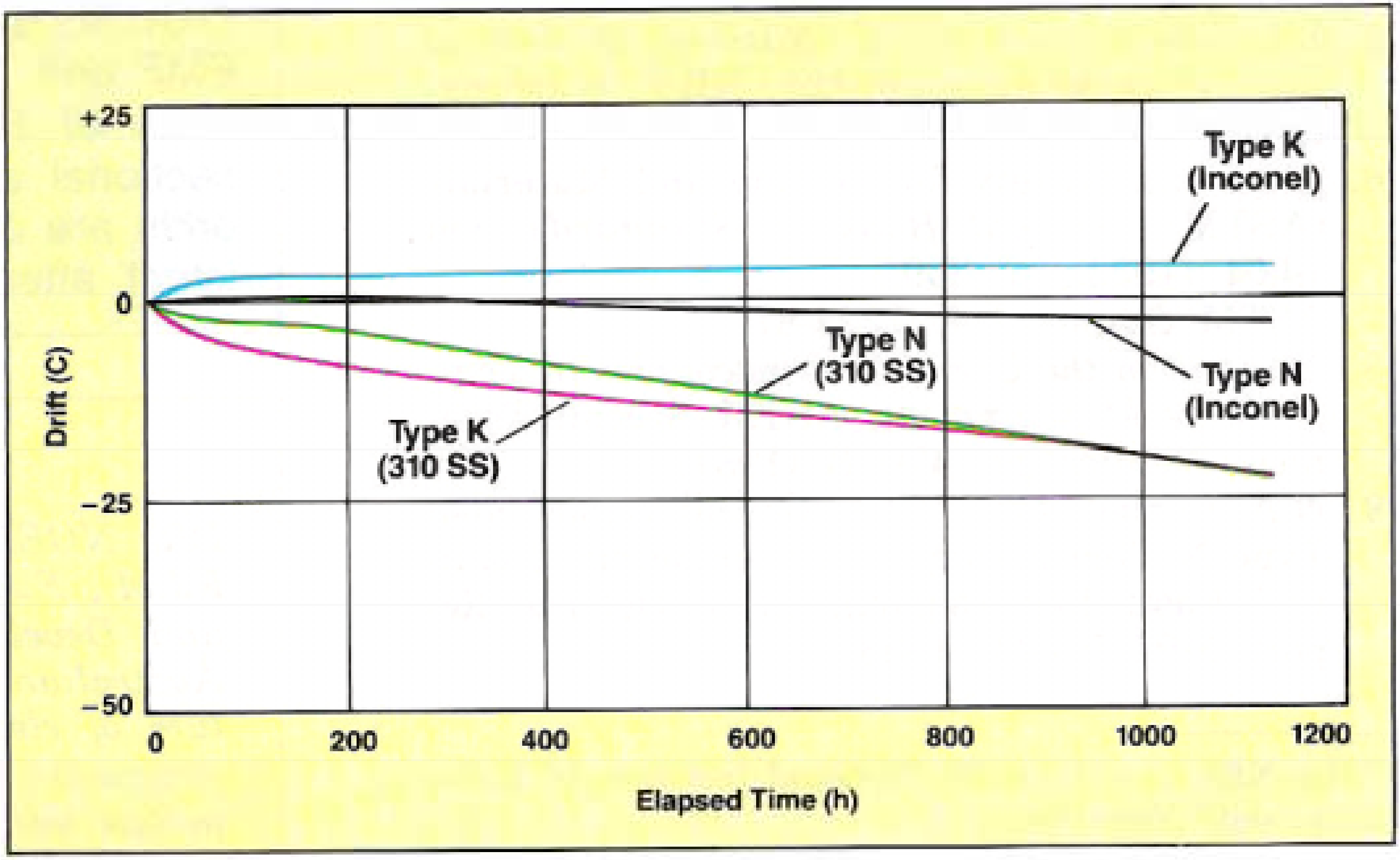


Figure 1. Drift of 3 mm diameter stainless steel sheathed and Inconel 600 sheathed type K and Nicrosil vs. Nisil thermocouples in 1200°C in vacuum. The dips in the drift curve are the result of the "in-place inhomogeneity test" where the samples were extracted from the furnace by 5 cm.

Drift and Loop Resistance

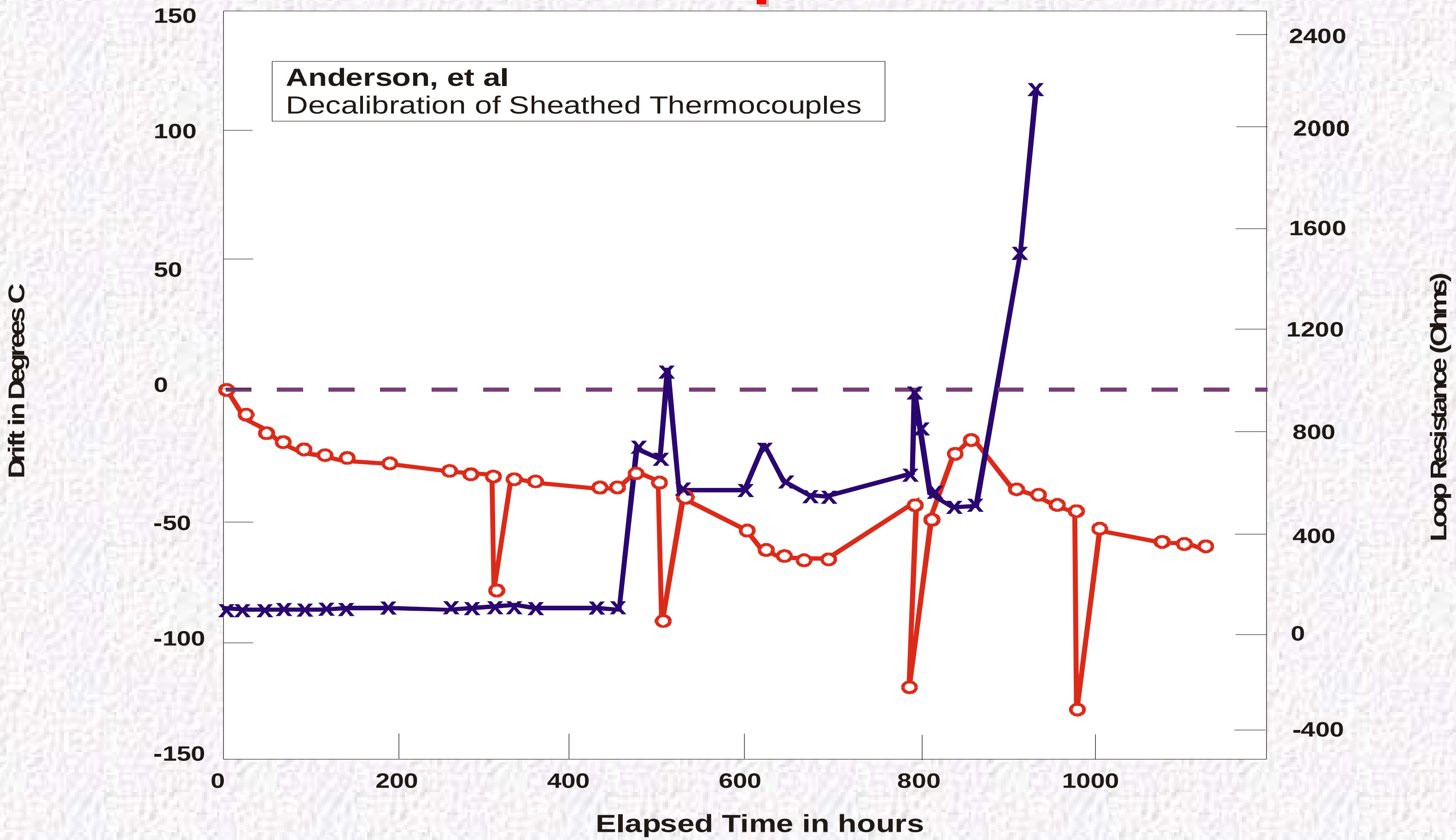


Fig. 27A. Drift of 1-mm-diameter stainless steel sheathed Type K thermocouples at 1200 C in vacuum indicated by the solid line and circles. The dips in the drift curve are the result of the "in-place inhomogeneity test" where the samples were extracted from the furnace by 5 cm. The loop resistance, shown by the solid line and crosses indicates that the temperature failed at 474 hours

Traditional ways to compensate

1. Scheduled Replacement
2. Redundant Sensors
   - Backups
   - Multipoints
   - Bundles
3. Cross-checking with other Sensors
   - Material balances
   - Energy balances
4. Calibrations
   - Traceable measurements
   - Regular Re-calibrations

The

RTD

Story

Two Types Of RTD's

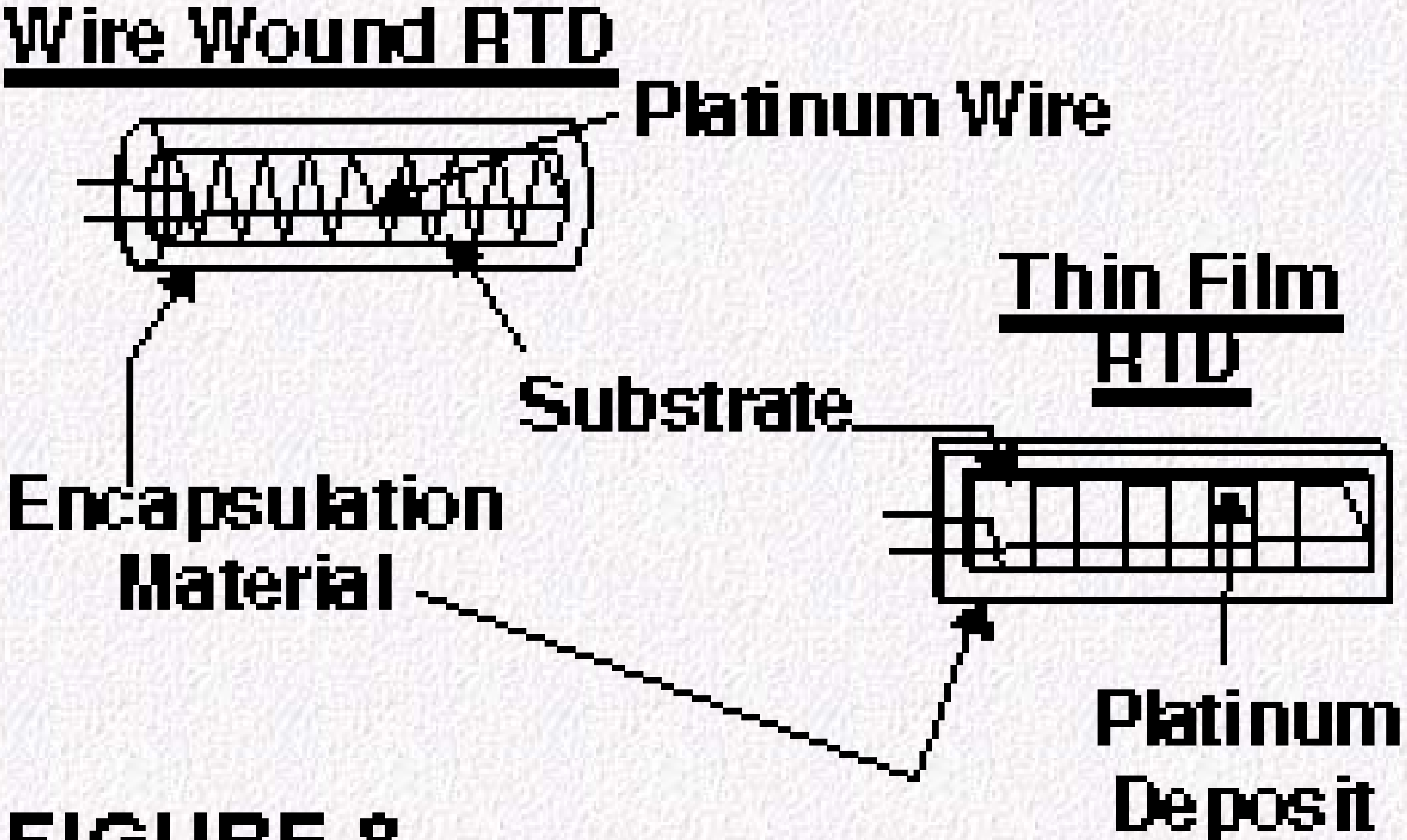
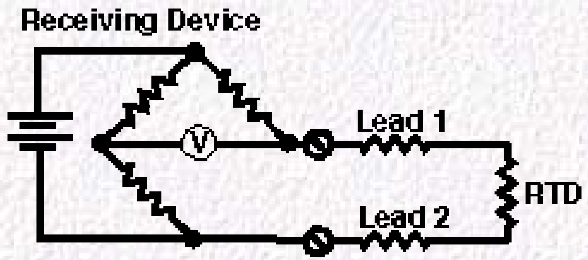
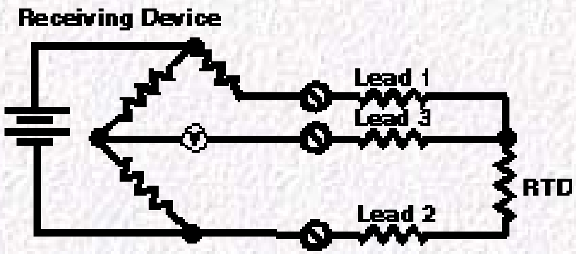
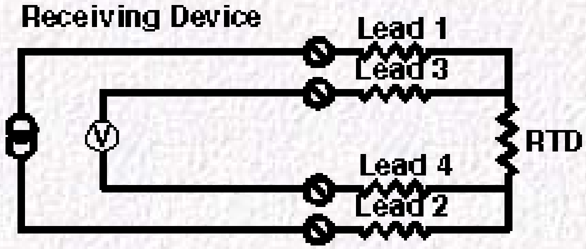


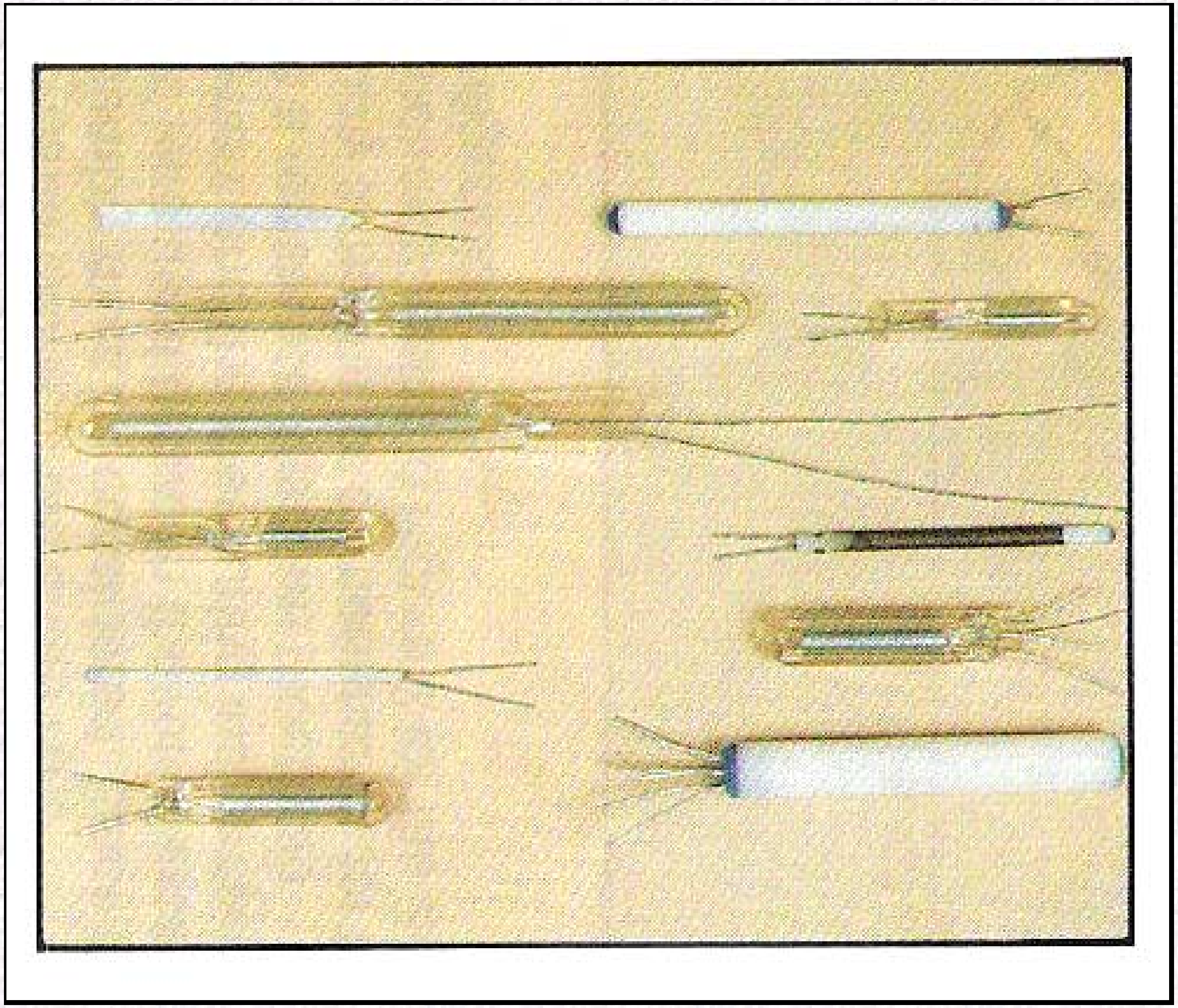
FIGURE 8.


Receiving Device
Lead 1
RTD
Lead 2


Receiving Device
Lead 1
Lead 3
RTD
Lead 2

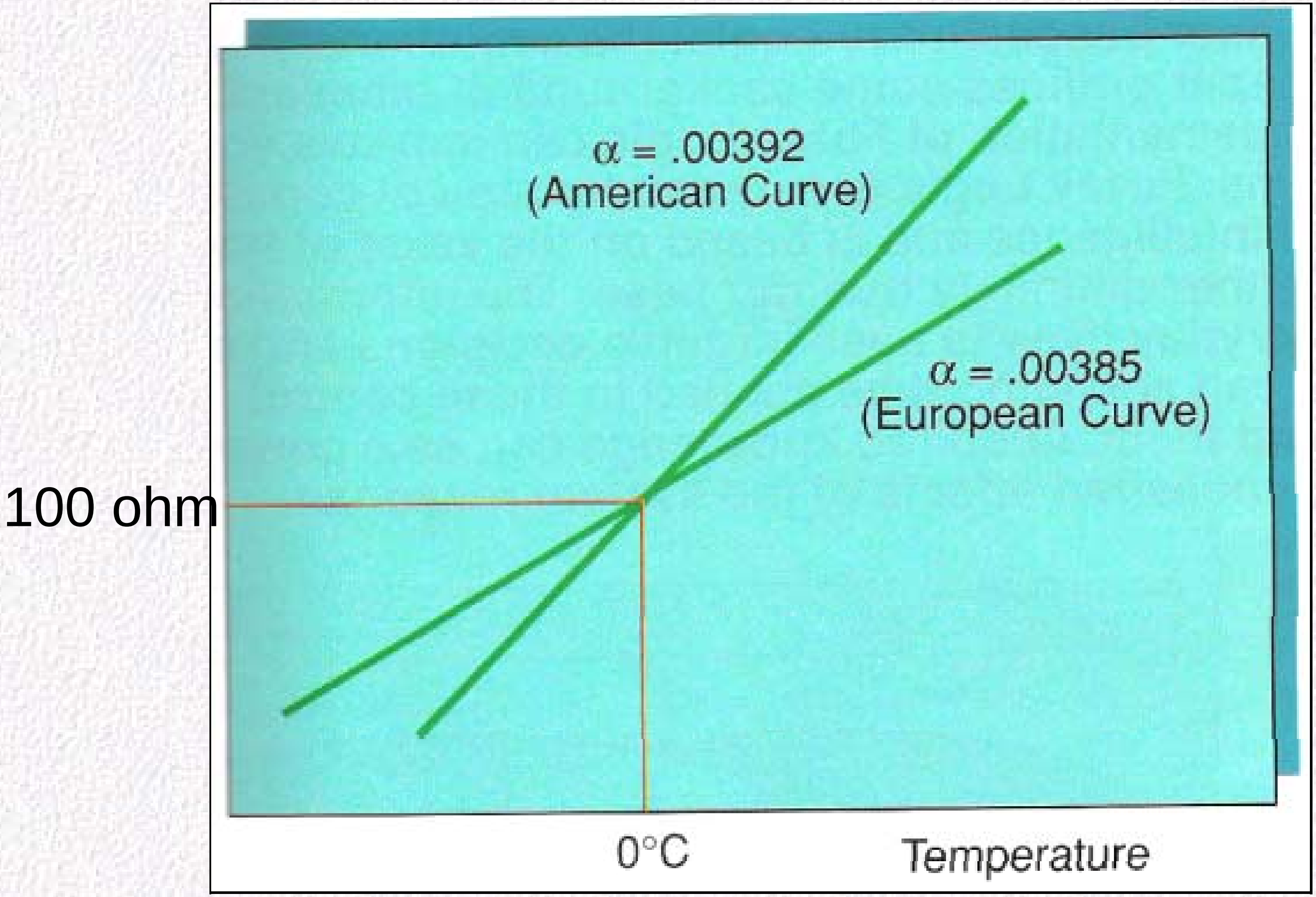

Receiving Device
Lead 1
Lead 3
RTD
Lead 4
Lead 2

Various fully supported RTD Bulbs



"Resistance begins at ohm."

RTDs have a Linear response curve



Nearly all industrial RTDs have a = 3.85x10-3/degC

RTDs can be very accurate

Tolerance Class	Tolerance (°C)
A	$0.15 + 0.002 \lvert t \rvert$
B	$0.30 + 0.005 \lvert t \rvert$
1/10th	$0.03 + 0.002 \lvert t \rvert$

where $|t|$ is the absolute value of temperature in degrees Celsius

Nominal Temperature (°C)	Measurement Uncertainty (°C)	
	Standard Class A RTD * (off-the-shelf)	Calibrated RTD § (Callendar-Van Dusen)
0	0.15	0.02
100	0.35	0.08
200	0.55	0.15
300	0.75	0.15
400	0.95	0.10

*The measurement uncertainty is equal to the tolerance of a class A RTD.

Calibration Comparisons

Temperature °C	RTD Class A		Type K Special Limits	
300	+/- 0.75		+/- 1.2	
200	+/- 0.55		+/- 1.1	
100	+/- 0.35		+/- 1.1	
0	+/- 0.15		+/- 1.1	

Primary Sources of Errors in RTDs

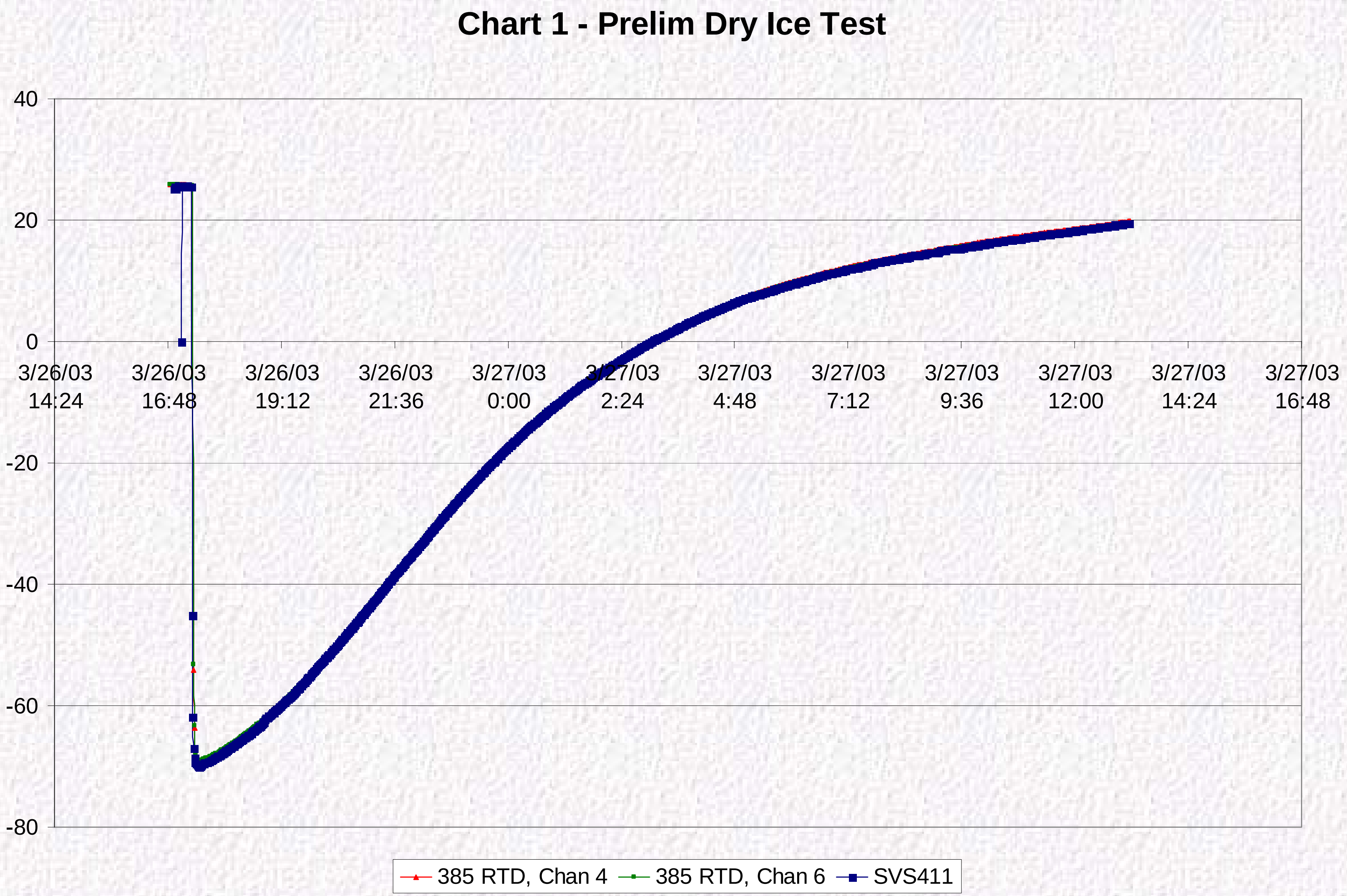
1. Shock/Vibration
2. Breakage
3. Shunting
4. Immersion (large size of element)
5. Heat Capacity
6. Self-heating
7. Slower response time (Dynamic measurement)
8. Radiation
9. Lead wire compensation

RTDs

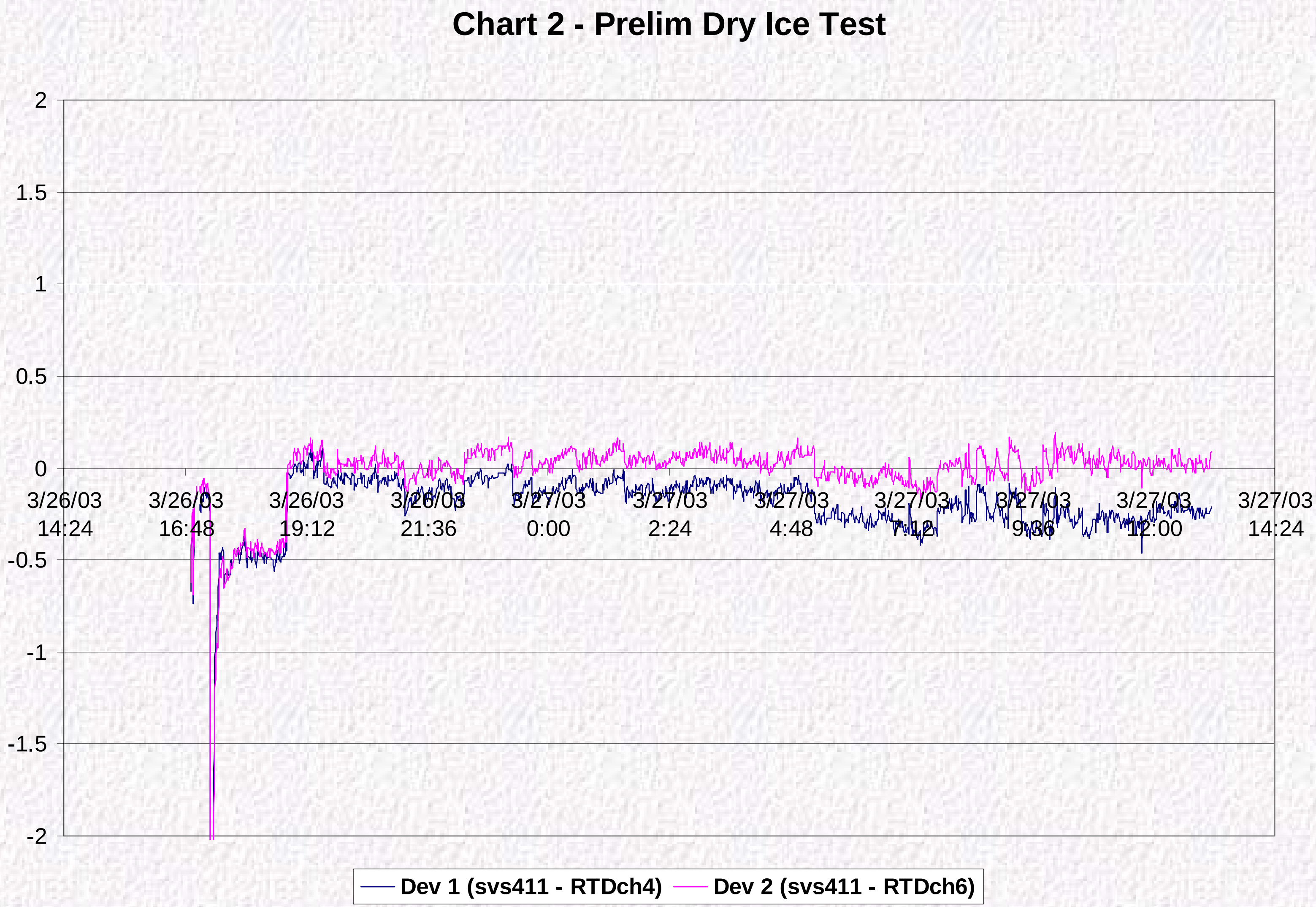
Advantages:
- More stable
- More accurate
- More linear than thermocouples

Disadvantages:
- More Expensive
- Current source required
- Self-heating
- Fragile
- Limited range
- Drift and fail unpredictably

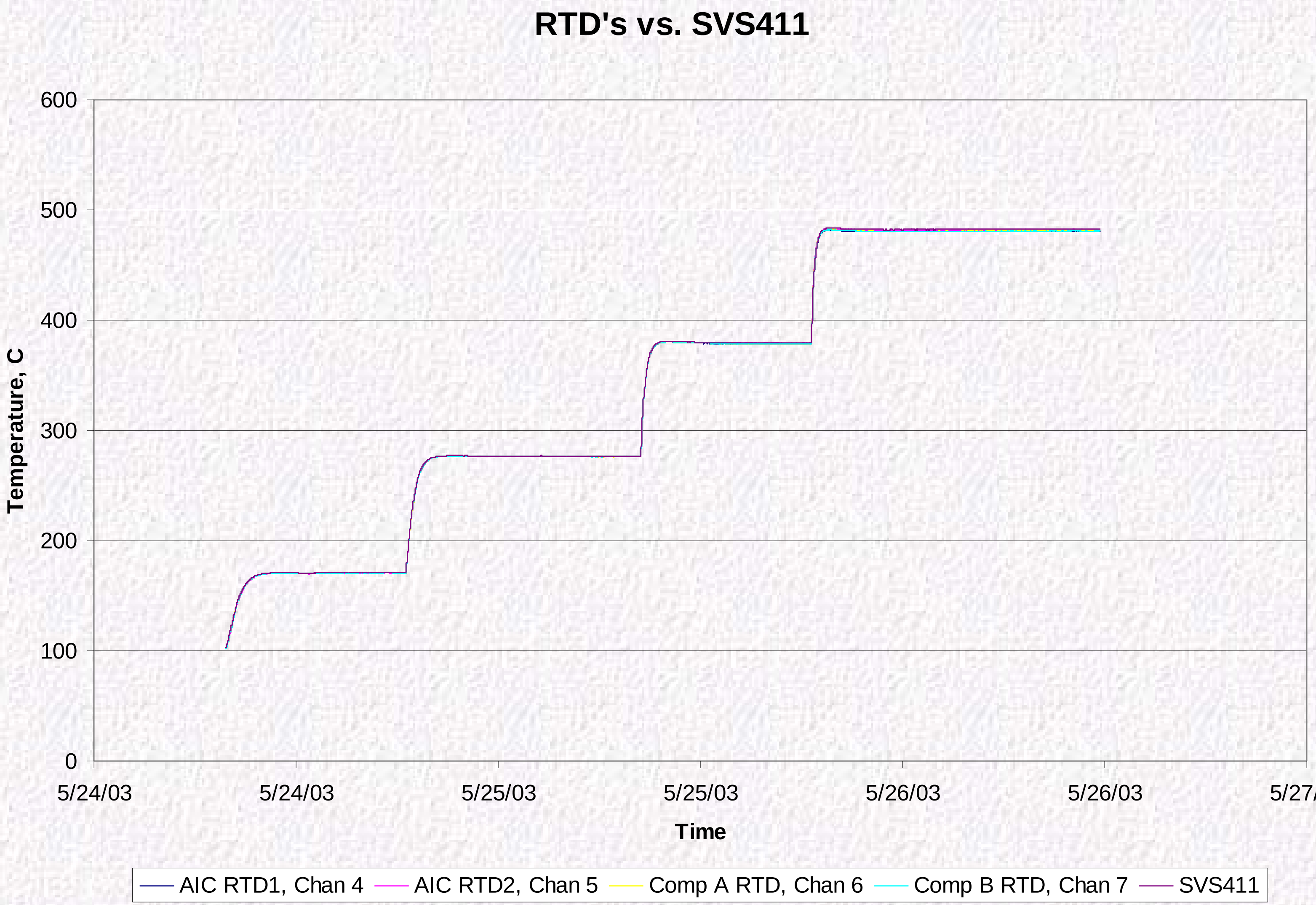
RTL Stability Test



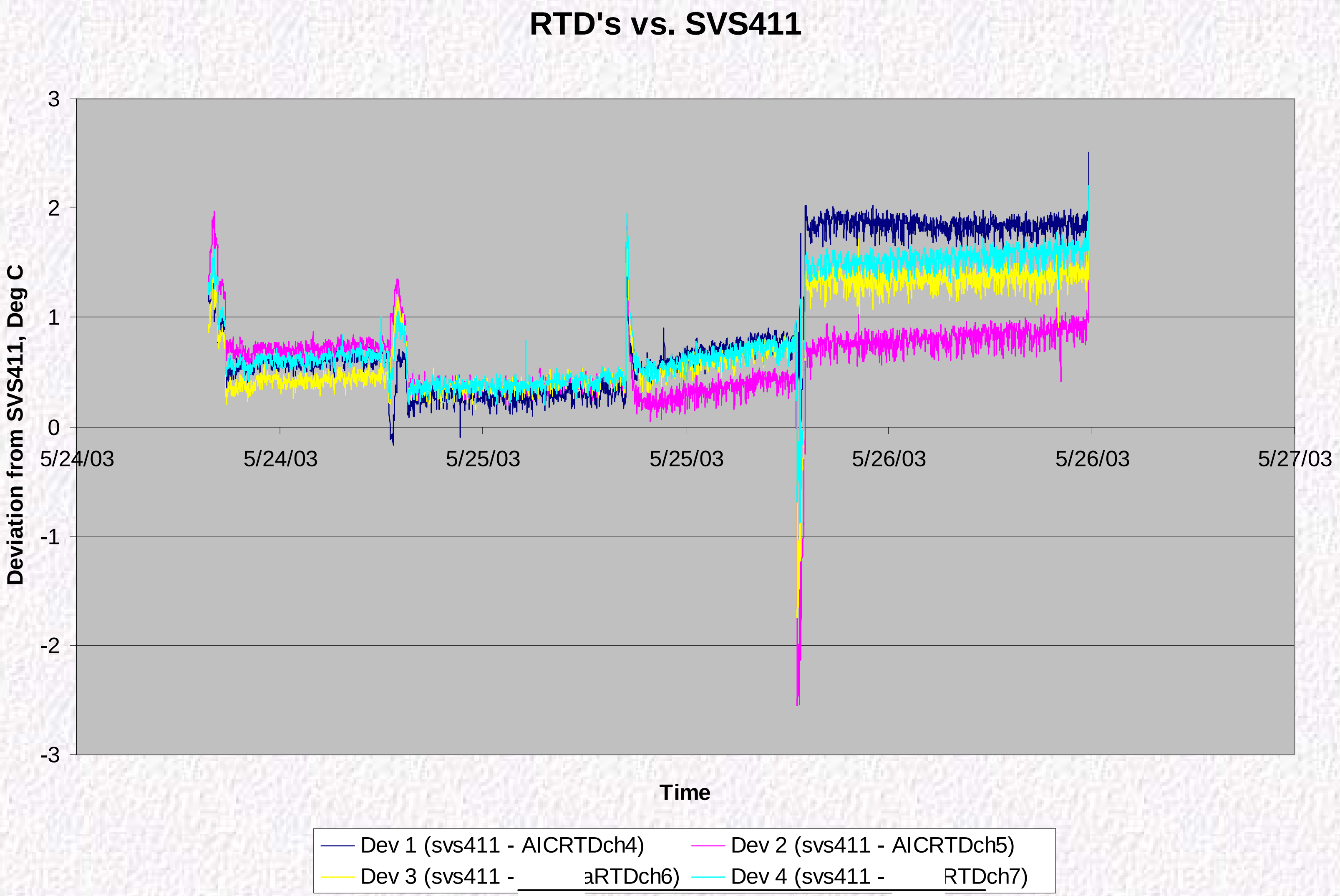
RTD Stability Test



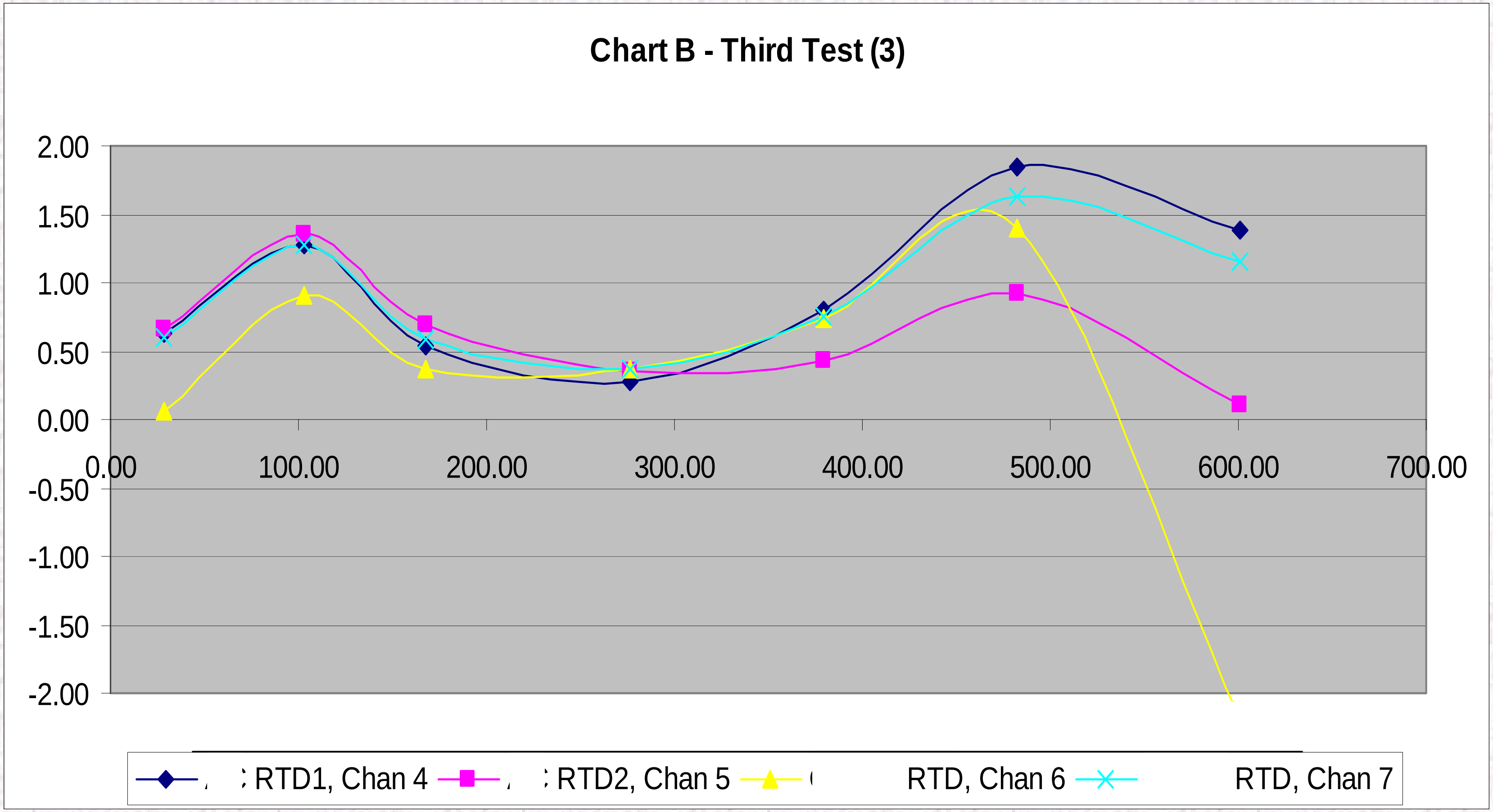
RTD Stability Test



RTD Stability Test



RTD Stability Test



Hints for RTDs

- Don’t use 2-wire
- Handle and store carefully
- Avoid shock and vibration
- Completely Immerse

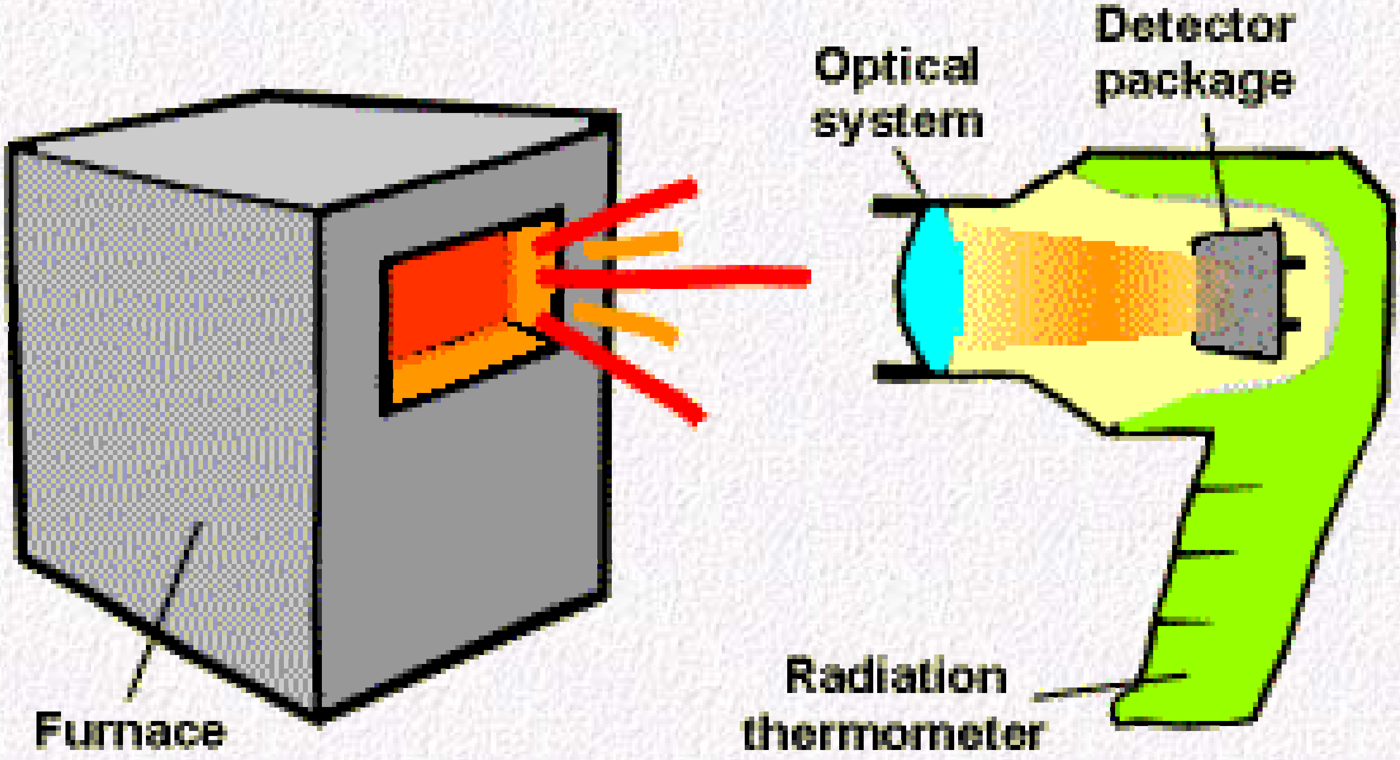
RTDs made with MI-Dry dielectric rather than MgO are less susceptible to shunting errors, moisture absorption and more reliable at higher temperatures

The

Radiation Thermometry

Story

Pyrometers are Non-Contact devices



Radiation Thermometry

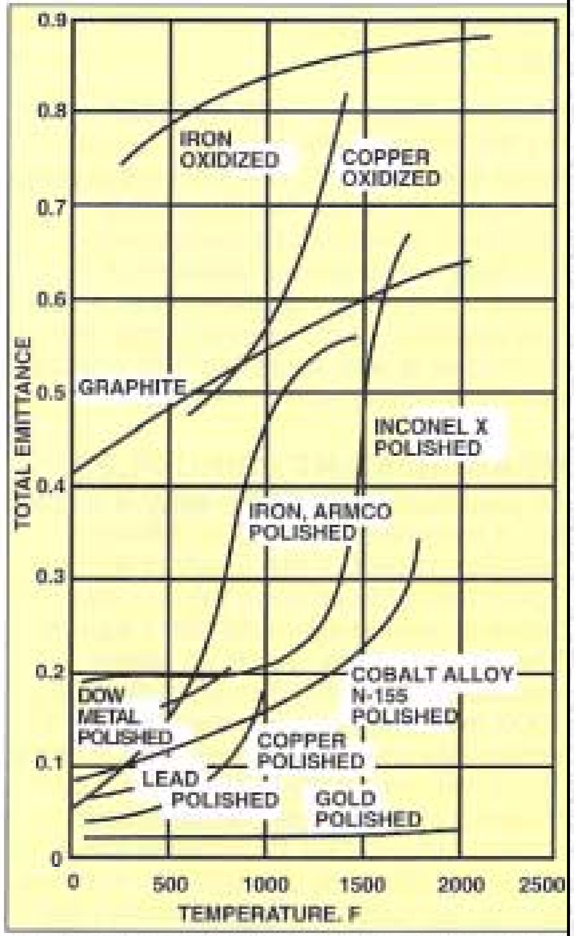


Figure 4: Many materials have emissivity levels that vary with temperature. Several of the most commonly used are compared here.

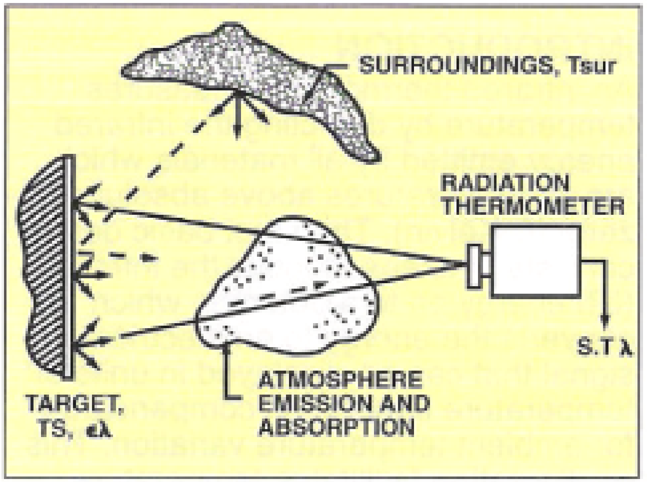


Figure 5: When selecting noncontact temperature measurement instruments, it is necessary to take into account not only the target and its emissivity, but also the surroundings and the invtervening atmosphere.

Surroundings and atmosphere

Emissivities range from 0 to 1.0

Knowing the Emissivity is the Name of the Game

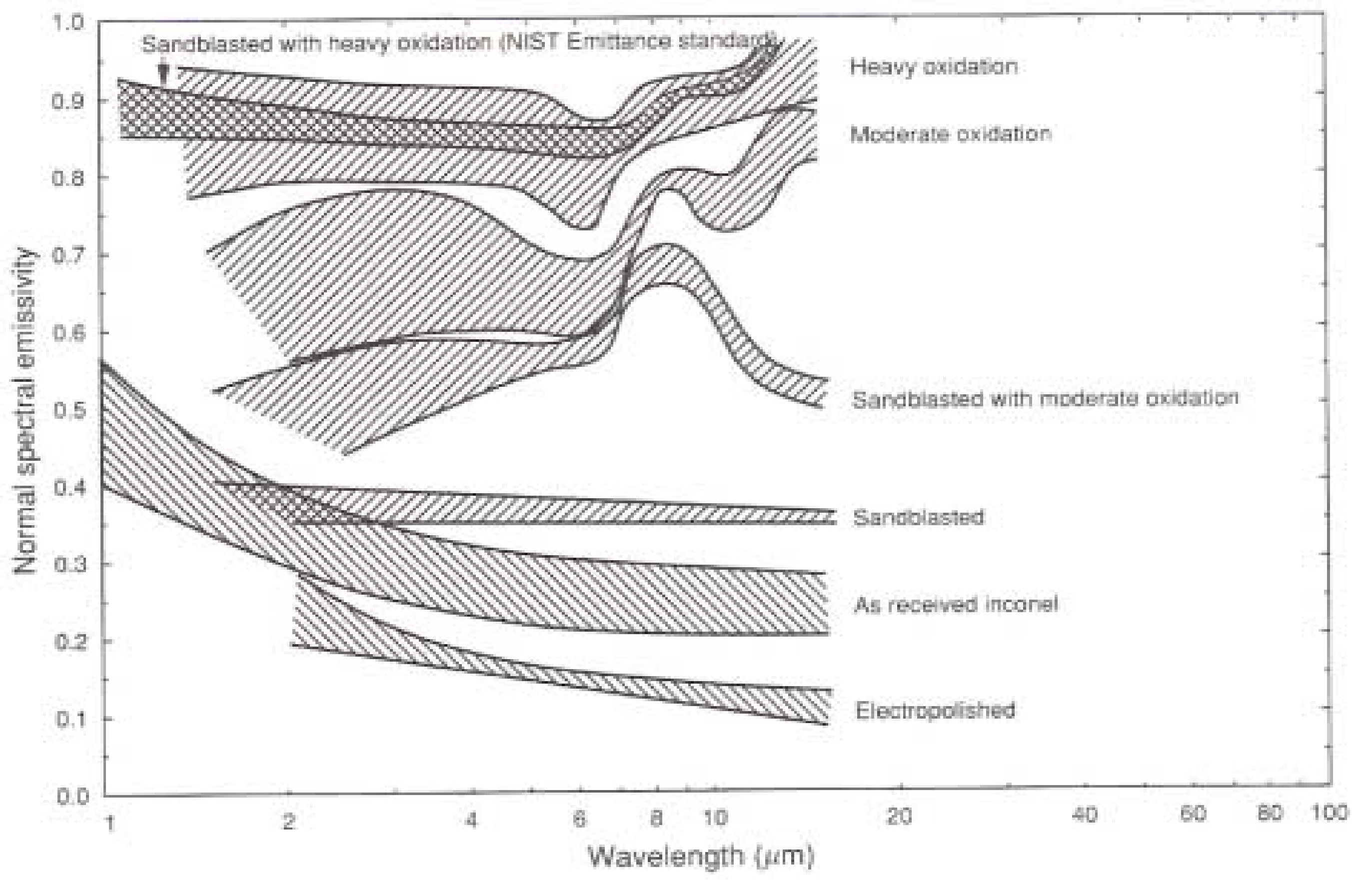


Figure 8.5
The spectral emissivity of inconel®. There is a wide range of emissivities depending on the surface finish.

Radiation Thermometry

Advantages:

- Non – contact
- Fast response
- Moving Targets

Disadvantages:

- Changing Emissivity
- Stray Radiation
- Sight Path Obscuration
- Ambient Temperature Drift
- More expensive than thermocouples or RTDs

The

Calibration

Story

Calibrations

"… calibration is to do something that is basically impossible, namely predict the future behavior of the instrument"

J. V. Nicholas & D. R. White
Measurement Standards Laboratory of New Zealand
"Traceable Temperatures"
John Wiley & Sons

Calibrations

Calibration is all about Uncertainty

"Uncertainty is an estimate of the range of values within which the True Temperature lies"

Thus 23 deg C +/- 0.05 C

During Calibration there are errors (and therefore Uncertainty) in:

- Reference thermometer readings
- Stability & Uniformity of calibration media
- Departure from ITS-90 relationship
- Hysteresis
- Drift
- Measuring electronics

“Traceability”

Traceability is about comparisons and record keeping

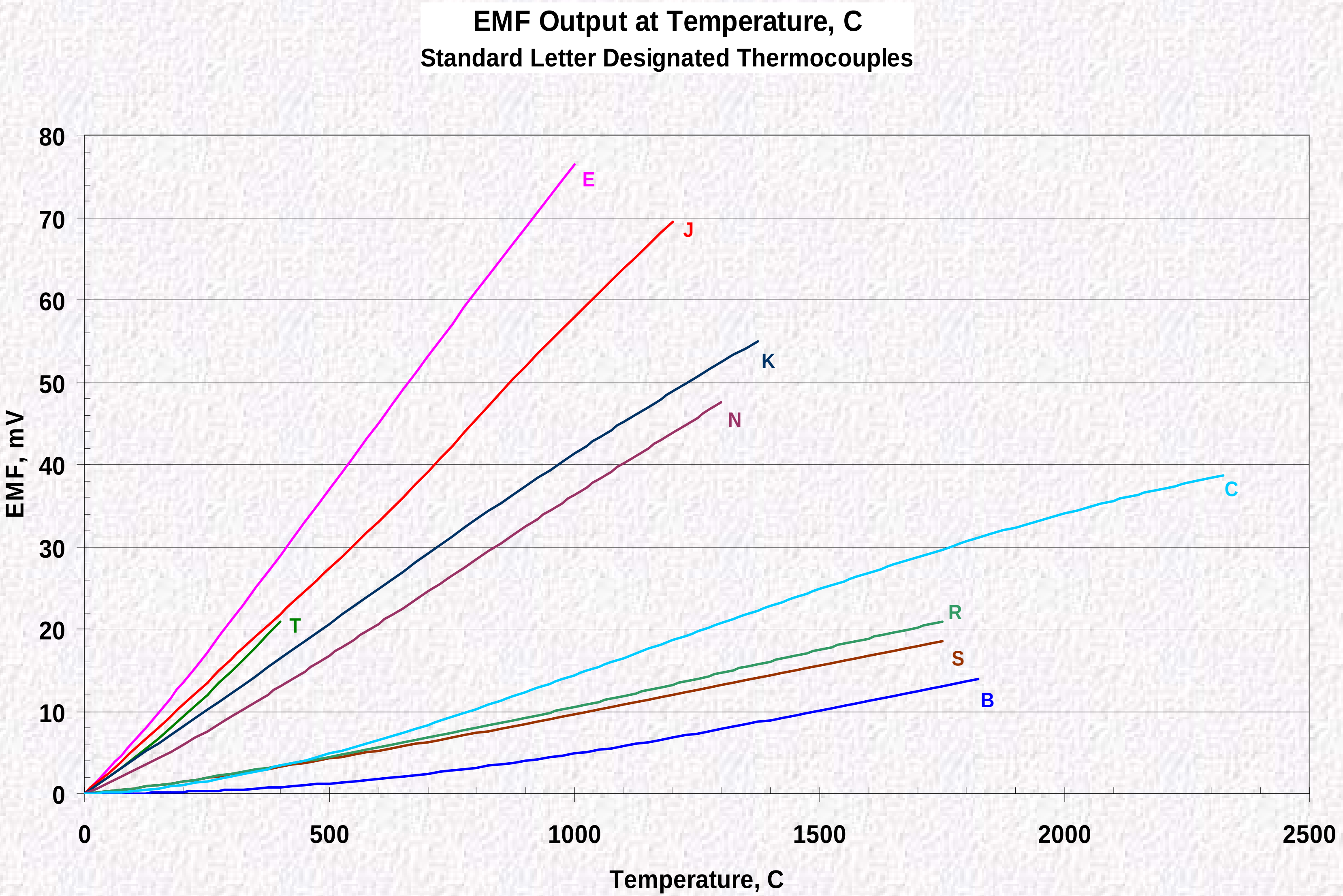
ISO Definition:

“Traceability is the property of a result of a measurement whereby it can be related to appropriate standards, generally international or national standards, through an unbroken chain of comparisons”

In other words:

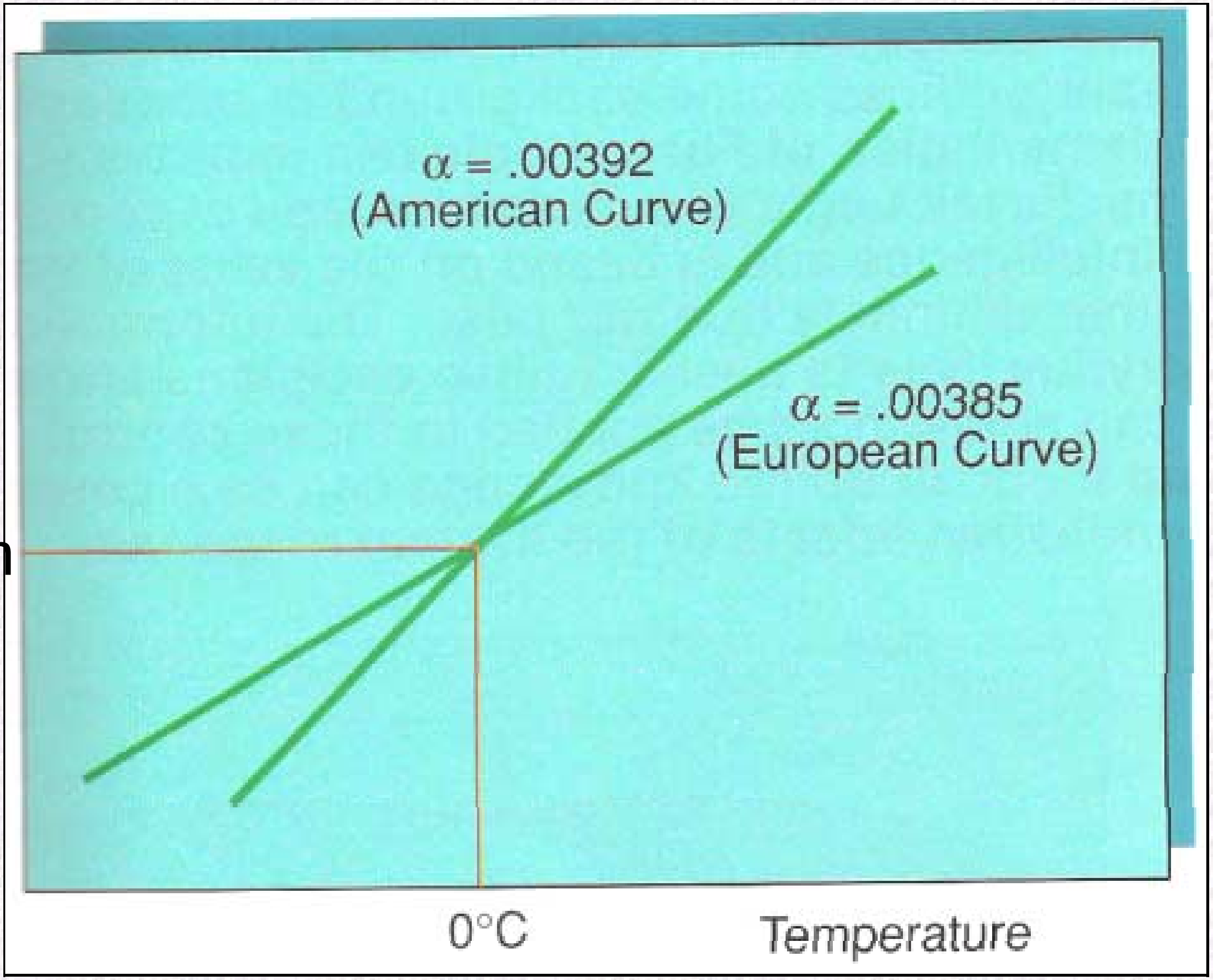
“Traceability is the ability to demonstrate the accuracy of a measurement in terms of SI Units” at some point in time.

Calibration and Traceability are accomplished using the Zeroth Law


EMF Output at Temperature, C
Standard Letter Designated Thermocouples
EMF, mV
Temperature, C
0
10
20
30
40
50
60
70
80
0
500
1000
1500
2000
2500
E
J
K
N
C
R
S
B
T

RTDs have a Linear response curve

100 ohm



Nearly all industrial RTDs have a = 3.85x10-3/degC

Standard Temperature Scale

Thermometry Fixed Points

THERMOELECTRIC FIXED POINT	MELTING POINTS FROM THE PRACTICAL INTERNATIONAL TEMPERATURE SCALE IPTS-68	
Boiling point of oxygen	−183.0 °C	−297.3 °F
Sublimation point of carbon dioxide	− 78.5	−109.2
Freezing point of mercury	− 38.9	− 38
Ice Point	0	32
Triple point of water	0.01	32
Boiling point of water	100.0	212
Triple point of benzoic acid	122.4	252.3
Boiling point of naphthalene	218	424.4
Freezing point of tin	231.9	449.4
Boiling point of benzophenone	305.9	582.6
Freezing point of cadmium	321.1	610
Freezing point of lead	327.5	621.5
Freezing point of zinc	419.6	787.2
Boiling point of sulfur	444.7	832.4
Freezing point of antimony	630.7	1167.3
Freezing point of aluminum	660.4	1220.7
Freezing point of silver	961.9	1763.5
Freezing point of gold	1064.4	1948
Freezing point of copper	1084.5	1984.1
Freezing point of palladium	1554	2829
Freezing point of platinum	1772	3222

Calibration – How useful is it?

Calibration Certificate?

SM SHORT MEASURES LTD

Certificate of Calibration

We certify that this instrument has been calibrated
and is traceable to
National Measurement Standards

Model No. ____________ Serial No. ____________ Date ____________

Certified by ____________________

Calibration Certificate

CALVIN, DeGRIES AND CO

1 Traceability Place, P O Box 31-310, Lower Hutt, New Zealand
Telephone (64) 4 566-6919 Fax (64) 4 569-0003

CALIBRATION CERTIFICATE

Report No.: T92-2001.

Client: ACME Thermometer Co, 100 Celsius Avenue, P O Box 27-315, Wellington, New Zealand

Description of Thermometer: ASTM 121C kinematic viscosity thermometer divided to 0.05°C. Serial number 2925, manufactured by Zeal.

Date of Calibration: 22 July 1992.

Method: The thermometer was compared with standard thermometers held by this laboratory. The temperature scale used is ITS-90.

Conditions: The thermometer was calibrated in total immersion.

Results:

Thermometer reading (°C)	Correction (°C)
0 (ice point)	+0.02
100.04	+0.06
101.02	+0.05

Note: Corrections are added to the reading to obtain the true temperature.

Accuracy: The uncertainty in the corrected thermometer readings is estimated to be ±0.025°C at the 95% confidence level.

Checked: ____________ W Thomson

Signed: ____________ R Hooke

Calibration (the fine print)

"Tolerances indicated in this table are not necessarily an indication of the accuracy of temperature measurement in use after initial heating of the materials.”

Unsung Heroes

“The Offensive Line”

Thermowells & Sheath Materials

Functions of the protection sheath/thermowell

•Prevent environmental contaminates from attacking the sensor internals

•Withstand process pressures, abrasion or chemical conditions

•Provide a means of attaching the sensor to a process

•Ensure that the sensor reading is dominated by the process temperature

•Provide a means for easily changing sensors

•Give the sensor a degree of robustness to survive handling and storage

Protection Tubes

Some Common Protection Tubes & Construction Techniques

Types of materials

- Stainless (304, 310, 316, 447…)
- Nickel Alloys (Inconel, Hastelloy...)
- Ceramic (Alumina, SiC…)
- Metal-Ceramic

Multiple Layer Protection Tubes & Coatings

A Good Place to Look

What's working well in the process?

Intermission Contemplation

A Party of Famous Physicists

One day, all of the world's famous physicists got together for a tea luncheon. Fortunately, the doorman was a grad student, and able to observe some of the guests...

- Ohm spent most of the time resisting Ampere's opinions on current events.
- Volt thought the social had a lot of potential.
- The Curies were there and just glowed the whole time.
- Wien radiated a colorful personality.
- Watt turned out to be a powerful speaker.
- Hertz went back to the buffet table several times a minute.
- Faraday had quite a capacity for food.

Tomorrow's Heroes

Today

Nicrosil/Nisil Type N Thermocouples

“A Better Choice”

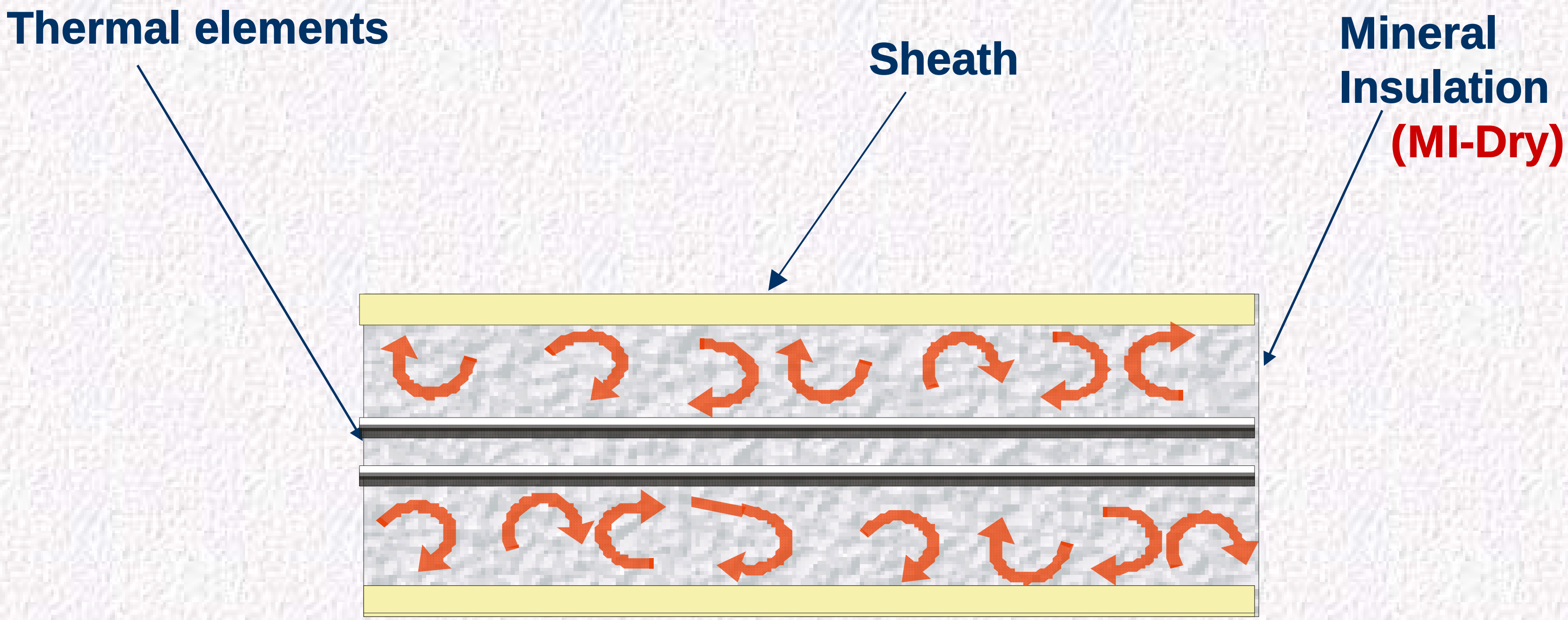
Type N

- Designed to minimize some instabilities of Type K
- Works very well in Inconel Sheath w/ MiDry dielectric
- Less susceptible to “Green Rot”.
- NP & NN legs contain Si, NP leg more Cr, & the NN leg contains small amount of Mg.
- Same Temperature range as a Type K
- Lower drift rates up to 1200ºC.
- Same environment as Type K.
- No short range ordering problem.

A Major Step Forward for Mineral Insulated, Metal Sheathed Thermocouples

"Mi-Dry Dielectric– a replacement for MgO insulate."

AccuTru's New ExL Sensor Blocks Failure Mechanisms



Made with High resistance, Non-hygroscopic MI-Dry, ExL cable slows or prevents common failure mechanisms

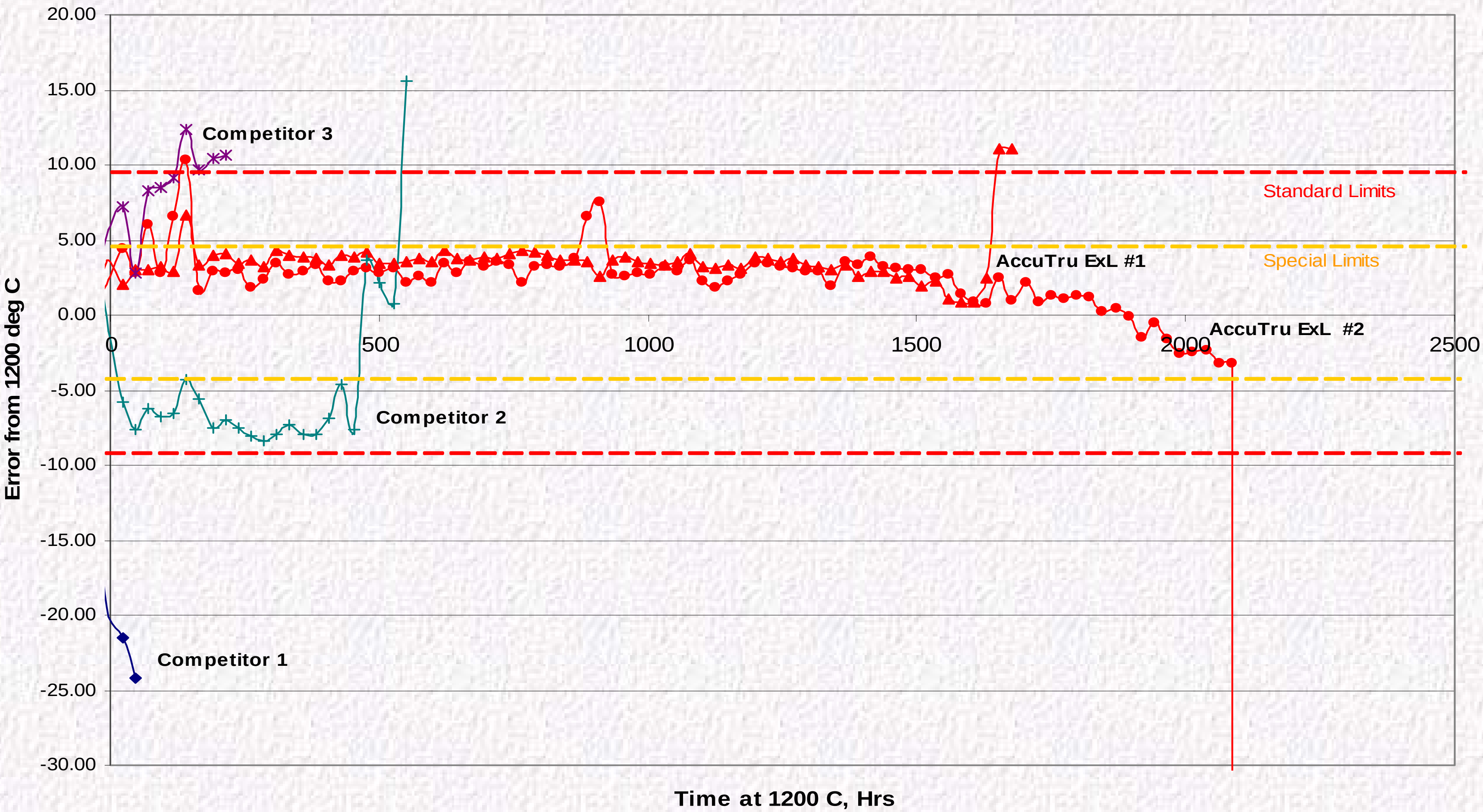
- Longer sensor life and greater stability

Experimental Oven Setup

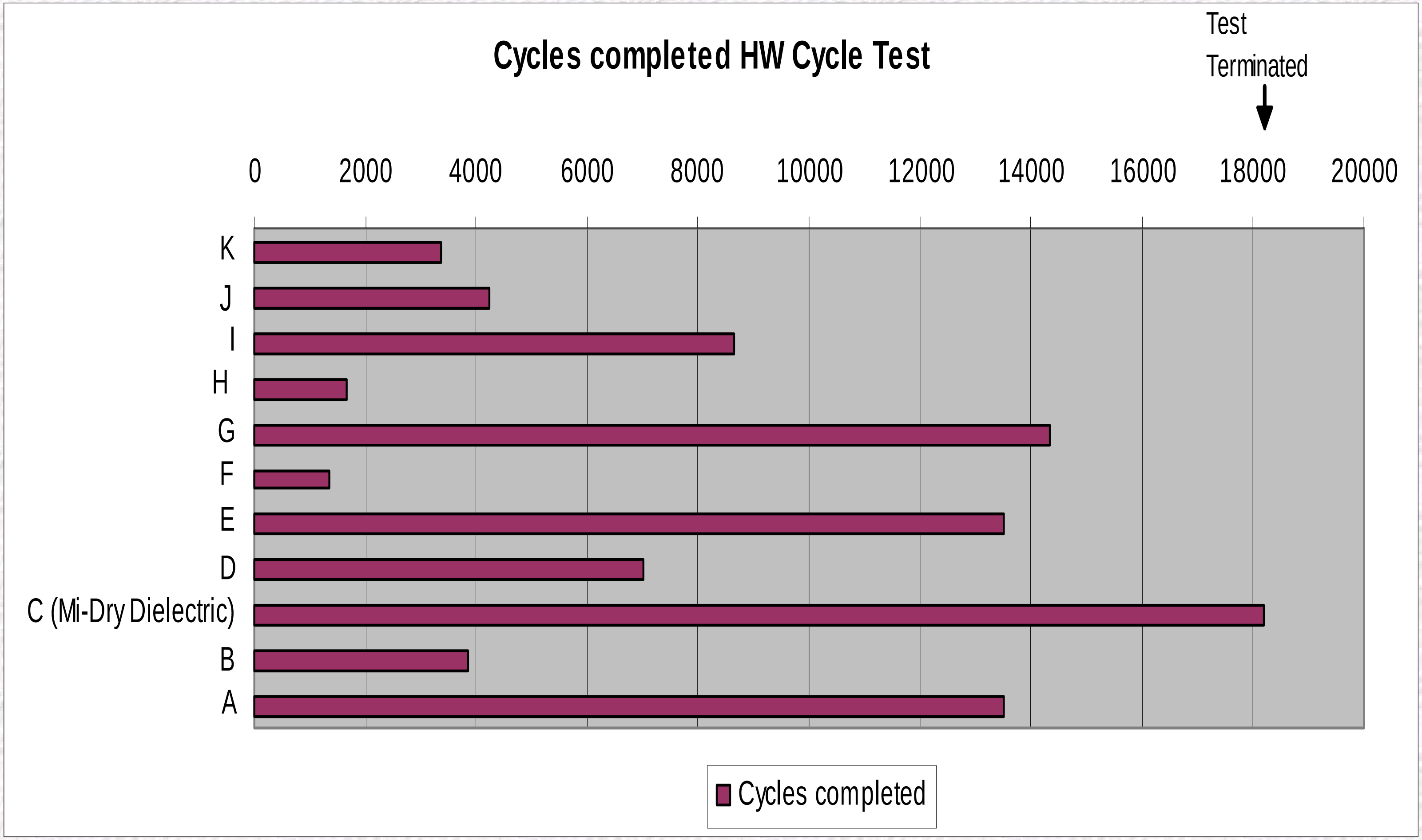
5 -¼” OD Type K’s in Inconel 600 sheaths at <u>1200C</u> (2200F)

New AccuTru ExL Sensors with MI-Dry demonstrate Longer Life and greater Stability

AccuTru ExL Type K's vs. Competitor Type K's



Third Party Testing Confirms Results



ExL products are generating longer life,greater signal stability and a lower life cycle cost.

“We have 8 critical temperature control loops on our ladle and sub dryer systems. The thermocouples we were using would last somewhere between 2 days and 3 weeks before failing. We replaced them with the AccuTru’s ExL, extended life thermocouples. Since replacement (5 months now) we have seen no failure with the AccuTru ExL product.”

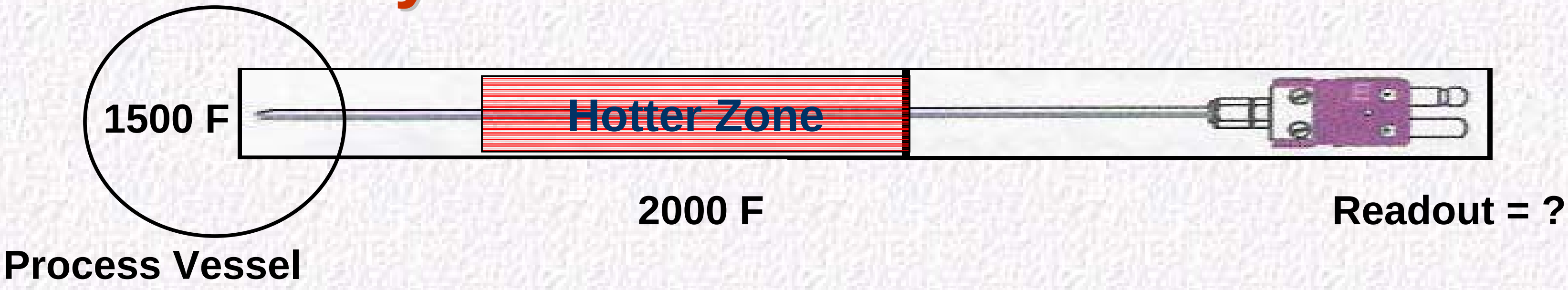
“Tom Byerly
Combustion Supervisor
BOF
Bethlehem Steel Corporation
Chesterton, Indiana”

ExL Sensors are generating economic benefits

"AccuTru Sensor Technologies has made a major improvement in thermocouple technologies. Their Extended Life Thermocouples with Mi-Dry is proving to be an economic benefit for us. We tested their ExL sensor in a process where we were losing sensors at least once a month. The ExL sensors have been in-service for over one year. We are in the process of installing ExL sensors in other processes in our plant."

Robert Colley
Atofina Petrochemicals
Deer Park Plant, TX

MI-Dry also solves another Problem

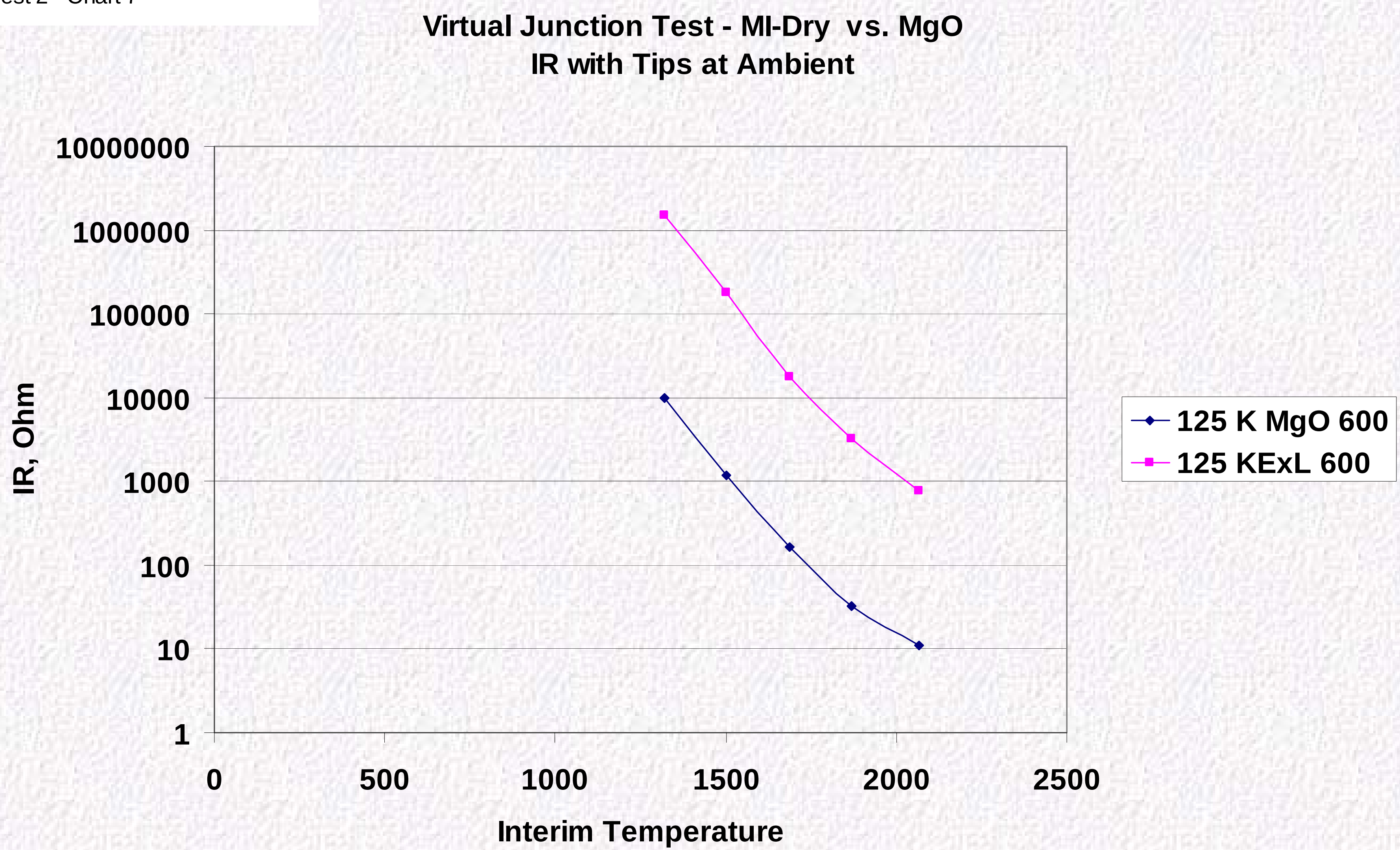


Virtual Junction Error:

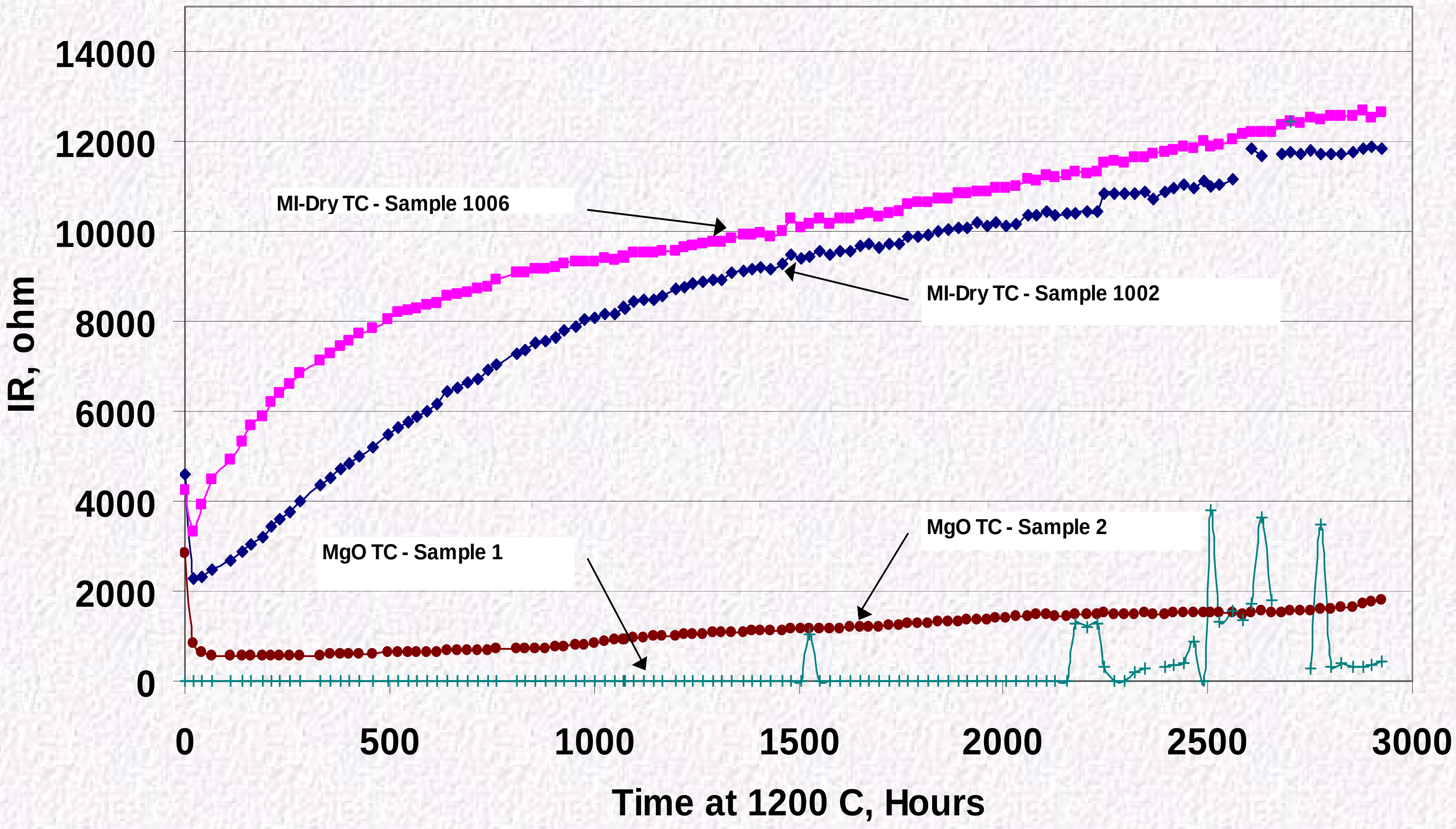
- Temperature along length exceeds that of the hot tip
- If MgO Insulation breaks down, shunting can occur
- Secondary – or a "virtual junction" is formed
- Error in the readout occurs

Industrial Brazing Operation

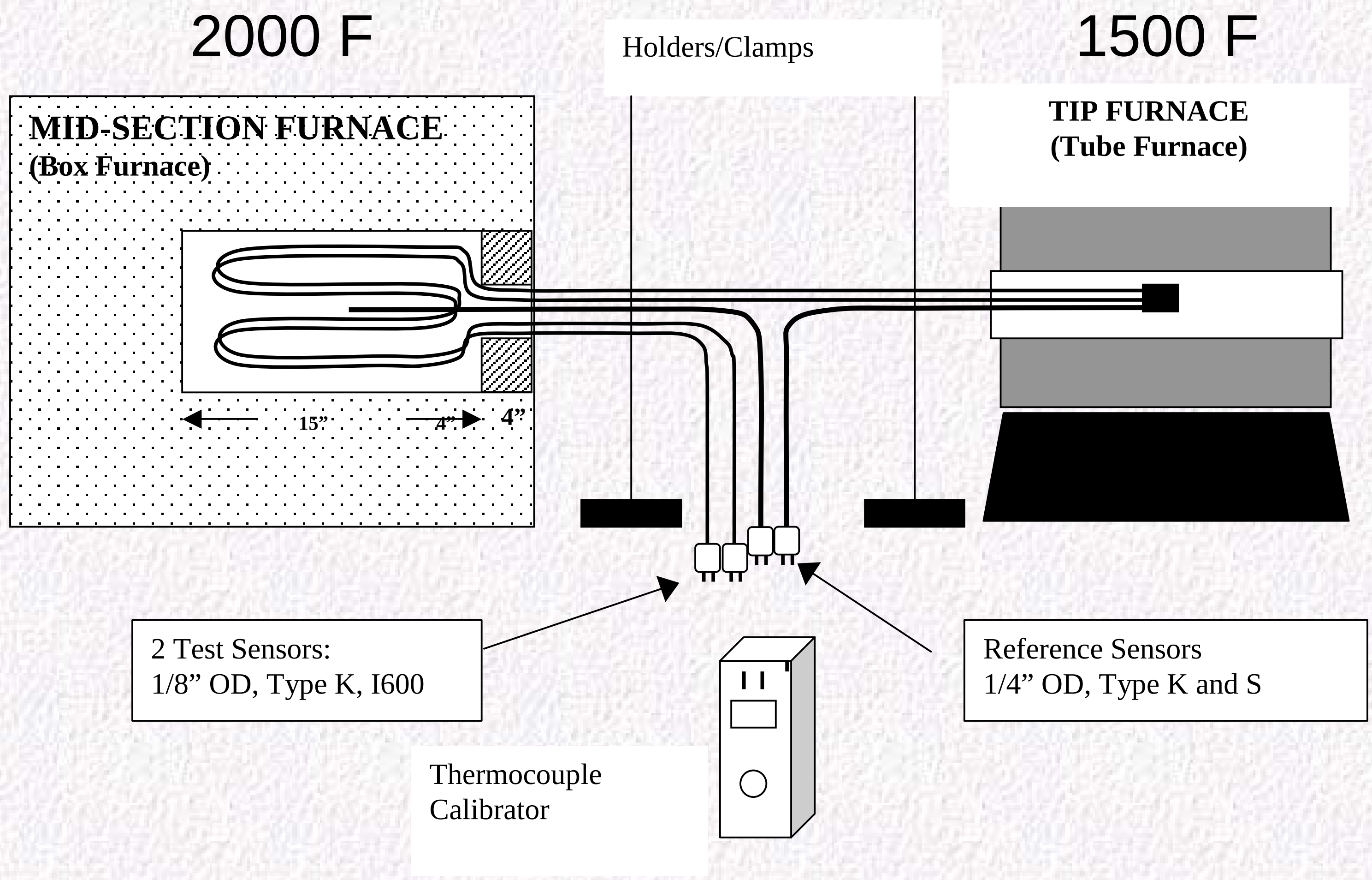
Test 2 - Chart 7



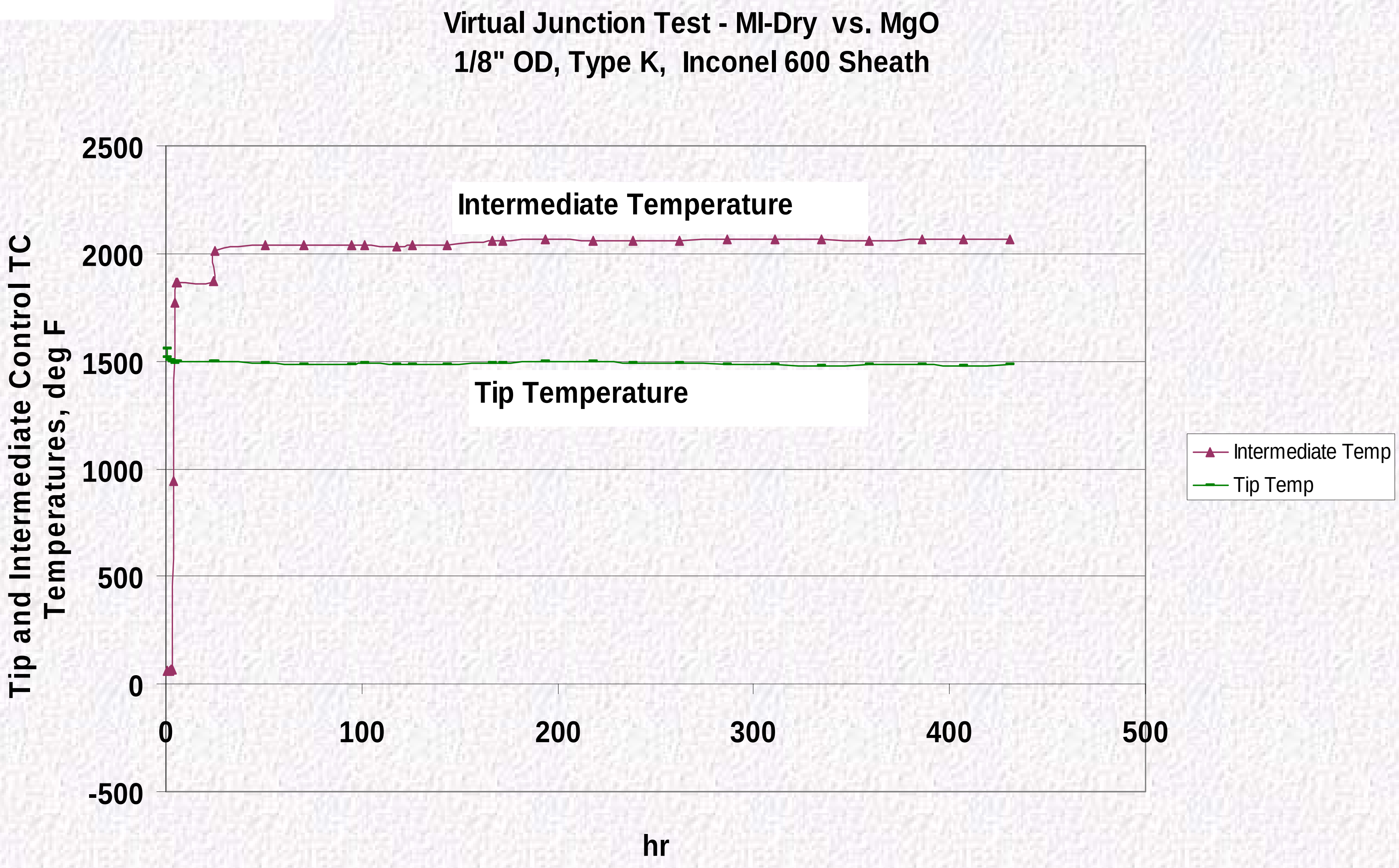
Insulation Resistance - Type K Thermocouples - 1200 C
(1/4" OD, Inconel 600 sheath material)



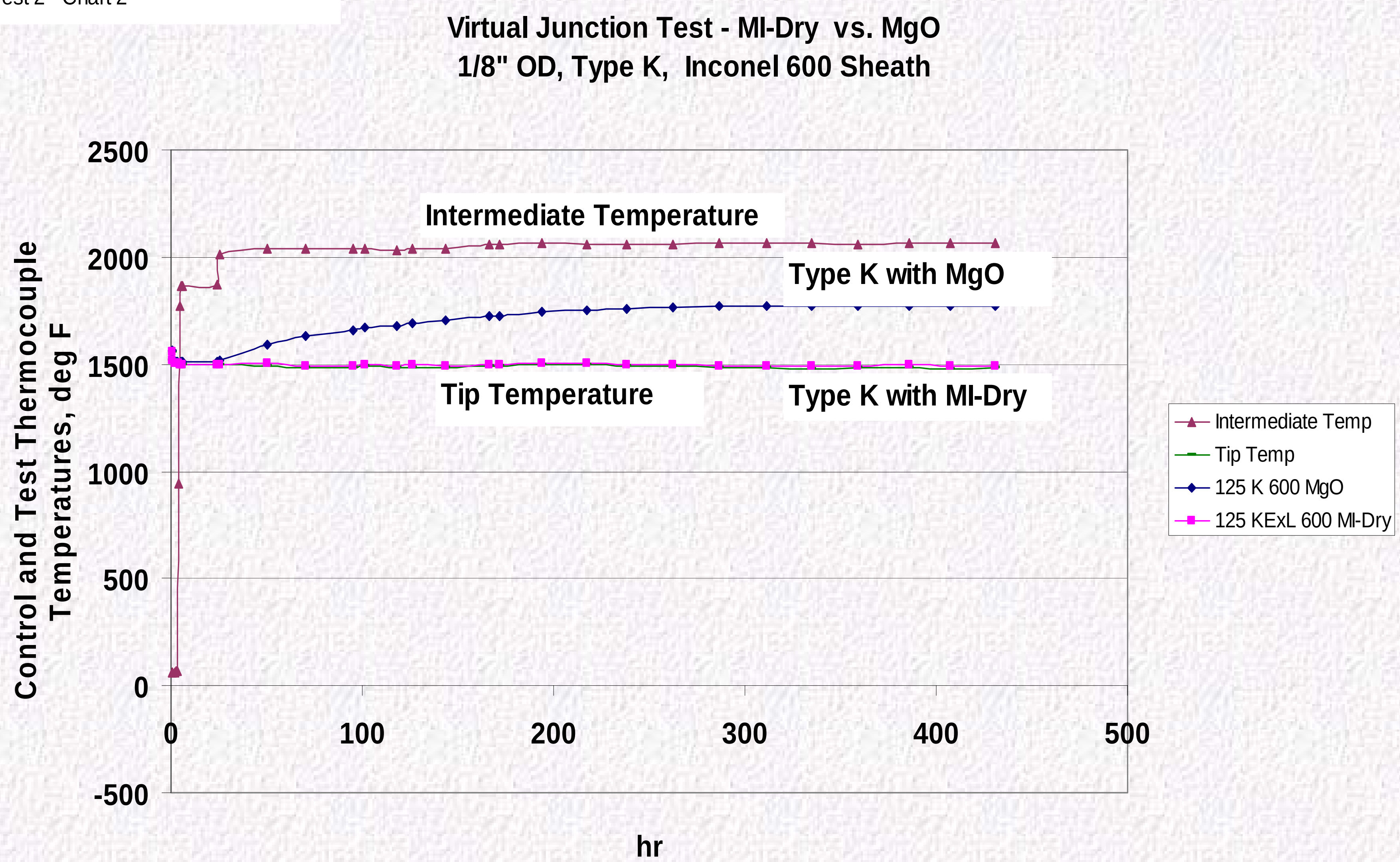
Virtual Junction Test



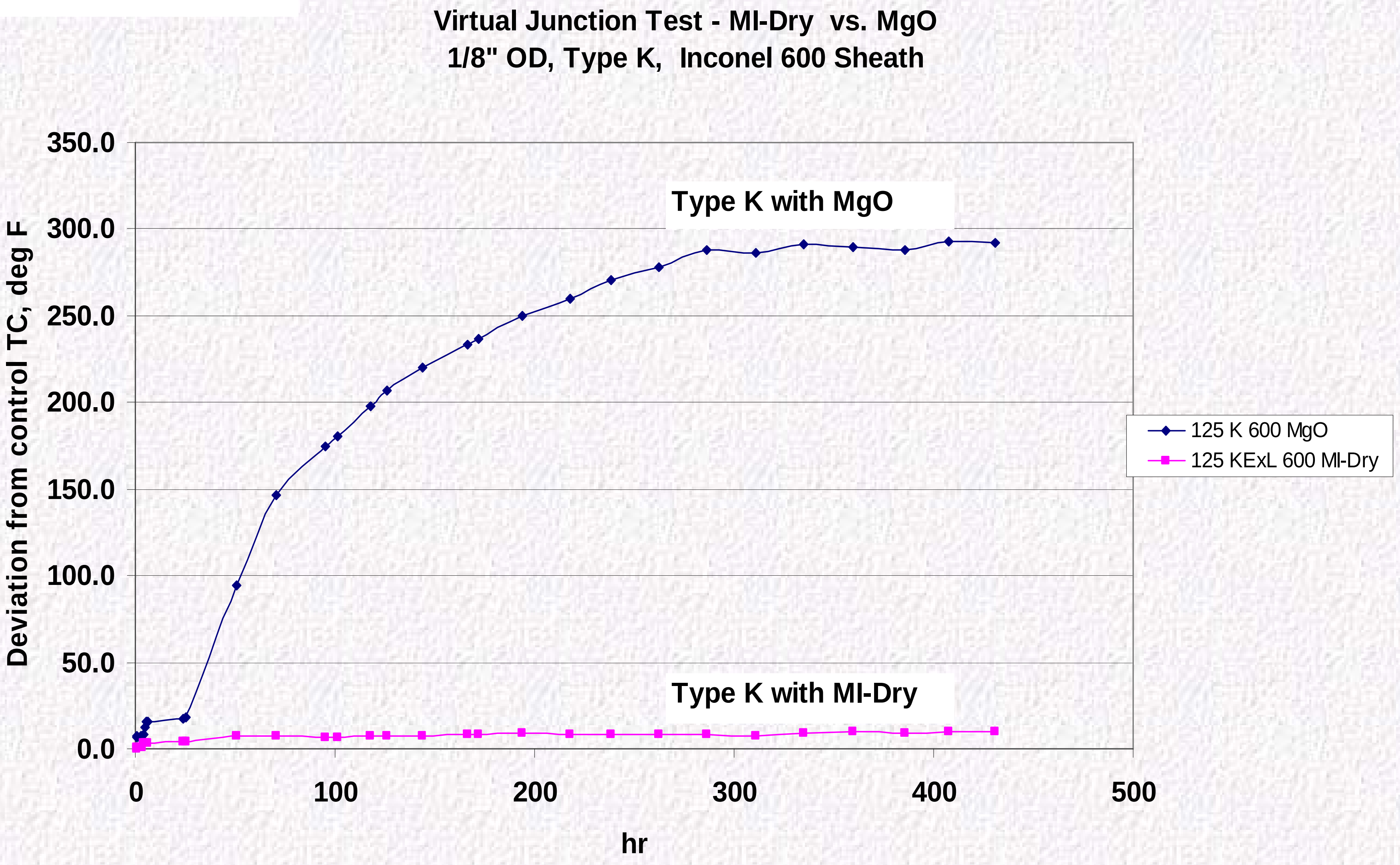
Test 2 - Chart 1



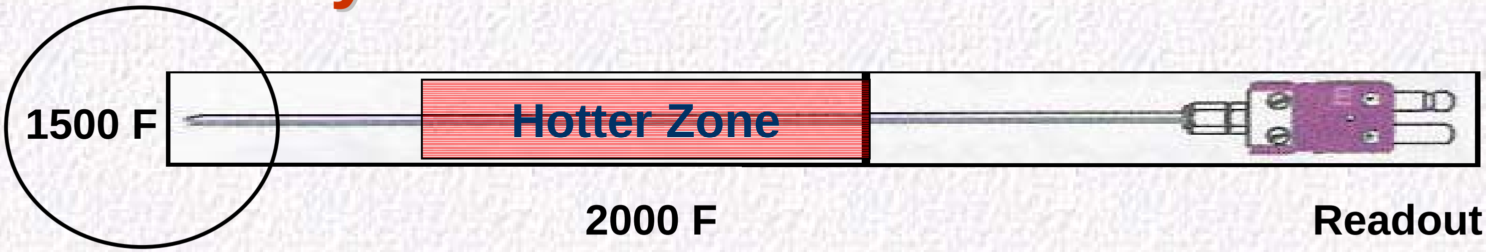
Test 2 - Chart 2



Test 2 - Chart 3



MI-Dry also solves another Problem



Process Vessel

Virtual Junction Error:

- Temperature along length exceeds that of the hot tip
- If MgO Insulation breaks down, shunting can occur
- Secondary – or virtual – junction is formed
- Error in the readout occurs

……. The advantages of MI-Dry significantly reduces or eliminates the risk of temperature uncertainties caused by Virtual Junction Error in furnace application

<u>Both RTDs and Thermocouples Decalibrate & Fail</u>

- The real problem? – RTDs and Thermocouples drift unpredictably in on-set, direction and magnitude. They fail without warning.
- This problem is very costly.

The solution is <u>In situ</u> <u>calibration</u>.

<u>A New class of Sensors</u> –
In Situ Self - Validating/Diagnostics Sensors

The 1st Truly Self-Validating Sensor is the <u>SVS</u>

A New Class of Temperature Device

"In-situ, Self-Validating, Self-Validating Sensors"

Self Validating/Diagnostic Sensor

"Smart Probe"

Self Validation, Self Diagnostic (in-situ calibration)

- ✓Unique Sensor Design (-200ºC to 1750ºC)
- ✓Specially designed Transmitter
- ✓Both Validated Temperature AND Sensor Health

SVS Sensor – Smart Probe

- ✓Accurate, Repeatable Temperatures – Test Data +/- 0.125% of range @ 1200ºC) for the in service life of the sensor.
- ✓Longer Life (Test Data SVS 2311 - > 2X)
- ✓Predictive Maintenance (Health Status)

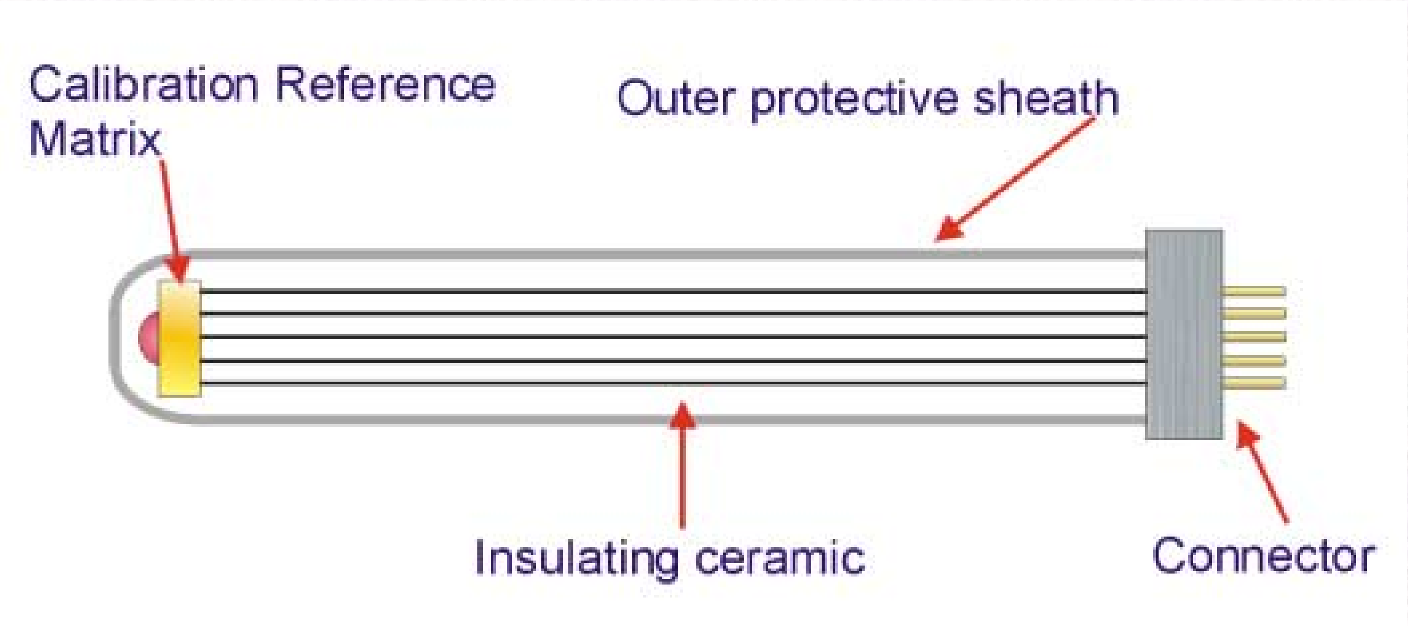
SVS - Self Validating Sensor

How does it work?

<u>Central Principals</u>:

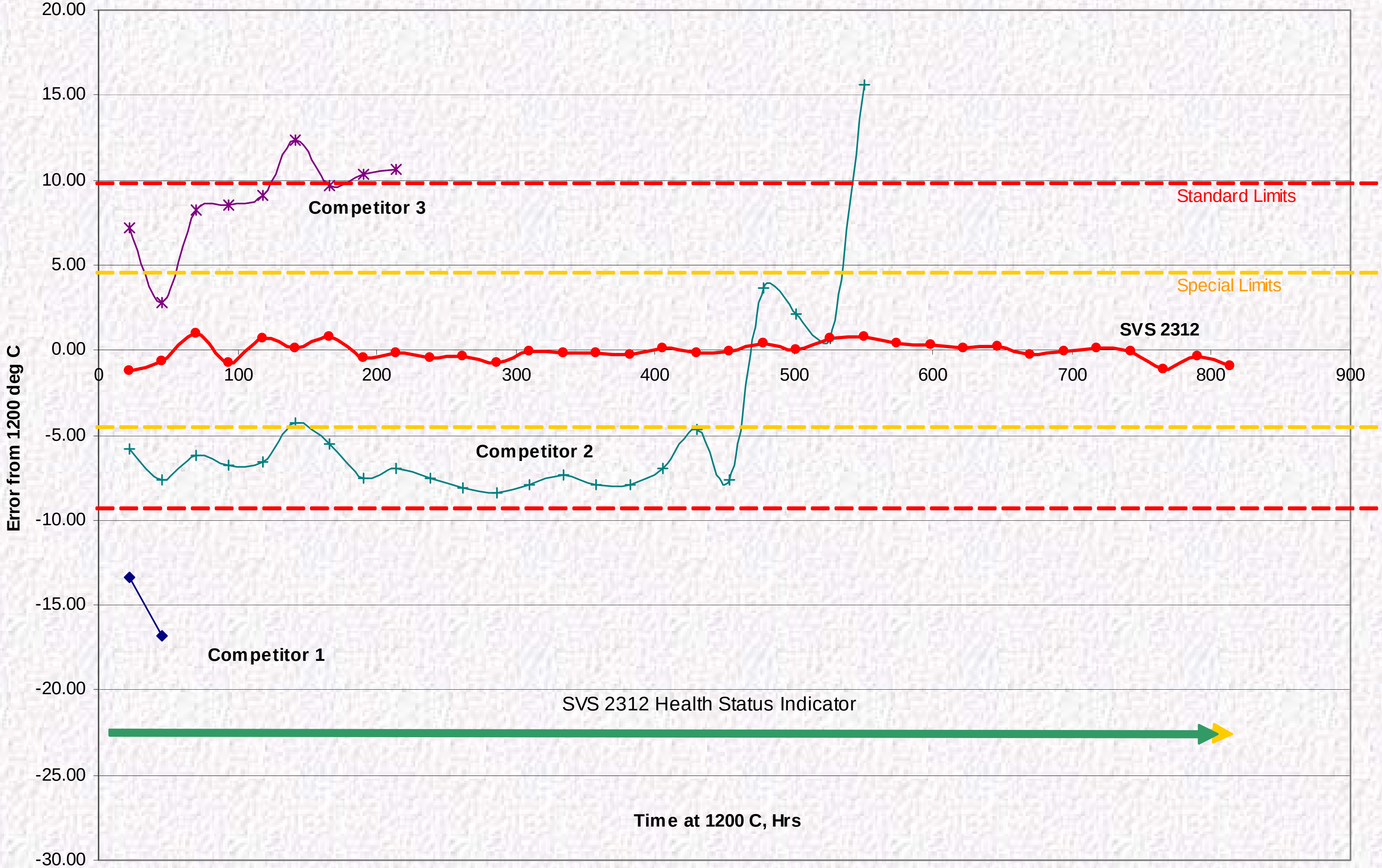
1. Accurately measure multiple, mutually exclusive thermoelectric signals from a combination of thermally sensitive materials in the tip of the sensor.
2. Monitor the "health" of each individual element in the matrix such that:
   - <u>no element can "drift" without detection</u>.
   - no signal from any combination of elements can "drift" without detection.
3. <u>Report</u> a validated, NIST traceable <u>Temperature</u> and <u>Sensor Health</u> for the life of the Sensor.
4. Warn the operator in advance of loss of Validation

AccuTru's Patented Self-Validating, Self Diagnostic Temperature Sensor (SVS™)



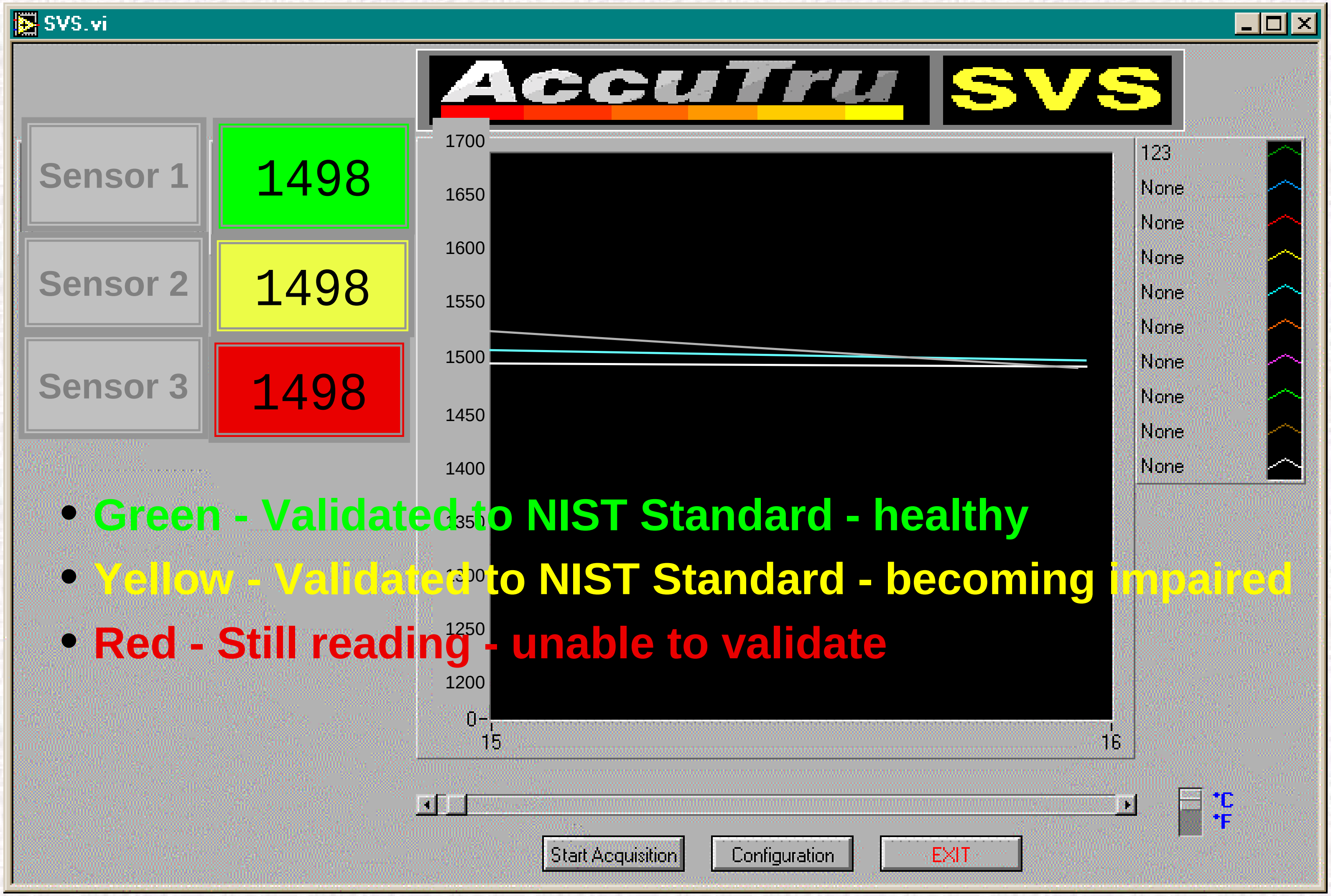
SVS™ System Accuracy and Stability

SVS 2311 vs. Competitor Type K's @ 1200 C



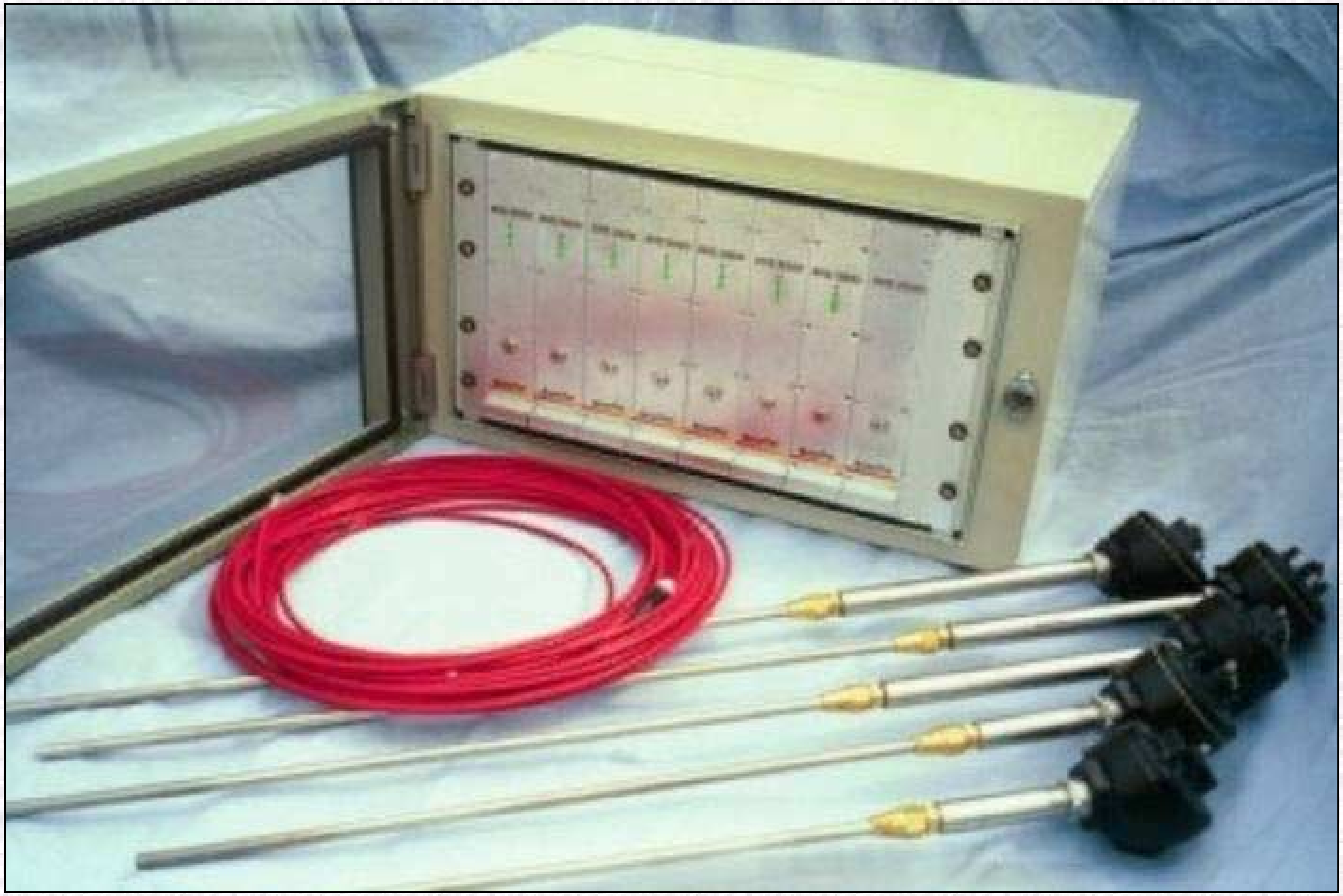
SVS Validating/Diagnostic Signal Conditioner Transmitters

- Green - Validated to NIST Standard - healthy
- Yellow - Validated to NIST Standard - becoming impaired
- Red - Still reading - unable to validate

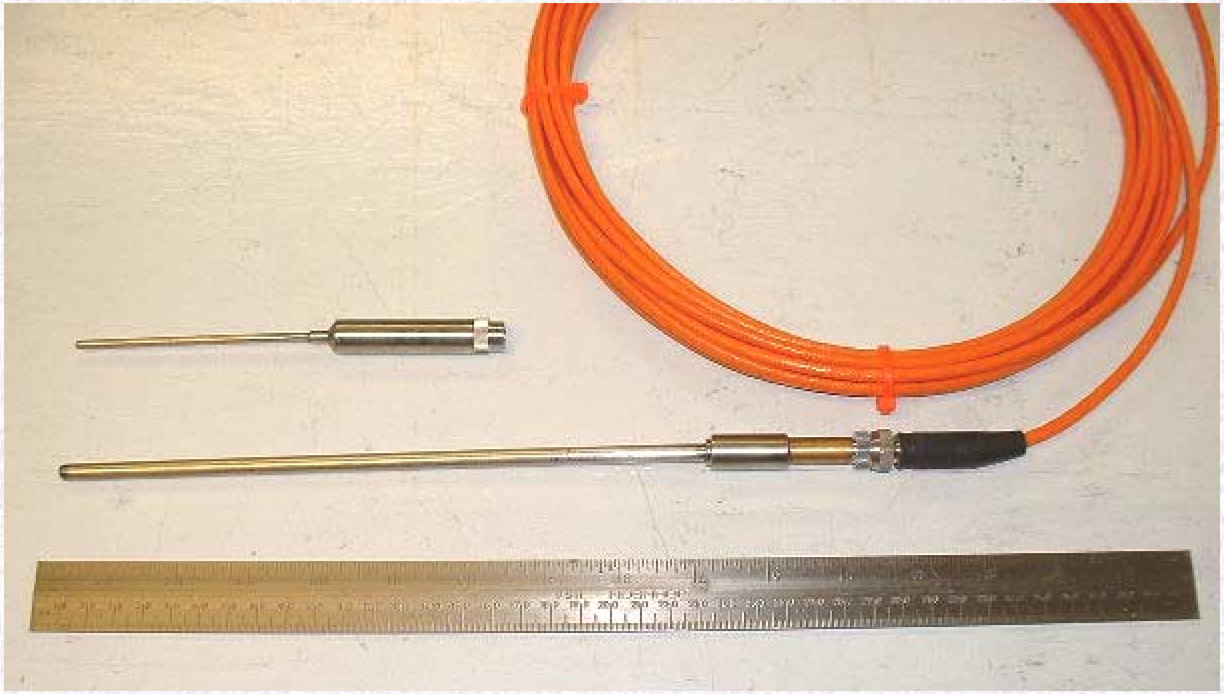


- Green - Validated to NIST Standard - healthy
- Yellow - Validated to NIST Standard - becoming impaired
- Red - Still reading - unable to validate

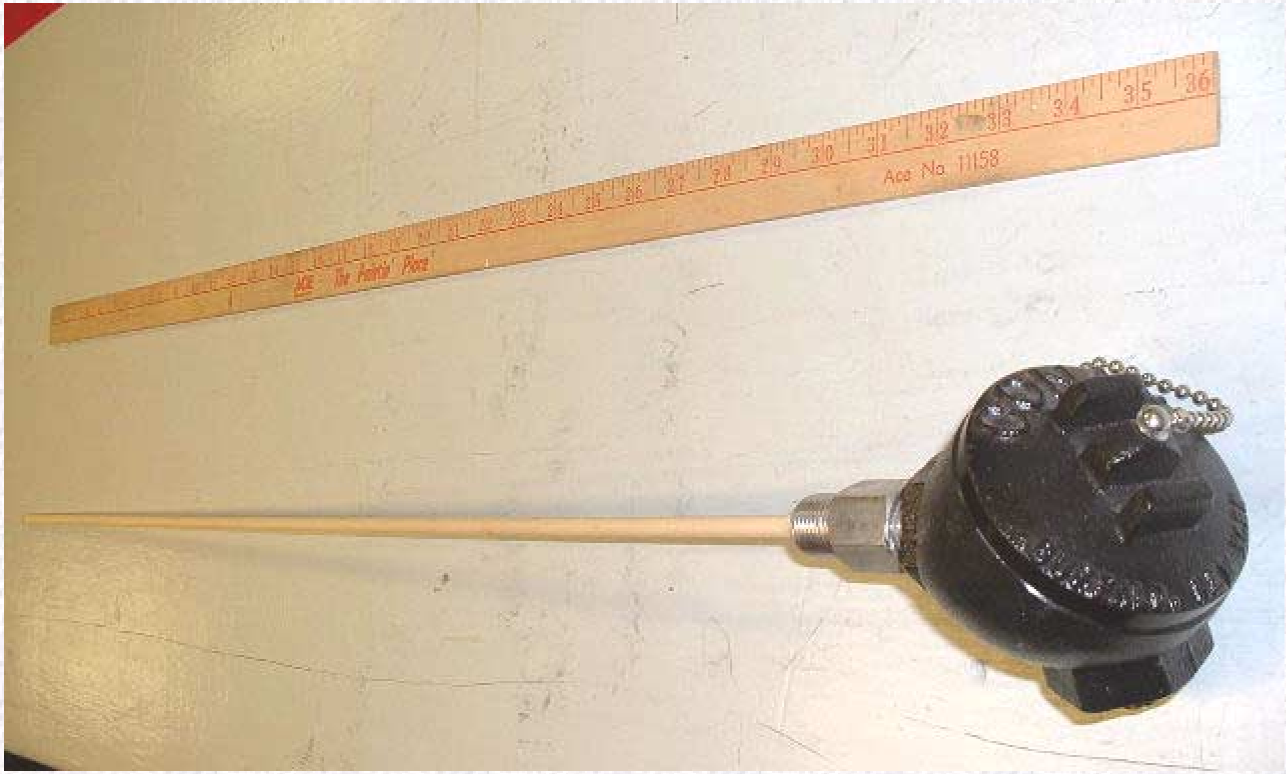
The SVS™ System



Metal Sheath SVS Sensor Probes



Ceramic Sheathed SVS Probe



SVS System Description

U.S. Patent **Feb. 3, 1998** **Sheet 2 of 2** **5,713,668**

FIG. 3

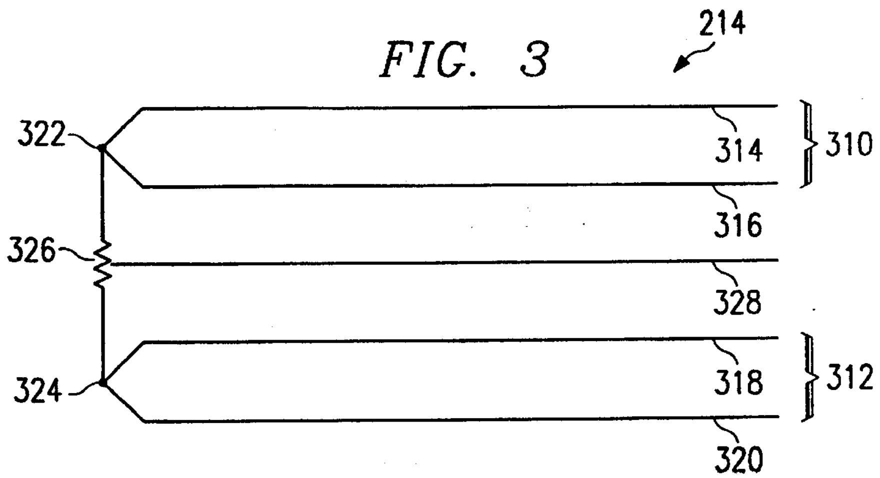
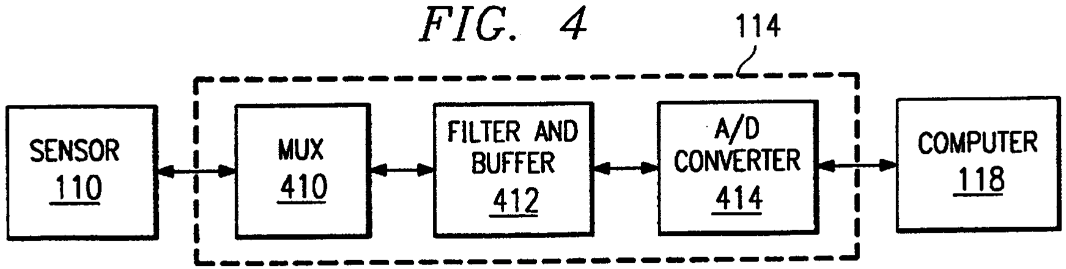
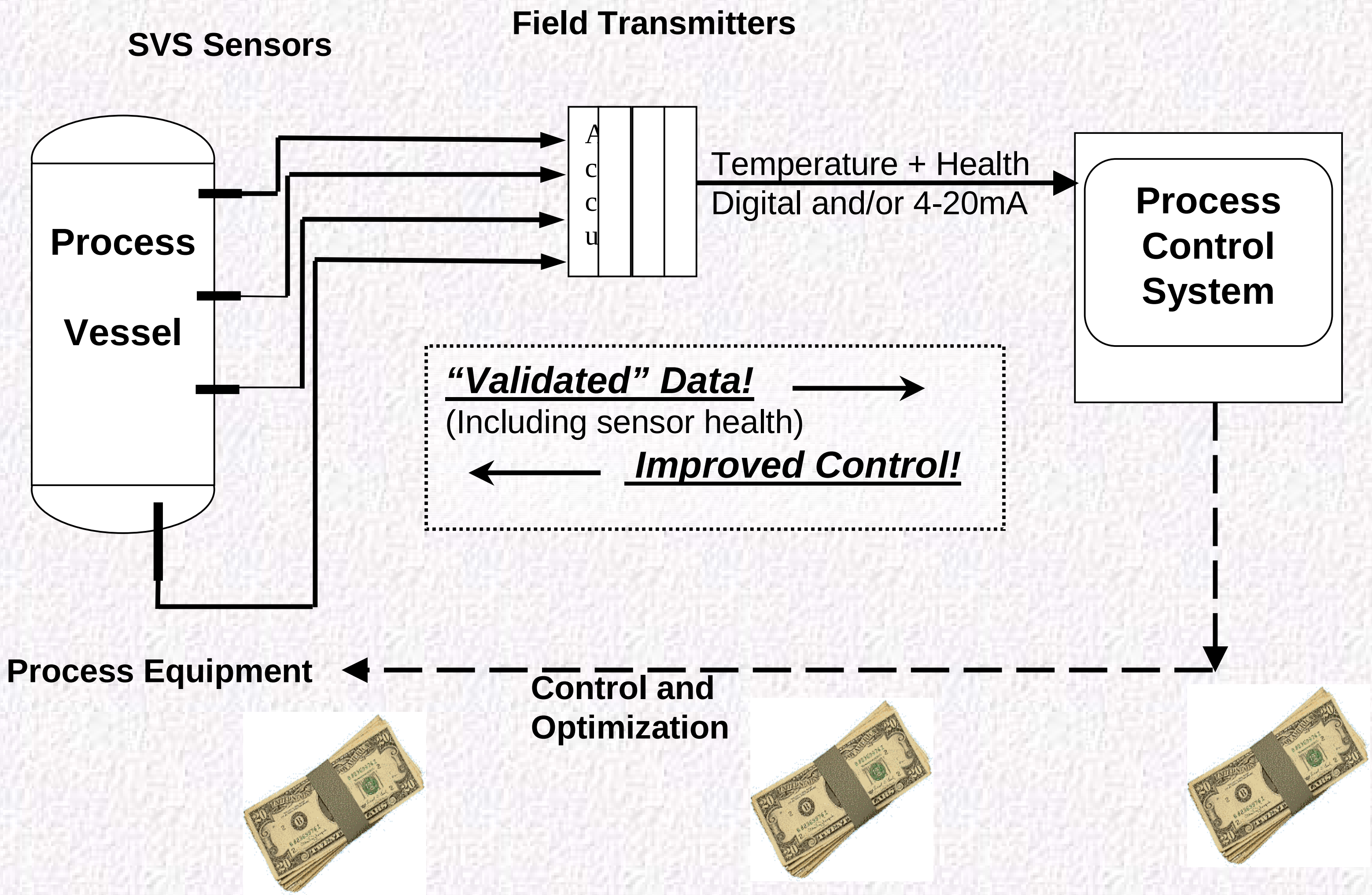


FIG. 4



The SVS Sensor Advantage



Types of SVS Applications

- Refineries
- Chemicals, Polymer Manufacturing
- Glass Manufacturers
- Waste Processing
- Brazing Furnace
- Heat Treating
- Calibrations Lab
- Petrochemicals
- Pharmaceuticals
- Turbine Engines
- Co-Gen Units
- Incinerator

Squeeze all the Juice from the Lemon

or

Do it right the first time

Design the Process with Measurements in Mind

New Projects – Check List
The Big Pieces

Define the NEED

(Look at the Process and the Control Objective!)

Calibration -> Temperature range, use of data

Accuracy, Repeatability, Stability, Response

Protection -> Process Environment

Gas, Liq, Corrosives, Particulates, Velocity, etc.

Connection -> Process Vessel

Process connection, configuration, Maintenance

Termination -> Human Interface

Cold End, Lead Wire, Signal Conditioner

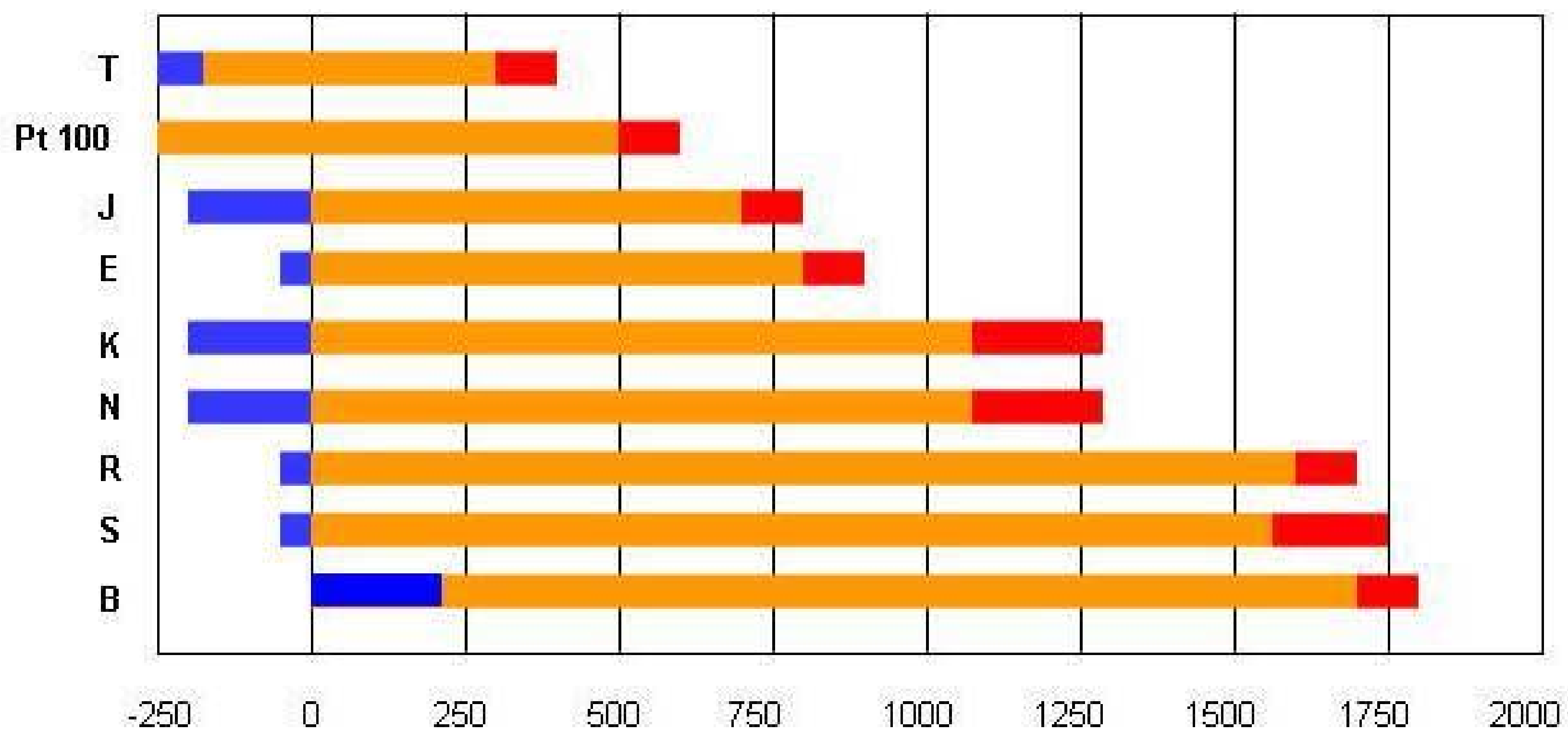
Consider Cost vs. Cost Savings

(Life cycle costs)

New Projects – Check List
More Big Pieces

- Quantity of sensors required
- Standard material sizes that are available
- Actual running and over-temp conditions
- Expected lifecycle and lifetime demands
- Potential reuse of components
- Scrap values
- New materials
- Calibration requirements
- Speed of supply

Recommended Sensor Temperature Ranges

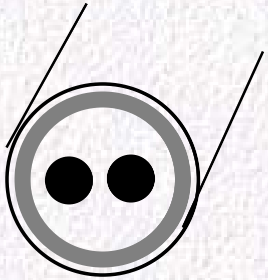


Device Comparisons

Characteristic	Thermocouple	RTD (Resistance Temperature Device)	Infrared	Thermistors
Temperature Range	-250 Cº to + 2600 C	-200º C to +850º C	-50º C to 3000º C	-60º C to 300º C
Accuracy	Less Accurate	More Accurate	Less Accurate	Less Accurate
Drift (Stability)	Limited Lifetime	Good—but does drift	Good	Good
Repeatability	Reasonable	Good	Fair	Good
Response	Fast	Slow	Medium	Fast
Linearity	Not Linear	Linear	Linear	Not Linear
Hysteresis	Excellent	Good	Good	Good
Vibration	Very Resistant	Marginal	Tolerant	Good
Reference Junction	Required	Not Needed	Not Needed	Not Needed
Measurement Area	Single Point (Tip)	Length of element	Bead (Small)	Varies
Size (Diameters)	From 0.25 mm Up	From 3.00 mm Up	Varies	From 0.5 mm
Lead Wire Resistance	Not an issue	Very Important	Not an issue	Not an issue
Contact Required	Yes	Yes	No	Yes

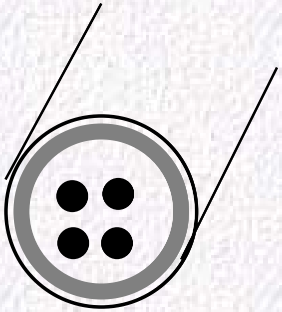
Duals vs. Singles

0.250 OD Thermocouples



Sensor Element

Single Construction



Sensor Element

Dual Construction

AWG 16

Diameter 0.0508 in.

Cross Sectional Area
0.002027 sq. in.

59% More area than AWG 18

AWG 18

Diameter 0.0403 in.

Cross Sectional Area
0.001275 sq. in.

Installation Check List

Immersion depth –

Thermal Lag/Capacity –

Inhomogenity –

Isothermal-

EMI –

Radiation –

VJE – “Phone a Friend” 1-281-358-5600 or team1@accutru.com

Summary
"Hints for good measurements"

- *Pick* ***the right sensor for the job*** *– be specific*
- *Choose the sensor* ***sheath*** *(&* ***Thermowell****) carefully – be specific*
- ***Bigger is better*** *when it comes to* ***thermal stability –*** *Only buy sensor made from* ***special limits wire/cable***
- ***Calibrations are no guarantee***
- ***Be careful of insertion depths***
- ***Lead wire & connectors*** *are part of the sensor*
- ***Transitions*** *must be "cool"*
- *Shield from* ***Radiation***
- ***Protect wiring junctions***
- ***Document***

Wiring Considerations (Ensure Good Practice)

Ground loops, (isolators)

Magnetic & Capacitive Coupling (twisted, shielded)

Radio Interference (Filters, RFI shielding)

Lead Resistance

……. Never run signal leads in the same conduit or tray as power mains, relay leads or other high level voltages or currents.

……. Never connect the shield of a wire to anything other than the circuit common of the input of the product being driven by a signal.

Troubleshooting Check List
(When a Sensor has a Problem)

•*Check* ***Connections***
•***Check resent run history***
•*Check against* ***other measurements***
•*Check* ***connections*** *again*
•*Keep* ***records of failures***
•***Save failed sensors*** *if you think they should perform better*
•***Post mortem analysis*** *may be a good investment.*

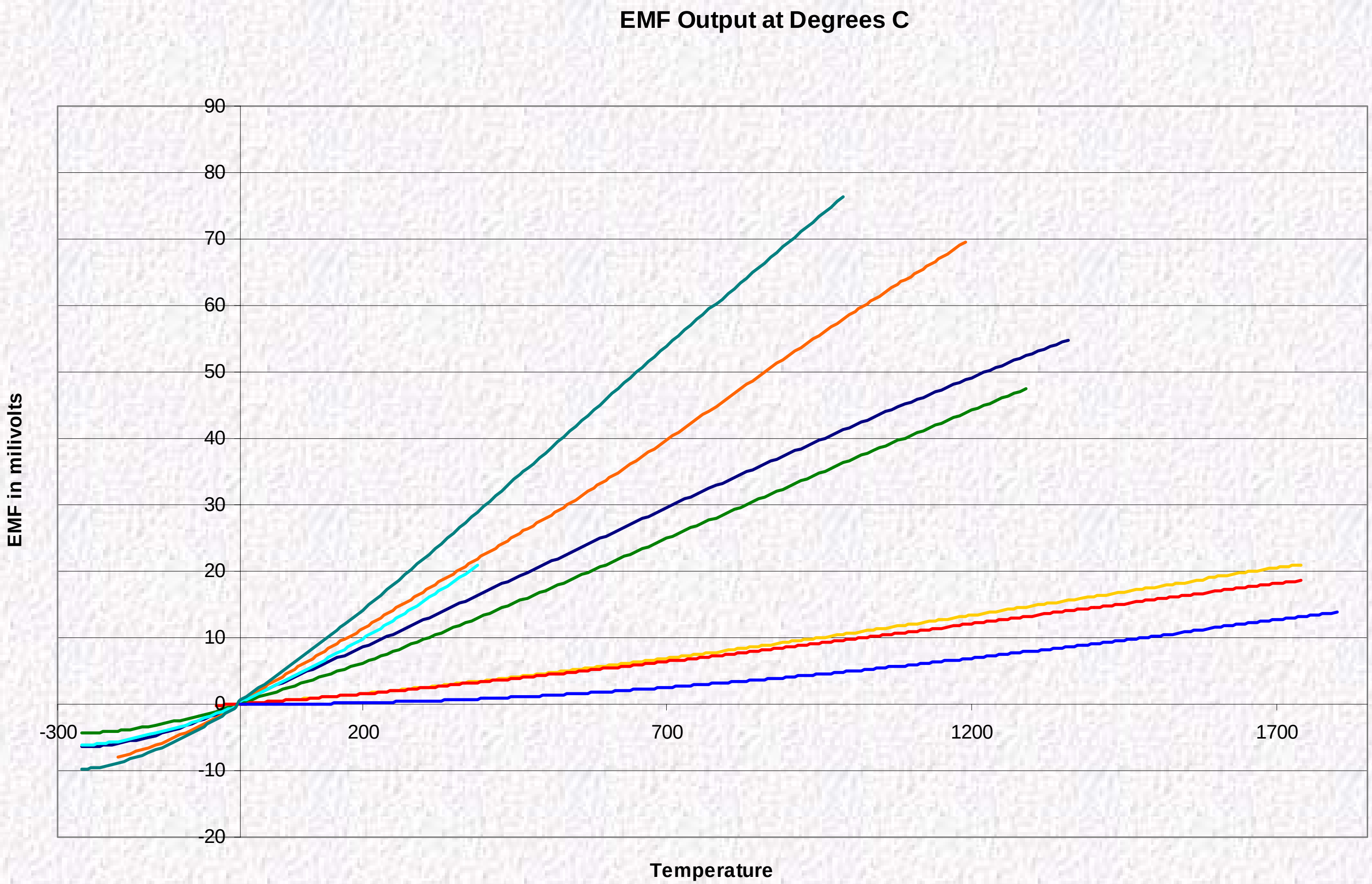
Dead Sensors do Remember

Bottom Line

You do not have to live with bad temperature data

- •Design with the sensor in mind
- •Specify for success (get help, quality)
- •Protection (Sensor, Signals)
- •Check (What you get, Installation)
- •Double Check (Operation, Reference)
- •Re-check connections
- •Watch for new technology

Old ways may not be the best/most cost efficient ways


EMF Output at Degrees C
EMF in milivolts
90
80
70
60
50
40
30
20
10
0
-10
-20
-300
200
700
1200
1700
Temperature

Both RTDs and Thermocouples Decalibrate & Fail

•The real problem! – RTDs and Thermocouples drift unpredictably in on-set, direction and magnitude. They fail without warning.

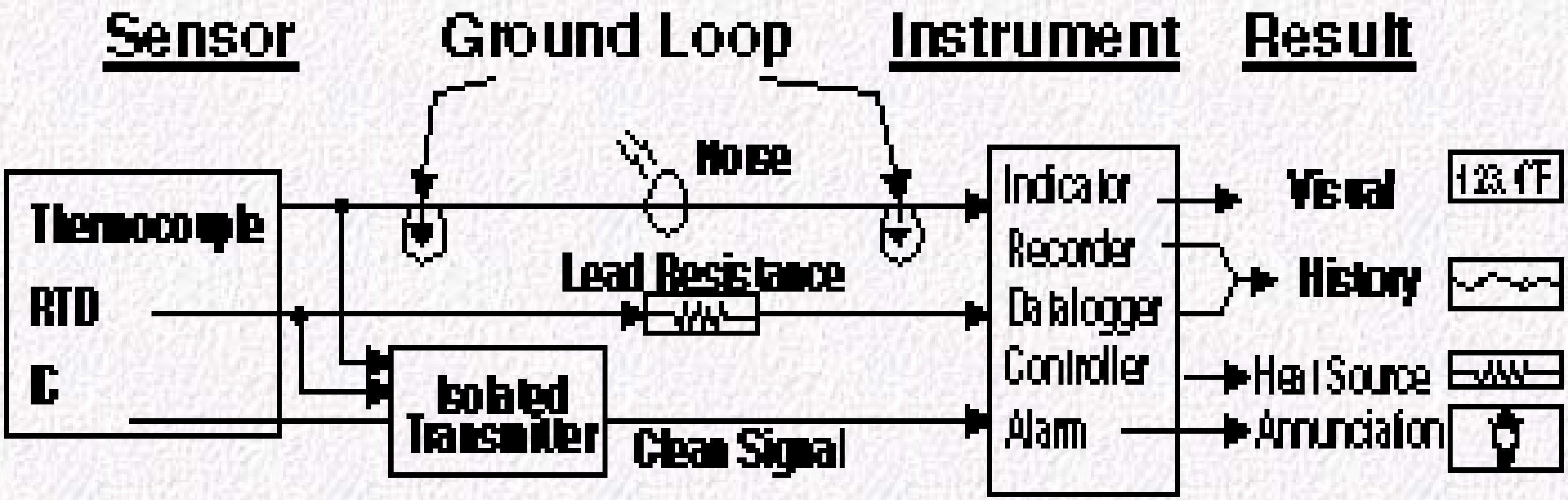
•This problem is very costly.

"Off spec products, false shut downs, poor fuel consumption, failed safety controls, increased emissions and loss of equipment life caused by unreliable sensors cost industry billions of dollars each year."

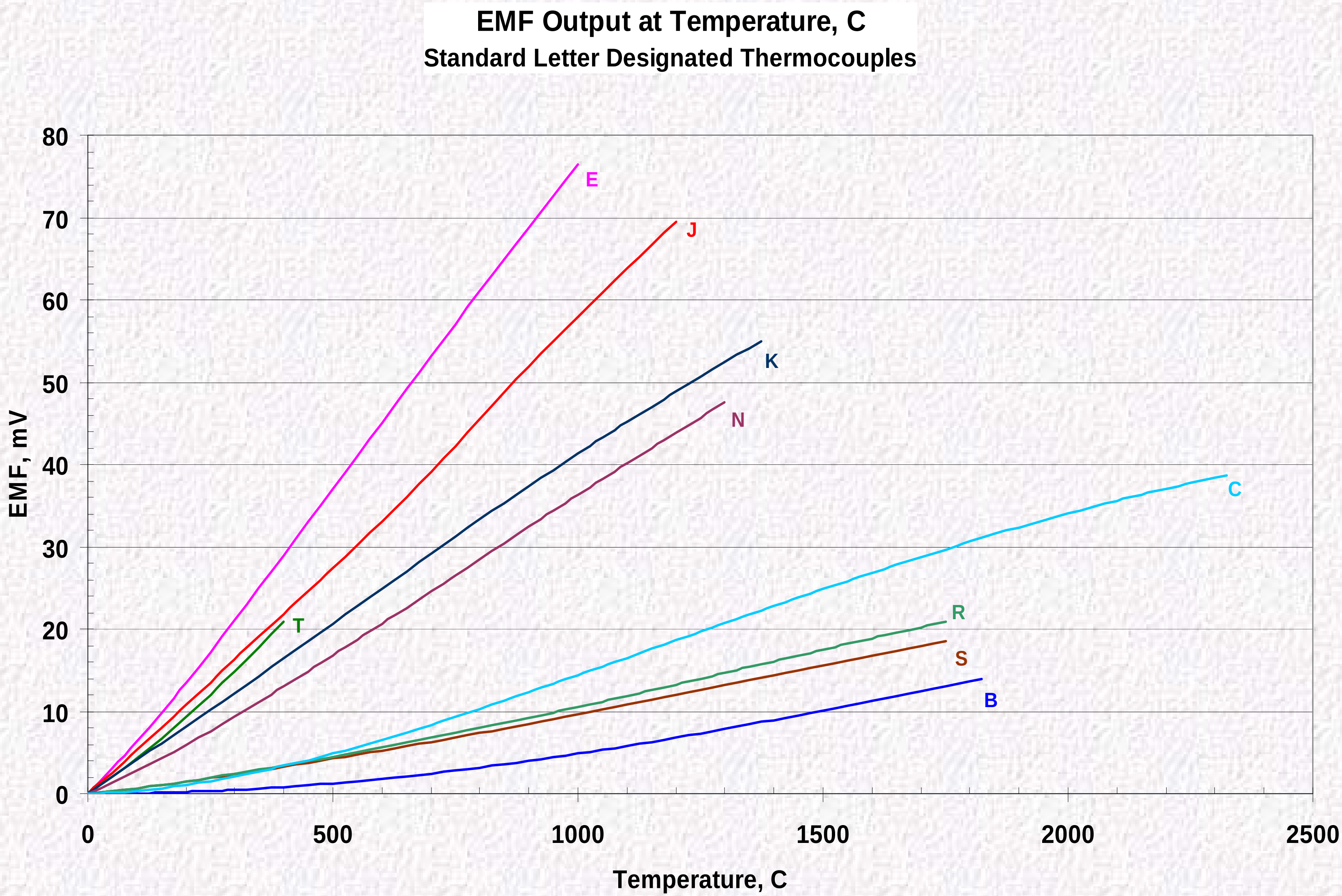
Materials Comparison

	Typical Fabricator	AST
Starting Cable	Open Market	Controlled Manufacture
Insulation	MgO	Mi-Dry
Thermal Wire	Industry Std	Industry Std
Sheath Material	Industry Std	Industry Std
Extension Wire	Extension Grade	Thermocouple Grade
Plugs	Hollow Pin	Solid Pin

Why Transmitters



Ground Loops = Errors
Noise = Errors
Lead Resistance = Errors
Clean Signal = No Problems


EMF Output at Temperature, C
Standard Letter Designated Thermocouples
EMF, mV
Temperature, C
0
10
20
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RTD's vs. SVS411