

A TEAM Industrial Services company

# Quantifying Infrared Temperature Corrections: From Art to Science

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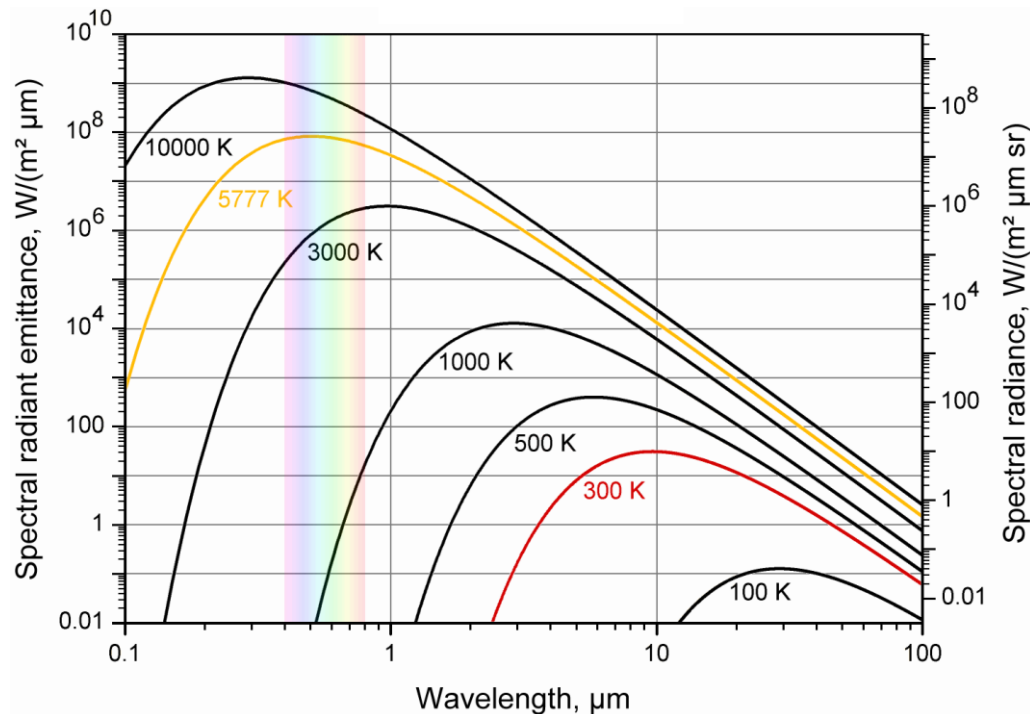
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# Presentation Outline

- Introduction to Infrared and Measurement Factors
- Case Study #1: Ideal Image Corrections:
  - Compare IR readings with Skin TI readings
- Case Study #2: Non-Ideal Image Corrections:
  - Background Temperature Scattering
  - Angle of Incidence
- Summary

# Infrared Inspection Introduction and Measurement Factors

*Blackbody spectral radiance*



Infrared radiation intensity is directly proportional to surface temperature.

- **True tube temperature**
  - Desired outcome
- **Environment Factors**
  - Tube emissivity
    - Angle of Incidence
  - Target reflectance
    - Background temperature
    - Heater geometry
  - Flue gas absorption and emission
- **Instrument Factors**
  - Wavelength
  - Calibration and Size of Source Effect
  - Instrument emissivity setting

# What to Expect when taking a Temperature Reading

- Heater & Camera & Skin thermocouple (TI) are unique!!
  - Need to be analyzed accordingly.
- Skin TIs **for this case study** have an insulated cover that can cause reading to be lower than actual
  - TI's have an (undefined) uncertainty in the reading ( $\pm 25$  °F on a well working skin TI is typical).
- IR Cameras read the tube scale surface temperature.
  - Oxidation scale build-up will cause IR reading to be higher than actual.
  - Typical IR (defined) uncertainty in the reading is  $\pm 30$  °F
- The true metal temperature falls between the IR reading and Skin TI reading:

**IR Temperatures > Actual Metal Temperature > Skin TI Temperature**

# Corrected IR Reading Comparison – Overall Good Agreement

IR Comparisons at Same Spot						
Skin TI Location	Tube	Sight Door	Reading Location	#2 Readings	#1 Readings	Difference
B05 TI2120	30A	E01	21	696.6	706.6	10.0
B06 TI2121	37A	E02	52	857.1	864.9	7.8
C12 TI2122	42A	W01	50	728.9	718.0	-10.9
B08 TI2123	45A	E01	19	741.1	723.6	-17.5
B07 TI2124	46A	E01	7	696.2	703.0	6.8
B04 TI2020	30B	E01	38	800.1	816.0	15.9
B03 TI2021	37B	E02	30	725.0	732.8	7.8
C14 TI2022	42B	W02	46	747.8	741.6	-6.2
B01 TI2023	45B	E02	21	797.8	786.7	-11.1
B02 TI2024	46B	E02	13	706.0	716.3	10.3
B09 TI2016	15B	E01	55	748.6	749.2	0.6
C13 TI2006	15B	W02	3	760.2	744.7	-15.5
B10 TI2116	16A	E01	53	709.2	710.2	1.0
C13 TI2106	16A	W02	1	711.7	691.6	-20.1

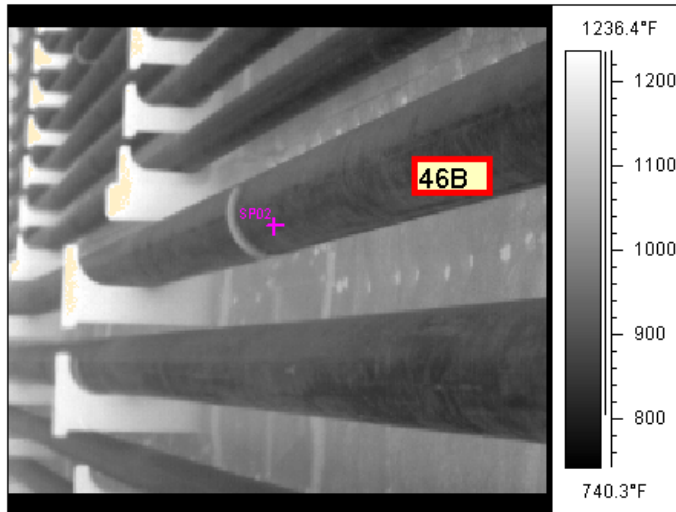
Reading difference falls within measurement uncertainty

# Target Tube Location - Ideal Spot

- Let's take a look at and compare values of an ideal IR Camera image:

## #1 Camera/Technician Image

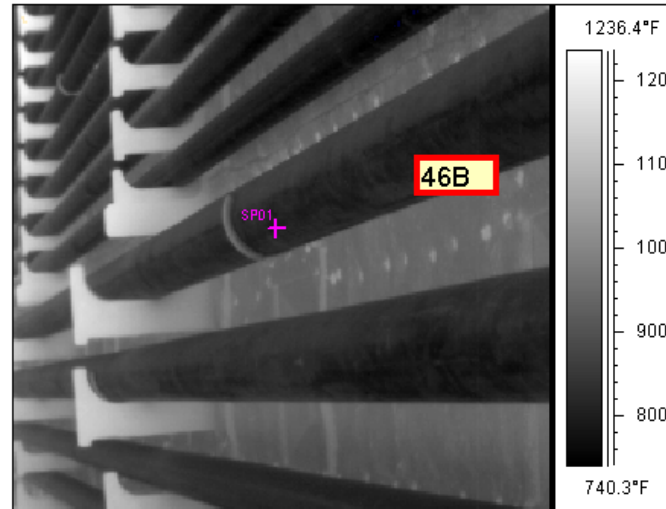
Area of Heater:	North Wall
Tube Location:	TI-2024 viewed from E02



IR information	Value
Date of creation	5/25/2018
Time of	6:47:23 PM
File name	B02.tif
Label	Value
SP02	*894.6°F

## #2 Camera/Technician Image

Area of Heater:	North Wall
Tube Location:	TI-2024 viewed from E02



IR information	Value
Date of creation	5/25/2018
Time of	12:39:36 PM
File name	B02.tif
Label	Value
SP01	*796.7°F

### Why Ideal?

- Isothermal objects in image, especially at the measurement spot.
- Line of sight is short distance and not looking through flame.
- Angle of incidence is greater than 40°<sup>6</sup>

# Target Tube Location - Ideal Spot

- Same spot, two different raw temperatures for both cameras/technicians.
  - Size of Source Effect (SSE) calibration is different for the two cameras.
- After applying the appropriate corrections to both cameras the final temperatures are compared:
  - #1: Raw Reading: 894°F -> Corrected Temperature: 716°F ± 44°F = 673 °F to 760 °F
  - #2: Raw Reading: 796°F -> Corrected Temperature: 706°F ± 39°F = 667 °F to 745 °F
  - Skin TI2024: 667°F ± 25°F
- After correcting the temperature and considering the uncertainty in instrument readings, we get very similar results between the skin TI and both cameras:

Group	Tube	Image #	#1 Lower Uncertainty Boundary	#2 Lower Uncertainty Boundary	Skin TI
17H1A Pass B	46B	B02 TI2024	673	667	667

- The true metal temperature reading is between 667°F and 706°F.

# Comparing IR and Skin TI Readings – Agreement?

IR and Skin TI Comparisons						
Skin TI Location	Tube	Sight Door	Reading Location	#1 Readings	Skin TI Readings	Difference
B05 TI2120	30A	E01	21	706.6	656.0	50.6
B06 TI2121	37A	E02	52	864.9	658.0	206.9
C12 TI2122	42A	W01	50	718.0	645.0	73.0
B08 TI2123	45A	E01	19	723.6	666.0	57.6
B07 TI2124	46A	E01	7	703.0	673.0	30.0
B04 TI2020	30B	E01	38	816.0	639.0	177.0
B03 TI2021	37B	E02	30	732.8	655.0	77.8
C14 TI2022	42B	W02	46	741.6	638.0	103.6
<b>B01 TI2023</b>	<b>45B</b>	<b>E02</b>	<b>21</b>	<b>786.7</b>	<b>657.0</b>	<b>129.7</b>
B02 TI2024	46B	E02	13	716.3	667.0	49.3
B09 TI2016	15B	E01	55	749.2	655.0	94.2
C13 TI2006	15B	W02	3	744.7	631.0	113.7
B10 TI2116	16A	E01	53	710.2	668.0	42.2
C13 TI2106	16A	W02	1	691.6	661.0	30.6

Let's look at these errors for Tube 45B

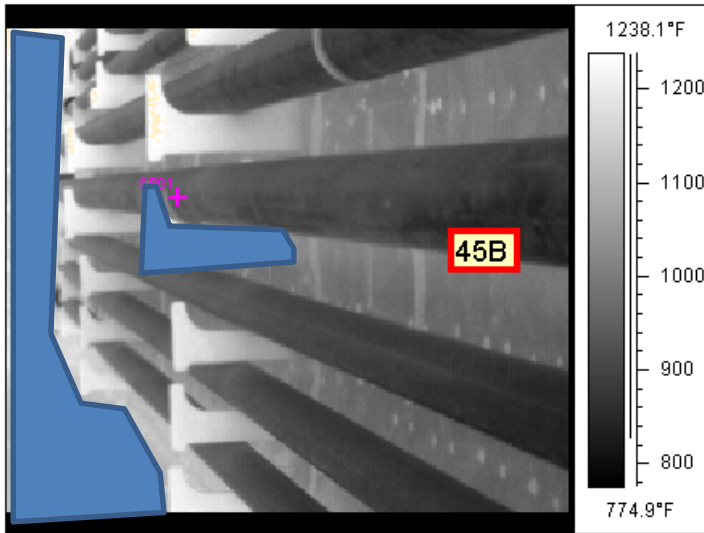


# Target Tube Location - Non-Ideal Spot

- Let's take a look and compare values for a non-ideal IR Camera image:

## #1 Camera/Technician Image

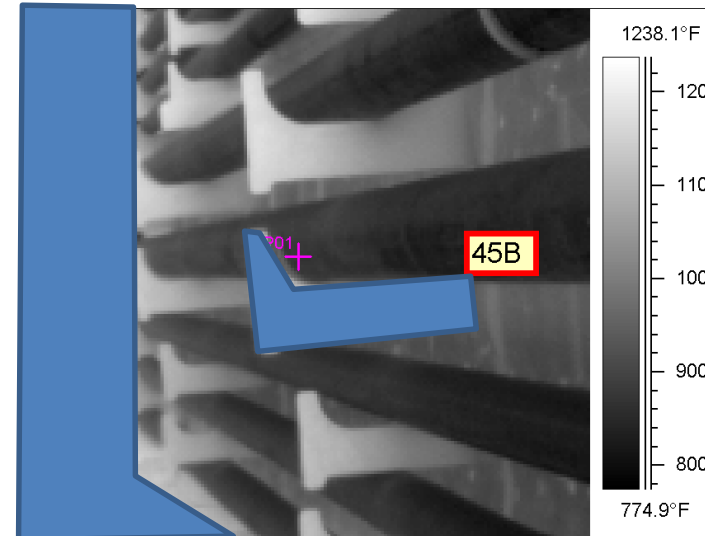
Area of Heater:	North Wall
Tube Location:	TI-2023, viewed from E02



IR information	Value
Date of creation	5/25/2018
Time of	6:47:12 PM
File name	B01.tif
<b>Label</b>	<b>Value</b>
SP01	942.0°F

## #2 Camera/Technician Image

Area of Heater:	North Wall
Tube Location:	TI-2023, viewed from E02



IR	Value
Date of	5/25/2018
Time of	12:39:26 PM
File name	B01.tif
<b>Label</b>	<b>Value</b>
SP01	*870.8°F

### Why Non-Ideal?

- Non-Isothermal objects (refractory) in image and immediately adjacent (Support) to target spot.
- Line of sight is long.
- Angle of incidence is narrow.

# Target Tube Location - Non-Ideal Spot

- Again we see non-consistent raw temperatures between the two cameras because of SSE error.
- After applying the same standard corrections to both cameras the final temperatures are as follows:
  - #1: Raw Reading: 942°F -> Corrected Temperature: 786°F ± 39°F = 747 °F to 825 °F
  - #2: Raw Reading: 870°F -> Corrected Temperature: 798°F ± 33°F = 765 °F to 831 °F
  - Skin TI2023: 657°F ± 25°F
- Notice that after correcting the temperatures both cameras have similar temperatures. However, there is still a noticeable difference between the camera temperatures and the Skin TI reading.

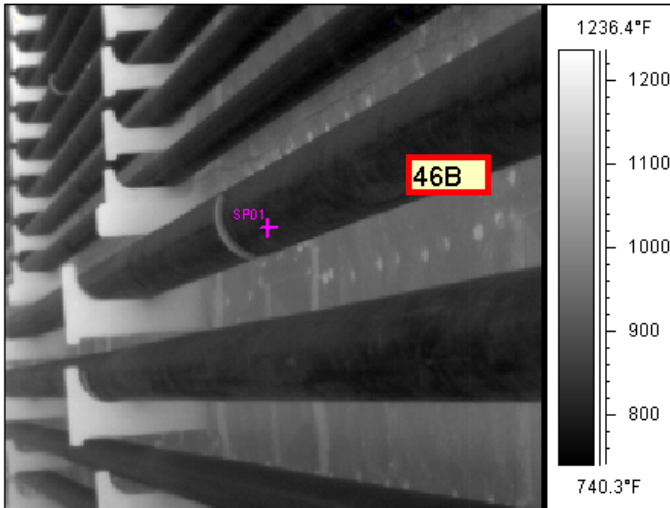
Group	Tube	Image #	#1 Lower Uncertainty Boundary	#2 Lower Uncertainty Boundary	Skin TI
Pass B	45B	B02 TI2023	747	765	657

# Target Tube Location – Ideal versus Non-Ideal Spot Comparison

- When comparing the two images (46B & 45B), they look similar, yet the same correction does not appear to yield good results:

## Ideal Spot

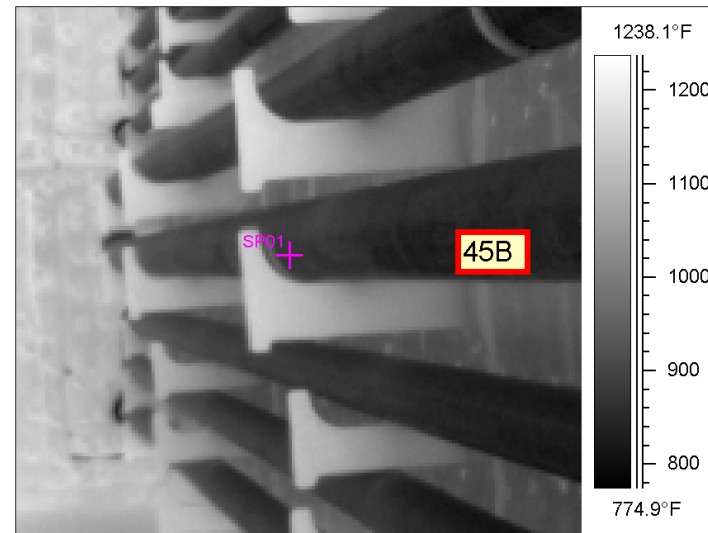
Area of Heater:	North Wall
Tube Location:	TI-2024 viewed from E02



IR information	Value
Date of creation	5/25/2018
Time of	12:39:36 PM
File name	B02.tif
<b>Label</b>	<b>Value</b>
SP01	*796.7°F

## Non-Ideal Spot

Area of Heater:	North Wall
Tube Location:	TI-2023, viewed from E02



IR	Value
Date of	5/25/2018
Time of	12:39:26 PM
File name	B01.tif
<b>Label</b>	<b>Value</b>
SP01	*870.8°F

- The issue here is a combination of the desired target location and how the image has been taken.
- Corrected IR temperature reading will be higher than actual metal temperature because of the effect of the tube support reflection and radiation scattering.

# Non-Ideal Spot Corrected for Tube Support Reflection Error

- After including the Tube Support readings as additional reflected radiation and running calculations, we get these results:
  - #1: Raw Reading: 942°F -> Corrected Temperature: 768°F ± 43°F = 725 °F to 811 °F
  - #2: Raw Reading: 870°F -> Corrected Temperature: 784°F ± 35°F = 749 °F to 819 °F
  - Skin TI2023: 657°F ± 25°F
- After adjusting the background reflection and rerunning the calculations, we have lower temperature values, however still a noticeable difference between the camera temperatures versus the Skin TI.

Group	Tube	Image #	#1 Lower Uncertainty Boundary	#2 Lower Uncertainty Boundary	Skin TI
Pass B	45B	B02 TI2023	725	749	657

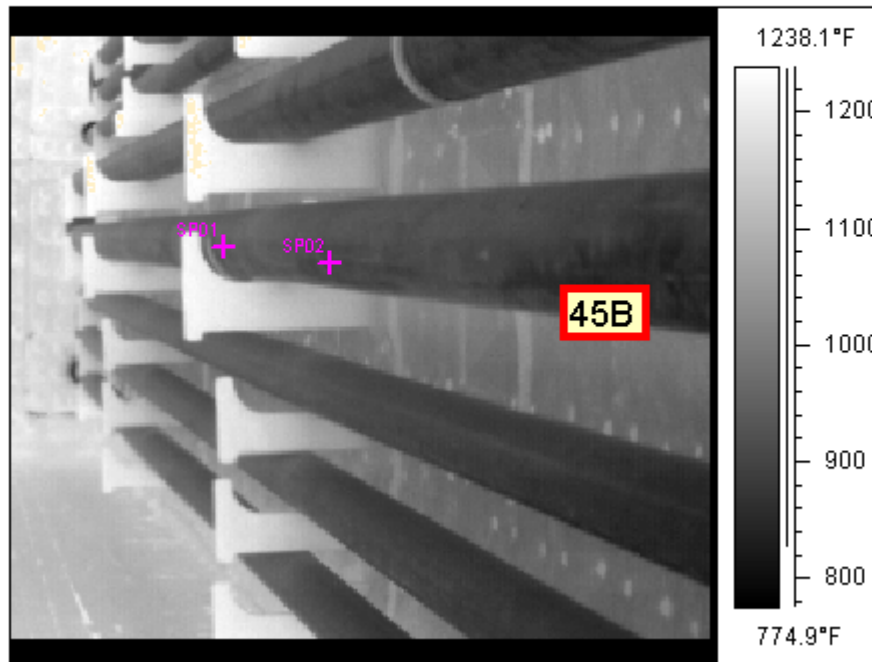
# Non-Ideal Spot Correction for Scattering and Angle of Incidence

- Tube Support radiation will be scattered such that some of its emitted radiation will appear in the image at the Target Spot.
  - This error is known as scattering and becomes an issue when objects of non similar temperatures are captured in an image. Scattering within the image causes a IR reading to be higher than actual metal temperature when hot refractory/tube support are captured in the image. The error magnitude is dependent upon the object temperature, percentage of image area, and proximity to target spot that captures non-isothermal objects. In this case the tube support elevates the corrected temperature at this target spot.
- Angle of incidence must also be accounted for in the images. At angle of incidences less than 41 degrees, the tube emissivity will decrease, causing the reflected radiation to increase.
  - Images taken on the far end of the heater (past the middle point) from a sight door immediately adjacent to the tube wall should not be done, because the angle of incidence would be well below normal (90 degrees) which is the ideal angle.
- These effects can be estimated by comparing tube readings nearer the sight door versus the Skin TI target spot.

# Non-Ideal Spot Correction for Scattering and Angle of Incidence

- We really want to know what SP01 is but since SP02 is in a location that is not affected by Support radiation and is greater than 40° angle then we can estimate the true temperature of the tube at SP01 by adjusting the SP01 to equal SP02. Note, both spots are still affected by scattering of the radiation off the hot refractory, i.e. higher IR reading than actual.

Area of Heater:	North Wall
Tube Location:	TI-2023, viewed from E02



IR information	Value
Date of creation	5/25/2018
Time of	6:47:12 PM
File name	B01.tif
Label	Value
SP01	942.0°F
SP02	*895.9°F

# Non-Ideal Spot Correction for Scattering and Angle of Incidence

- Assuming the tube metal temperature is the same at both spots, the corrected temperatures for both spots should be identical.

Spot	Tube	Location (ft)	Reading	Corrected Temperature	Emissivity
SP02	45B	16	896	722	0.82
SP01	45B	21	942	768	0.82

- We see that after the standard calculations we have a difference of 46°F (768 to 722 °F).
- In the following chart, calculations were done with different emissivity's in order to find the proper emissivity for SP01, which should be the one reading closest to 722 °F, removing the reading errors due to Scattering and Angle of Incidence.

# Non-Ideal Spot Correction for Scattering and Angle of Incidence

Spot	Tube	Location (ft)	Reading	Corrected Temperature	Emissivity
SP01	45B	21	942	764	0.81
SP01	45B	21	942	759	0.80
SP01	45B	21	942	755	0.79
SP01	45B	21	942	750	0.78
SP01	45B	21	942	745	0.77
SP01	45B	21	942	740	0.76
SP01	45B	21	942	734	0.75
SP01	45B	21	942	729	0.74
SP01	45B	21	942	722	0.73
SP01	45B	21	942	716	0.72
SP01	45B	21	942	710	0.71

Spot	Tube	Location (ft)	Reading	Corrected Temperature	Emissivity
SP01	45B	21	942	703	0.70
SP01	45B	21	942	695	0.69
SP01	45B	21	942	688	0.68
SP01	45B	21	942	679	0.67
SP01	45B	21	942	671	0.66
SP01	45B	21	942	663	0.65
SP01	45B	21	942	652	0.64
SP01	45B	21	942	640	0.63
SP01	45B	21	942	630	0.62
SP01	45B	21	942	617	0.61
SP01	45B	21	942	606	0.60



# Non-Ideal Spot Correction for Scattering and Angle of Incidence

- From our simulation we found that an emissivity value of 0.73 matches the readings at SP01 and SP02.
- After applying these changes we now get these results:
  - #1: Raw Reading: 942°F -> Corrected Temperature: 722°F ± 59°F = 663 °F to 781 °F
  - #2: Raw Reading: 870°F -> Corrected Temperature: 750°F ± 46°F = 704 °F to 796 °F
  - Skin TI2023: 657°F ± 25°F
- After adjusting the background AND emissivity and rerunning the calculations we now have corrected temperatures that are consistent with the Skin TI reading.

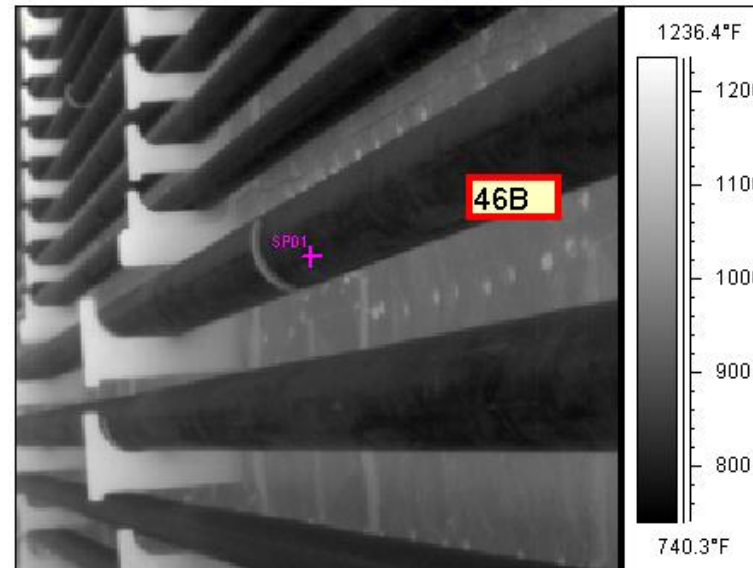
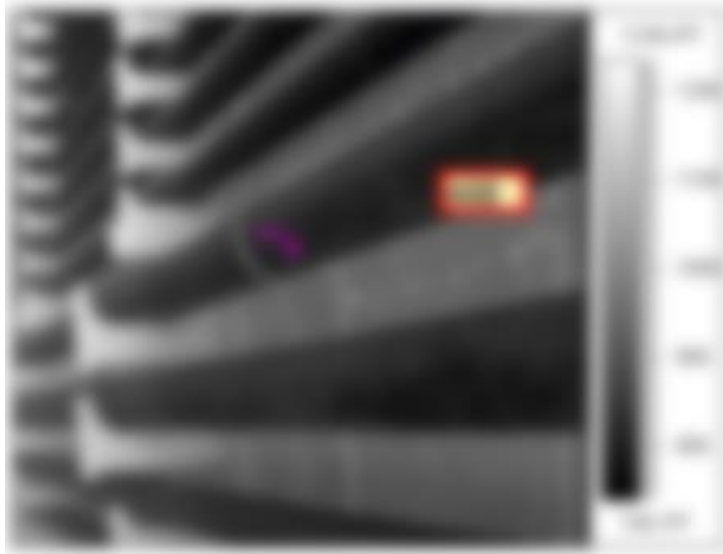
Group	Tube	Image #	#1 Lower Uncertainty Boundary	#2 Lower Uncertainty Boundary	Skin TI
Pass B	45B	B02 TI2023	663	704	657

- The true metal temperature reading is between 657°F and 722°F.

# Summary : Art to Science

- Both Skin TI and IR readings are uncertain. The IR uncertainty may be calculated. The Skin TI uncertainty is unknown.
- To capture the full capability of IR thermometry, a proven methodology is required to measure accurate temperatures in a repeatable process.
- When we correct for ALL of the environmental and instrument factors, we get corrected temperatures that are consistent, accurate and repeatable by different personnel using different instruments.

ART



SCIENCE