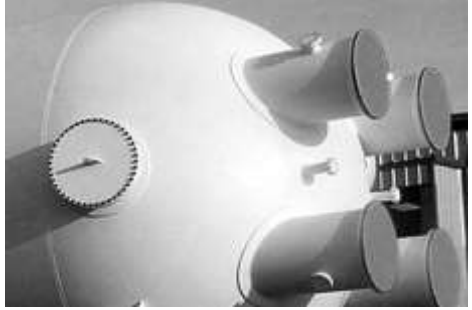
CURTISS-WRIGHT

Nuclear Division



HX Performance Testing

FSRUG – January 26, 2016

GRAFTEL LLC.

CURTISS-WRIGHT

Agenda

- **Why Heat Exchanger Performance Testing (HXPT) is required**
- **GL 89-13 Overview**
- **Typical HXPT Methodology**
- **Typical Setup**
  - Tube & Shell
  - Plate & Frame
  - Tube & Frame
- **Measured vs Calculated Parameters**
- **Measurement devices**
- **HXPT OE**

Why Test

Generic Letter (GL) 89-13

Action 1

Reduce incidence of flow blockage problems resulting in biofouling

Action 2

Verify heat transfer capability of all S/R HXs cooled by service water

Action 3

Ensure that corrosion, erosion, protective coating failure, silting, and biofouling does not degrade the performance of the S/R systems supplied by service water

Action 4

Confirm that the service water system will perform its intended function in accordance with the licensing basis for the plant

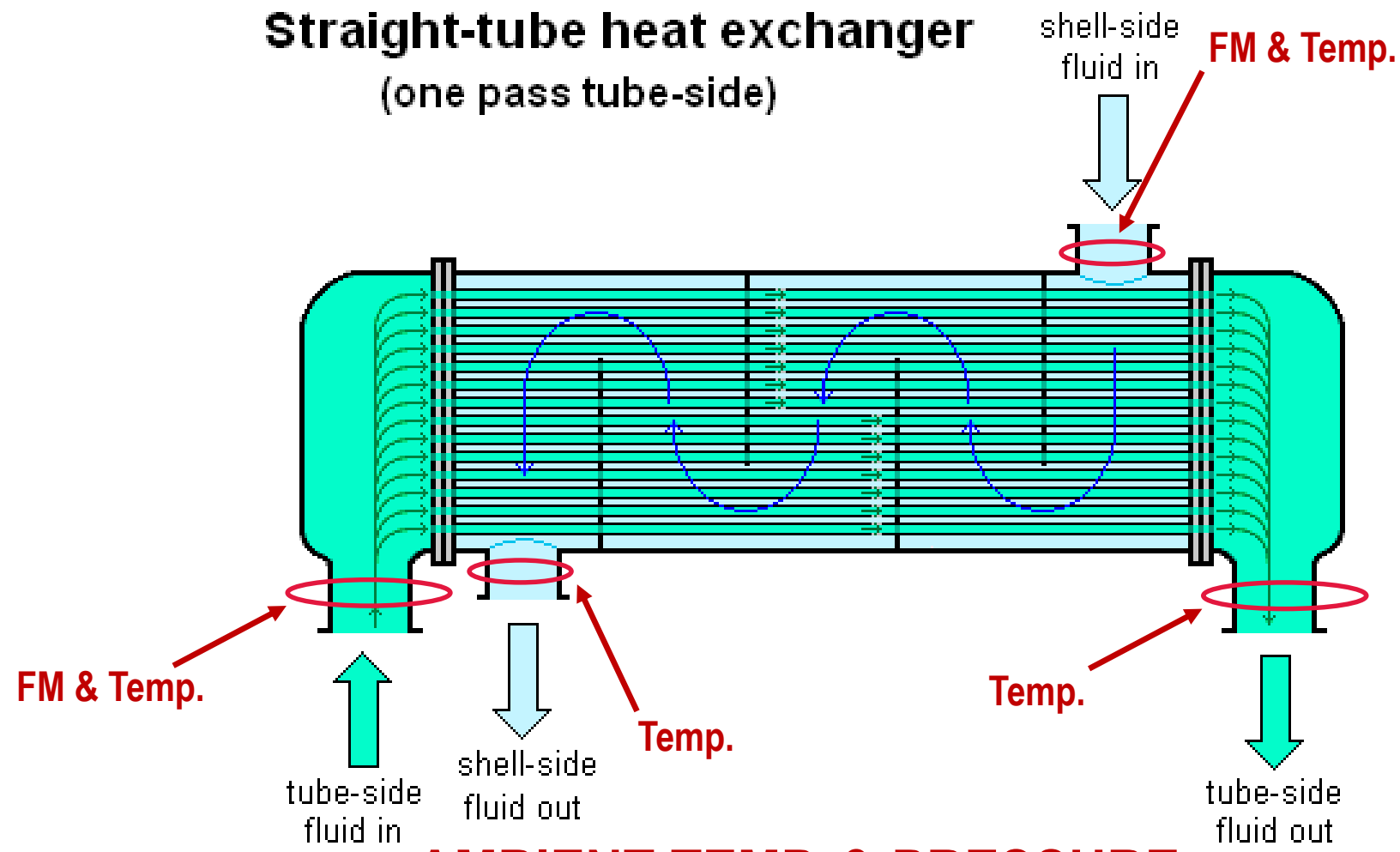
Action 5

Confirm that maintenance practices, operating and emergency procedures and training that involve the service water system, are adequate to ensure that safety-related equipment cooled by the service water system will function as intended and that operators of this equipment will perform effectively

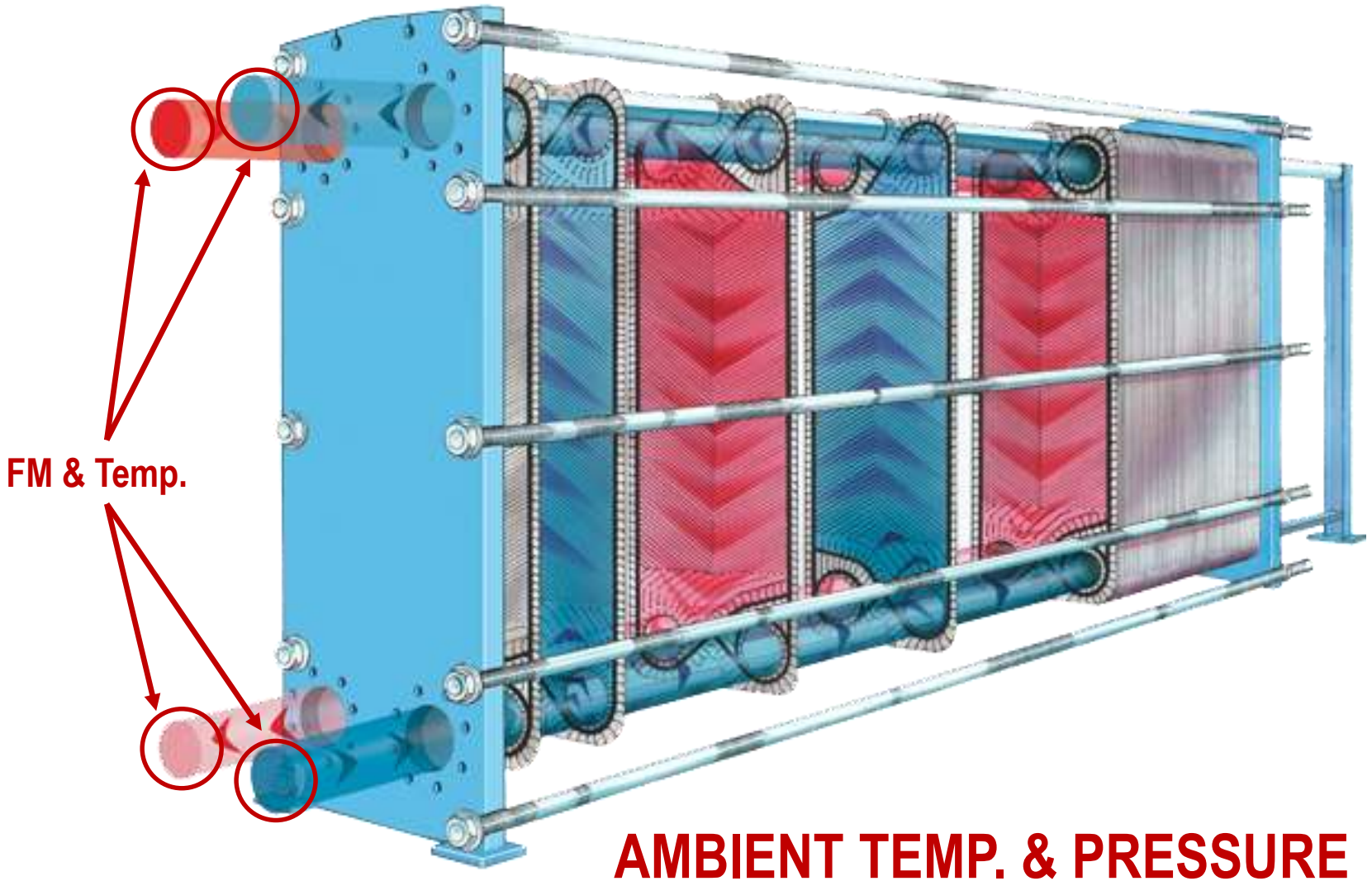
HXPT Methodology

- Development of the test plan
- Development of the test procedure(s)
- Implementation
- Data analysis / performance evaluation

Typical Tube & Shell HXPT Setup



Typical Plate & Frame HXPT Setup



Measured vs Calculated Parameters (T&S and P&F)

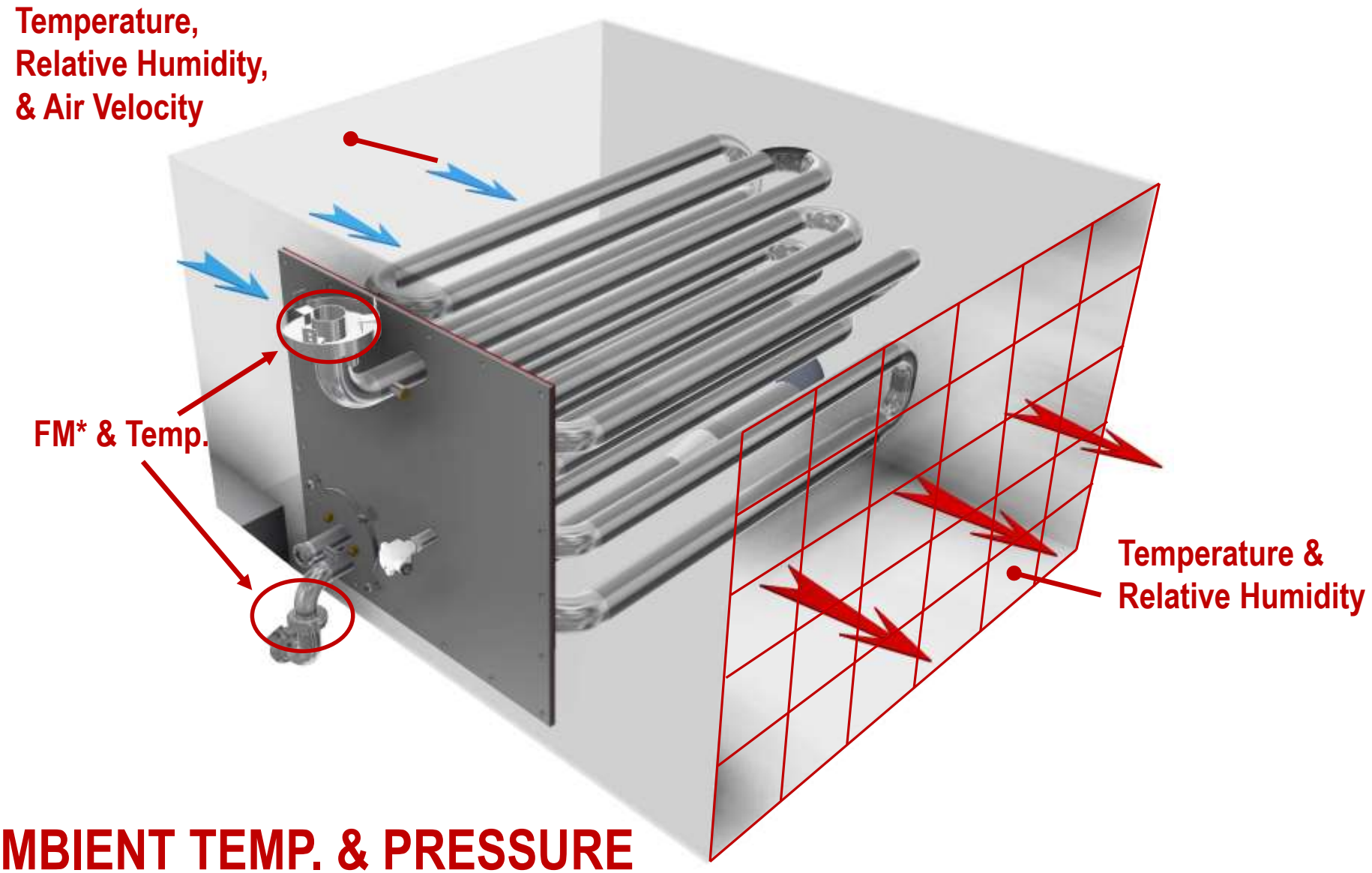
MEASURED

- Temperature – both legs, Inlet and Outlet
- Flow – both legs, Inlet or Outlet*
- Ambient Temperature
- Ambient Pressure

CALCULATED

- Scaling Factor
- Overall Heat Transfer Coefficient
- Heat Transfer Rates
- Post LOCA Heat Transfer Rates (extrapolation)
- Future conditions (extrapolation)
- Amount of cross leakage or blockage
- Total fouling factor and film thickness

Typical Tube & Plate HXPT Setup



Air Cooled HX Measured vs Calculated Parameters

MEASURED

- SW Temperature – both legs, Inlet and Outlet
- SW Flow – both legs, Inlet or Outlet*
- Air Temperature – fixed on one end and traversed on the other
- Air Flow – traversed (one side only)
- Air Relative Humidity – fixed on one end and traversed on the other
- Ambient Pressure
- Ambient Temperature

CALCULATED

- Scaling Factor
- Overall Heat Transfer Coefficient
- Heat Transfer Rates
- Post LOCA Heat Transfer Rates (extrapolation)
- Future conditions (extrapolation)
- Amount of cross leakage or blockage
- Total fouling factor and film thickness

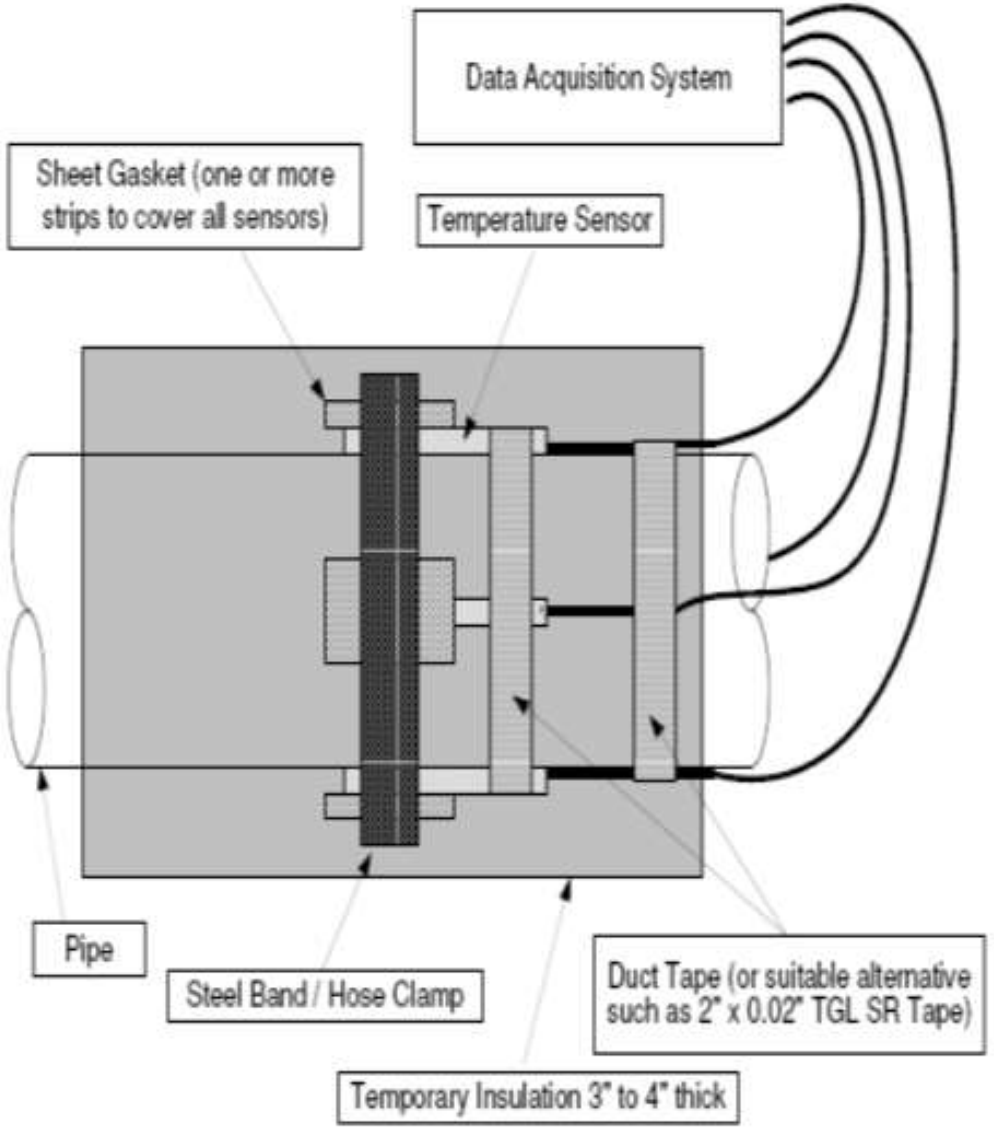
Measurement Device Overview

- **Temperature**
  - Thermocouple, RTD, Thermistors
- **Relative Humidity**
- **Pressure**
- **Liquid Flow**
  - Ultra Sonic, Orifice Plate, BFM, SONARtrac
- **Air Velocity**
  - Vane, Hot Wire, and 3D Ultra Sonic Anemometers, and Pitot Tube

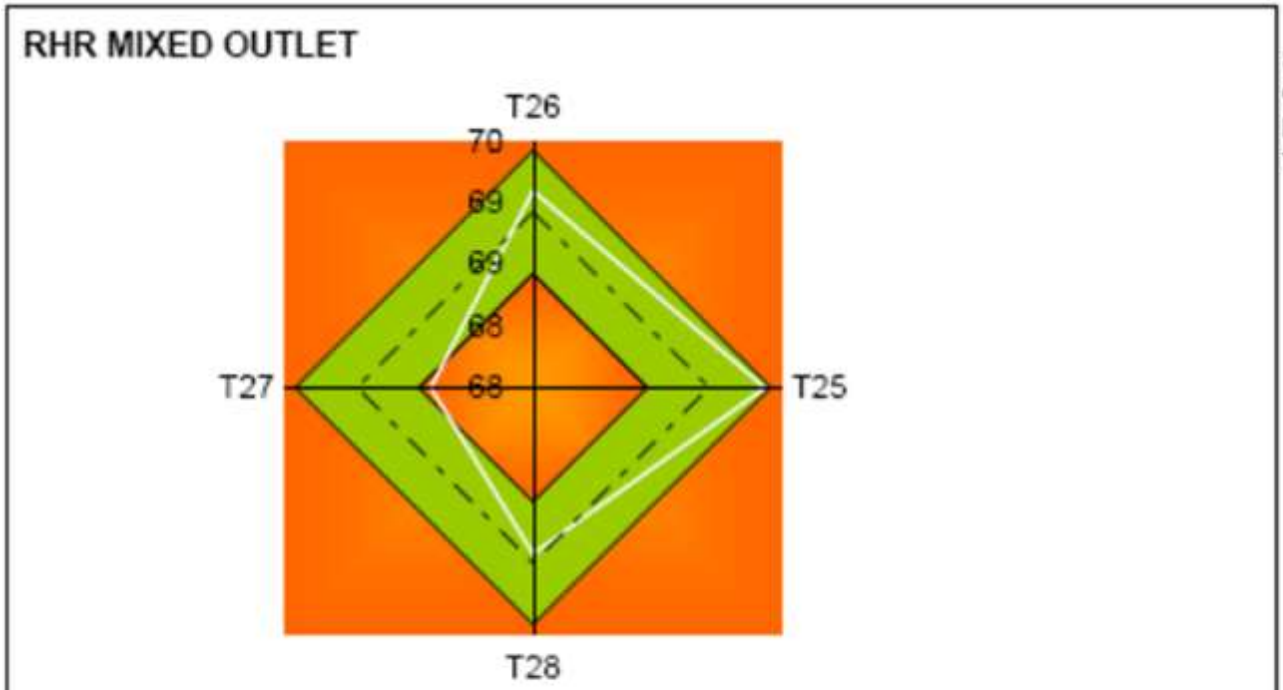
Temperature Sensors

Criteria	Thermocouple	RTD	Thermistor
Temp Range	Very Wide	Wide	Narrow
Accuracy	Good	Better	Best
Linearity	Better	Best	Good
Sensitivity	Good	Better	Best
Cost	Best	Good	Better

Placement of Temperature Sensors (T&S and P&F)



Unacceptable Temperature Variation (T&S and P&F)

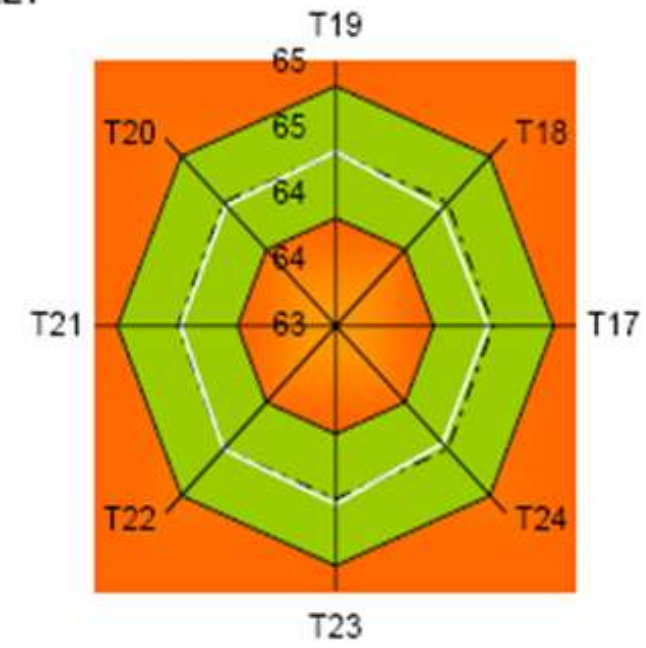


START TIME	8:23 PM
CURRENT TIME	21:41:07
DATA SETS	79
TEMP LIMIT (+/-)	0.5 F

RHR MIXED OUTLET	Sensor #	Latest Value, (F)	Max, (F)	Min, (F)	Mean, (F)	Std Dev, (F)	Sx (Std Dev of Data Sample), (F)	β spatial (F)
RHR M O/L, 0°	T25	69.38	69.43	68.43	68.93	0.3207	0.3095	0.1195
RHR M O/L, 90°	T26	69.1	69.43	68.43	68.93	0.1227	0.3095	0.1195
RHR M O/L, 180°	T27	68.33	69.43	68.43	68.93	0.4218	0.3095	0.1195
RHR M O/L, 270°	T28	68.85	69.43	68.43	68.93	0.0541	0.3095	0.1195

Acceptable Temperature Variation (T&S and P&F)

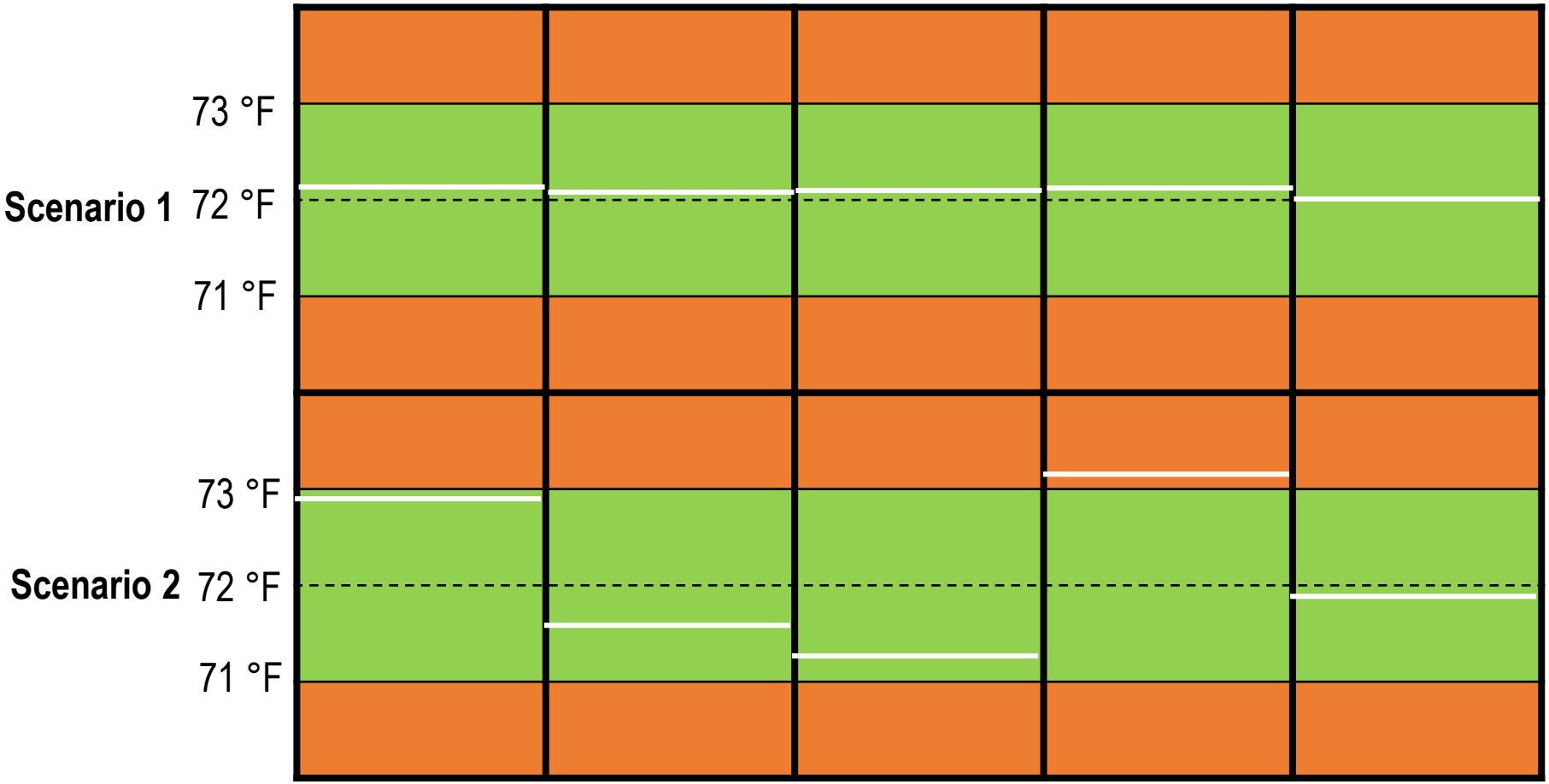
RHR OUTLET



START TIME	8:23 PM
CURRENT TIME	21:41:07
DATA SETS	79
TEMP LIMIT (+/-)	0.5 F

RHR OUTLET	Sensor #	Latest Value, (F)	Max, (F)	Min, (F)	Mean, (F)	Std Dev, (F)	Sx (Std Dev of Data Sample), (F)	β spatial (F)
RHR Outlet, 0°	T17	64.267	64.82	63.82	64.32	0.0351	0.1895	0.0573
RHR Outlet, 45°	T18	64.25	64.82	63.82	64.32	0.0471	0.1895	0.0573
RHR Outlet, 90°	T19	64.32	64.82	63.82	64.32	0.0024	0.1895	0.0573
RHR Outlet, 135°	T20	64.29	64.82	63.82	64.32	0.0188	0.1895	0.0573
RHR Outlet, 180°	T21	64.29	64.82	63.82	64.32	0.0188	0.1895	0.0573
RHR Outlet, 225°	T22	64.32	64.82	63.82	64.32	0.0024	0.1895	0.0573
RHR Outlet, 270°	T23	64.35	64.82	63.82	64.32	0.0236	0.1895	0.0573
RHR Outlet, 315°	T24	64.26	64.82	63.82	64.32	0.0400	0.1895	0.0573

Temperature Variation (Air Cooled)



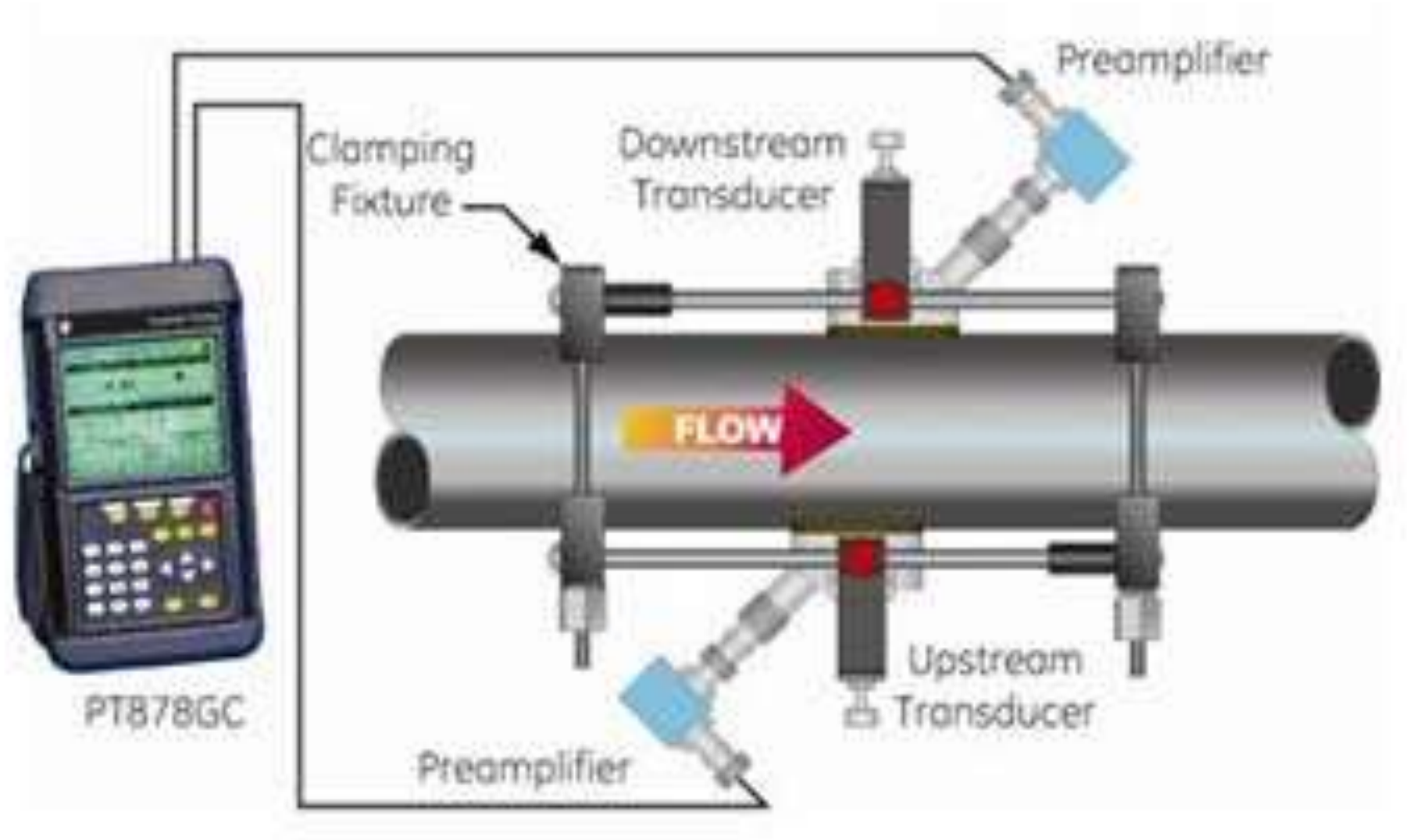
Thermal Stability

- **Thermal Stability is achieved when temperature variation is less than 0.2 degF per 5 minutes (EPRI TR-107397)**
- **Often difficult to achieve stable conditions**
- **Must be planned with operations prior to testing**
- **Have Software Check all Sensors Prior to Starting the Test**
- **Visual representation of the data for ease of operation/troubleshooting**
  - Designate stable readings in Green and unstable in Red
- **Start test when the "green light" is obtained**

Relative Humidity & Pressure

- Generic RH Sensor
- Generic Barometers
- Generic Pressure Transducers

Ultrasonic Flow Meters



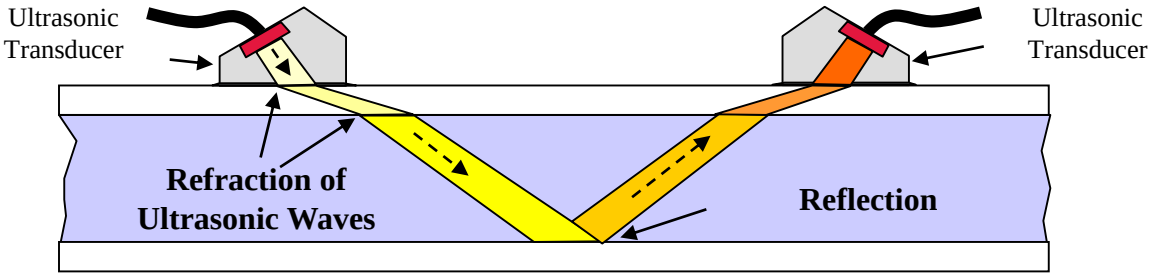
Ultrasonic Flow Meters

- Require proper entrance and exit lengths
- Pipe must be round and diameter and wall thickness known to obtain optimal accuracy
- Require good acoustic conduction through pipe wall and liners.
- Will not work well for pipes with cemented lining.
- Will have problems with fiberglass pipes
- Scaling, corrosion, and position have an affect on the accuracy of the flow meter
- Actual measurement uncertainties often exceed 5%

Ultrasonic Flow Meters

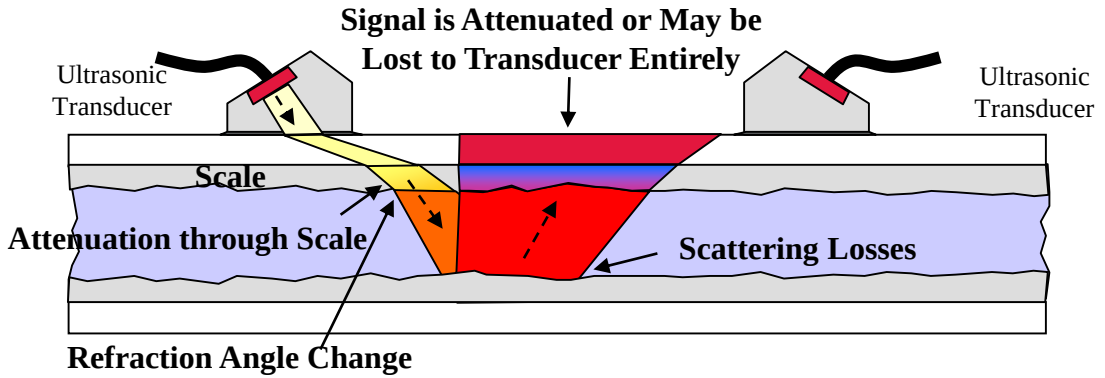
Clear Fluids:

Normal Operation



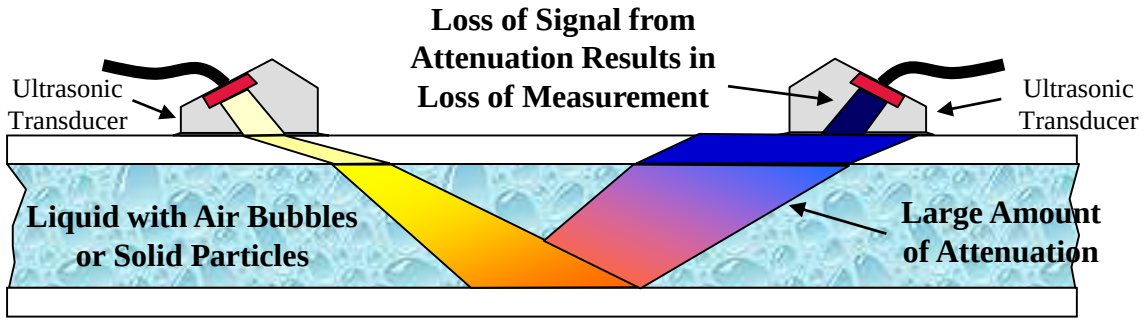
Scale Buildup:

Loss of accuracy and eventual loss of signal



Bubbles and Solids:

Loss of signal



Ultrasonic Flow Meters Rotational Check

SW – Inlet Line							
Position	0°	60°	120°	180°	240°	300°	Average
Measured Flow Rate, gpm	1241.48	1245.76	1238.88	1234.28	1243.16	1248.44	1242.00
Difference from Mean, gpm	-0.5	3.8	-3.1	-7.7	1.2	6.4	**-1.29**
% Difference from Mean	-0.04	0.30	-0.25	-0.62	0.09	0.52	**-0.10**

	Highest	*Lowest*	*Difference*
gpm	*1248*	*1234*	*14*

SW – Outlet Line							
Position	0°	60°	120°	180°	240°	300°	Average
Measured Flow Rate, gpm	1233.20	1233.90	1223.90	1234.90	1224.40	1235.80	1231.02
Difference from Mean, gpm	2.2	2.9	-7.1	3.9	-6.6	4.8	**-0.96**
% Difference from Mean	0.18	0.23	-0.58	0.32	-0.54	0.39	**-0.08**

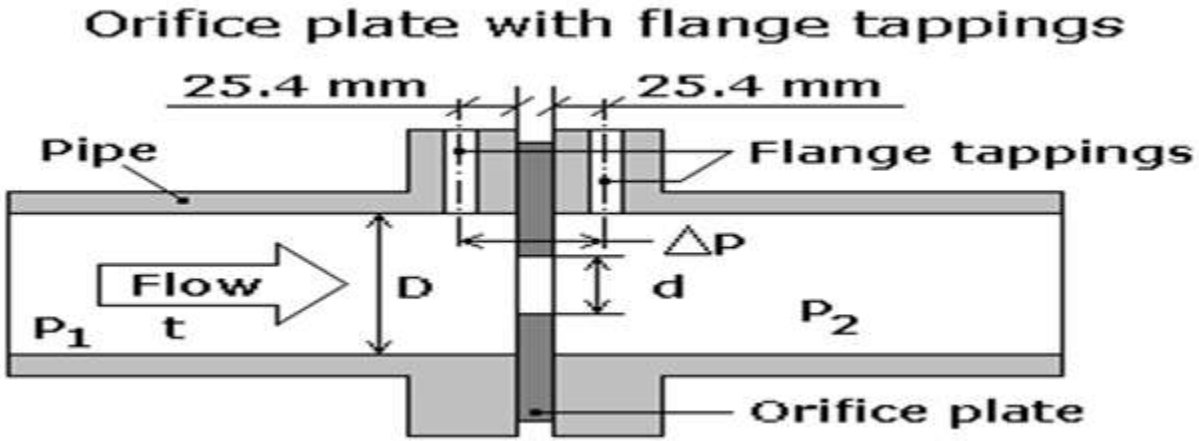
	Highest	*Lowest*	*Difference*
gpm	*1236*	*1224*	*12*

Ultra Sonic Flow Meters OE

- Whenever possible use redundant meters, (Inlet and Outlet)
- Rotational checks should always be performed
- Verification versus installed plant flow meters should be done when possible
- Always have a spare meter on hand
- Transducers easily damaged by impact or surface scratching

In-Line Orifice Plates

- Orifices require the measurement of DP across the plate
- Subject to scaling and erosion, resulting in loss of accuracy
- Often not removable for periodic calibration
- Proper entrance and exit lengths required for accuracy
- Actual measurement uncertainty may approach 5%



In-Line Orifice Plates OE

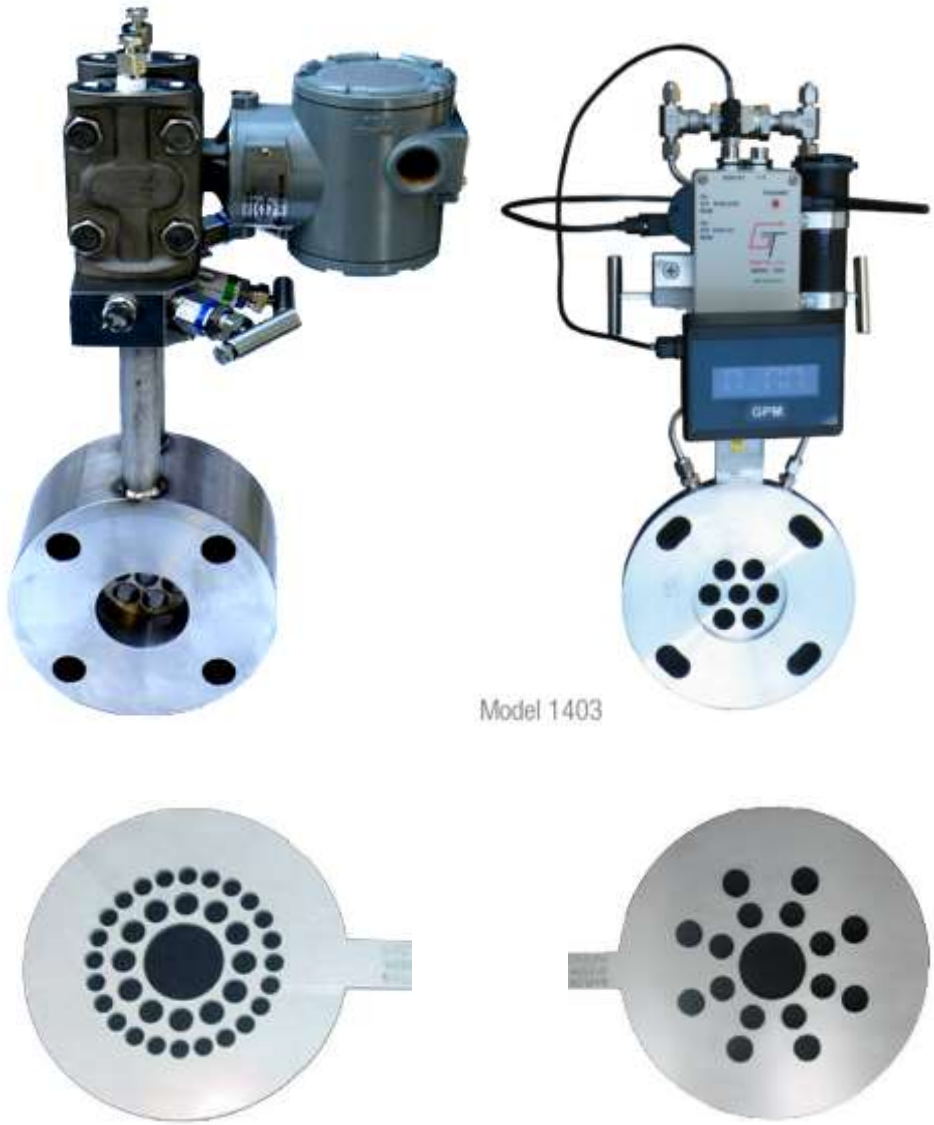
- Often found to be more accurate and reliable than Ultra Sonic flow meters
- Sometimes found to be very inaccurate
- Need to somehow cross-check accuracy prior to use
- Use portable ΔP instruments recently calibrated and properly ranged

Balanced Flow Meters

- Balanced flow meter technology conceived, created and tested through the Marshall Center's Technology Investment Program
- Licensed in August 2003, the technology was developed by NASA
- Originally designed for potential use in space shuttle main engines
- Further development made this invention suitable for commercial applications
- Awarded 2007 NASA/MSFC invention of the year
- Graftel LLC. has exclusive rights to distribute BFMs to the nuclear power industry

Balanced Flow Meters

- Accuracies of 0.25% of reading
- Accuracy unaffected by entrance and exit lengths
- Reduced system pressure drop and vibration
- Acts as both flow meter and flow conditioner
- Direct drop-in replacement to an orifice plate



Balanced Flow Meters

- Balanced flow meters may be supplied with temperature probes inserted into holes cross-drilled into them from the edges
- This allows for the most accurate measurement of bulk average water temperature flowing though the pipe
- Bulk temperature and flow rate may be measured simultaneously at the same point and time with great accuracy
- This allows for extremely accurate measurement of heat flux past that point

Balanced Flow Meters vs Orifice Plates

- 10x improvement in accuracy
- 100% increase in pressure recovery
- No need for straight pipe runs before or after the plate
- Extreme resistance to Scaling
- 15x reduction in noise energy/vibration
- Permanent pressure loss, accuracy and discharge coefficient comparable with a venturi meter

SONARtrac Flow Meters

- Clamp on meters that use the principle of sonar
- Up to 1% of reading accuracy
- Pipe coatings may be left on
- Effected by entrance length effects to a lessor degree than orifice plates or ultrasonic meters
- Pipe diameters and wall thickness are required
- Rotational checks are not required
- Increased reliability verses ultrasonic flow meters

Vane Anemometer

- Most commonly used instrument to measure air velocity
- Measures actual velocity
- Readings highly dependent upon distance from face and angle
- Accuracy not highly effected by turbulence
- Accurate for low flow rates

Hot Wire Anemometer

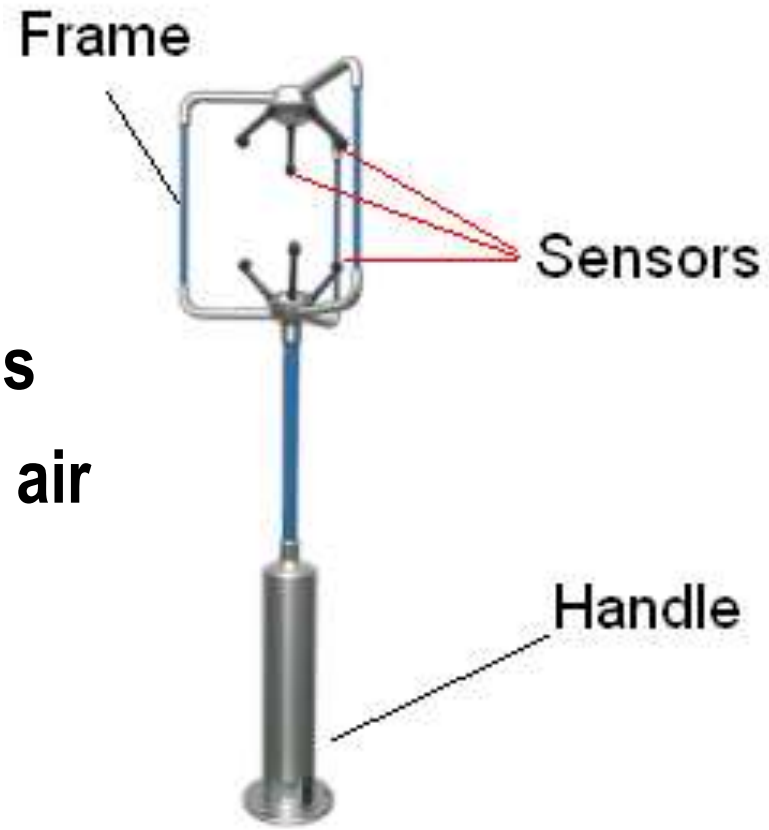
- Measures standard velocity
- Readings highly dependent upon distance from face and angle
- Accuracy is greatly effected by turbulence
- Not good for very low flow rates

Multi-Port Pitot Tube

- Placed in blower inlet
- Measures actual velocity
- Can be used only when all of blower's inlet air passes through the HX face being measured
- Good in cases when incoming the air is traveling straight along the fan's axis

3D UltraSonic Anemometer

- Measures both magnitude and direction of air velocity
- Measures standard velocity
- Not effected by turbulence
- Good for low velocity applications
- The only solution in cases where air flow gets turned



HXPT OE

- By far the biggest challenge is air velocity measurement
- The correct velocity instrument must be used for specific application
- Velocity instrument calibration conditions must match test conditions
- Coordination with OPS needed to insure no condensation during test
- Coordination with OPS needed to insure stable test conditions
- Real time heat balance needed to validate results while testing
- Pretest analysis required to determine optimum system conditions to maximize resolution
- Straight pipe runs to measure flow

RX Cooler HXPT

RHR HX Testing

RHR inlet

Service water outlet temp

Spent fuel outlet temp

Questions?

Thank you

Questions?

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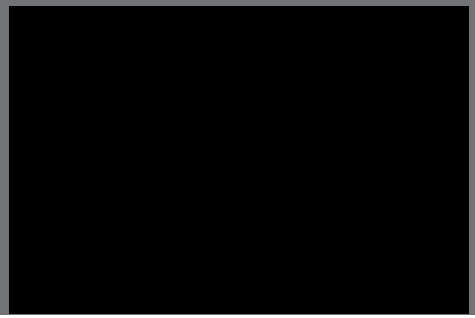

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