Advanced Energy | TEGAM®

A GUIDE TO

Temperature Measurement

When the Measurement Matters, Be Certain with TEGAM.

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Forward

A group of our engineers were conversing with one of our home brewing friends about his production process. We were attempting to answer this question: “What was the best temperature probe to use for brewing beer?” The lively discussion produced as many answers as there were engineers at the table. That led to a follow-on discussion: “What do you need to know to select the best temperature probe for an application?” This ultimately led to the production of this temperature measurement selection guide.

We decided that although temperature measurement seems simple, it actually requires a complex system of sensors, instruments, and interconnections. Each of these system components must be thoughtfully evaluated in light of each user’s needs. Based on that evaluation, each user’s choices must then be compatible with the environment, the media being measured, and any regulatory and safety requirements.

Multiple engineers with many years of temperature measurement experience across multiple industries contributed their expertise to this guide. Their expertise was aimed at one goal: To help you select the best temperature probe for your application.

The Chapters walk you through the selection process.

Chapter I gives an overview of the requirements needed to make a probe and instrument selection. It then details the selection criteria for each of the three main types of temperature sensors. The guide then describes and compares the three main types of sensors: thermocouples, RTDs, and thermistors with range and accuracy data. This provides you, the reader, with the knowledge base to select the most appropriate sensor for your measurement task.

Chapter II details probe construction and how to select the right configuration.
The options include sensor type, hot end style, materials, insulation, and connection technology. In combination, these choices enable you to establish clear requirements for the probe portion of your new temperature measurement instrument.

Chapter III completes your measurement system selection process.
It details the specifications necessary to select the proper instrument for your application.

These include the difference between accuracy and repeatability and compares the differences between budget and more expensive instruments . Once you have selected the instrument, you often need to adjust its zero so the instrument reads zero when at zero degrees. It also discusses some of the more subtle elements that are often overlooked but can be very important in probe and instrument selection. These include the impacts of the system response time, screen lighting, keypad/control design, and battery life. It concludes with a review of the types of data collection, an often overlooked but critical need for any system.

The ADDENDUM provides information about intrinsic safety to inform you about the availability of special instruments (often required) in areas with explosive fumes or materials.

In addition, the ADDENDUM also includes an overview of the TEGAM calibration warranty and measurement traceability.

The SUMMARY is a brief review of what you need to consider to make your selections.

> [By the way, our home brewer friend uses a 2-temperature whole-grain extraction process to produce a sour beer. In addition to verifying the two proper mash temperatures, he also needed to hold the mash temperature at 100°F for 12 hours to assure proper souring.
>
> **The solution:** A 0.125" diameter 18" long Stainless Steel immersion style type E thermocouple probe. Additional features included an FEP (waterproof) insulation with a mini thermocouple connector attached to a handheld data thermometer. The battery-powered instrument specified a 500 hour battery life from 3-AA batteries. It also included a wireless Bluetooth® connection to a cloud database from a smartphone. That allowed our friend to perform other tasks around the house and still monitor the souring temperature. He was also able to download the log of the entire temperature routine to the cloud, then download it to his laptop for future reference. P.S. The beer was delicious!]

Table of Contents

CHAPTER I – Temperature Measurement Is a System

CHAPTER II – Temperature Probes Types and Use

CHAPTER III – Thermometry Instrument Selection

Chapter I

There are so many factors at play in selecting the best temperature probe and thermometer for a measurement in industry. This chapter tries to cover the details and give you the knowledge base you need to make the selection of the probe.

Selection begins with answering basic questions to characterize the actual measurement you want to make.

Defining Your Measurement Needs

SAFETY FIRST!

- Are hazardous or explosive materials present?
- If a human is involved in the measurement, are the conditions safe for the person?
- Is the measurement area compliant with all electrical and safety codes?

How frequently do you need to measure?

- One-time
- Intervals
- Continuous

Data from the Measurement

- Do you need to record or log the data for later verification?
- Will the technician also need to write down relevant notes?
- Will the measurement trigger an automatic action?

What Accuracy and Repeatability of the Temperature Measurement is required?

- Temperature range
- Measurement accuracy
- Measurement repeatability

Key Assessments Affecting the Instrument Selection

The media you are measuring primarily determines the form factor of the sensor

- Liquid requires immersion probes
- Gas generally requires a fast response “air” probe
- Surface measurements need a spring, flat ribbon or surface mountable probe
- Measurements inside a chamber require a probe that can withstand extremes
- A corrosive environment is a factor in all of the above
- Presence of explosive materials

Location parameters of what you are measuring

- Indoors or outdoors?
- Excessive heat or cold?
- Is it a washdown area?
- Is there movement or vibration during the measurement?

Regulations

- Are there regulatory standards that require you to document your measurements such as food safety, cleanability, or other standards?
- Will your instruments require an ISO 17025 traceable Calibration Certificate?
- Do you need a calibration certificate with documented readings?

Additional Selection Criteria

- **Data requirements:** Where does the measurement data need to be transmitted as compared to the actual measurement point? Example: The measuring point may be inside an oven while the monitoring point may be in an air-conditioned control room. Or the measurement may need to be routed into a database that assesses temperature data for “out-of-range” readings.
- **Portability of the measurement system:** Temperature measurement is often used to monitor multiple locations within a facility to spot check key production metrics. Rather than installing multiple fixed location systems, a technician with a portable handheld thermometer and probe can monitor multiple measurement locations.
- **Sensor type based on temperature range:** The sensor and all components must be able to withstand the temperatures in the measurement environment. High temperatures over 500°C/1000°F typically use a thermocouple. Measurements at lower temperatures can use RTD, thermistor, or thermocouple sensors.
- **Probe construction:** The probe must be made of the appropriate materials to withstand both the corrosiveness and the temperature in the measured environment.
- **Sensor selection and response time:** For each different type of sensor, the construction materials and the size of the sensor impact the response time.
- **Variety of sensor accuracy ranges:** Each type of temperature sensor is available with a range of accuracies to meet individual measurement environments.
- **Sensor selection depends on the type of measurement required:**
  - Surface measurement
  - Immersion into a liquid
  - insertion into a pipe of flowing liquid
  - Insertion into a gas
  - Insertion into frozen material or soil
  - Meeting special sanitary requirements
  - Non-contact measurement

Comparing the Three Main Types of Temperature Sensors

Now that you have an overview of all the details that go into the selection process let's start with comparing the three main types of temperature sensors. Once you make your selection, we will move on to configuring this into the most useful probe configuration.

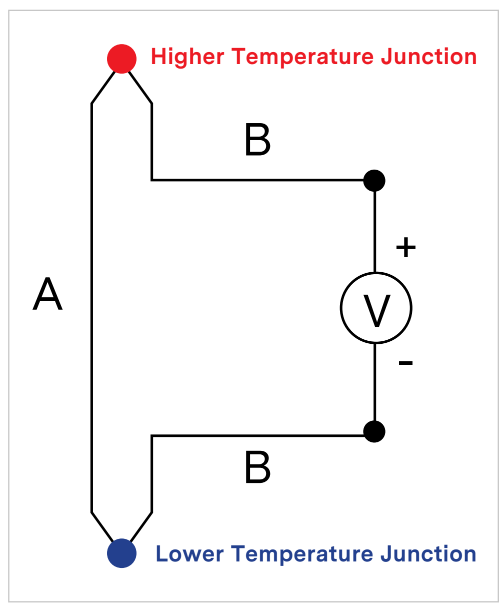
This section compares the three (3) main types of sensors most commonly found in measurement instruments today; thermocouples, Resistance Temperature Detectors (RTDs), and thermistors. At the end of this chapter, you will find a table that compares the characteristics of each of these sensors.

Sensor Type #1: Thermocouple Sensors

Thermocouples			
Range:	-250 to 1372°C (-418 to 2502°F) or up to 1700°C using Platinum TC.	**Form Factors:**	Very Broad; from a fine 36 AWG wire to 0.375 dia. SS or Inconel tube.
Time Response:	Can be mS up to Seconds	**Durability:**	Excellent, some drift at extended high temperatures
Cost:	Low to Medium	**Accuracy (Two Levels)::**	1. Special Limits of Errors: 0.1 to .6°C (0.2 to 1°F) 2. Standard Limits of error: 0.5 to 2°C (0.9 to 3.6°F) *See Table 8*
Wiring Considerations:	Thermocouples require Cold Junction Compensation (CJC). (Usually provided by the instrument.) Wire made from Thermocouple material must be used from the sensor back to an instrument or transmitter which has CJC. From a transmitter, copper wire can then be used.		

A thermocouple's low cost, ruggedness and broad measurement range makes it the most popular sensor for industrial applications. A thermocouple is formed by the junction of two dissimilar metals. They are self-powered because the thermocouple creates a small thermoelectric voltage known as the Seebeck Effect. This voltage is proportional to the difference in the temperature between the hot end and the cold end of the thermocouple. As a result, the instrument requires a known temperature at one end of the thermocouple to calculate the temperature at the other end. The calculation is based on thermocouple voltage tables normalized for the "cold" end at 0°C /32°F. Historically, one end of the thermocouple was literally immersed into a bath of ice water. This method became known as cold junction compensation (CJC). Today, this calculation is done electronically by all thermocouple

The Seebeck Effect



instruments at the connection point of the thermocouple to the instrument.

Thermocouple probes are available in a variety of forms. These range from fine gauge wire, possibly with a washer for attachment up to a metal clad, mineral insulated (MI) cable for industrial applications. Wire thermocouples are available in heavy gauges (8 or 10 AWG) for high temperature measurements or insertion into thermowells down to a very fine gage (36 AWG) which offers very fast response times. MI cable probes can have three different junctions: An exposed junction for air/gas measurement and fast response; a tip-sensitive grounded junction that has fast response in liquids but maintains the protection of the outer jacket; or an ungrounded junction which offers noise and electrical isolation but has a slower response time. MI thermocouples can also be used for such heavy duty applications as penetration probes for frozen food or insertion into the earth.

Thermocouples are available in different alloys. These were developed over the years to meet specific measurement application requirements.

Base metal thermocouples: Types E, J, K, N and T

- Types T and E are the most accurate
- Types K and N perform best at high temperatures
  - N has less drift at prolonged high temperature
- Type J is an industry standard because it is the oldest

Noble Metal thermocouples: Types B. R, S and (unofficially) Type P

- Types B, R, and S are Platinum Rhodium and used for High Temperature Measurements
- Type B is for extreme high temperatures
- Type P, also known as Platinel, was formulated to approximate the K curve. It contains some gold and palladium and is also used for high temperature measurements. It has a higher output than the Platinum Rhodium types

Tungsten Based Thermocouples: Types G, C, D

- Types G, C, and D are used in Hydrogen, inert, or Vacuum Atmospheres at very high temperatures
- Selection can be based upon instrumentation and availability

See **Tables 2 and 3** *for ranges and accuracy.*

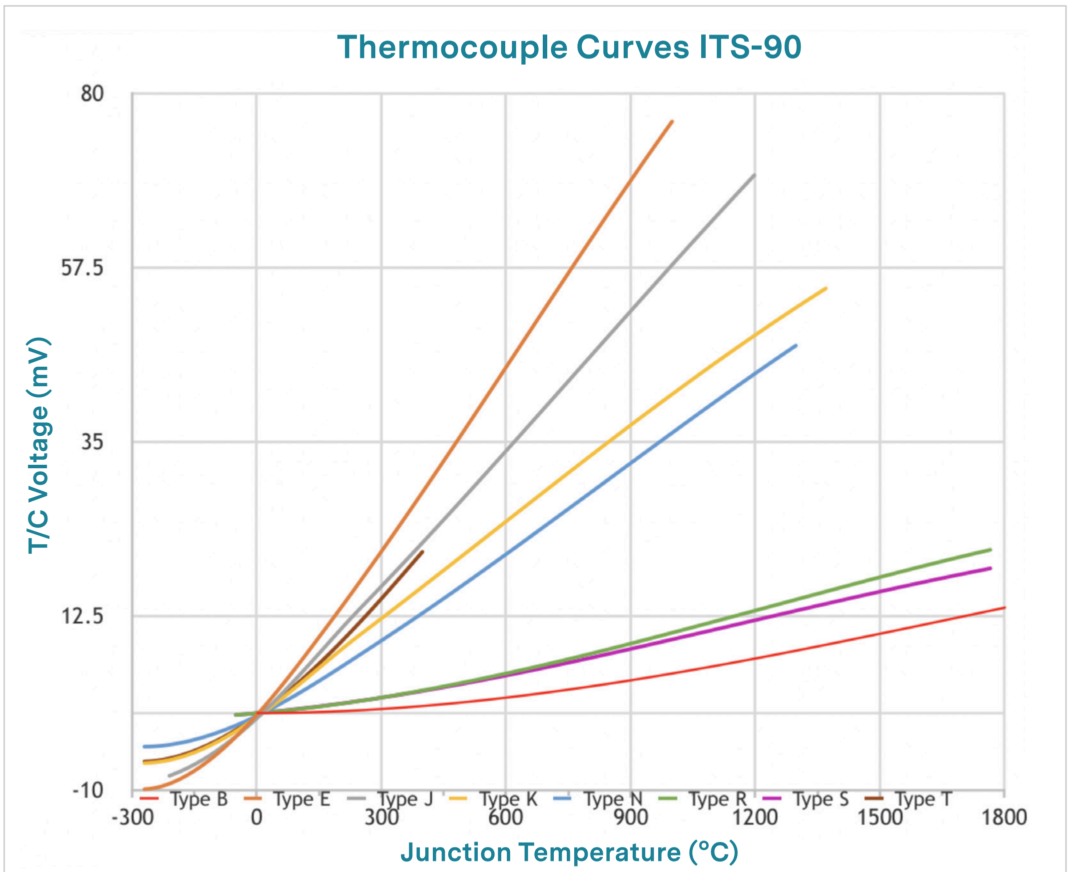
Thermocouples have the broadest operating ranges with good accuracy.

Table 2

	Sensor Type	+ Leg	- Leg	Recommended Range*	
				Range °C	Range °F
Base Metal Thermocouple	E	Chromel	Constantan	-20 to 900°C	-4 to 1600°F
	J	Iron	Constantan	-20 to 760°C	-4 to 1400°F
	K	Chromel	Alumel	-20 to 1260°C	-4 to 2300°F
	N	Nisil	Nicrosil	-20 to 1260°C	-4 to 2300°F
	T	Copper	Constantan	020 to 370°C	-4 to 700°F
Noble Metal TC	B	Pt-30% Rh	Pt-6% Rh	0 to 1705°C	32 to 3100°F
	R	Pt-13% Rh	Pt	-20 to 1480°C	-4 to 2700°F
	S	Pt-10% Rh	Pt	-20 to 1480°C	-4 to 2700 F
Tungsten Metal TC	G (W)	W	W-26% Re	0 to 2315°C	32 to 4200°F
	C (W5)	W5% Re	W-26% Re	0 to 2315°C	32 to 4200°F
	D (W3)	W3% Re	W-25% Re	0 to 2315°C	32 to 4200°F

*E, K and T can be used at subzero temperatures, but this usually requires special selection for sub-zero thermoelectric properties at the time of ordering to meet error limits. See ANSI E-230 for the sub-zero limits.

Table 3



Comparison of the full range of the Thermocouples from Type B through Type T (on X-axis).
The mV output (Y-axis) at temperature (X-axis).
Type E has the highest output and Type B has the lowest output.

A Thermocouple System

For any temperature measurement system, it is critical to examine the application's requirements from end to end.

At the point where the temperature probe attaches to the instrument, the thermometry instrument measures the temperature and uses that cold junction temperature as its algorithm to calculate the temperature of the process being measured. The thermocouple alloy wire must be consistently uniform from the point of measurement to the instrument. It must also withstand temperature along the route, be abrasion resistant, and allow flexing and/or motion.

To display, control, or log temperature data, **thermocouple thermometers** are readily available and relatively inexpensive. These instruments are available in a variety of forms including panel meters, controllers, data loggers and handheld devices. Thermocouple wire is available with many types of insulation including PVC, Teflon, Fiberglass, Kapton, and Ceramic Fiber. Metal over-braiding is also available to add abrasion resistance. For the most rugged needs, a mineral insulated metal jacketed (Stainless Steel (SS) or Inconel) thermocouple cable provides optimum protection.

Industrial components, like thermowells for insertion into pipes, tank walls, or probes with metal heads to protect the connections, are also available for thermocouples. Thermocouples for scientific applications come in forms such as thin ribbon elements for surface measurement, adhesive backed, hermetically sealed, or very fine exposed wire for fast response in air or gas.

Sensor Type #2: Resistance Temperature Devices a.k.a. RTD Probes

The electrical resistance in Resistance Temperature Detectors (RTDs) changes as a function of temperature. The most common RTD Probes are made from high-quality conductive metals, most commonly platinum. RTDs are offered in four different levels of accuracy (Class AA through Class C) as shown in Table 4. The linear resistance change from RTDs results in very accurate temperature measurements as shown for each of the four classes in **Table 5**.

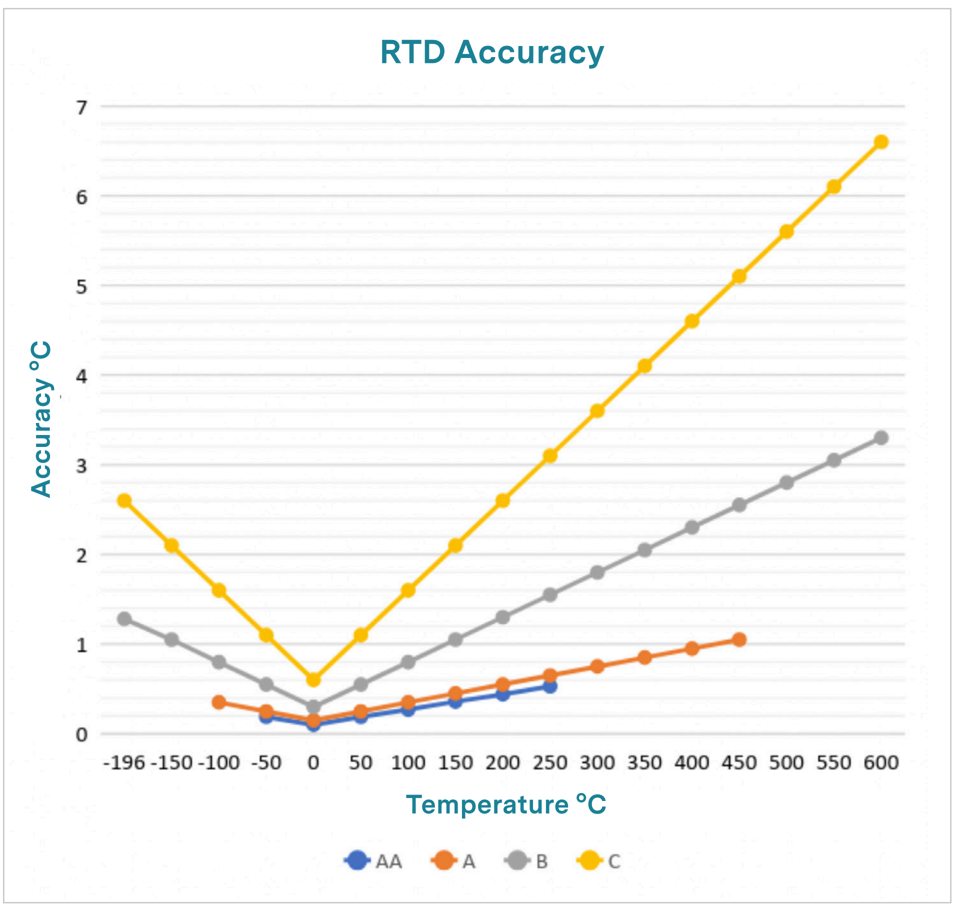
Sensor Type #2: Resistance Temperature Devices a.k.a. RTD Probes

Platinum RTD [PT100] (Resistance Temperature Detector)			
Range:	-200 to 550°C (-328 to 1022°F) (Special purpose elements to 700°C (1292F)	**Form Factors:**	Scientific to Industrial
Time Response:	Typically Seconds	**Durability:**	Shock, vibration sensitive (wire wound)
Cost:	Medium to High	**Accuracy:**	Better than 0.1 to 0.6°C (0.2 to 1°F) *See Tables 4 and 5*
Wiring Considerations:	Because RTDs measure a low resistance change, a 3-wire or 4-wire connection is used and lead length is limited and typically less than 10 feet. Longer leads are possible with the appropriate wire gauge and stimulus current.		

Table 4
RTD Elements are available in 4 levels of accuracy per IEC 60751:2008

°C	Class AA	Class A	Class B	Class C
-196			1.28°C	2.6°C
-150			1.05°C	2.1°C
-100		0.35°C	0.80°C	1.6°C
-50	0.19°C	0.25°C	0.55°C	1.1°C
0	0.10°C	0.15°C	0.30°C	0.6°C
50	0.19°C	0.25°C	0.55°C	1.1°C
100	0.27°C	0.35°C	0.80°C	1.6°C
150	0.36°C	0.45°C	1.05°C	2.1°C
200	0.44°C	0.55°C	1.30°C	2.6°C
250	0.53°C	0.65°C	1.55°C	3.1°C
300		0.75°C	1.80°C	3.6°C
350		0.85°C	2.05°C	4.1°C
400		0.95°C	2.30°C	4.6°C
450		1.05°C	2.55°C	5.1°C
500			2.80°C	5.6°C
550			3.05°C	6.1°C

Table 5
Accuracy plotted for the 4 classes of RTD Elements



A PT100 (Platinum 100 ohm) RTD System

It is important to consider several factors when determining if an RTD is appropriate for your measurement. For example, an RTD element is larger than a thermocouple junction so this must be considered when determining how to mount the sensor. The lead wire can be copper, but because the RTD is a resistance measurement, a compensating method of resistance measuring such as 3-wire or 4-wire system should be used to compensate for lead resistances. (The equipment to which you plan to attach the RTD may well determine the type of wire system needed.) Make sure the insulation can withstand the temperature ranges in the application and is strong enough to protect the leads from abrasion. If there is flexing involved, consider using stranded wire as it is more flexible than solid wire. Keep your leads as short as possible to minimize errors. The instrument will also have a maximum lead resistance specification. Do not exceed it! In some industries such as food or pharmaceutical, there may be environmental or special regulations that could require a specific type of wire insulation.

Vendors offer **RTD thermometers** in a wide variety of standard form factors such as panel meters, controllers, data loggers and handheld devices. These are readily available and relatively inexpensive. RTDs are often used in high accuracy applications. If that is the case, double-check that the instrument's specifications support the accuracy you need for the application.

RTD/Copper sensor wire is available with many types of insulation including PVC, Teflon, Fiberglass, Kapton, and Ceramic Fiber. Metal over-braiding is another option available to add abrasion resistance. For the harshest environments, select a 3-wire or 4-wire copper conductor mineral insulate metal jacketed cable for RTD sensors.

RTD termperature probes are available in many of the same form factors as thermocouples. Typical RTD systems offer a variety of add-on industrial components, such as thermowells for insertion into pipes or tank walls and probes with metal protection heads. Scientific style RTD probes, such as small thick film or thin film elements with adhesive backing or elements hermetically sealed in Teflon(™) PFA are also available. Additionally, small thin film element style RTDs provide relatively fast response times in air or gases.

Although most RTDs are platinum, vendors do offer special purpose RTDs made of copper for use in motor windings and nickel RTDs for low-cost, narrower range applications like air conditioners and consumer goods.

Sensor Type #3: Thermistor Probes

Thermistors			
Range:	-80 to 150°C (-112 to 302°F) (Typical)	**Form Factors:**	Small and can be a custom design
Time Response:	Can be milliseconds up to Seconds (Similar to a thermocouple)	**Durability:**	Good
Cost:	Low	**Accuracy / Interchangeability:**	±0.1°C (±0.2°F)
Wiring Considerations:	Thermistors have large resistance changes so wire length is more relaxed but still limited by total resistance		

A Thermistor System

Like an RTD, a thermistor is a type of resistor which varies with temperature. Thermistors differ from RTDs in the material used. Generally they use a ceramic or polymer embedded in glass versus the pure metals used in RTDs. Thermistors come in many forms, such as beads, rods, and discs, also many leaded and surface mount packages are available. Thermistors typically deliver greater accuracy, but within a more limited temperature range than RTDs. The key distinction for thermistors: They deliver a large change in resistance as an almost parabolic function over a small temperature range. The Steinhart-Hart equation (with parameters supplied by manufacturer) is most often used to define the curve, or the Alpha/Beta formulation, which is a narrow-range simplification and usually calculated from the S-H parameters.

When selecting a **thermistor probe**, review the resistance curves of the thermistor of interest for the desired application. If you are using an Alpha/Beta formulation be sure that the center of the temperature range or control point is in the middle of the thermistor's range. If you are using the full range of the thermistor's range where some areas have small resistance changes the use the full Steinhart-Hart equation.

Thermistor accuracy is usually stated as "interchangeability" which can be as close as 0.1°C or 0.18°F. Thermistors are found in applications that require fine temperature control and this interchangeability. Because their mass is very small with a limited range of 150°C, they deliver a response time comparable to a small thermocouple. Many thermistor probes are used in appliances, so their form factors are often designed for mounting in a small chamber rather than in a more industrial setting. Many forms are available in surface mount styles, but immersion and surface models are also available.

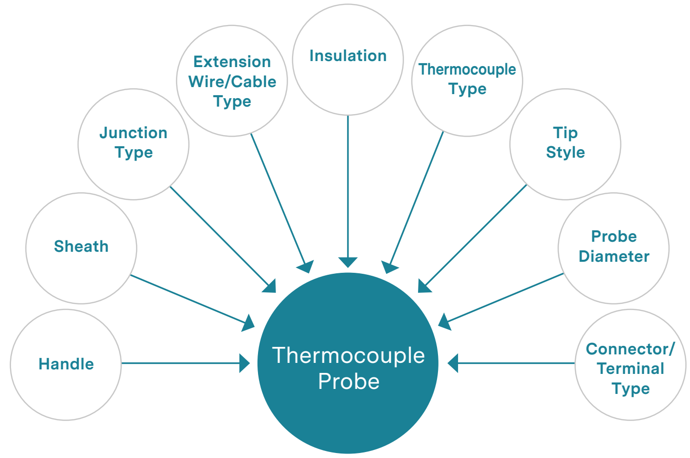
A thermistor system uses a copper connecting wire. The measurement is still a resistance measurement, so for best accuracy use a 3-wire or a 4-wire connection to compensate for lead resistance. Be sure to protect the leads through the entire wire path back to the instrument. Leads must be kept as short as possible and take abrasion and flexing into account when selecting lead wire. Copper sensor wire is also available with many types of insulation including PVC, Teflon, Fiberglass, Kapton, and Ceramic Fiber. Metal over-braiding is again an available option to add abrasion resistance. For the most rugged needs, 3-wire and 4-wire copper conductor mineral insulate metal jacketed cable can be used with the thermistor.

Thermistor instruments must be able to work within the resistance curve of the thermistor. Panel meters, controllers, data loggers and handheld devices are not as common for thermistors as for thermocouple or RTD instruments but are available relatively inexpensively. Heavy duty industrial components, like thermowells for insertion into pipes or tank walls and probes with metal heads are not as readily available for thermistor systems.

Chapter II

Temperature Probe Types and Use

Elements of a Temperature Probe



PROBE DESIGN CONSIDERATIONS

After selecting a sensor technology, the next step is to match the probe with a form factor appropriate to the application. This section goes into the details of a thermocouple probe as they require a little more detail than an RTD probe or Thermistor probes. They are covered also and the form factors apply to all three types of temperature sensors. Careful attention to probe selection leads to accurate long-term temperature measurement.

The 4 Components of a Temperature Probe

1. **The Electrical Connection:** The probe connections must be compatible with the equipment in the measurement environment, and the electrical requirements of the sensor. Connections may vary from short lengths of exposed wire to lengths of insulated wire with any type of standard connector or flying leads. A thermocouple requires that the thermocouple wire runs from the probe to the cold junction compensation in the instrument. RTDs and thermistors can have lead wire resistance limitations and thus require 3, or 4 copper wire connections to keep measurement errors minimal.

2. **The Cold End:** During the selection process, the cold end of the sensor is often overlooked. In many cases a comfortable handle can make the probe much more useful. A prospective user often assumes that if the sensor can measure 700°C, then the whole probe can withstand a 700°C environment. This is often not the case. Only the “hot end” of the probe is rated to 700°C, for instance. The cold end carries a much lower temperature specification due to the wire insulation and sealants used. The environmental media, moisture and liquid exposure (as in washdown areas) must also be considered at the cold end.

3. **The Body:** Obviously, the body of the probe must withstand all conditions in the working environment. For high-temperature and/or corrosive environments, stainless steel or Inconel bodies perform well. Mechanical factors involved include the mounting threads or a washer, sealed metal tube for immersion, or a pointed tip for penetration.

4. **The Hot End:** In use, the hot end is the part of the probe exposed to the measurement medium, which can be as benign as water or as corrosive as hot combustion gasses. Determine if the measurement atmosphere is oxidizing or reducing since each condition requires different materials. In addition, identify the application’s maximum and minimum temperature exposure for the hot end. The construction of the hot end also impacts the response time of the sensor. For example, an exposed sensor can be fastest but will fail in a liquid.

Handle Material:

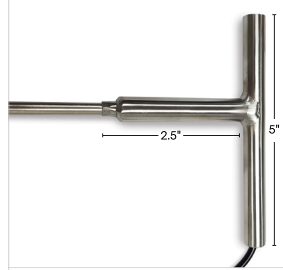
[TEGAM temperature probes](#) come standard with an ABS tri-shape handle. Probes can also be ordered with a stainless-steel T-Handle or no handle at all. Applications vary widely so custom handles can be special ordered to meet unique applications.

- ABS Plastic Handle
- Mini Stainless-Steel T-Handle
- Heavy Duty Large Handle
- No Handle

HANDLE OPTIONS

No Handle (None) 0

T Handle 1

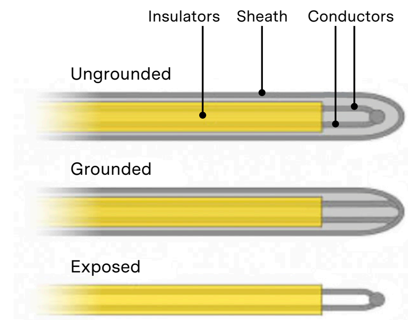


Tri Shape Handle 6

Sheath:

The outer sheath of the probe is most commonly made from one of these materials:

- General Purpose Stainless Steel
- Penetration Stainless Steel
- FEP1 Coated, Stainless Steel Reduced Tip (.156" to .093")
- Heavy Duty Stainless Steel Reduced Tip (.250" to .125")
- General Purpose Inconel 6002
- Penetration Inconel 600



Thermocouple Junctions:

The tip connection can be constructed as grounded, ungrounded or exposed. A thermocouple is called "grounded" when the sensing junction is connected (physically and electrically) to the metal case. There are advantages and disadvantages. Generally either works well despite ungrounded probes providing a slower response time. *(See illustration and Table 6).*

Table 6

Thermocouple	Advantages	Disadvantages
Grounded	Provides intimate contact for a faster response time	Grounded tip construction is susceptible to induced noise from ground loops, resulting in a less accurate reading
Ungrounded	Provides a more accurate reading because it is isolated from ground loops	Slower response time due to additional space and insulation around the sensor
Exposed	Fastest possible response using fine diameter wire	For Gas measurement only. The element is not protected from any corrosive effects or solids in gas stream
*All TEGAM probes are grounded probes unless otherwise specified.		

1 FEP (fluorinated ethylene propylene) nonstick coatings melt and flow during baking to provide smooth non-porous films with excellent abrasion resistance. This coating has excellent release properties and is often used as a mold release coating. This coating is typically applied to a thickness of 1-2 mils. www.metcoat.com/fep-coating.htm

2 INCONEL 600 is a nonmagnetic, nickel-based high temperature alloy possessing an excellent combination of high strength, hot and cold workability, and resistance to ordinary form of corrosion. This alloy also displays good heat resistance and freedom from aging or stress corrosion throughout the annealed to heavily cold worked condition range.

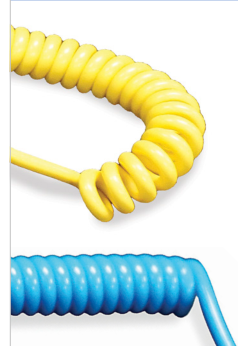
Extension Wire/Cable Type:

The wire/cable type can be either coiled or flat in the following options:

- PVC Coiled Cable (with 5 Ft Extension)
- Fiberglass Insulated Wire Cable
- Fiberglass Insulated with Stainless Steel Overbraid Wire Cable
- Fluorinated Ethylene Propylene (FEP) Insulated Wire Cable
- Fluorinated Ethylene Propylene (FEP) with Stainless Steel Overbraid Wire Cable
- Polyvinyl Chloride (PVC) Insulated Wire Cable

The majority of TEGAM probes come with the PVC coiled cable, pictured here.

CORDS



All probes (except wire tip) come with a coiled cord (Retracted 1'; Stretches to 5')

Insulation:

Insulation is most commonly found around the thermocouple wire in either of these two designs:

- Over each of the two conductors
- A jacket to wrap the two insulated conductors together

The two insulations are often specified as one material "over" another. If the conductors are insulated by Teflon and the jacket is also Teflon, then the thermocouple wire insulation is called Teflon (jacket) over Teflon. Note: Be sure to consider the temperature range of the insulation to select the proper probe. These specifications may not always be easy to find. Some thermocouple wire manufacturers even offer stainless steel braiding over cables for durability. In this case, consider the temperature characteristics of stainless steel for high temperature applications. Table 7 provides an example of insulation options and specifications from a thermocouple wire manufacturer.

Table 7

Insulation Code	Wire Insulation Type	Shield	Abration Resistance	Moisture Resistance	Insulation Temperature Rating
GG	Fiberglass Braid		Good	Fair	900°F (482°C)
GW	Fiberglass Wrap		Good	Fair	900°F (482°C)
HTG	Ceramic Braid, High Temperature		Fair	Poor	2200°F (1205°C)
KK	Kapton (Fused Tape)		Very Good	Excellent	500°F (260°C)
NN	Nylon		Excellent	Excellent	350°F (176°C)
PM	Polyvinyl Chloride (PVC)	Mylar Drain Wire	Good	Excellent	221°F (105°C)
PV	Polyvinyl Chloride (PVC)		Good	Excellent	221°F (105°C)
TF	Teflon, TYE (Fused Tape)		Good	Excellent	500°F (260°C)
TT	FEP		Very Good	Excellent	400°F (204°C)
TP	PFA		Very Good	Excellent	500°F (260°C)
VS	Vitreous Silica Fiber		Poor	Poor	1400°F (760°C)
Option	Metal Overbraiding	Good	Excellent	Dependent on Wire	

Table 8

Red Text: Denotes the positive terminal material of the thermocouple.

◆ Noble Metals: A metal (e.g.: gold, silver, or platinum) that resists chemical action, does not corrode, and is not easily attacked by acids.

* L and U are obsolete. DIN-43710 was withdrawn long ago. The last tables published are based on the 1968 Temperature scale and on the Pre-V90 definition of the Volt. L and U may still be available but they are not suitable for new designs and will be difficult to measure traceably. T and J as defined in EN 60584-1 2013 are a much better choice for new work.

TC Type/ Color	Temperature Range °F - °C	Element/Alloy Material	Standard Tolerances	Applications
B Grey ◆	32°F to 3092°F 0°C to 1700°C	Platinum 70%, Rhodium 30% vs. Platinum 94%, Rhodium 6%	±0.5%	Type B is used in pure, oxidizing atmospheres, neutral atmospheres and in vacuums.
C (W5) Red	32°F to 4208°F 0°C to 2320°C	Tungsten 95% Rhenium 5% vs. Tungsten 74%, Rhenium 26%	±4.4°C or ±1%	Tungsten-Rhenium thermocouples can be used at very high temperatures, up to 2315 °C. The more common type comprises 95% tungsten, 5 % rhenium versus 74% tungsten, 26% rhenium. This is sometimes referred to as W5Re/W26Re or letter designated type C.
D (W3) Red	32°F to 4208˚F 0°C to 2320˚C	Tungsten 97% Rhenium 3% vs. Tungsten 75%, Rhenium 25%	4.5°C or 1.0%	Suitable for high temperatures but not for use in oxidizing high temperatures due to embrittlement.
G (W) Red	32°F to 4208˚F 0°C to 2320˚C	Tungsten (100%) vs. Tungsten 74%, Rhenium 26%	±4.5°C or 1.0%	Suitable for high temperatures but not for use in oxidizing high temperatures due to embrittlement.
E Purple	-328°F to 1652°F -200°C to 900°C	Chromel (90% nickel 10% chromium)vs. Constantan (55% copper 45% nickel)	±1.7°C or ±0.5%	Type E is used in in pure, oxidizing (air), or neutral atmosphere (inert gases) environments. It has high resistance against corrosion, small thermal conductivity.
J Black	346°F to 1400°F -210°C to 760°C	Iron (100%) vs. Constantan (55% copper 45% nickel)	±2.2°C or ±0.75%	The Type J is a popular thermocouple that is commonly used to monitor temperatures of inert materials and in vacuum applications. This thermocouple is susceptible to oxidization so is not recommended for damp conditions or low temperature monitoring.
K Yellow	-328°F to 2300°F -200°C to 1260°C	Chromel (90% nickel 10% chromium) vs. Alumel (95% nickel, 2% aluminum, 2% manganese, 1% silicon)	±2.2°C or ±0.75%	The Type K is a 'general purpose' thermocouple with a wide temperature range. With a variety of probe types available, it is suitable for use across many industries and processes.
N Orange	-450°F to 2372°F -270°C to 1300°C	Nicrosil (Nickel 84.1%, Chromium 14.4%, Silicon 1.4% Magnesium .1%) vs. Nisil (Nickel 95.5%, Silicon 4.4%, Magnesium .1%)	±2.2°C or ±0.75%	The Type N also has a wide temperature range, but is better suited to high temperature monitoring than the Type K because it is more stable and resists oxidization.
R Green ◆	32°F to 2642°F 0°C to 1450°C	Platinum 87%, Rhodium 13% vs. Platinum 100%	±1.5°C or ±0.25%	The Type R is used in very high temperature applications. It is also sometimes used in lower temperature applications because of its high accuracy and stability.
S Green ◆	32°F to 2642°F 0°C to 1450°C	Platinum 90%, Rhodium 10% vs. Platinum 100%	±1.5°C or ±0.25%	Type S is used in pure, oxidizing atmospheres (air), non aggressive (inert-) gases, and short-term in vacuum above +1200°C type B is more appropriate.
T Blue	-328°F to 662°F -200°C to 350°C	Copper (100%) vs Constantan (55% Copper, 45% Nickel)	±1.0°C or ±0.75%	The Type T is a very stable thermocouple and is often used in extremely low temperature applications such as cryogenics or ultra low freezers. It is found in other laboratory environments as well. The type T has excellent repeatability between –380F to 392F (–200C to 200C)
P Platinel No color assigned	32°F to 2540°F 0°C to 1390°C	Palladium 55% Platinum 31%, Gold 14% vs. Gold 65%, Palladium 35% (aka Platinel II)	±1.0 %	Mimics the type K over the range 500 °C to 1400 °C, however they are constructed purely of noble metals and so shows enhanced corrosion resistance.
L* Chromel No color assigned	-328°F to 1652°F -200°C to +900°C	Chromel (90% nickel 10% chromium) vs. (C)kopel (Nickel 43%, Iron 2-3%, Copper 53%)	+100 to +400 °C: ±3°C +400 to +900 °C: ±0.0075 x temp	The type L thermocouple is similar to type J; the materials being iron versus copper-nickel alloy. It is defined by the DIN 43710-1985 standard for the range -200 °C to 900 °C.
U* Green	-328°F to 1112°F -200°C to +500°C	Copper 99.95%, oxygen, 0.02-0.07% 0.01% impurities vs 55% copper, 45% nickel approx. 0.1% cobalt, iron, and manganese	+100 to +400 °C: ±3°C +400 to +600 °C: ±0.0075 x temp	The type U thermocouple is similar to type T, the materials being copper versus copper-nickel alloy. It is defined by the DIN 43710-1985 standard for the range -200 °C to 600 °C.

Thermocouple Type:

The vast majority of thermocouple applications are covered by Type J, Type K and Type T. Table 8 provides a complete list of Thermocouple types with relevant information.

Temperature Probe Tip Styles:

The probe tip style chosen depends on the application. Common styles are shown here.

Temperature Probe Diameter:

Probes diameters are measured in inches from largest (1/4 inch) to smallest (1/25 inch).

- .040” (1/25”)
- .062” (1/16”)
- .125” (1/8”)
- .188” (3/16”)
- .250” (1/4”)

Connections/Terminal Types:

- Stripped Ends or “flying leads”
- Spade Lugs
- Standard Male Plug & Standard Female Jack (round pins)
- Mini Male Plug & Mini Female Jack (flat pins)

Currently available standard TEGAM connector types shown here.

Probe Response Time:

When a manufacturer specifies a response time, pay careful attention. Check to see if they are telling you how long in seconds it takes the probe to reach one time constant or full target temperature. A single time constant (TC) is the time it takes for the probe to reach 63.2% of its target temperature. 3 TC gives about 95%, 5 TC gives about 99% and 7 time constants is considered full temperature (99.9%).

See calculations [(Table 9)]() *and Graphs* [(Table 10)]().

PROBE TIP STYLES

Wire 02

Immersion / General Purpose (Non-Tapered) 03

Immersion / General Purpose (Tapered) 13

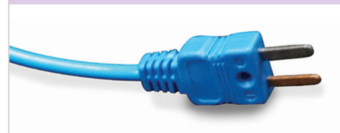
Penetration 04

Surface 05

Air / Gas 06

Hypodermic 07

CONNECTOR TYPES



MTC

PHN

TA4

M12

Thermal Time Constant:

Table 9 | Thermal Time Constant

The thermal time constant indicates a time required for a temperature sensor to respond to a change in its ambient temperature. When the ambient temperature is changed from T1 to T2, the relationship between the time elapsed during the temperature change t (sec.) and the sensor temperature T can be expressed by the following equation.

$$T = (T_2 - T_1)\left(1 - \exp(-t/\tau)\right) + T_1$$

τ (tau in sec.) in the equation denotes the thermal time constant.

Now, assuming t and τ (tau) are equal ($t = \tau$), the equation can be expressed as follows.

$$T = (T_2 - T_1)(1 - e^{-1}) + T_1$$

$$\frac{T - T_1}{T_2 - T_1} = 1 - e^{-1} = 1 - \frac{1}{2.718} = 0.632$$

This shows that the constant τ (sec.) is defined as a time for the sensor to reach 63.2% of the total difference between its initial and final body temperatures.

The sensor body temperature does not reach its ambient temperature when a time period defined by τ is elapsed.

The temperature change rate at n times the constant τ (sec.) is as follows, showing that the sensor body temperature reaches its ambient temperature approximately within 7 times the constant.

Table 10

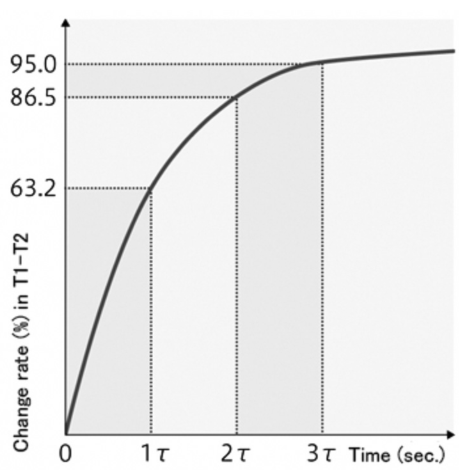
τ = 63.2%,

2τ = 86.5%,

3τ = 95.0%,

. . . .

$7\tau \fallingdotseq$ 100%



Probe Zero Offset and Measurement Error

You can get more accurate readings if you can set the zero point of the probe as all sensors/probes have a zero offset. Thermocouples have the largest; RTDs and thermistors are more controlled.

Zeroing a probe requires at least one of two methods depending on the application, one for cold applications, the other for high temperature measurements. For cold temperatures, an Ice Bath3 at 32°F / 0°C uses crushed ice in a slurry. After inserting the temperature probe, the reading on the instrument should be 32°F. If not, use the "OFFSET" feature of the instrument and adjust it to 32°F. This calibrates both the probe and the instrument simultaneously. Calibrating an instrument for hot temperature requires a "Dry Block Probe Calibrator." It provides a known hot temperature for the probe (each manufacturer of Dry Block Probe Calibrators reports the accuracy for their product). This is the recommended method to calibrate a thermocouple for use in high temperature applications.

Table11 | Instrument:

The **TEGAM 900 Series Thermometer** accuracy is ±(0.04% |rdg| + 0.3 °C). ("rdg" is "reading")
For example, let's assume you need to know the accuracy at 250°C .
The 931B at 250°C is: (.0004 * 250) = .1
.1° + .3° = .4°. The range is ±.4°C.
Therefore, the range of accuracy at 250°C = **[249.6°C to 250.4°C]**

Table 12 | Probe:

The accuracy of the Thermocouple Type K wire is ± 2.2°C or ±.75%, whichever is greater.
The accuracy of the probe at 250°C = [247.8° to 252.2°]
or
250° * .0075 = 1.875 [248.125° to 251.125°]
The first calculation is greater therefore the accuracy range used for the probe must be **[247.8°C – 252.2°C]**. This is the system accuracy of this instrument and probe together because the instrument range falls within the accuracy of the probe range.

Zeroing a system by either an Ice Bath or a Dry Block Probe Calibrator establishes a reference temperature which helps lower overall measurement error. One manufacturer reports that a standard Dry Block Probe Calibrator has an accuracy of ±1.5°C. Therefore, in the above example by using the Dry Block Probe Calibrator set at 250° and applying the offset feature, the new accuracy range is **[248.5°C to 251.5°C]** based on the Dry Block Probe Calibrator.

3 Please see Appendix for more information regarding Ice Baths and Dry Block Probe Calibrators.

Ice Bath:

An Ice Bath establishes a reference temperature for the instrument as close as possible to 0°C /32°F. Other chemicals can accurately produce below freezing temperatures for use in very low temperature applications. However, for the majority of applications, the Ice Bath works well.

Three Basic steps to insure ice-point accuracy: [4]

1. Ensuring Water Purity

For most purposes, ice made from ordinary culinary water is sufficient. However, since most dissolved minerals affect the freezing point, it is common to use only demineralized ice and water. For an ice point with less than 0.01°C uncertainty, only distilled water and ice made from distilled water should be used and the container should be either carefully-cleaned glass or stainless steel. As little as 12 PPM of some salts can cause a 0.01°C reduction in the ice point.

2. Ensuring Minimum Heat Flux

To ensure that the sensor being tested is unaffected by ambient conditions, place it in the center of a relatively large mass of ice and water (normally two liters or more). Position it well away from the walls of the container, and make sure the container is insulated to minimize melting of ice. Adequately immerse the sensing element being calibrated to minimize heat transfer through its housing.

3. Ensuring Equilibrium

The following procedure guards against temperature rise due to insufficient ice and ensures against poor heat transfer due to air in the bath: Fill the container with crushed or chipped ice.

(a) Fill the container with water to an overflow condition.

(b) Add more ice until ice is tightly packed to bottom of container, allowing water to overflow.

(c) Insert sensor to be calibrated and allow temperature to reach equilibrium (normally 5 minutes or more).

(d) If the test continues more than a few minutes, add more ice periodically. As before, ensure that the ice is packed tightly to bottom of container each time. The goal is to ensure that at all times the sensor is in contact with an ice/water slurry mixture over its entire surface.

---

4 Includes excerpts from "Calibration with Confidence – the assurance of temperature accuracy" R.D. Collier. Taylor Instrument / Consumer-Industrial Products / Sybron Corporation Arden, NC 28704.
Retrieved 12/4/17 from https://web.stanford.edu/group/csp/cs21/calibration.htm

Dry Block Probe Calibrator:[5]

Dry blocks are versatile temperature calibrators that work by heating, and in many cases cooling, a metal block to a specific temperature and maintaining that temperature. Most dry blocks use one or more interchangeable inserts into which holes are drilled. These holes accommodate a range of temperature sensors to be calibrated. The size of the holes corresponds to the diameter of the temperature sensors under test.

- Dry block calibrators can be designed in either portable or benchtop configurations. Though specifications can vary considerably between models, dry blocks typically offer an accuracy better than ±0.5°C and temperature ranges from about −25°C to 650°C. Hole-to-hole temperature uniformity is typically ±0.05°C.

Dry block calibrators provide a solid combination of accuracy, portability, stability, and price. They excel in performing both field- and industrial-level calibrations on nearly any type of temperature sensor including: RTDs, thermocouples, thermistors, PRTs, bi-metal thermometers, etc.

Good heat transfer between insert and sensor is critical for accurate calibrations when using a dry block temperature calibrator. This transfer depends on a very close fit between the sensor and the insert. Ideally, there should be no more than a couple of thousandths of an inch clearance between the two. Select the proper insert that matches your sensor, critical to achieve a correct calibration.

Please view and download TEGAM's free Temperature Probe Selection Guide here.

5 "About Dry Block Calibrators" https://www.instrumart.com/categories/785/dry-block-calibrators

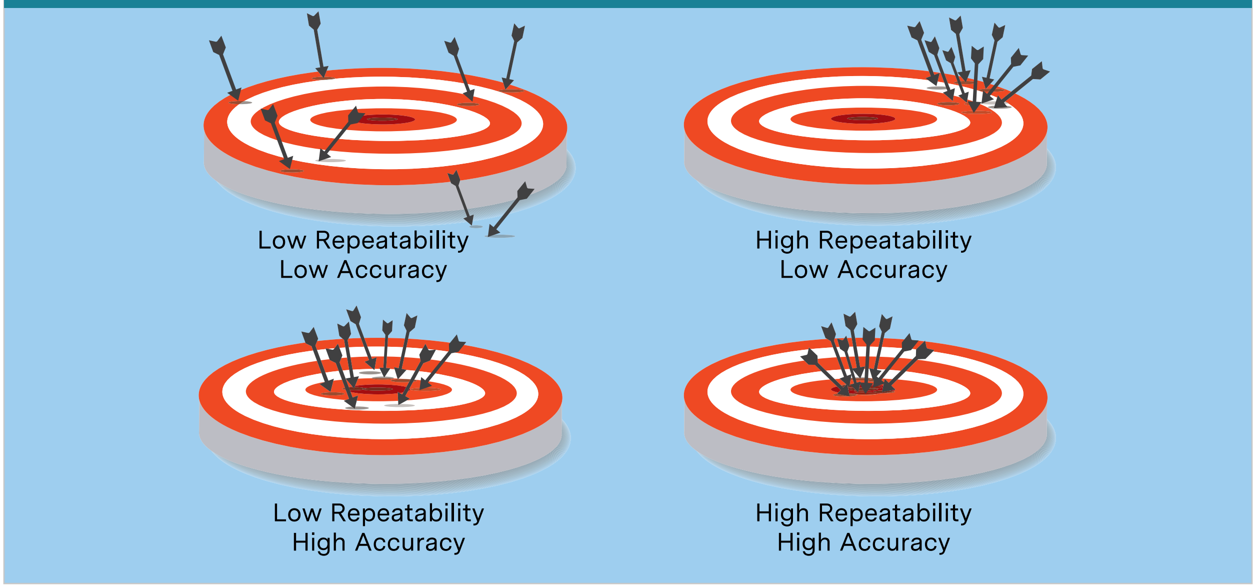
Chapter III

Digital Thermometer Selection

Now that you have selected your temperature sensor type and probe configuration, you have to consider the requirements of the digital thermometer. This chapter covers the details you need to address when selecting the instrumentation for your measurement such as; do you need datalogging, or wireless communications? What level of accuracy, and/or repeatability do you need and how do you calibrate the instrument?

ACCURACY is an instrument's degree of measurement uncertainty.

REPEATABILITY is an instrument's degree of variability from reading to reading.



Accuracy and Repeatability

Accuracy is defined as how close a measurement is to the expected value. Against a temperature standard for 100° C, if the instrument reports a measured value of 100°C, then the instrument is accurate. Note that accuracy varies between instrument models and temperature ranges. Typically, instrument vendors specify accuracy as a percentage such as 0.5%. Converting that specification against an actual reading at 165°F, multiply 165 x 0.5% to get 0.83°F. If the thermometer was reporting the temperature as 165°F, the true temperature is actually between 165°F ± 0.83°F (or from 164.17°F to 165.83°F).

Unfortunately, thermometers typically don't read exactly zero. They are always off by some amount beyond the accuracy specification. Low cost thermometers don't report how much they are off at 0° which means the reported temperature and actual range is at best a guess. Higher quality **digital thermometers** specify their error. The accuracy specification will read something similar to this: Accuracy 0.1% ± 1°C (or 1.8°F). In this example, the ± 1°C is called the *zero error.*

Recalculating the accuracy example above including the *zero error*

- Accuracy 0.5% of 165°F = 0.83°F plus the zero error of 1°C (or 1.8°F) = 165°F ± (1.8°F + 0.83°F= 2.63°F) or an accuracy range of 162.37°F to 167.63°F.
- The thermometer that appeared to be accurate to 0.5% in the initial calculation could be over 2° off of the reported reading.
- The point: Application requirements dictate the level of accuracy required to meet either safety or product quality issues.

Repeatability (also called “Precision”) is important to achieve consistent results. An accuracy specification defines the variation of the true temperature from the temperature measurement reported by the instrument. A repeatability specification states the consistency of thermometer readings through multiple subsequent measurements.

> **Grandma Ruth’s Famous Buttermilk Donuts**
>
> - Thermometer reads 20°F low but is always off by this amount.
> - Fry oil needs to be exactly 340°F to get the correct browning on the outside while cooking the dough all the way to the center.
> - Using the thermometer’s known repeatability of zero and the systemic offset error of -20°F, adjust the temperature of the fryer until the thermometer reads 320°F to achieve the desired result.
> - This allows the production process to achieve the desired result even though the actual measurement is always wrong!
> - The most accurate thermometers perform within their repeatability specifications. Repeatability is usually specified as 95% confidence, or two standard deviations Thus, a higher quality instrument delivers <u>both</u> accuracy and repeatability.

Instrument Types

Chapter II above noted the two basic principles used for temperature sensors. Thermocouples detect voltage changes in proportion to temperature. In contrast, RTDs and thermistors, detect the resistance of the metals in the sensors, which changes proportionally to temperature. The key point is to match the appropriate sensor with the right instrument. With few exceptions, a single model of an instrument is based on one of these three types of sensors. An RTD sensor requires an RTD instrument, for example.

Ideally, the instrument would automatically configure itself to whatever temperature sensor was attached. However, in the real world, that capability adds complexity and cost that provides no ongoing benefit beyond the first use of the instrument. To emphasize, first match the sensor to the application, then match the sensor to the appropriate instrument.

If a thermocouple matches the application, understand that the single greatest source of error is the thermocouple itself. Different grades of thermocouple wire and variations in manufacturing processes create differences in each thermocouple. Standard Limits Wire can have up to 4°C of error, whereas special Limits Wire has half that error at 2°C. Quality instruments feature the ability to adjust the sensor offset to remove some of this error. When a new thermocouple instrument enters service, it can be calibrated using one of two methods.

Method 1: If an application requires the utmost accuracy, third party calibration laboratories will calibrate the sensor against a series of known temperatures. This provides the user with a means to correct any final measurement errors due to the sensor. Note that this process is tedious and expensive, but is available if required. An Example is an ISO 17025 calibration with numbers.

Method 2: The second method to improve thermocouple measurement accuracy uses only ice water. Using distilled water and distilled ice, the user can create an ice water slurry to validate the instruments measurement of 0 degrees C (32F).

Any offset can then be compensated for manually in other measurements.

This method provides the thermocouple-based instrument with the temperature of the application's environment and is performed by the vendor prior to shipping a new instrument. The CJC process begins when an internal sensor measures the temperature where the thermocouple connects to the instrument and compares it to the temperature detected by the probe. Normally, these two temperatures vary widely, for instance, when measuring a hot liquid the probe will detect the temperature of the liquid whereas the internal instrument sensor reports the room temperature.

Instrument users need to understand the distinction between premium and bargain instruments. Bargain instruments must cut costs somewhere, often either performing only rudimentary compensation or ignoring it altogether. This means that the user cannot rely on readings in either extreme cold or heat environments with a bargain instrument. When evaluating an instrument, note the operating range of the thermometer's specifications for compensation. **Bargain** instruments are limited to a narrow range around room temperature. If an application in fact is at or near room temperature, that may be fine. However, when a user takes that budget thermometer into either a cold environment (such as a walk-in freezer or cooler) or a hotter environment (such as near heat treat ovens, under the hood of a car, or even in direct sunlight), the same temperature reliability problem occurs at either extreme. By comparison, **Premium** thermometers properly adapt to the temperature of the operating environment throughout their entire specified range because they have been properly tested and compensated at the factory. Note that they will need some period of time to adapt to a large change in ambient, such as going into a heated room into a refrigerator.

Response Time

When the probe is placed in a different temperature environment, it needs time to warm or cool to the new environment. Errors result when the operator removes the probe while the temperature is still changing. The operator needs to wait until the reading has stabilized before recording it, which requires some training. Depending on instrument model, thermometers update their readings from two (2) times per second to once every four (4) seconds. As an alternative, a premium instrument comes equipped with a trend indicator. This informs the operator when the reading has stopped changing, which simplifies the measurement task and reduces errors.

Brief Review

With this background, a user or manager can now interpret the accuracy specification of any digital thermometer to pinpoint the total error, plus or minus, for any temperature measured. The specified temperature range of an instrument also reveals whether it will operate correctly in the target environment. Successful ongoing measurements depend on three elements:

- The application requirements – selecting the correct sensor and then the appropriate matching instrument.
- Appropriate instrument accuracy and repeatability to meet required process, safety and/or regulatory requirements.
- Proper training of technicians so they allow for instrument response times (or proper use of the instrument's trend indicator).

Other Considerations

Environmental

The impact of environmental factors can degrade operation of the instrument unless it is designed to withstand them. Consider these factors when selecting an instrument: Fluids, dirt, drops, and food.

Fluids and Dust

If fluids can easily get into a digital thermometer, it will eventually stop working. Fluids can enter via the connectors, through the case, the battery compartment, or the keypad. For best performance, select an instrument with sealed keypads, few connector openings, and a battery compartment sealed with a gasket.

Dirt and dust can also cause failures if the instrument case is not well sealed. A case designed to withstand water will also protect from dust intrusion. Dirt on the outside of the case can be a problem if it contaminates the workspace, such as in a food or chemical processing facility. An instrument that can withstand washdowns with water and a cleanser helps prevent such contamination.

Shock and Vibration

Every measurement instrument needs to withstand normal drops from a counter to the floor without affecting its accuracy or operation. Instrument vendors employ different preventive approaches, one of which is a rubber "boot" to surround the instrument. Besides increasing the weight and bulk of the instrument, the boot solution also creates an additional place where contaminants can reside and complicates the cleaning process. Premium vendors provide instruments that can withstand rougher handling without need of a boot.

Keypad Design

Many vendors overlook keypad design even though it can be a daily aggravation to the user. The keypad needs to provide noticeable tactile feedback so the user knows that the key has actually been pressed. The keypad designer must also space the keys properly to allow for operation with a gloved hand, necessary in sterile environments. In addition, the text and symbols on the keypad must endure repeated day-in and day-out use so they do not wear off. One-handed operation is also vital because the user's other hand will be holding the probe. Like the rest of the instrument, a properly sealed keypad allows no dirt or food to be trapped and thus become a source of contamination.

Backlight Screen

The design of the instrument's display also affects ease of use. For instance, the numbers on the display must be large and clearly legible without reading glasses. A backlit screen makes for ease of reading and automatically turns off when not in use to extend battery life. Any quality instrument will also include auxiliary indicators to clearly communicate the state of the instrument.

Battery Life

Battery life is always critical in a portable instrument like a digital thermometer. Users painfully discover that bargain digital thermometers often "eat" batteries, greatly increasing ongoing operating costs. The **extra battery cost of such an instrument** multiplies when the operator needs to frequently remove the instrument from service due to battery failure. Consider the cost of the walk to the other end of the facility just to replace batteries and then return to resume work.

Type of Battery

The type of battery impacts to battery life as well. Many bargain instruments use 9V batteries that have a higher cost per unit of energy. Premium instruments usually require AA batteries for both cost and energy density.

Data Collection

Manufacturing, processing, and laboratory facilities today generate a huge quantity of temperature measurements. Often, that data is recorded by an error-prone antiquated method - pencil and paper. Since data collection precedes analysis, accurate data collection matters. As a core objective, data analysis aims to protect the business and processes from existential threats such as out-of-spec, contaminated products, or unsafe process conditions.

Best Practices of Documentation

Many applications require well-documented temperature measurements to conform with process and/or regulatory requirements. In addition, this data provides product liability protection. For example, publicly reporting that a facility has a process in place that prevents salmonella contamination of peanut butter is actually a weak statement. By contrast, data that verifies the effectiveness of a preventative process presents potent evidence. The actual temperature readings constitute the data. The data becomes actionable information following an analytical process that improves processes, reduces costs, enhances quality, and keeps the company out of court.

Four Levels of Data Collection Systems: Costs and Challenges of Each Approach

The Level One process relies solely on paper and pencil.

In this method, a quality assurance worker records temperature readings on a clipboard. After the technician fills a sheet with temperature recordings, she/he then files it in a physical file. This method introduces unnecessary costs and a high potential for errors. The most expensive cost could well threaten the continued existence of the facility. For example, an out-of-range temperature reading that suffered from a delayed response or been overlooked altogether could result in a recall in the food processing industry.

Using paper and pencil, the data is not readily accessible within the organization. It is therefore not actionable and difficult to impossible to analyze. The relatively modest cost-of-goods loss pales against the damage inflicted on the product's brand and market position in the event of an out-of-range process. Including legal costs, liability can potentially run into the millions.

For food processors, pencil and paper methods also carry the inherent potential as a source of food contamination. Perhaps worst from a legal perspective, there's no documentation of a proper chain-of-custody of the data, a situation certain to prove costly in court. Further, paper and pencil records are easily faked after the fact and therefore subject to question. Another tangible expense is the simple cost of storage space and filing cabinets.

Level Two adds a bit of technology to the paper and pencil process of Level One.

In this method, the quality technician goes one step beyond filing the data in a filing cabinet. Instead, the technician still gathers and records the data by hand on a clipboard. She/he (or an admin) then enters it in the department computer to either a local or enterprise database. Unfortunately, this method is also fraught with shortcomings one of which actually compounds the shortcomings of Level One. Even good typists make about 8 errors per 100 words.[6]

Once entered, the data can be analyzed and decisions made about the quality of the process and the product. However, inevitable delays can range from hours to days until the data is actually analyzed and decisions made, increasing the cost of dealing with a problem. In this scenario, it's quite likely that dangerous or non-conforming product has already entered the supply chain.

Level Three introduces the first steps to modern automated data collection.

In this scenario, the technician collects the temperature readings using an instrument capable of storing data. He/she (or an admin) then downloads the file into a computer. The file may or may not need to be manipulated into a file type compatible with the corporate database or Statistical Process Control software. Level Three data collection greatly improves the accuracy of the data by virtually eliminating transcription and data entry errors. Data can still be manipulated but the opportunity and motive to do so are greatly reduced. As compared to Levels One and Two above, Level Three reduces the required

6 Average Typing Speed Infographic, http://www.ratatype.com/learn/average-typing-speed/

tasks and time invested in computer data entry, which increases productivity. The delay from the time of an out-of-range measurement until data analytics signals corrective action constitutes the primary shortcoming of Level Three. If the data is only downloaded a few times per day, the delay could add up to significant liability exposure.

Level Four data collection achieves fully automated real-time temperature monitoring and benefits from productivity gains because non-value added tasks are eliminated. This level eliminates all manual tasks except for the actual measurement. This includes eliminating all hand writing, typing, or data manipulation. With a Level Four system in place, when the technician takes each individual reading, it instantly and automatically enters the database for immediate analysis and action. Any out-of-range readings trigger an immediate alarm and set of notifications to appropriate managers and operators. Affected products can often be immediately quarantined before they enter the supply chain. The immediacy of real-time alerts and notifications reduces the possibility of a recall, the associated costs noted above and other liability exposures.

The fully automated data logging system delivers an inviolable chain-of-custody that ensures data integrity and makes it difficult to tamper with the data. Yet, data can be readily retrieved to demonstrate process compliance. Finally, a simplified, yet full-featured implementation of an automated data acquisition system reduces project execution risk and cost.

The simplest approach uses a thermometer and a smartphone to relay data to an existing cloud database. The advantage of this approach is that a non-technical person can fully implement this solution in one day or less. The downside is that this approach limits real-time monitoring and data notification functions and may compromise data security.

A better implementation system integrates an excellent Statistical Process Control (SPC) software that directly connects to the instrument. Now the real-time data import capability drives analysis, enabling immediate alerts and notifications for out-of-range readings. This approach offers strong functionality but with a higher cost of ownership. Industry experts recommend that customers evaluate several different SPC packages to identify and match the functions and limitations of each to the application's requirements.
TEGAM, for example, offers our own line of datalogging thermometers for this process.

However, some applications require a custom data collection and analytics system, despite the fact that it is generally more cost effective to purchase an existing SPC software solution. However, many businesses and processes have unique challenges that warrant a custom software solution. Although the most expensive approach, it may be the only way to connect multiple business software systems such as process control, procurement, and logistics.

A premium thermometer vendor provides customers with a software development kit that includes code examples. This enables the instrument customer to readily interface with related applications, smartphones, tablets, and laptops. Wireless standards also play a role in a custom system. Proprietary wireless standards require more developmental efforts to establish a proper interface. The best advice: Choose modern, stable, and well-developed standards like Bluetooth LE or WIFI for optimum compatibility.
View TEGAM's Software Developer's Kit for our datalogging thermometers here.

About TEGAM

TEGAM, Inc. specializes in the design, manufacture, and support of a diverse line of electronic test and measuring equipment, including **digital thermometers** and **temperature calibrators**, **ohmmeters** and **bond meters**, and **RF power sensor calibration systems**. Founded in 1979, TEGAM supports its governmental and commercial customers in the U.S. and throughout the world through its commitment to quality and customer service. Visit **aei.com** to learn more about TEGAM.

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ADDENDUM

Intrinsically Safe

Intrinsic safety (IS) is a protection technique for safe operation of electrical equipment in hazardous areas. This is accomplished by limiting the energy, (electrical and thermal), available for ignition. An intrinsically safe system is one with energy levels so low they cannot cause an ignition. A potentially explosive atmosphere exists when a mixture of air gases, vapors, mists, or dusts combine in a way that can ignite under certain operating conditions. Areas with dangerous concentrations of flammable gases or dust are found in applications such as petrochemical refineries and mines.

There are two methods that certify intrinsic safety equipment: systems or parameters. Systems approval requires approvers to specify every component and evaluate the entire system. A variance to any of those components voids the approval. Parametric approval requires approvers to evaluate each device separately and assign it a set of safety or entity parameters. Entity approval allows you to connect a field device to any barrier[7] with compatible safety parameters.

Please note that there are separate agencies that provide approvals for certain environments. Note that many of these agencies today are coordinated. For example the EN 60079 family of standards has been adopted by UL and CSA.

For instance, MSHA (Mine Safety and Health Administration – U.S. Department of Labor) is the governing agency for any equipment used in mining locations in the U.S. TEGAM did not seek approval from MSHA, therefore the TEGAM 921 Thermometer is not approved for use in mines.

For areas other than mining, the government agency responsible is OSHA (Occupational Health and Safety Administration). OSHA has authorized a group of NRTL (Nationally

7 An Intrinsic Safety Barrier is a circuit design that safely passes fault current to ground (rather than into the hazardous area) for equipment mounted in hazardous areas. See Appendix for a more thorough explanation.

Recognized Testing Laboratories) to certify equipment. At this time the following laboratories are recognized.

- CSA (Canadian Standards Association)
- ETL Testing Laboratories Incorporated
- Factory Mutual Research Corporation
- MET Laboratories
- UL (Underwriters Laboratories Inc.)
- United States Testing Co. Inc.

For intrinsically safe equipment used in transportation, the Federal Motor Carrier Safety Administration (U.S. Department of Transportation) is the governing agency.

In Europe the governing agency is the European Union, (EU). The ATEX Directive 2014/34/EU covers equipment and protective systems intended for use in potentially explosive atmospheres. The Directive defines the essential health and safety requirements and conformity assessment procedures, to be applied before products are placed on the EU market. It is aligned with the New Legislative Framework policy, and it is applicable from 20 April 2016, replacing the previous Directive 94/9/EC. The latest revision at the time of this writing is December 2017.

National authorities are responsible for implementing the Directive in the EU by transposing its provisions into their legislation. As a result, EU countries and others who apply the Directive's requirements are responsible for implementation and enforcement, as well as the management of notified bodies.

In Canada the government agency responsible is the Standards Council of Canada. Standards Council of Canada has authorized a group of testing laboratories to certify equipment. At this time the following laboratories are authorized.

- CSA (Canadian Standards Association)
- ETL Testing Laboratories Incorporated
- UL (underwriters Laboratories Inc.)
- C-UL (Underwriters' Laboratories of Canada)

Calibration Guarantee

What TEGAM has accomplished is the combination of exquisite design with tried and proven numbers.

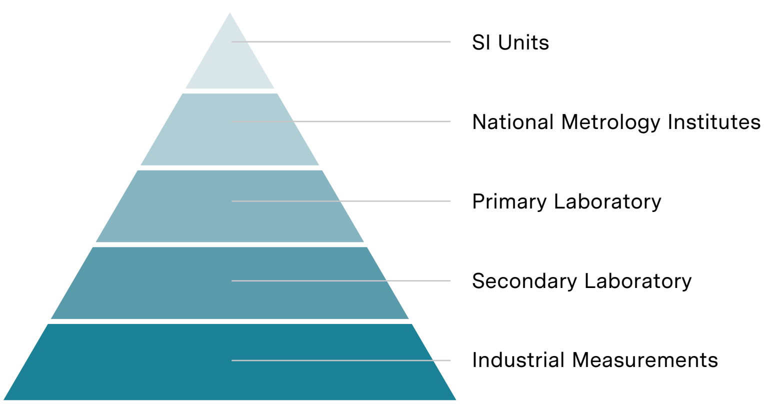
TEGAM, Inc. warrants the calibration of this product for a period of two (2) years from date of shipment. During this period, TEGAM, Inc. will recalibrate any product, which does not conform to the published accuracy specifications. We are confident on the two (2) year calibration cycle of the instrument from the data we have witnessed over time with this circuit design. By the way, the warranty to be free from defects in material and workmanship is for three (3) years.

What is a "Certificate of Calibration"

When you purchase this instrument, it is calibrated and comes with an actual "Certificate of Calibration". The certificate text is below.

> *"This instrument has been inspected and tested in accordance with specifications published by TEGAM, Inc.*
>
> *TEGAM, Inc. certifies the above listed instrument has been inspected and calibrated and meets or exceeds all published specifications and has been calibrated using standards whose accuracies are traceable to the International System of Units (SI) through the National Institute of Standards and Technology (NIST) or other recognized National Metrology Institutes."*

Measurement Traceability Pyramid



"Measurement traceability is an important factor for your laboratory to meet the requirements of ISO/IEC 17025 accreditation. In fact, measurement traceability is one of the top 10 cited deficiencies of all ISO/IEC 17025 audits."[8]

8 "What is Measurement Tracability" http://www.isobudgets.com/measurement-traceability-complying-iso-17025-requirements/ Image and quote Retrieved 4/27/2018

Summary

TEGAM, Inc., is a world-wide leader in the design and manufacture of state-of-the-art test, measurement and calibration instrumentation. The company presents this book as a basic guide for IT managers, executives, quality control managers, and technicians. This guide emphasizes the importance of accurate temperature measurement and explores the various measurement technologies. After reading this guide, the reader should have a clear roadmap of how to select the best instruments for their particular applications. Temperature measurement applications can range from heat treating in aerospace industries to pharmaceutical, automotive, and food processing.

Selecting the right instrument depends on a variety factors including; industry, application, accuracy, and data traceability. Instrument selection also depends on the potential implications of your measurements, which may include regulatory compliance, specifications, and safety. This guide should give you a clear understanding of which measurement solution is best for your particular application.

We hope you now have more than enough information to choose a probe and an instrument that fits your needs and environment. On the following page is a quick checklist to help you evaluate instrument offerings. We are here to help anyone with Temperature Measurement problems, so call us if you need help or want to bounce your ideas off us. (We can also set you up with a brewing system or a BBQ system).

Instrument Selection Checklist

1. **Temperature Range to be measured**
   a. Thermocouple – Broadest Range: -250 to 1705°C
   b. RTD – Medium Range: -200 to 600°C
   c. Thermistor – Lowest Range: -80 to 150°C
2. **Accuracy & Repeatability Requirements**
   a. Thermocouple: 0.5 to 1°C
   b. RTD: 0.1 to 0.6°C
   c. Thermistor: 0.1°C
3. **Response Time**
   a. Thermocouple: 1 to 10 sec Typical
   b. RTD: 5 to 10 sec Typical
   c. Thermistor: 1 to 5 sec Typical
4. **Media being measured**
   a. Liquid
   b. Solid
   c. Gas
   d. Corrosive
   e. Explosive
5. **Location**
   a. Indoors or outdoors
   b. Remote Location with no Utilities
   c. Excessive heat or cold
   d. Washdown area
   e. Movement or Vibration
   f. Excessive Dirt or Dust
   g. Special Requirement Area
      i. Medical/Sterile
      ii. Food Service/Storage
      iii. Hazardous Location
      iv. Mine
      v. Shipboard
      vi. Offshore Rig
      vii. Dark area
6. **Data Management**
   a. Local Display
   b. Remote Display
   c. Can data be written on paper
   d. Need to datalog locally
   e. Need to datalog remotely
   f. Need fully automated datalogging
7. **Probe Design**
   a. Mounting Style
      i. Handheld
      ii. Permanently installed
      iii. Magnetic mount
      iv. Clip Mount
      v. Adhesive mount
      vi. Pipe Seal
      vii. Thermowell
8. **Probe Style**
   a. Liquid immersion
   b. Solid Penetration
   c. Surface: Flat or curved; still or moving
   d. Air/Gas
   e. Special Mounting
9. **Type of Wire**
   a. Abrasion Resistant
   b. Liquid Resistance
   c. High heat resistant
10. **Connection to Instrument**
   a. Wire Leads
   b. Connector to mate with instrument
11. **Probe Jacket Material Compatibility**
   a. Stainless Steel
   b. Inconel
   c. Ceramic
   d. None