Standards Defining Temperature Sensors

Your Host and Presenter

Host

Jeff Wigen, National Sales Manager

- 24 years in sales and marketing of custom designed made-to-order products for the industrial and biotech markets.

Presenter

Bill Bergquist, Sr. Applications Engineer and RTDologist™

- 30 years experience in temperature measurement with RTDs and thermocouples in the aerospace, industrial, and laboratory markets.

Topics Covered Today

Why do I care about standards?

Resistance Temperature Detector (RTD) standards
- RTD history
- Common standards
- Uncommon standards

ASTM E20

Thermocouple Standards

Other thermometer types
- ASME B40.9

Thermowell Standards
- ASME PTC 19.3 TW-2010
- ASME B16.5 flange
- ASME B16.11 socket weld and threaded fittings

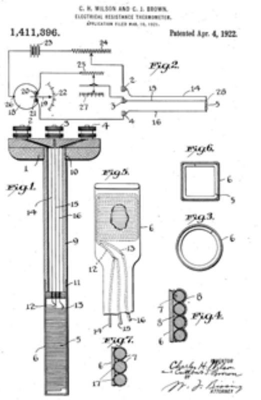
ASME-BPE

3A Sanitary Standards

RTD History

*The application of the tendency of electrical conductors to increase their electrical resistance with rising temperature was first described by Sir William Siemens at the Bakerian Lecture of 1871 before the Royal Society of Great Britain. The necessary methods of construction were established by Callendar, Griffiths, Holborn and Wein between 1885 and 1900.

Electrical Resistance Thermometer, U.S. patent 1,411,396, was issued on April 4, 1922 to C.H. Wilson and C.J. Brown



* From Wikipedia: http://en.wikipedia.org/wiki/Resistance_thermometer#History

The RTD (resistance temperature detector) was first described in 1871. In the US the oldest patent I could find was from 1922 and it was for an improvement.

First RTD Standard

*Callendar gave a detailed review of gas thermometry at the 1899 meeting of the British Association for the Advancement of Science (BAAS) and made these recommendations:

- Platinum resistance thermometer be adopted as the defining instrument of the scale
- Calibrated at the freezing point of water and the boiling points of water and sulphur
- Particular batch of platinum wire be selected from which the thermometers defining the scale be manufactured
- Wanted the scale to be called the British Association Scale of Temperature
- Related to the ideal temperature scale through chosen gas thermometer measurements of the sulphur point

*http://www.bipm.org/en/si/history-si/temp_scales/its-27.html

The oldest evidence of a standard for RTDs was suggested by Hugh Longbourne Callendar in 1899 in which he identified platinum as the best metal to use. He used the ice point and boiling points of water and sulphur for calibration.

Temperature Standards

*ASTM Committee E20 on Temperature Measurement was formed in 1962.

- Meets twice a year in May and November
- Has 40 members that attend 2 days of technical meetings
- Current membership of approximately 120 has jurisdiction over 43 standards, published in the Annual Book of ASTM Standards, Volume 14.03
- 6 technical subcommittees
- These standards have and continue to play a preeminent role in all aspects of temperature measurement

*http://www.astm.org/COMMITTEE/E20.htm

Today the ASTM E20 committee meets twice a year to update and write standards that define and control temperature measurement.

Temperature Standards

E20.02 Radiation Thermometry
E20.03 Resistance Thermometers
E20.04 Thermocouples
E20.05 Liquid-in-Glass Thermometers and Hydrometers
E20.07 Fundamentals in Thermometry
E20.09 Digital Contact Thermometers
E20.90 Executive
E20.91 Editorial and Terminology
E20.94 Publication
E20.96 Newer Thermometers and Techniques

The list of standards covers every type of sensor from RTDs and thermocouples to non-contact types and also any new technology.

Temperature Standards

E20.03 Resistance Thermometers

- E644-11 Standard Test Methods for Testing Industrial Resistance Thermometers
- E879-12 Standard Specification for Thermistor Sensors for General Purpose and Laboratory Temperature Measurements
- E1137/E1137M-08 Standard Specification for Industrial Platinum Resistance Thermometers
- E2593-12 Standard Guide for Accuracy Verification of Industrial Platinum Resistance Thermometers
- E2821-13 Standard Specification for Compacted Mineral-Insulated, Metal-Sheathed Cable Used in Industrial Resistance Thermometers

Within the subgroup resistance thermometers, there are further standards that cover testing, accuracy verification, materials of construction, and performance. Of these, the ASTM E1137 is the one that covers the platinum resistance thermometer.

RTD Standards (International)

IEC 60751 supersedes DIN 43760

- Interchangeability tolerance classes, wire color codes, expands the range of alpha values used in CVD equations
- R vs. T tables

In addition, the IEC standard covers performance parameters such as hysteresis and time response.

RTD Standards (USA)

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ASTM E1137

- Similar to IEC 60751, interchangeability tolerances are smaller
- R vs. T tables

 Standards Defining Temperature Sensors RTDology™

RTD Calibration Standards

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IPTS-68 – defines temperature scale and transfer standard, Callendar van Dusen equation

ITS-90 – improved version of IPTS 68

Calibration of RTDs

- ISO/IEC 17025
- ANSI/NCSL Z540-1

 Standards Defining Temperature Sensors RTDology™

Accredited labs follow the IEC 17025 and ASNI/NCSL Z540 standards. This insures a consistent outcome of calibration information.

RTD Standards

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Four most important items from the standards - IMO

- Interchangeability
- Insulation resistance
- R vs. T tables
- Lead wire color codes

 Standards Defining Temperature Sensors RTDology™

I pulled four items from the standards that I consider the most important for RTDs. These are necessary to specify a sensor and insure that it is performing correctly for an accurate temperature measurement.

RTD Standards

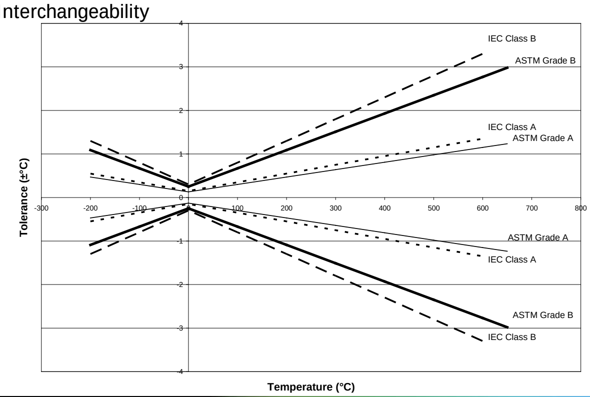
Standard	Tolerance	Defining Equation[1]
ASTM E1137	Grade A	± [.13 + 0.0017 | t |]
ASTM E1137	Grade B	± [.25 + 0.0042 | t |]
IEC 607512	Class AA	± [.1 + 0.0017 | t |]
IEC 60751	Class A	± [.15 + 0.002 | t |]
IEC 60751	Class B	± [.3 + 0.005 | t |]
IEC 607512	Class C	± [.6 + 0.01 | t |]

Note 1: | t | = absolute value of temperature of interest in °C

In a perfect world, the RTD manufacturer would build sensors to the nominal values. Unfortunately that is not possible so the standards define a tolerance band called the "interchangeability". These equations can be used to calculate the interchangeability at any temperature. Note that the temperature 't' is an absolute value in °C. The resultant is the interchangeability in ± °C.

RTD Standards

Interchangeability



Note that the ASTM standard has slightly tighter tolerances for the two grades of sensors. All RTDs are built with the tightest tolerance at 0°C and as the temperature diverges from 0°C the tolerance increases. The vertical line on the graph represents 0°C and the tolerance on the y axis is expressed in ± °C from nominal.

RTD Standards

Insulation resistance is the first and most important electrical check to make on an RTD

- Low IR can cause a low temperature measurement due to shunting between the sensing element wires
- Most IR failures are due to moisture and/or contaminants that may have entered the probe

This is a typical wire wound sensing element. They are about 1" long and 1/16" diameter and are potted inside a stainless steel sheath. If moisture gets into the sheath and/or sensing element the result can be a shorter path for the excitation current and the result is a low resistance measurement.

Insulation Resistance

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Test method

- Lower insulation resistance = lower measured temperature
- Test at 50 VDC
- IR should be >100 megohms at 25°C

Insulation Resistance (IR) decreases with an increase in temperature so at room temperature a value much higher than what is really needed for an accurate measurement is required. Industrial Grade RTD accuracy is not significantly affected until the IR drops below a few megohms. The measurement is made by touching one lead of a megohmeter to the leads and the other to the probe sheath. Some Industrial Grade probes are tested to higher levels to insure maximum performance at high temperatures.

RTD Standards

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60751/Ed.2 CDV © IEC 13

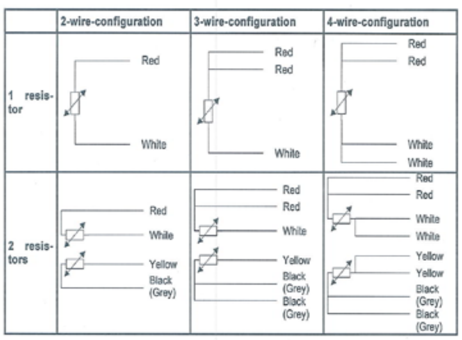

Figure 1 - Connecting configurations

IEC 60751 lead wire colors

Lead wire color may vary by manufacturer

RTD Standards

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Other less common standards

- JJG 229 Chinese – similar to IEC
- BS-1904 – similar to IEC
- JIS C 1604 – equivalent to IEC, adds .003916
- Edison Curve 7 - Nickel 120 ohm
- SAMA RC21-4-1996 - .003923, Copper 10 ohm
- US Department of Defense MIL-T-24388 - 0.00392 100

Thermocouple Standards

ASTM E230 / ANSI MC96.1

- Contains reference tables for temperature-electromotive force (emf) relationships for types B, E, J, K, N, R, S, T, and C thermocouples
- standard and special limits of error tolerances on initial values of emf versus temperature
- insulation color coding for thermocouple and thermocouple extension wires
- Upper temperature limits
- Negative lead is red

IEC 60584

- Most widely used standard
- Negative lead is white

Other standards

- NBS Monograph 125 and BS 4937 parts 1-7 emf tables
- BS 1843 UK and Czech Republic
- DIN 43710 Germany
- JIS C1610 Japan
- NFC 42-324 France

The biggest difference in the thermocouple standards is how the lead wire colors are designated.

Thermocouple Standards

ANSI and IEC color code differences

Thermocouple Type	ANSI	IEC
	+ lead/- lead	+ lead/- lead
J	White/Red	Black/White
K	Yellow/Red	Green/White
T	Blue/Red	Brown/White
E	Purple/Red	Purple/White
N	Orange/Red	Pink/White

It is necessary to know the standard that the thermocouple was built to when identifying a thermocouple by color code. There are other standards with different color codes depending on which part of the world you're in but these are the two most common.

Thermocouple

Limits of error ASTM E230 / ANSI MC 96.1

Temperature Range & Initial Calibration Tolerances			
Thermocouple Type	**Temperature Range**	***Standard Limits** greater of	***Special Limits** greater of
T	-200°C to 350°C	± 1.0°C or ± 0.75%	± 0.5°C or ± 0.4% **
J	0°C to 750°C	± 2.2°C or ± 0.75%	± 1.1°C or ± 0.4%
E	-200°C to 870°C	± 1.7°C or ± 0.5%	± 0.5°C or ± 0.4% ***
K	0°C to 1180°C	± 2.2°C or ± 0.75%	± 1.1°C or ± 0.4%
* % applies to temperature measured in °C			
** -200°C to -62.5°C error is 0.8% *** -200°C to -170°C error is 0.8%			

Initial accuracy of a thermocouple is defined by the standards as either 'Standard' or 'Special Limits of Error'. Expressed as ± degrees C or F or ± % of reading, whichever is greater.

Other Temperature Standards

ASME B40.200

- Consolidation and revision of four individual standards
  - B40.3, Bimetallic Actuated Thermometers
  - B40.4, Filled System Thermometers
  - B40.8, Liquid-in-Glass Thermometers
  - B40.9, Thermowells for Thermometers
- These individual standards provide terminology and definitions, dimensions, safety, construction and installation issues, test procedures and general recommendations.

Thermowells

RTDs and thermocouples are often protected with a thermowell. Strength and wake frequency factors need to be considered and there is a standard that defines safe configurations

- ASME PTC 19.3 TW-2010
  - Wake frequency and strength calculations
    - Uses length, diameter, material, fluid properties, and temperature to estimate a safe flow velocity
- Immersion length – balance between sufficient length to avoid stem conduction and still stay within wake frequency and strength limits. Too long and it may break, too short and you will have an inaccurate measurement.

Measurement accuracy can be adversely affected by a thermowell unless a few precautions are taken. Wake frequency and strength calculations are probably the most important. These calculations will tell you how far the well can be immersed into your process based on the flow conditions (more on this later). This has to be balanced with the accuracy needs of the sensor to be immersed sufficiently to prevent stem conduction or immersion error.

Finally, time response is slower with the addition of a thermowell and for processes that change temperature rapidly this can be a significant error source.

ASME PTC 19.3 TW-2010

***ASME PTC 19.3 TW - 2010**

PTC 19.3 TW-2010 is a completely new standard that establishes the practical design considerations for thermowell installations in power and process piping. This code is an expanded version of the thermowell section contained in the PTC 19.3-1974, and incorporates the latest theory in the areas of natural frequency, Strouhal frequency, in-line resonance and stress evaluation. ASME responded to changing industry demands for a more comprehensive set of thermowell evaluations. Key enhancements over the 1974 edition include:

- Expanded coverage for thermowell geometry
- Natural frequency correction factors for mounting compliance, added fluid mass, and sensor mass
- Consideration for partial shielding from flow
- Intrinsic thermowell damping
- Steady state and dynamic stress evaluations
- Improved allowable fatigue limit definition

*http://staging.files.asme.org/Catalog/Codes/PrintBook/25750.pdf

The new release of the Thermowell Section of the Power Test Code incorporates the latest theory for wake frequency and strength calculations. If you're a piping designer all this probably means a lot to you. For someone selecting a thermowell it may be a little like learning how to build a chainsaw to cut down a tree. Interesting but not really necessary. Your thermowell supplier will provide the calculations based on your process conditions and desired thermowell configuration. You need to specify that you want the calculations done to the 2010 version of the standard.

Von Kármán Vortex

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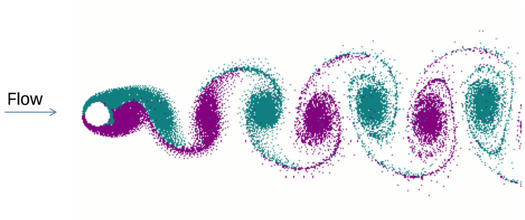

Von Kármán vortex street, by [http://www.mcef.ep.usp.br/staff/jmeneg/cesareo/Cesareo_HomePage.html Cesareo de La Rosa Siqueira

When a cylindrical object is placed in a flow there is a disturbance created on the downstream side that oscillates back and forth. The frequency of the oscillation increases as the flow rate increases. If the resonant frequency of the thermowell matches the frequency of the vortices the well will start to vibrate and will first damage the RTD and then the well will fail.

There are a lot of good illustrations of this phenomena on the internet. A search for Von Karman or wake frequency will return several.

Thermowell Selection

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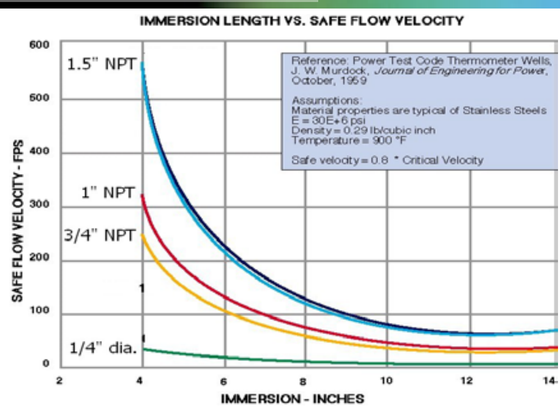

This graph shows the acceptable flow rates for various thermowell designs and a ¼" diameter direct immersion RTD. Note that a short increase in immersion length has a large affect on the allowable flow rate.

Thermowells

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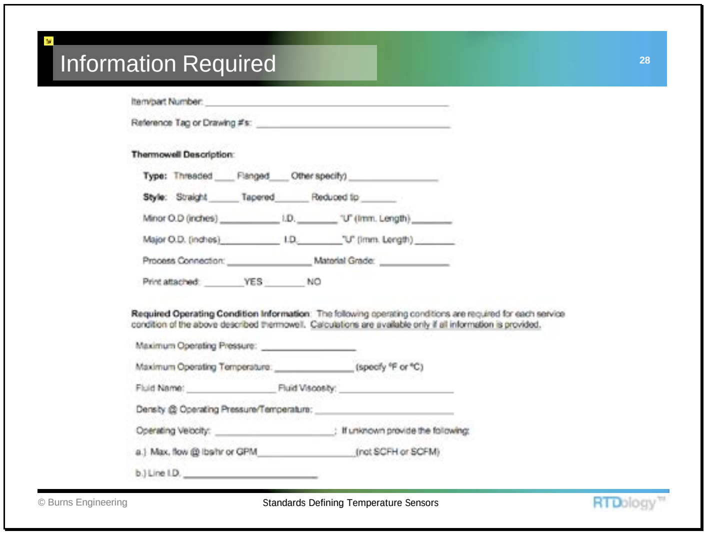
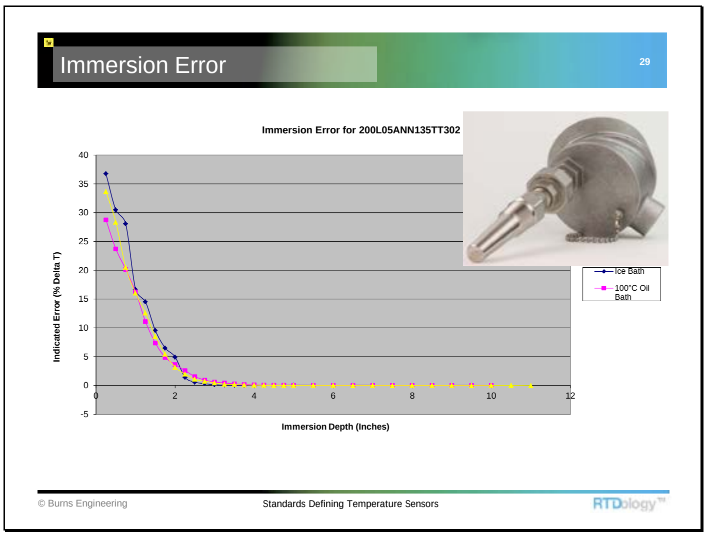
Maximum Fluid Velocity
feet per second
(See Section on Velocity Ratings on page 6.)

Well Type	Material	Insertion Length - "U" 2-1/2	4-1/2	7-1/2	10-1/2	13-1/2	16-1/2	19-1/2	22-1/2
3/4" - 260H and 3/4" - 260H L	Brass	305 (97.5)	93.8 (54.1)	33.9	17.1	10.5	7.0	5.5	3.7
	Carbon Steel	386 (175)	180 (97.2)	65.3 (59.3)	33.0	20.1	13.4	9.6	7.1
	A.I.S.I. 304 & 316	440 (243)	197 (135)	71.2	36.0	22.0	14.7	10.5	7.8
	Monel	354 (195)	155 (108)	56.1	28.4	17.3	11.6	7.5	5.6
1" - 260H and 1" - 260H L	Brass	354 (161)	108 (89.5)	39.4	19.8	12.2	8.1	5.8	4.3
	Carbon Steel	448 (289)	209 (161)	75.7	38.4	23.3	15.5	11.1	8.2
	A.I.S.I. 304 & 316	490 (403)	228 (225)	82.5	41.8	25.5	17.1	12.2	9.1
	Monel	410 (322)	179 (178)	65.1	33.0	20.1	13.5	8.7	6.5

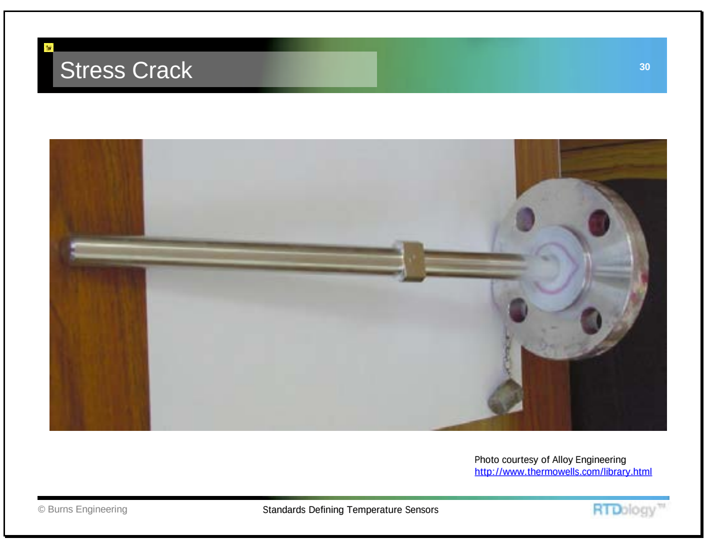
Table provided by Alloy Engineering



This is typical of the information that is needed to perform the thermowell calculations.



A thermowell/RTD assembly was immersed in a bath to determine the stem conduction at various depths. At 4.5 inches most of the error has disappeared. As you can see the error is mostly independent of the bath temperature used. The error is expressed as a percentage of the delta T between ambient and process conditions.



An example of what can happen if the wake frequency and strength calculations are not done. This well incorporates a support part way down the stem to provide support but it wasn't enough. A crack formed as outlined around the stem.

ASME PTC 19.3 does not recommend the use of supports such as this. Shorter immersion or larger diameters are the preferred solutions.

Stress Crack

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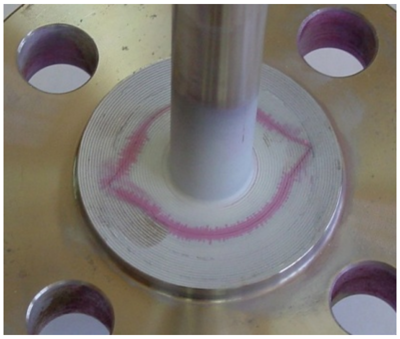

Photo courtesy of Alloy Engineering
http://www.thermowells.com/library.html

A little better view of the crack that formed.

Process Connection

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Connection styles

- Flanged
  - ANSI B16.5 pipe flanges used as process connection
    - Raised face
    - Flat face
    - Van Stone
    - Ring joint
- Threaded
  - ANSI/ASME standard B1.20.1 for NPT threads
- Sanitary
  - ASME-BPE and 3-A Sanitary Standards, Inc.
    - Defines process connections and installation details
    - 3A requires periodic audit of manufacturer
      - » Parts are labeled with 3A symbol

Connections to the process are accomplished with tapered pipe threads or adaptations of pipe or sanitary tubing flange connections. A blank or blind flange is modified to accept the thermowell stem and then easily attaches to standard flanges.

Weld-in styles are used for convenience or where exposed threads may collect contaminants such as in food processing or pharmaceutical production.

A specialty type of connection incorporates an O-ring to seal inside a sleeve welded to a tank. Sometimes referred to as an Ingold® fitting after the company that invented it for ph and oxygen sensors.

BURNS ENGINEERING

Summary

Know which standard to specify to insure you get the accuracy desired from the temperature sensor – IEC-60751 vs. ASTM-E1137 interchangeability for example

Thermocouple standards define the initial accuracy and lead wire color codes. There are many variations.

Thermowell selection is more than picking a length and process connection type. Follow the standard for wake frequency and strength requirements.

3A and ASME-BPE define the configuration and installation of temperature sensors and related thermowells

Questions? Comments?

Use the chat window to send us a question.

Contact Bill later at 800-328-3871 ext. 13
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