

Infra Red Inspection of Joints

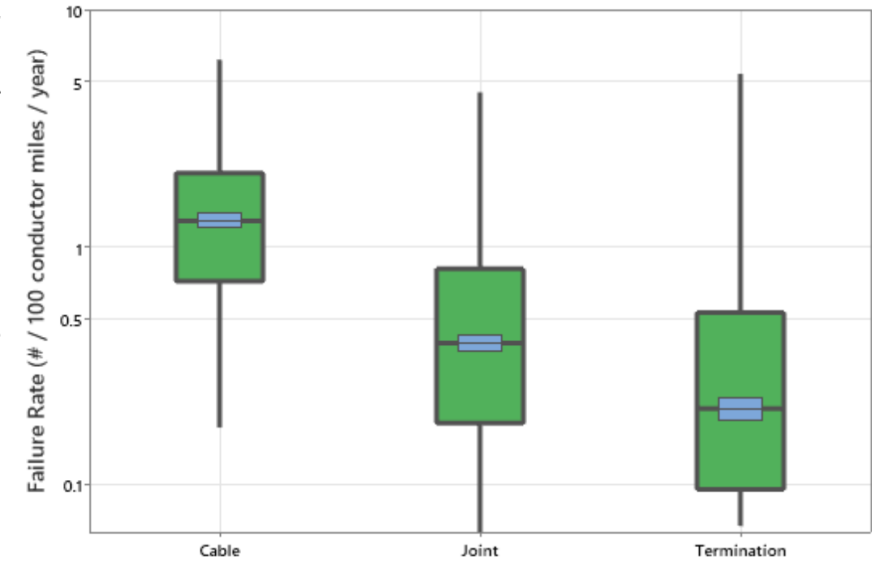
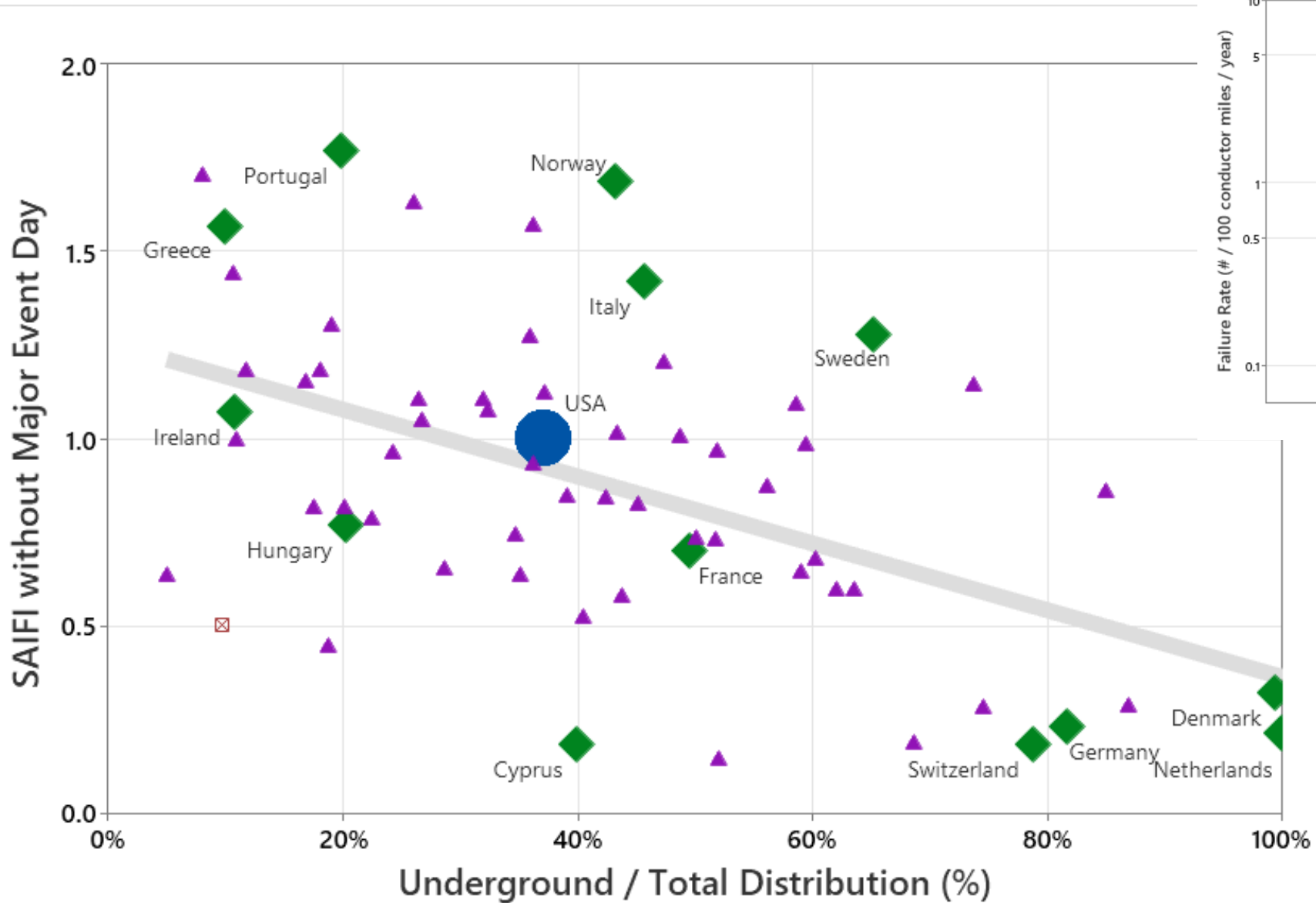
- Is it straightforward

Spring ICC Education Session



E. Barriere
A. Bologna
N. Hampton
J. Perkel

Reliability Benefits of Undergrounding



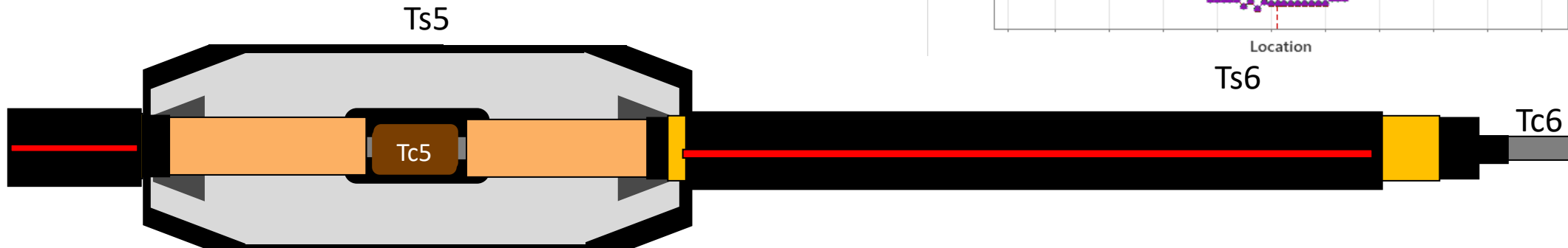
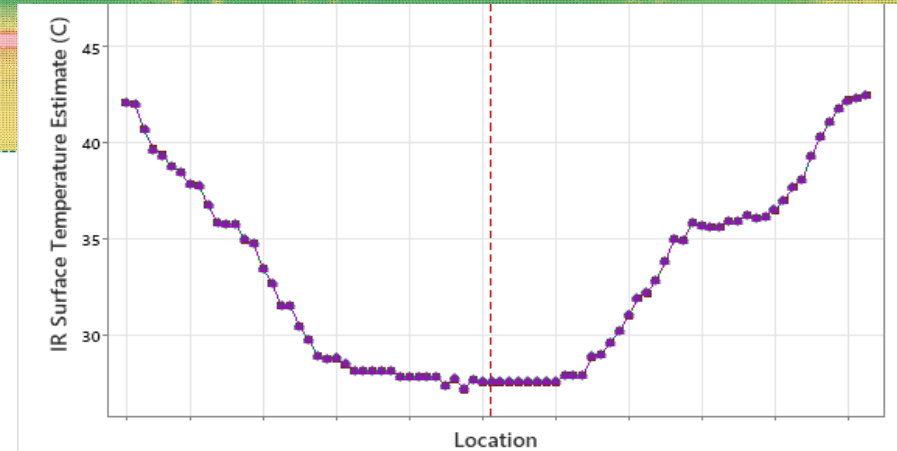
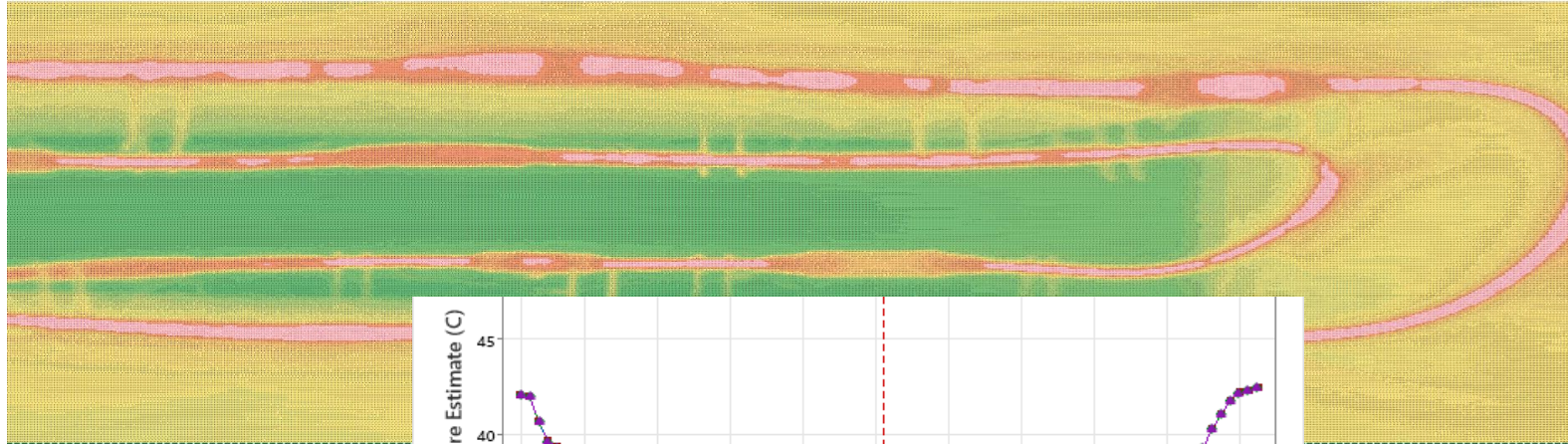
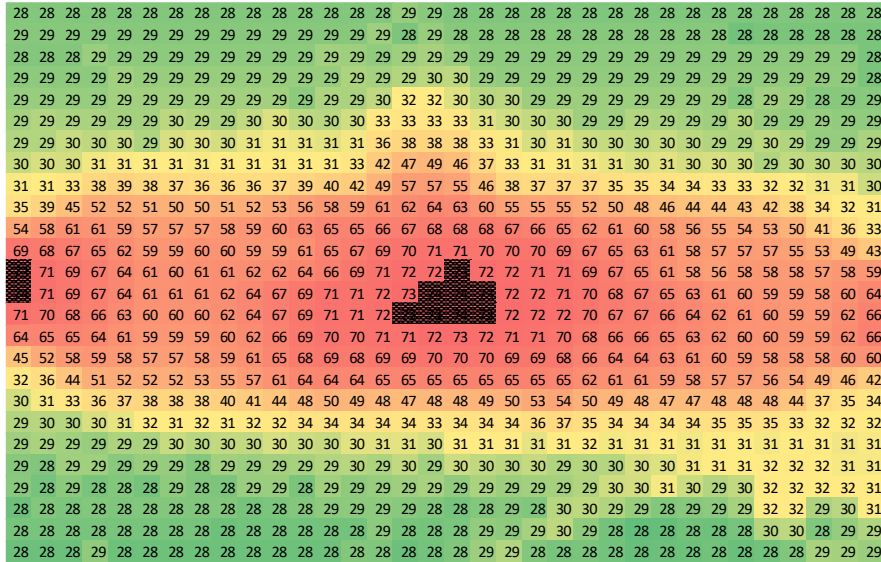
Condition Based Maintenance

Estimate future risk

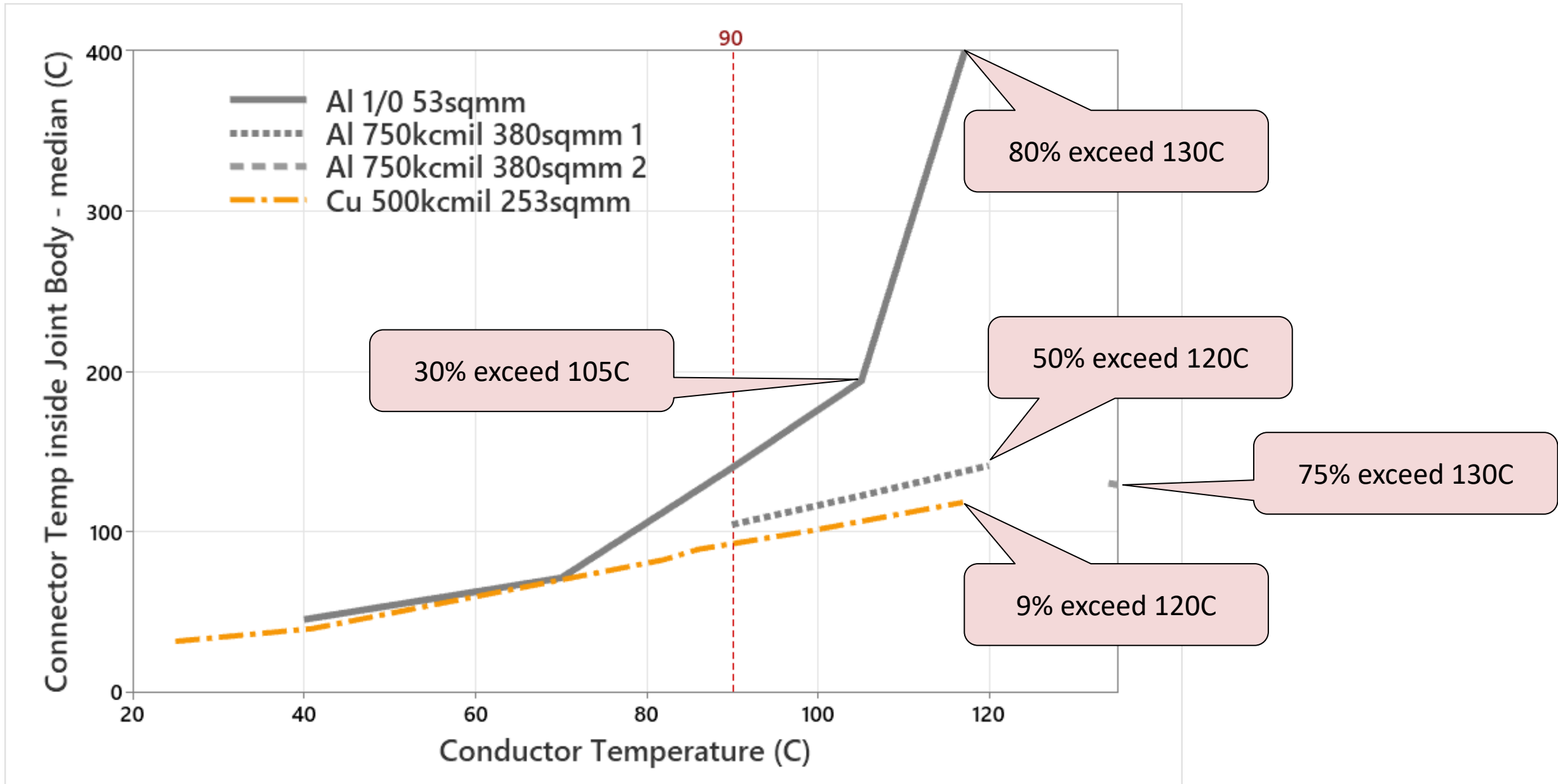
- Non invasive
- Simple
- Predictive

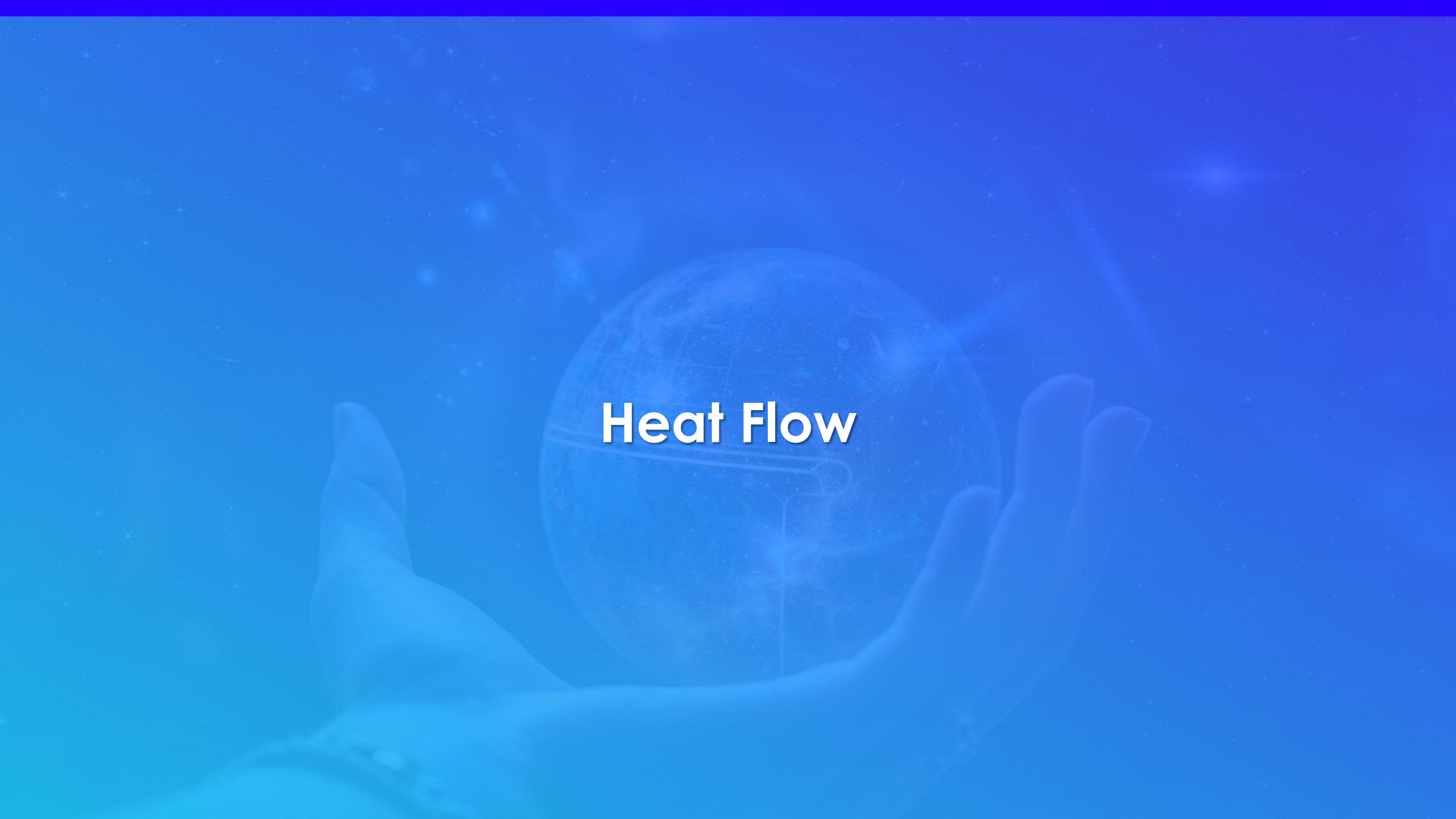
Route

Most routes for assessing joints involve Infra Red imaging



Connector – Cu (this work), Al (legacy)





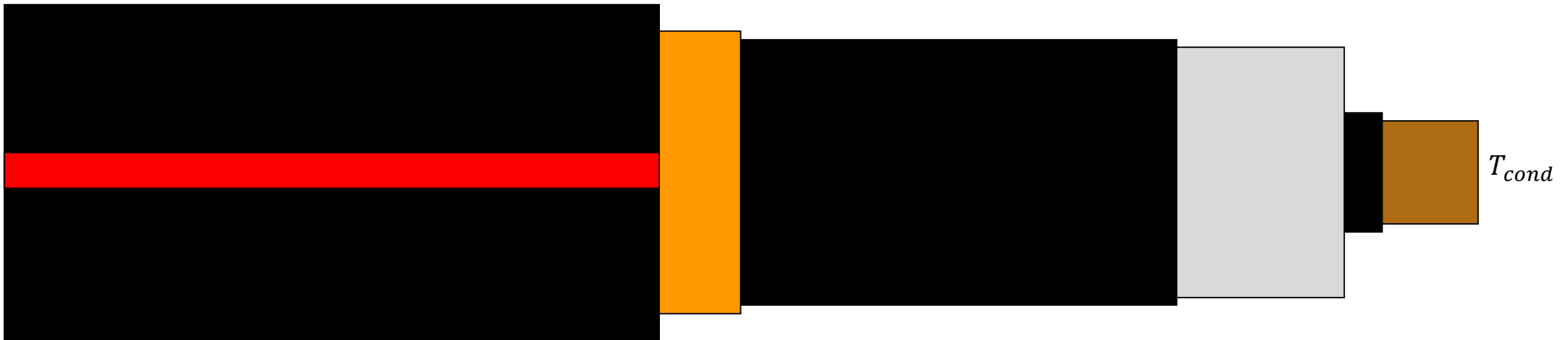
Heat Flow

Surface Temperature – cable estimates

$$\Delta T = T_{cond} - T_{jkt} = W_{cond} * TR_{1/2} = I^2 R * TR_{1/2}$$

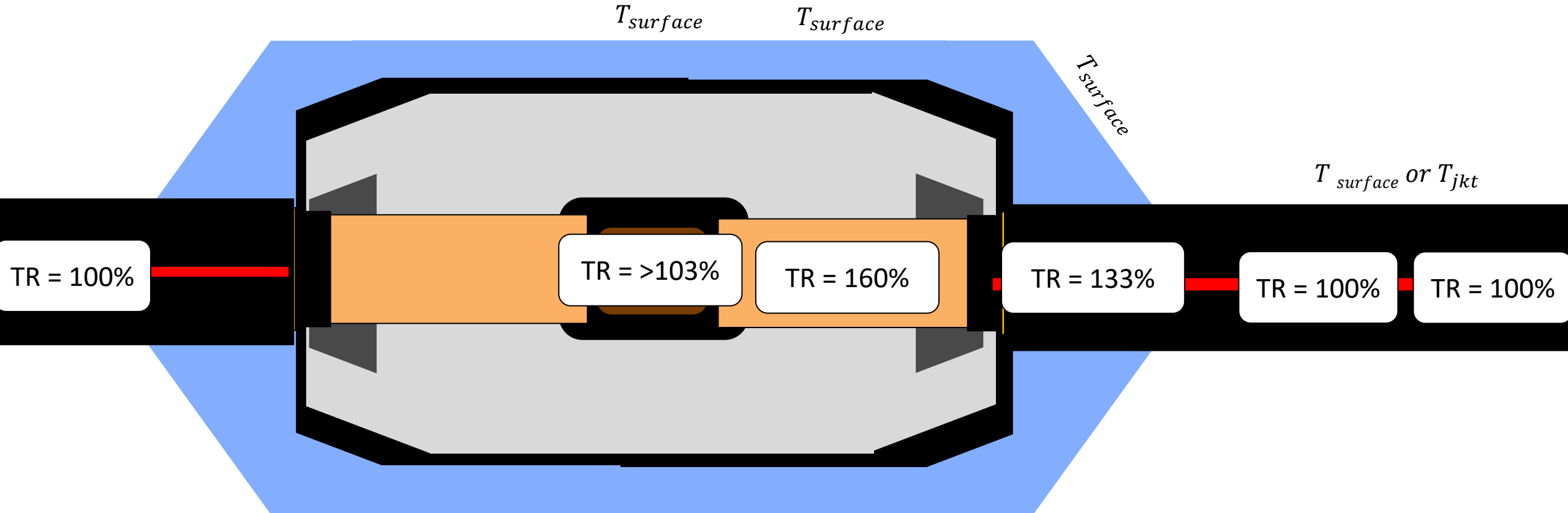
$$TR = \frac{\rho_{th}}{2\pi} \ln \frac{D/2}{d/2}$$

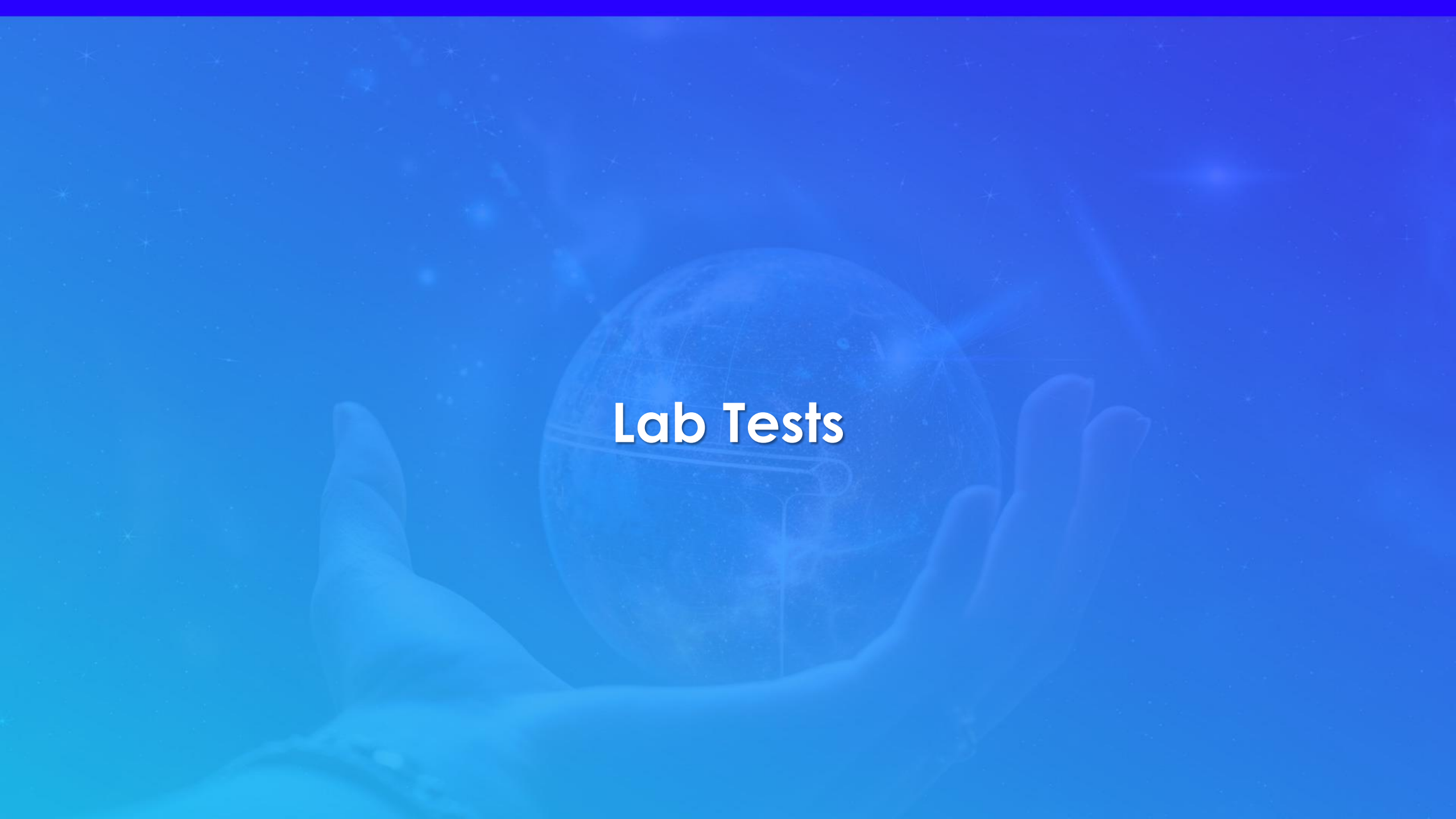
$T_{surface} \text{ or } T_{jkt}$



Surface Temperature – joint estimates

$$TR = \frac{\rho_{th}}{2\pi} \ln \frac{D/2}{d/2}$$





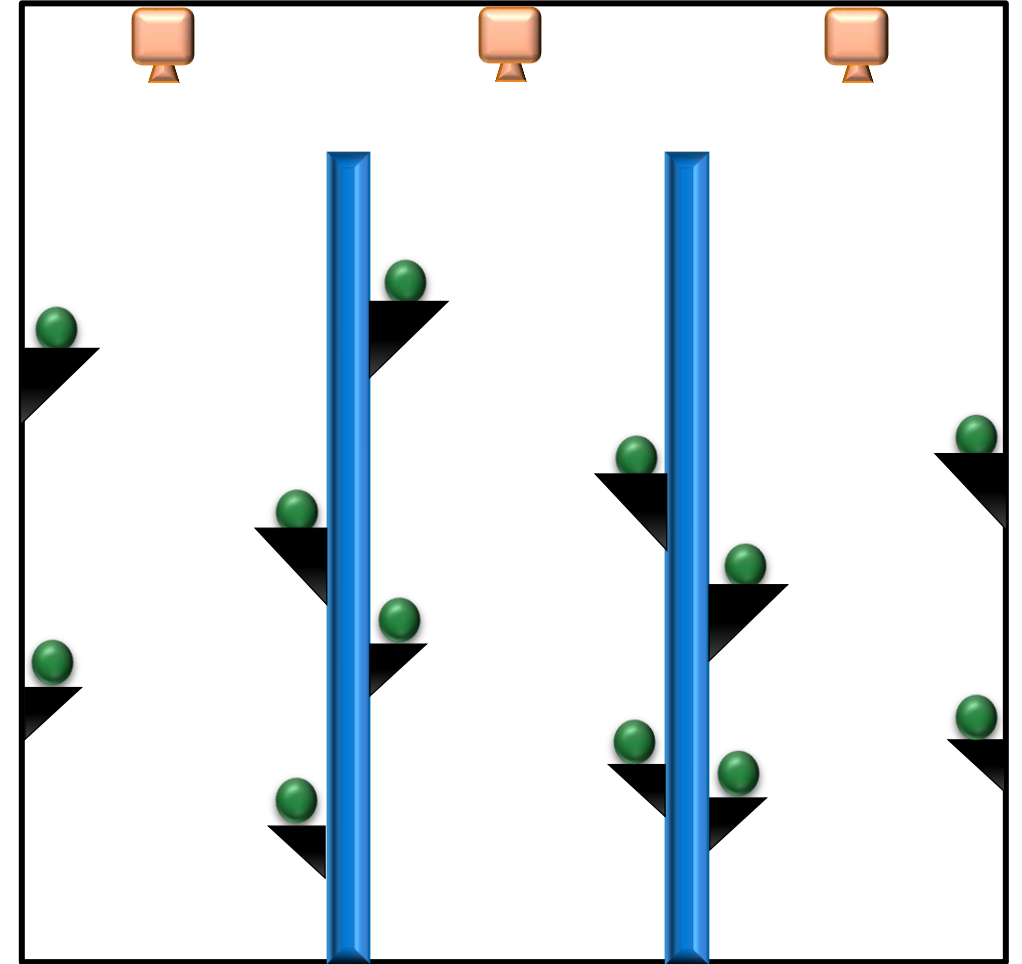
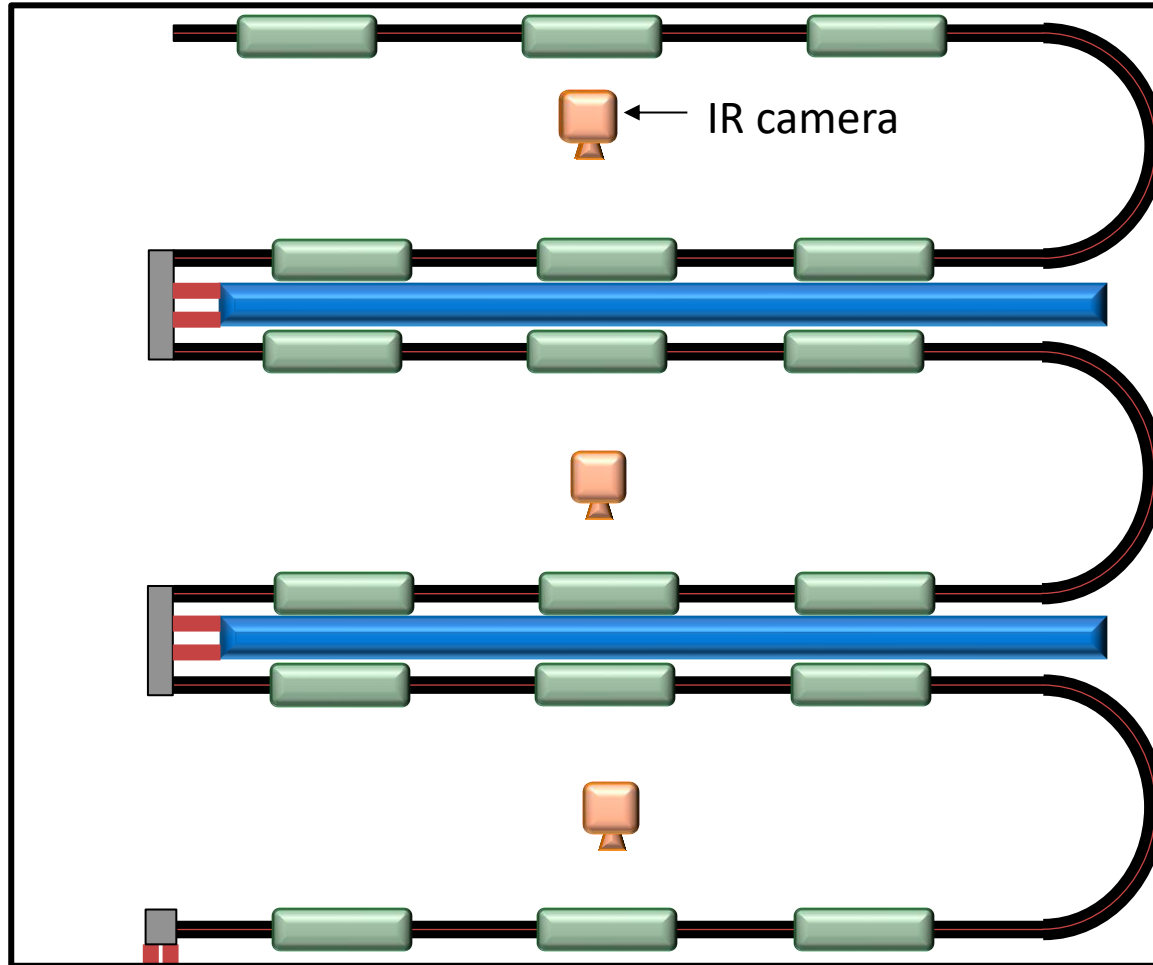
Lab Tests

Accessory Test Bed

Test Bed

dc
current
supply

DAQ



Accessory Test Bed

Test Bed

dc
current
supply

DAQ

← IR camera

Measurements

1. Multiple wide-angle IR Cameras
2. Internal joint connector temperatures
3. External joint housing surface temperatures
4. Real-time connector resistance
5. External surface temperature of applied tapes



Experiment Design

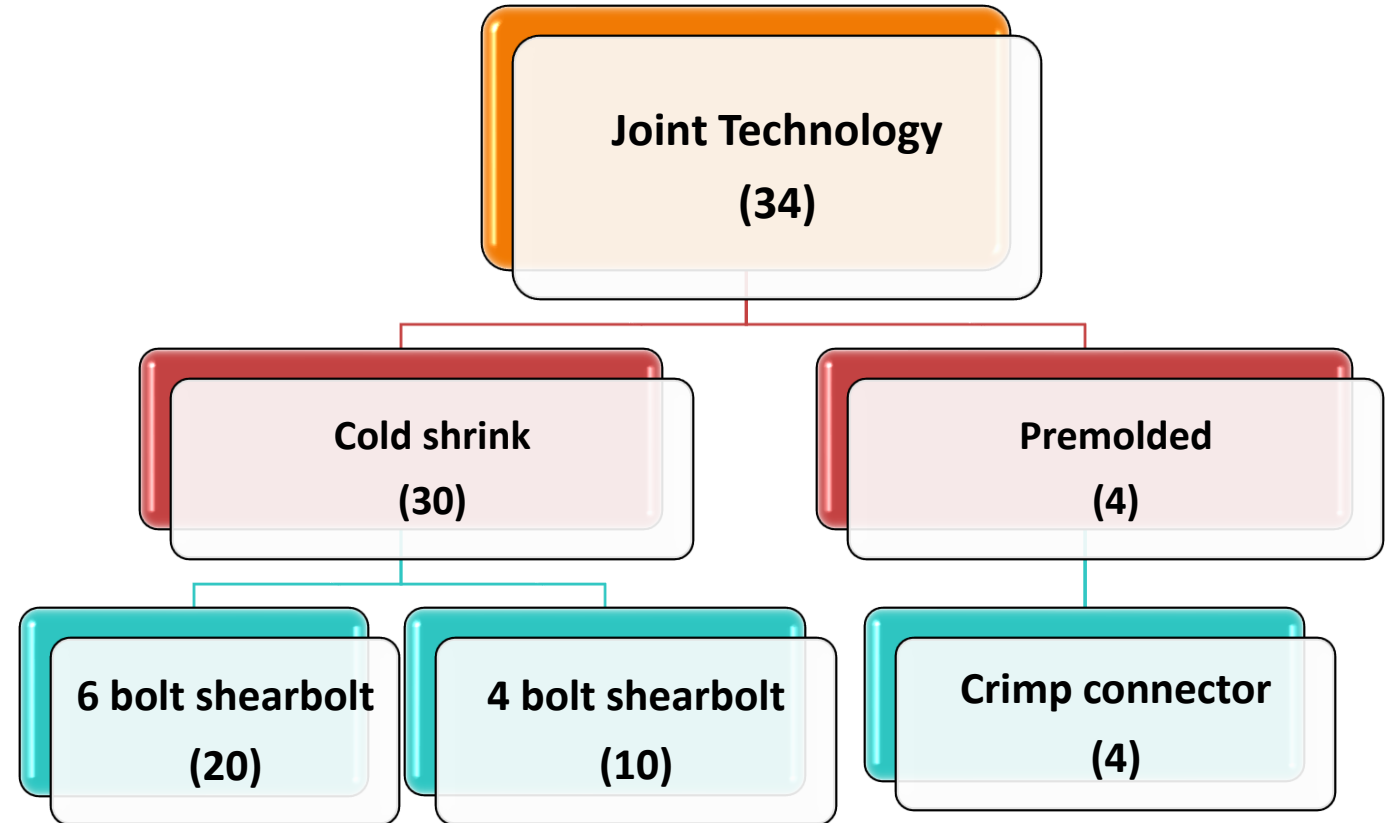


500kcmil 15kV Cu
EPR Cable



As a first step
Only consider conductor
connections

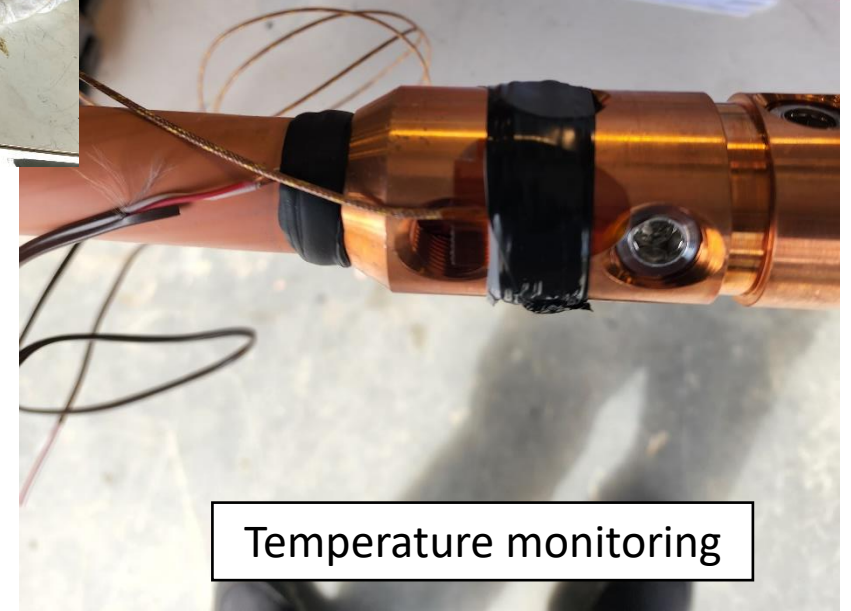
Metallic shield connections later



Connector Construction



dc resistance monitoring



Temperature monitoring



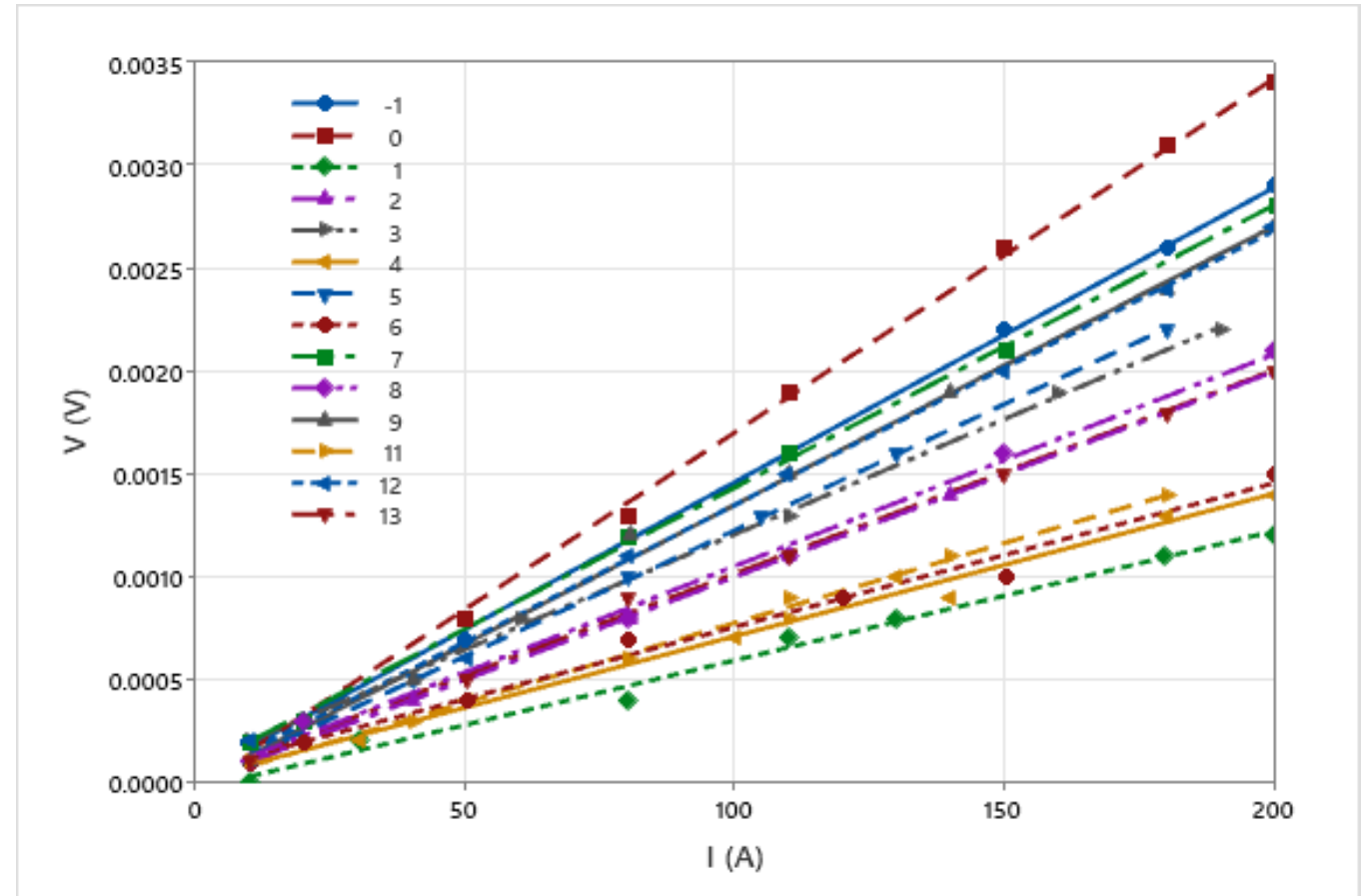
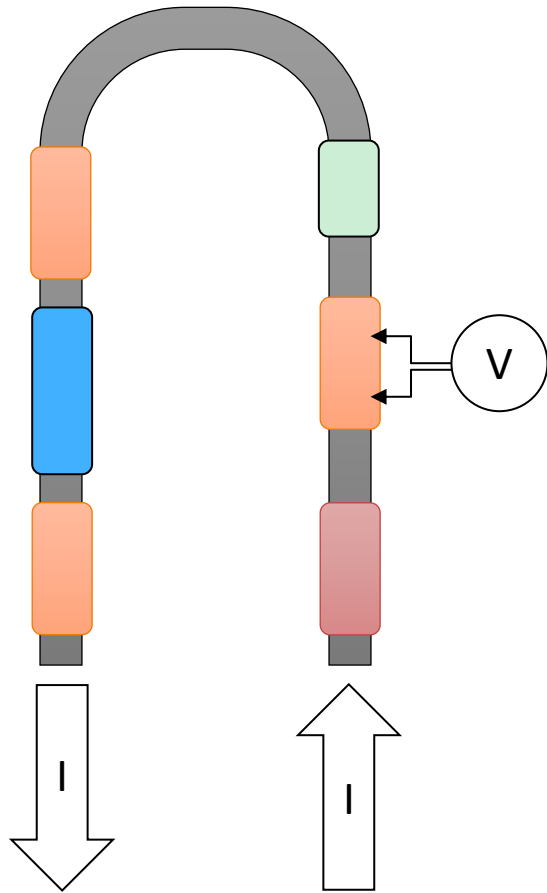
Connector installation factors



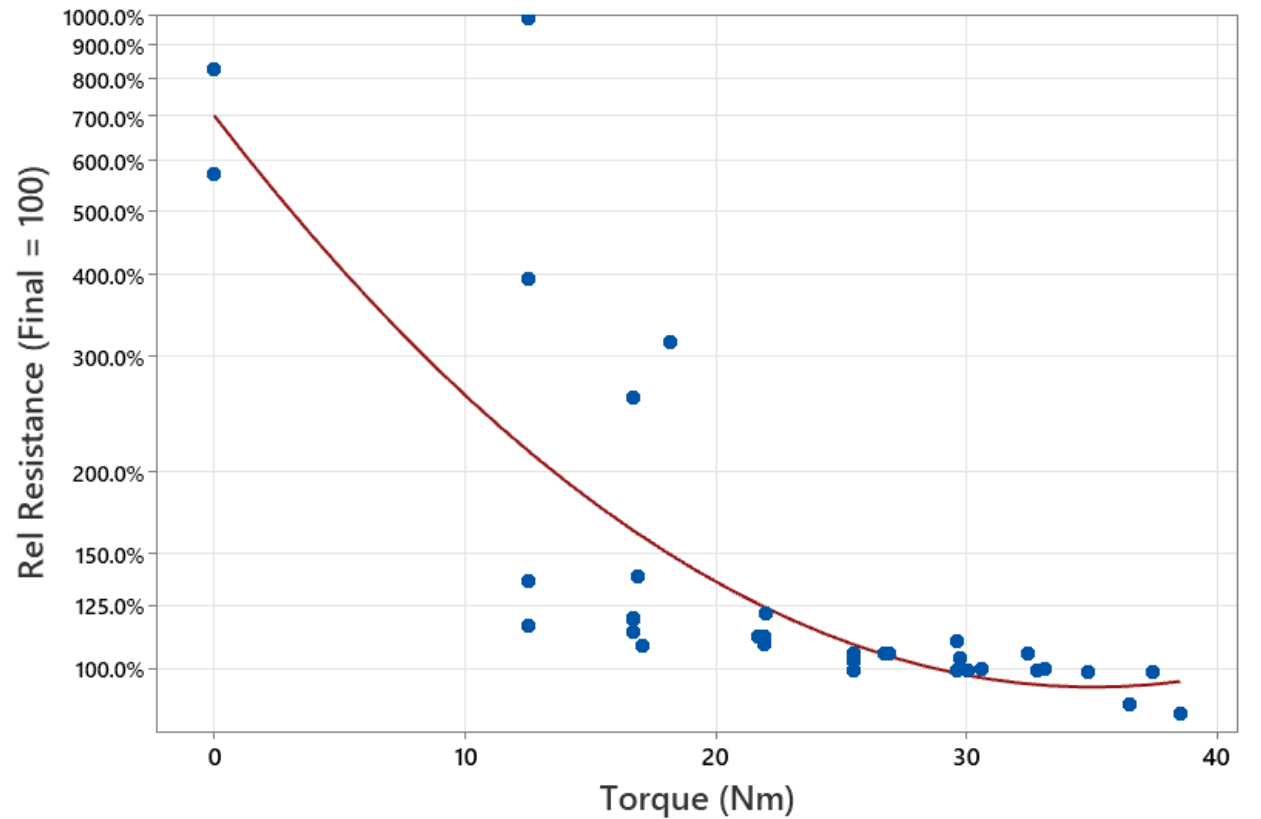
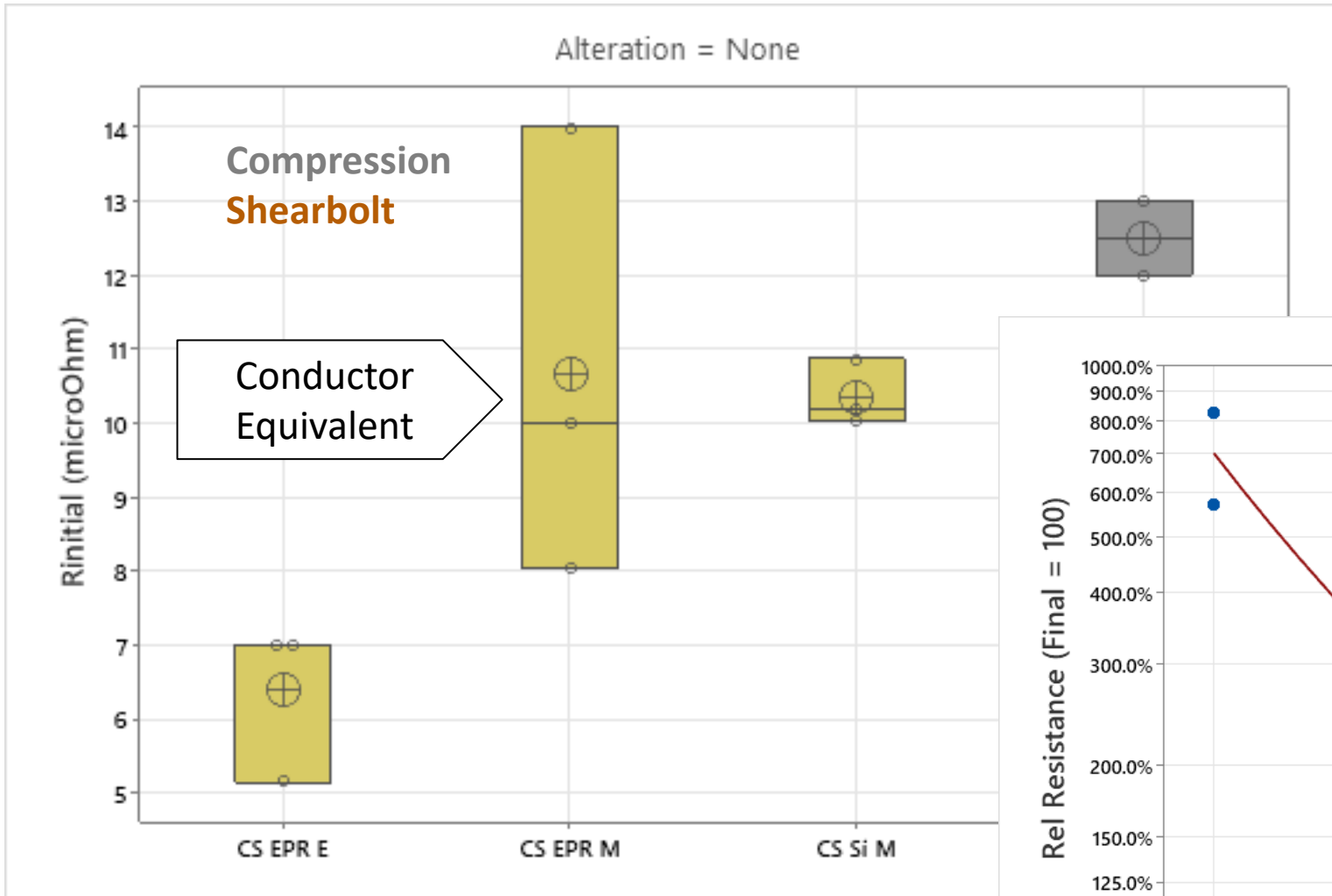
Resistances

Connector Resistances

- 4 wire measurement – impact of leads and contact resistances is eliminated



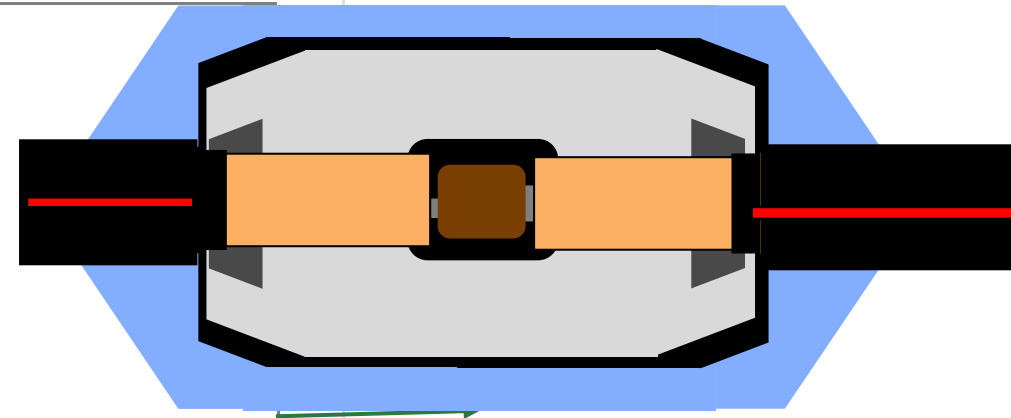
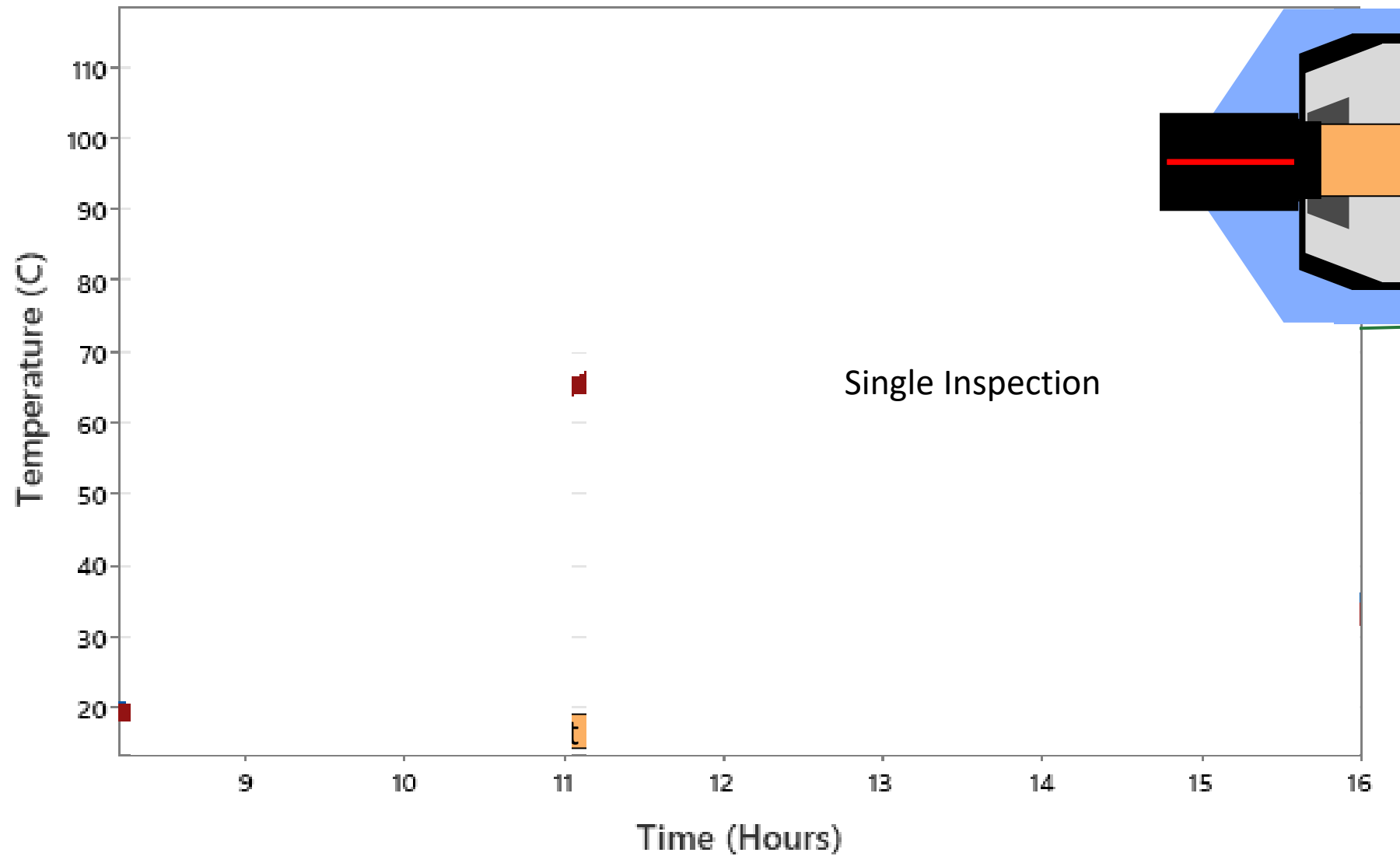
Not all connectors are the same





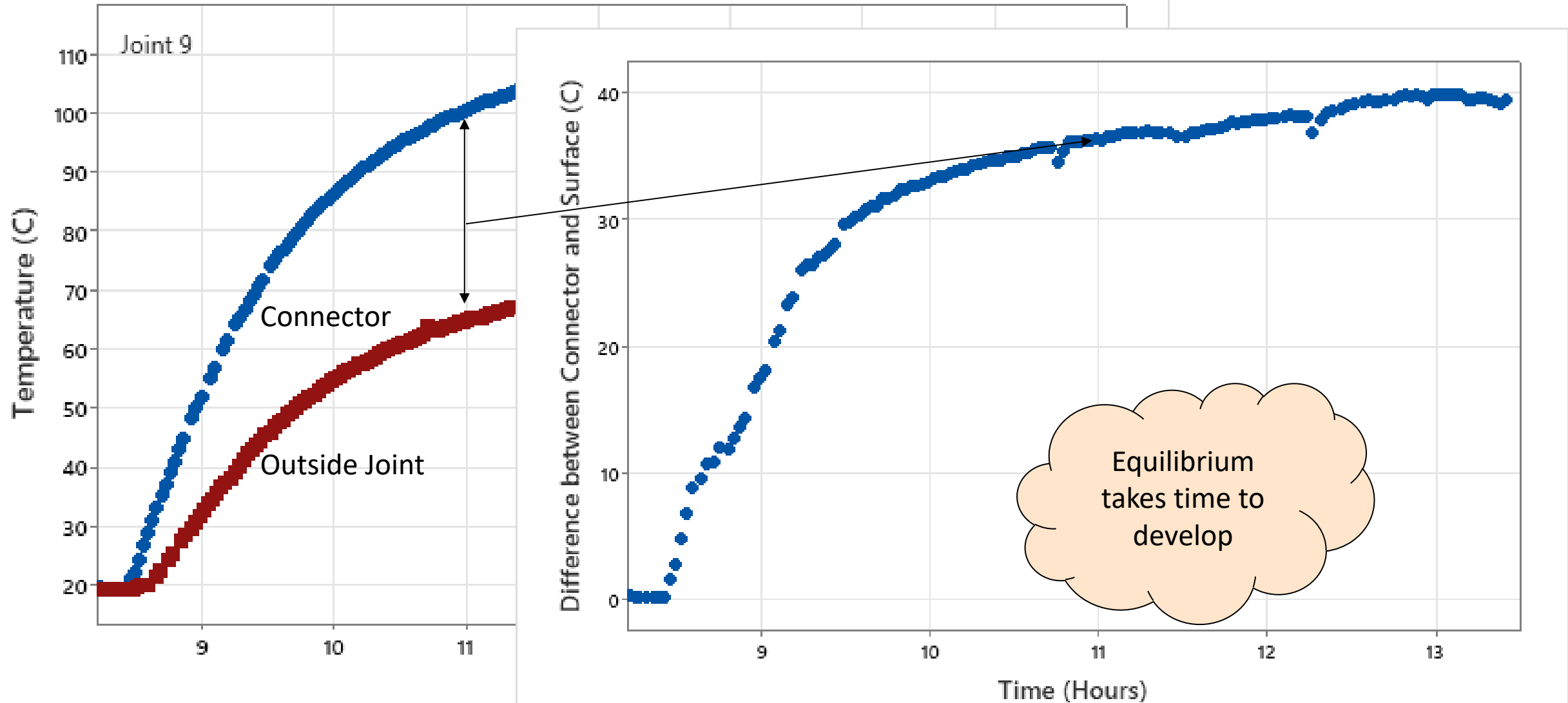
Temperatures

Measured Temperatures - - Conductor = 117 C

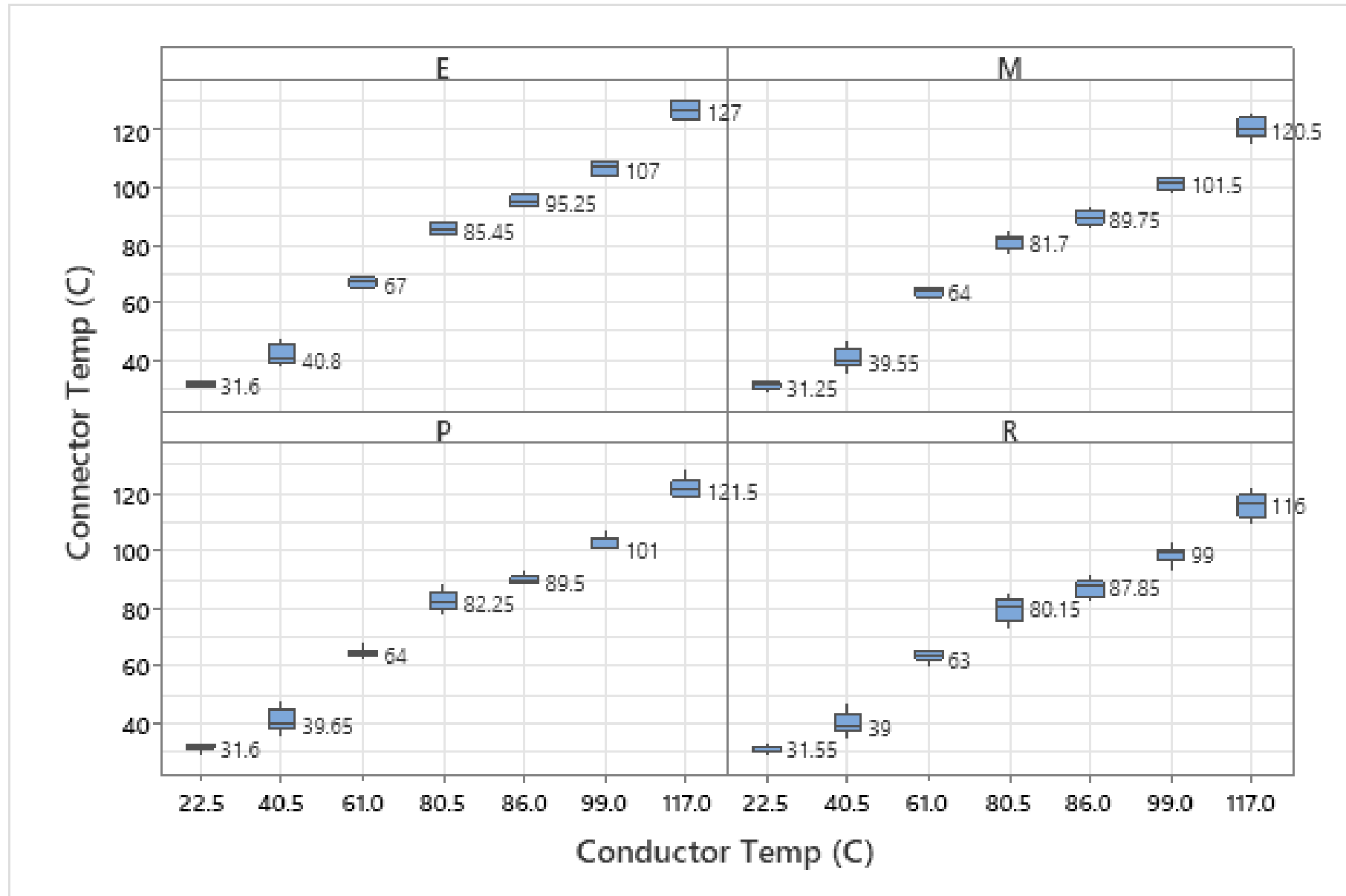


Measured Temperatures - - Conductor = 117 C

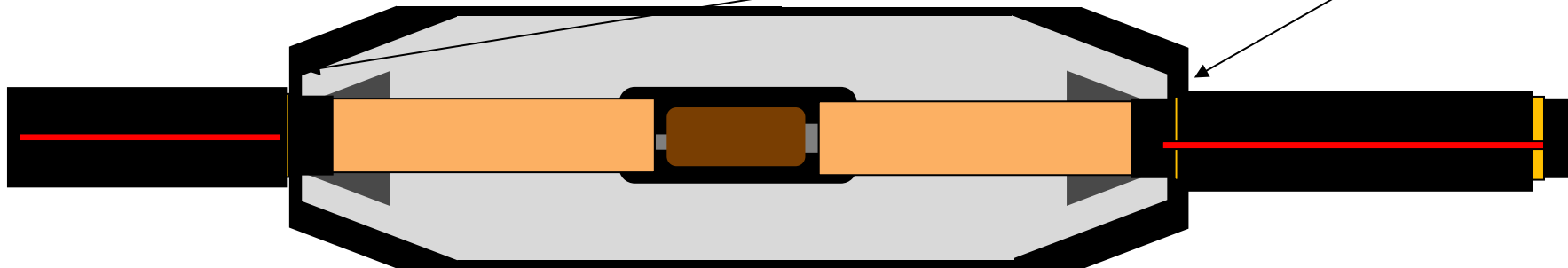
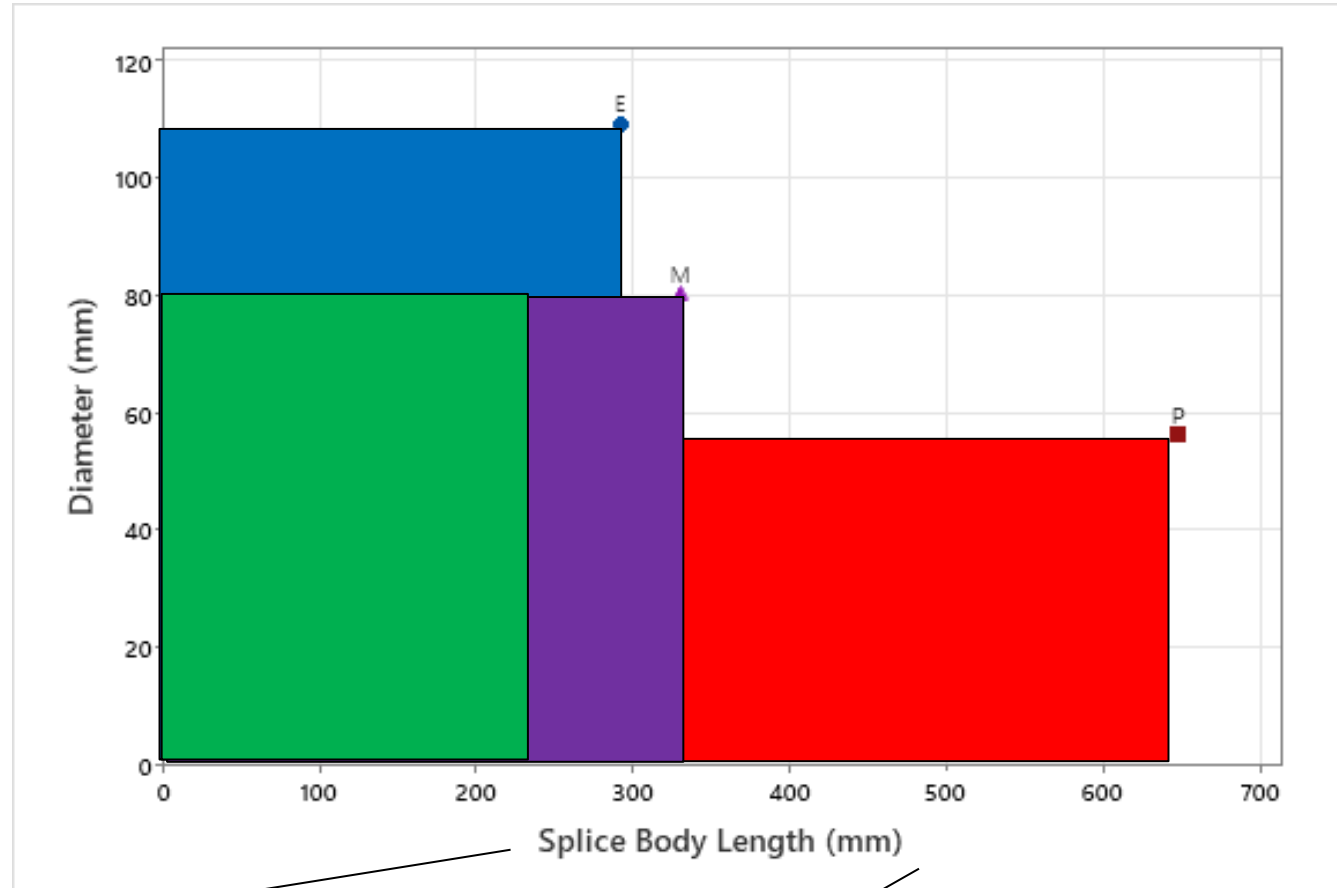
Temperatures - TC



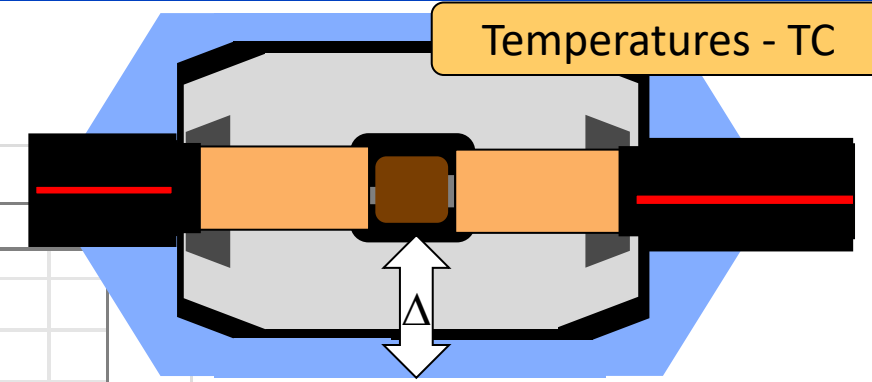
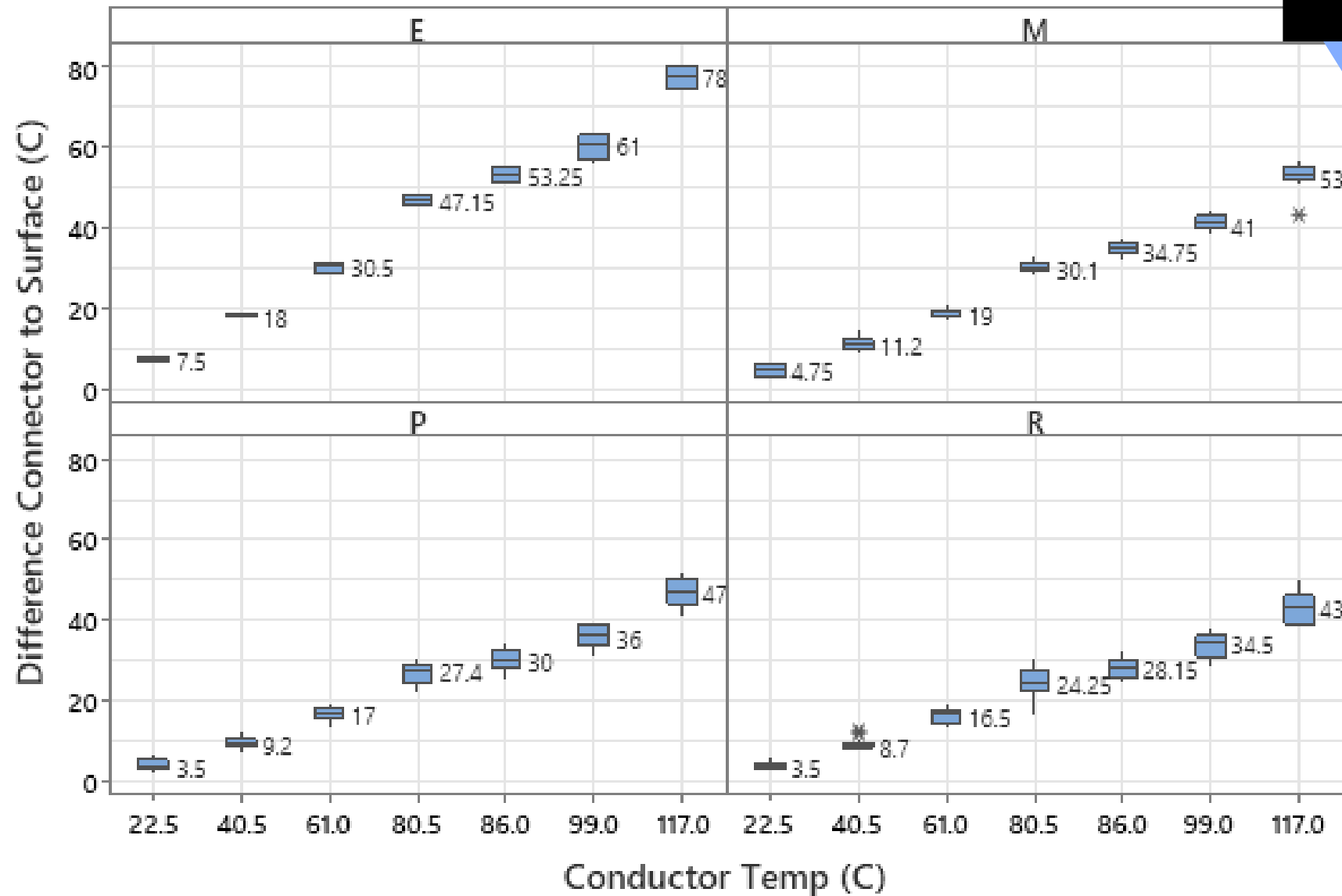
Impact of Joint Type



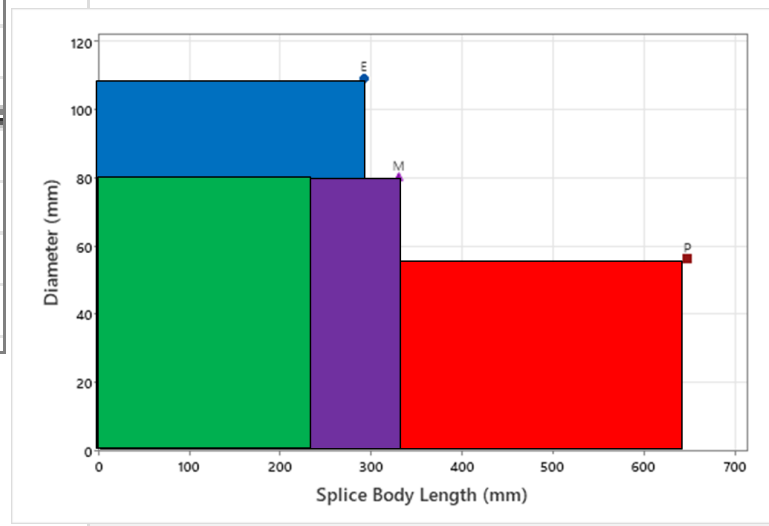
Joint Dimensions

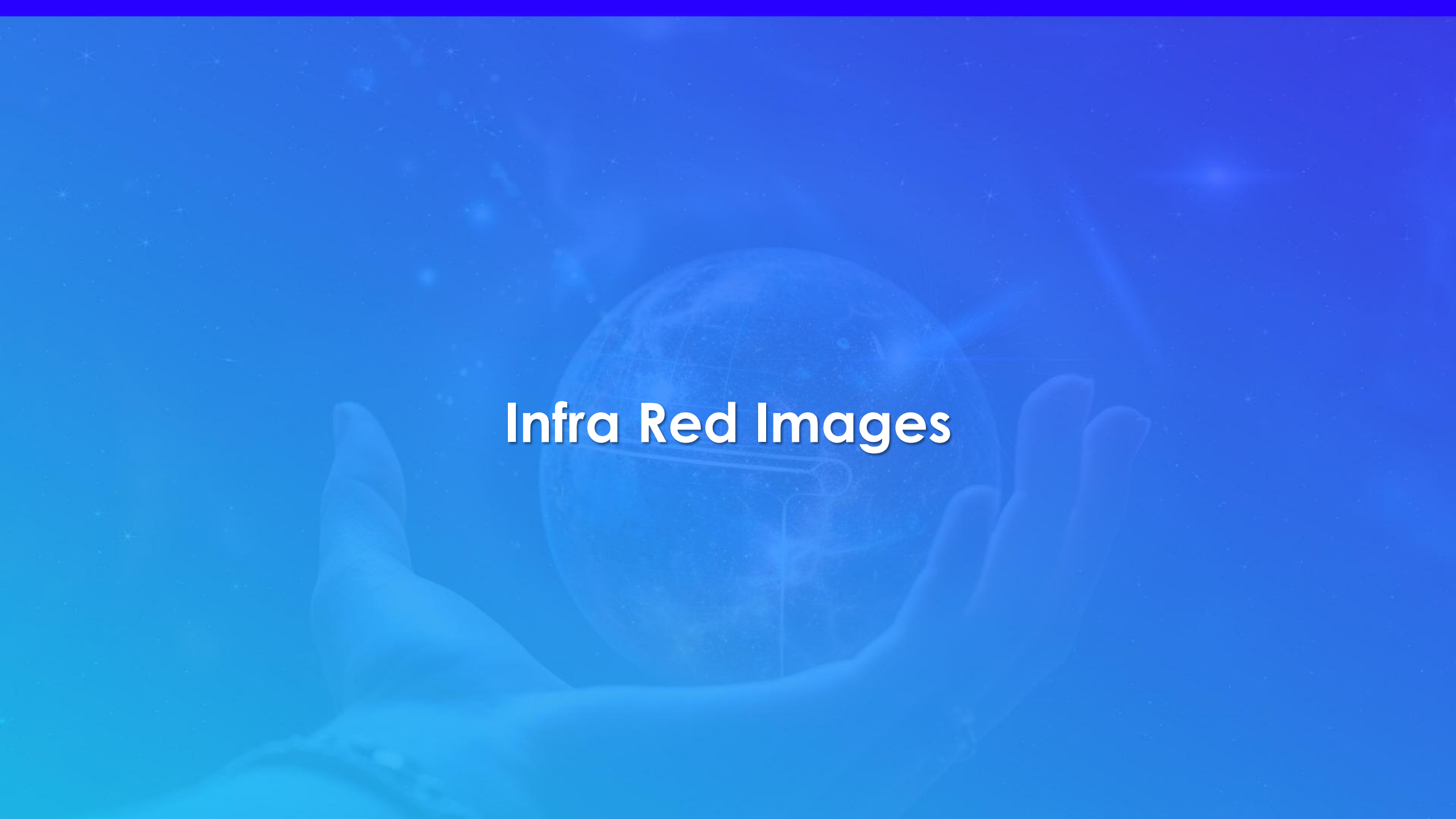


Surface to Connector Difference



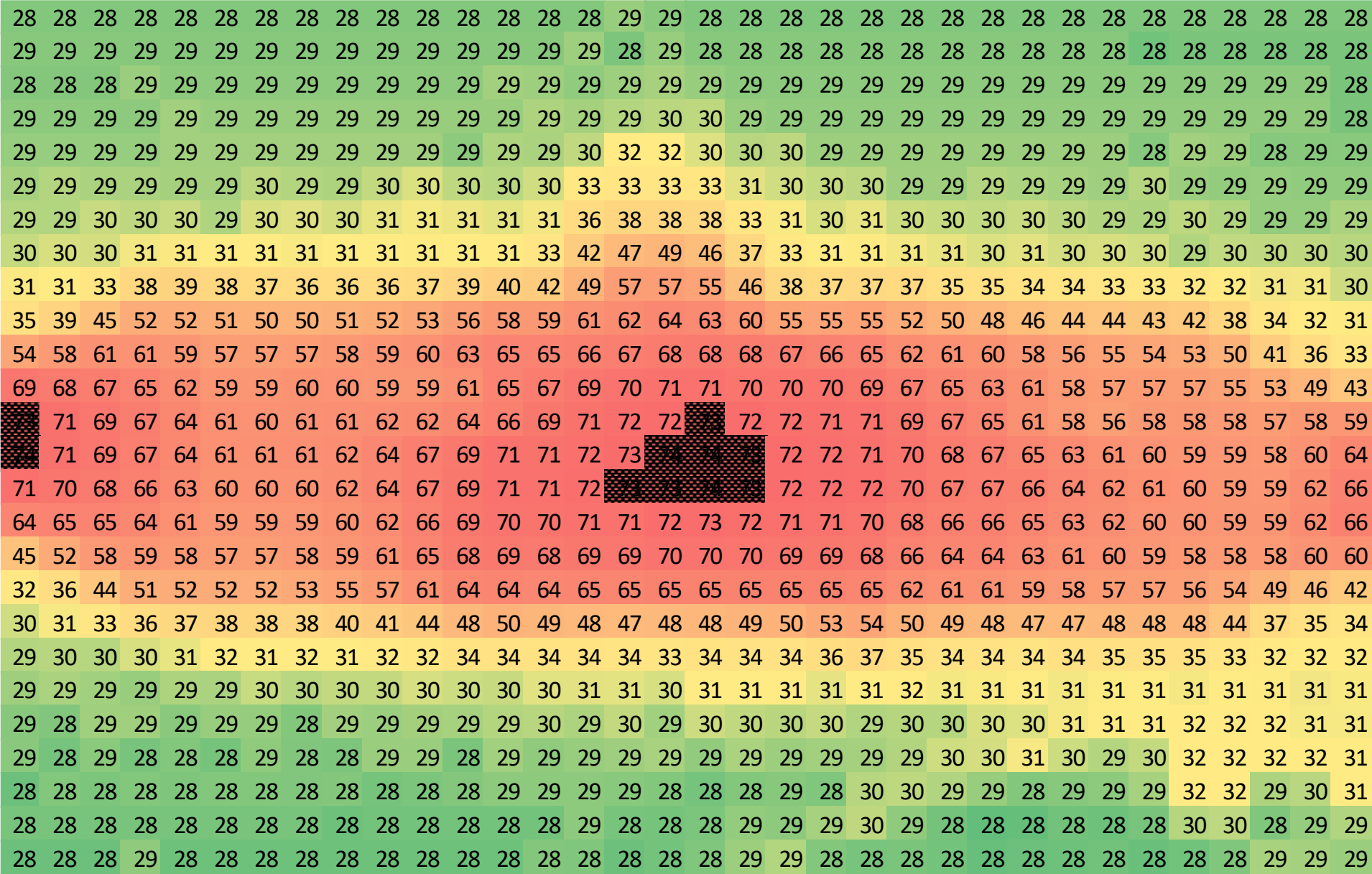
Delta T Corrections are Joint specific and Temperature dependent



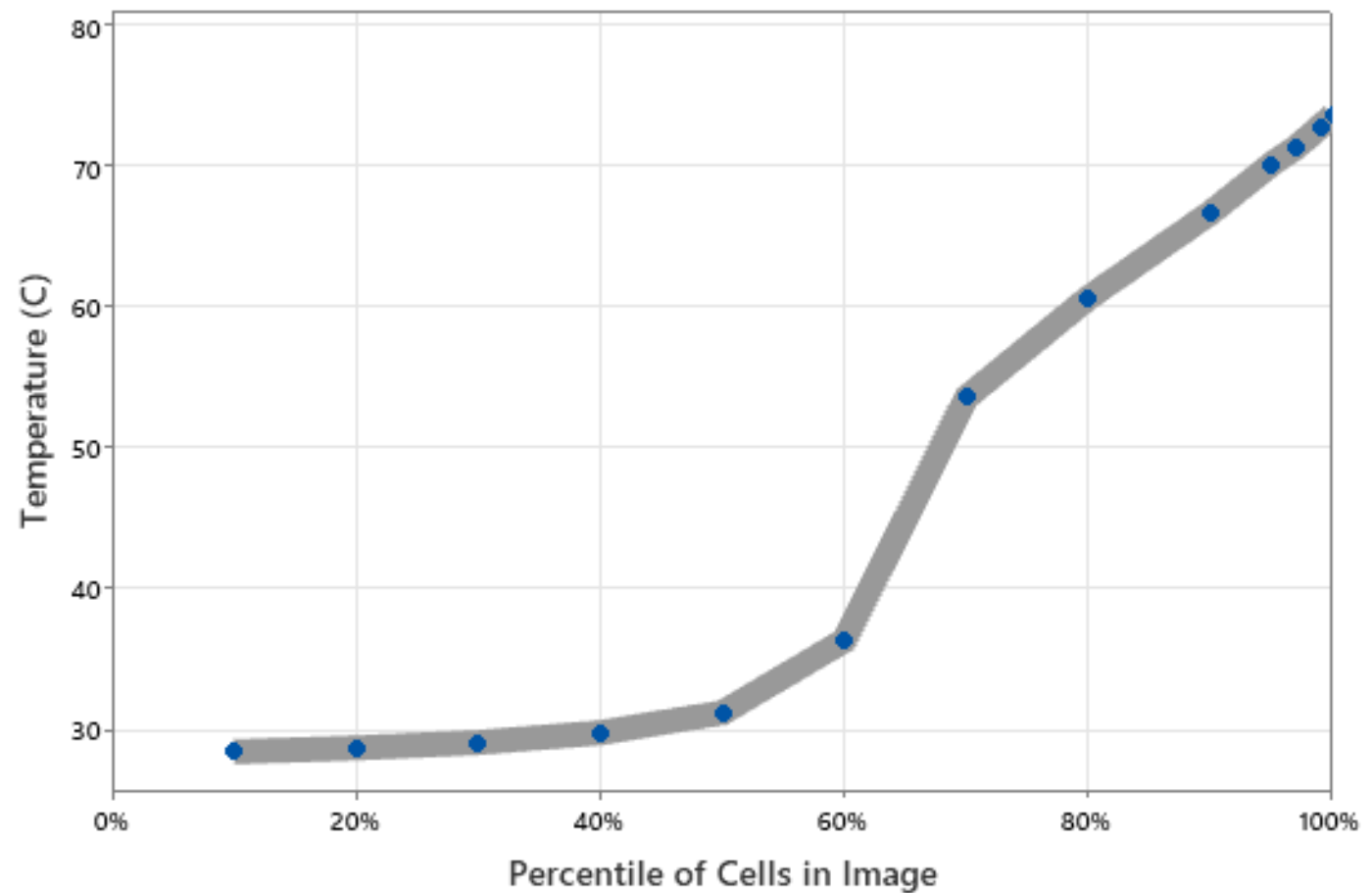
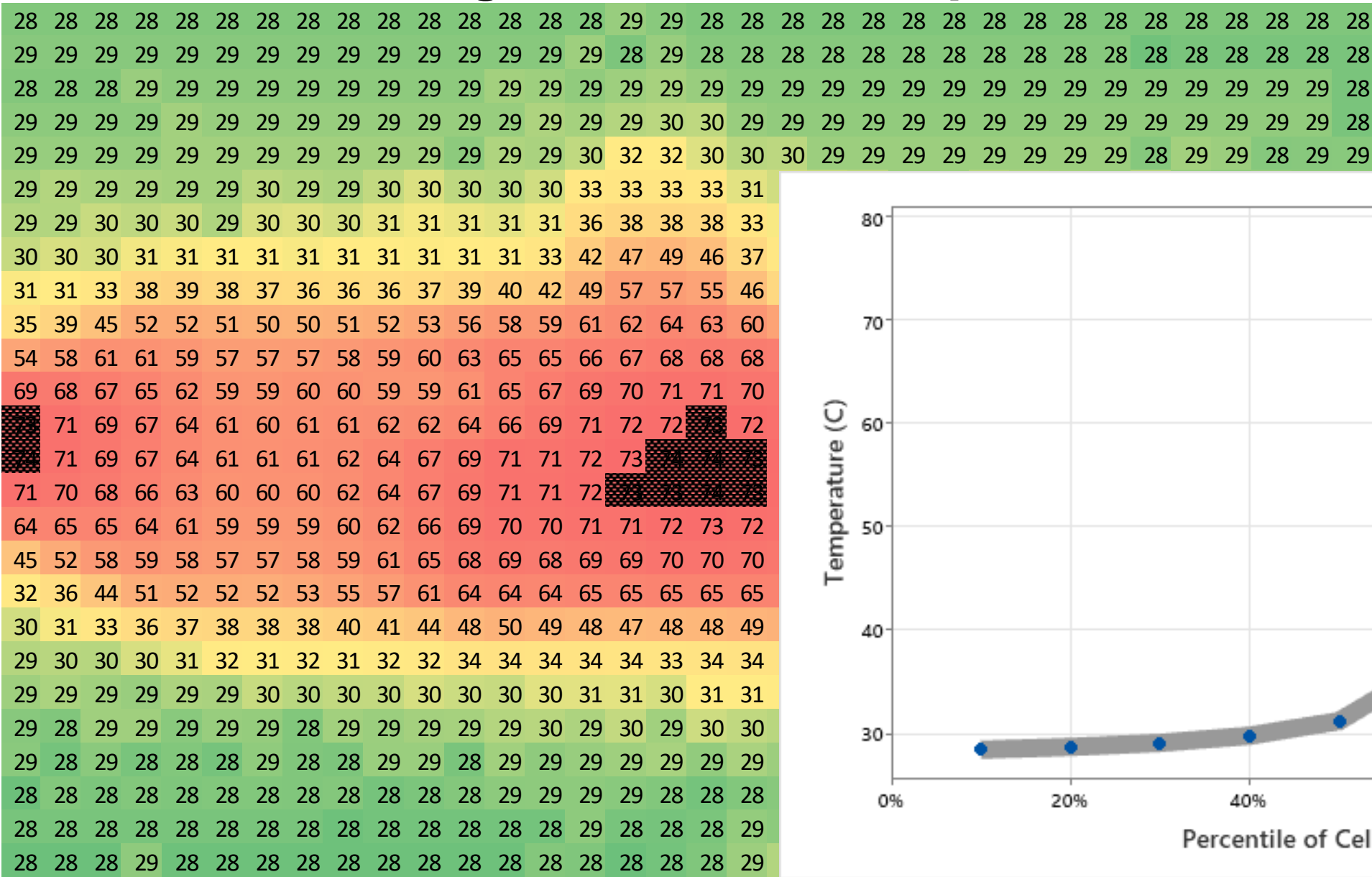
The background of the slide is a deep blue gradient. In the center, there is a faint, glowing image of a globe with a grid of latitude and longitude lines. Below the globe, a pair of hands is visible, palms up, as if holding or presenting the globe. The overall aesthetic is futuristic and technological.

Infra Red Images

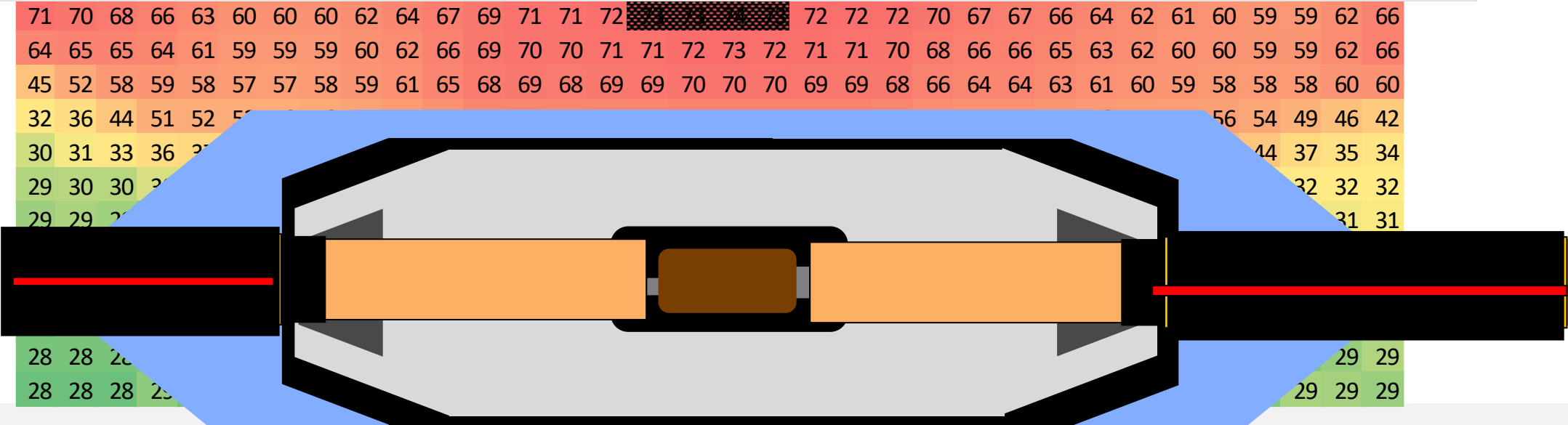
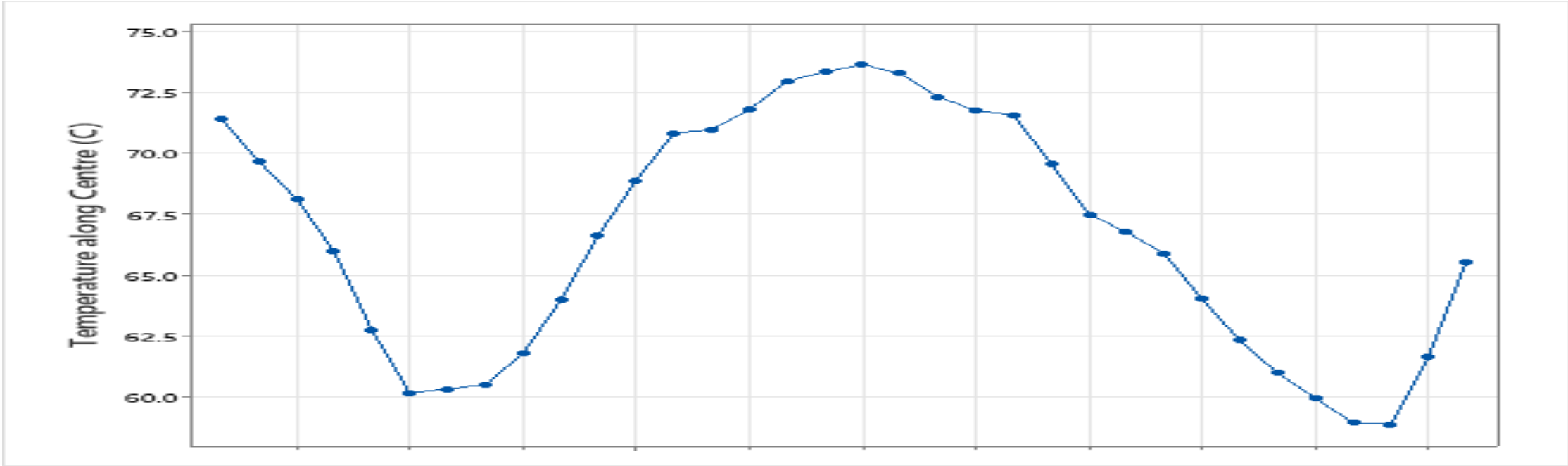
Infra Red Image – Joint 9 at Equilibrium



Infra Red Image – Joint 9 at Equilibrium



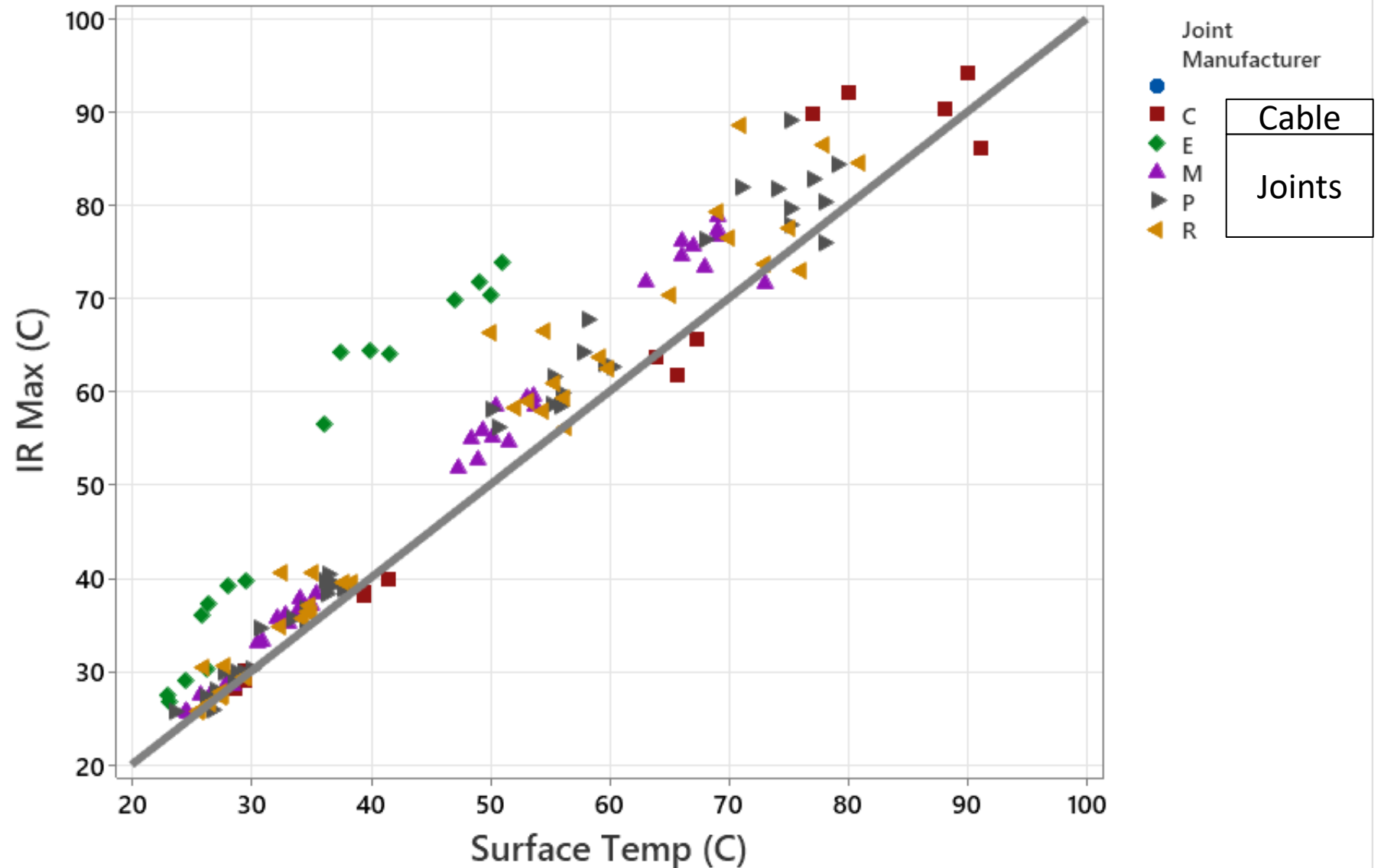
Infra Red Image – Joint 9 at Equilibrium



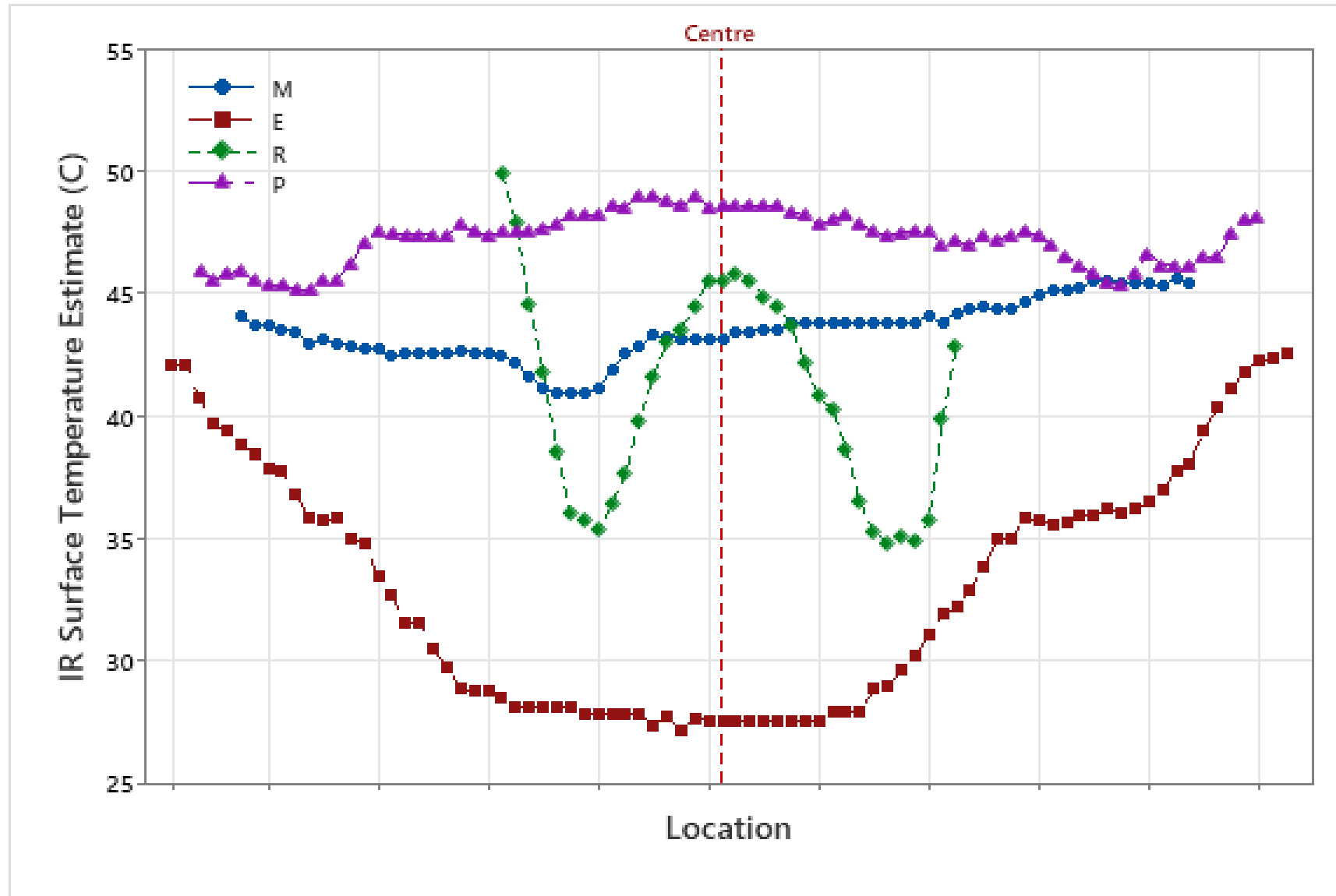
TC to IR – work in progress – joint bodies

Current implementation overestimates the surface temperature

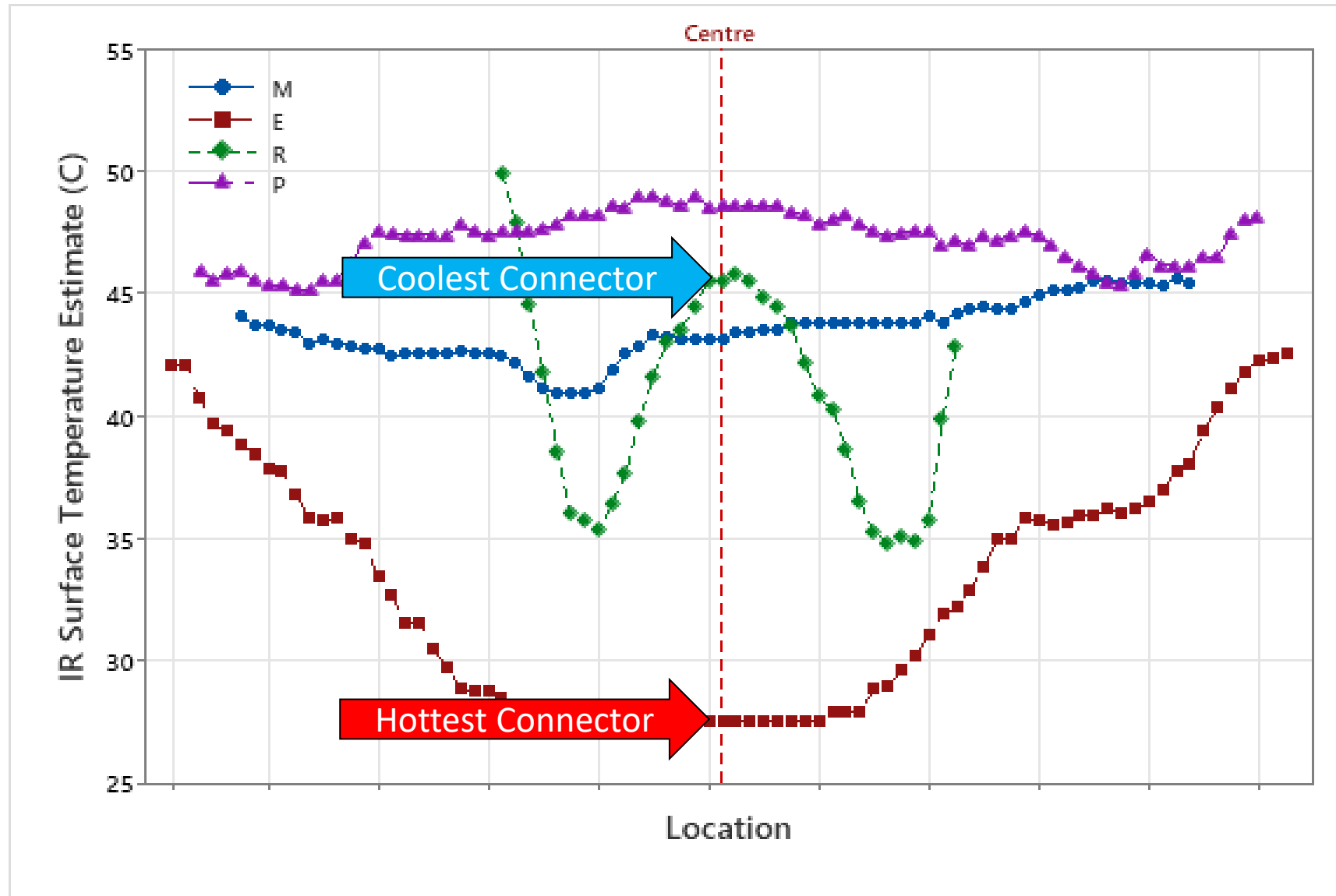
Might be an easy fix



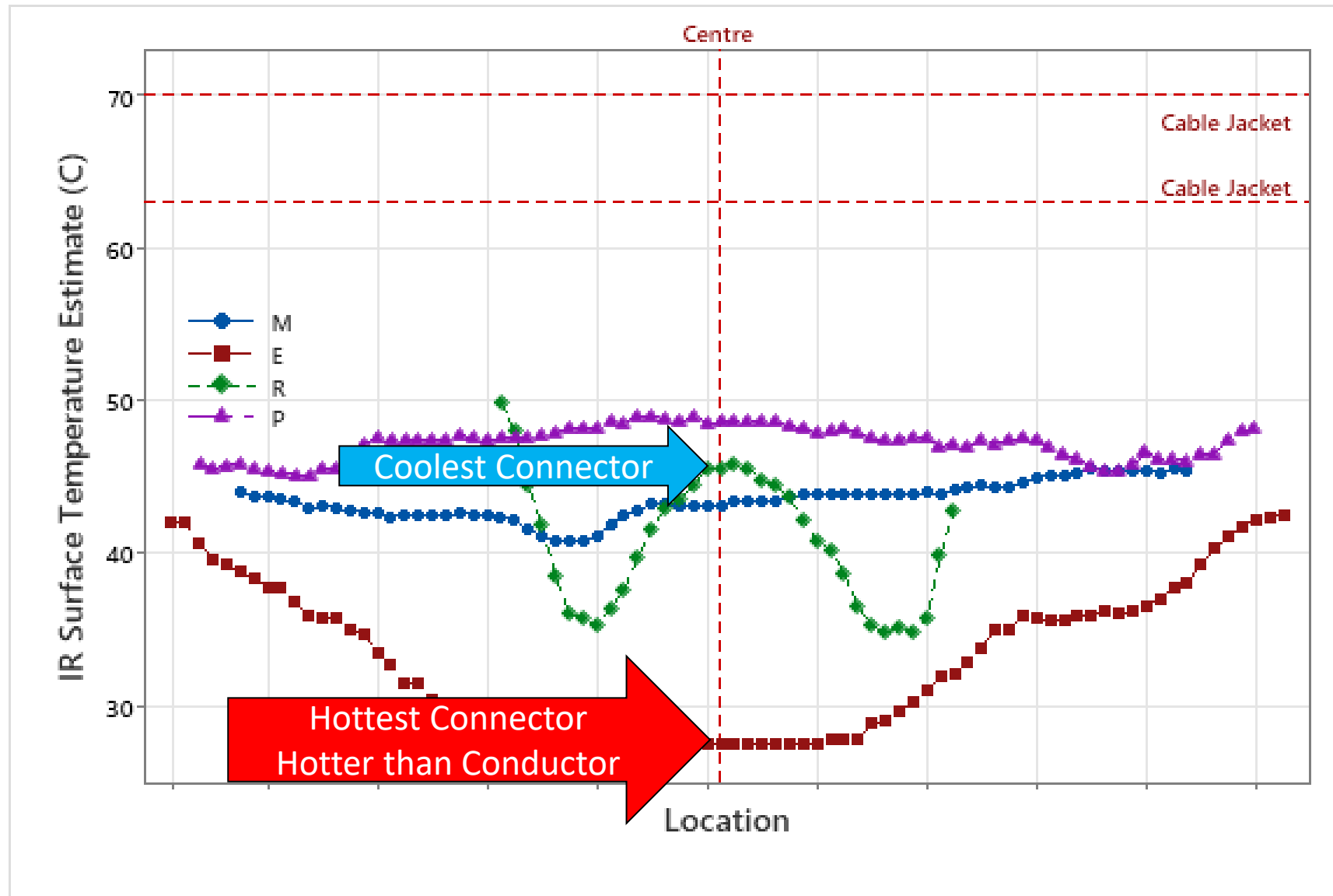
Joints – no Defects



Joints – no Defects

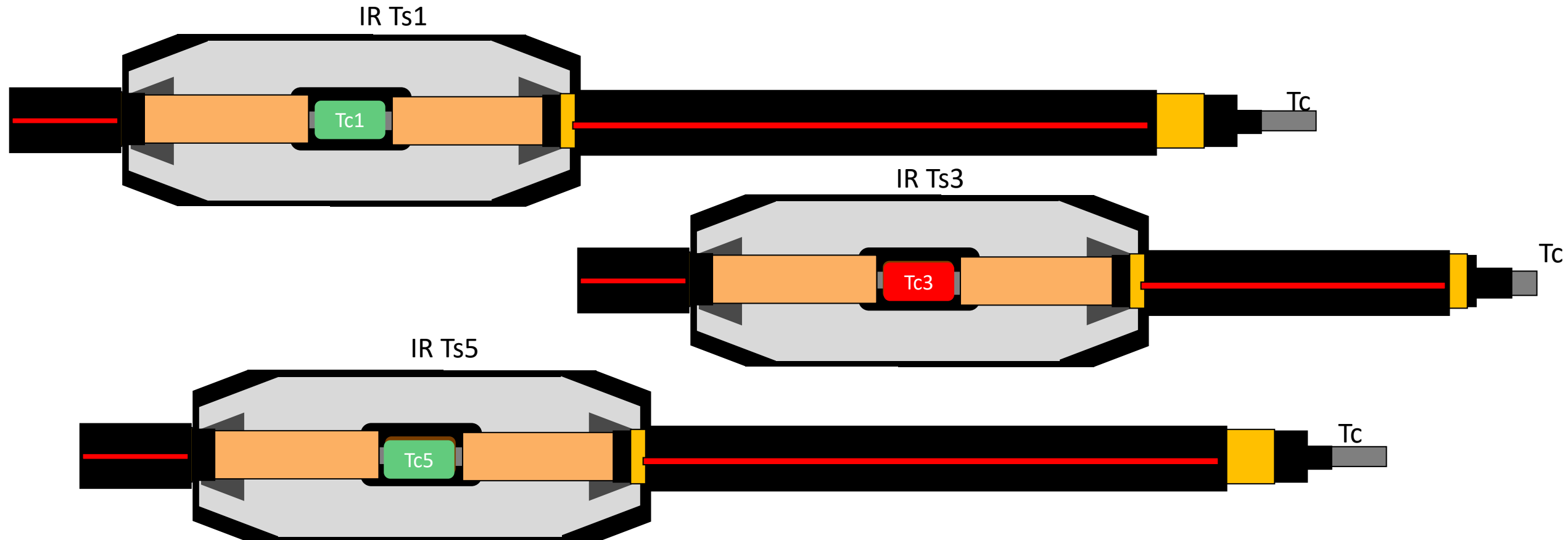


Joints – no Defects



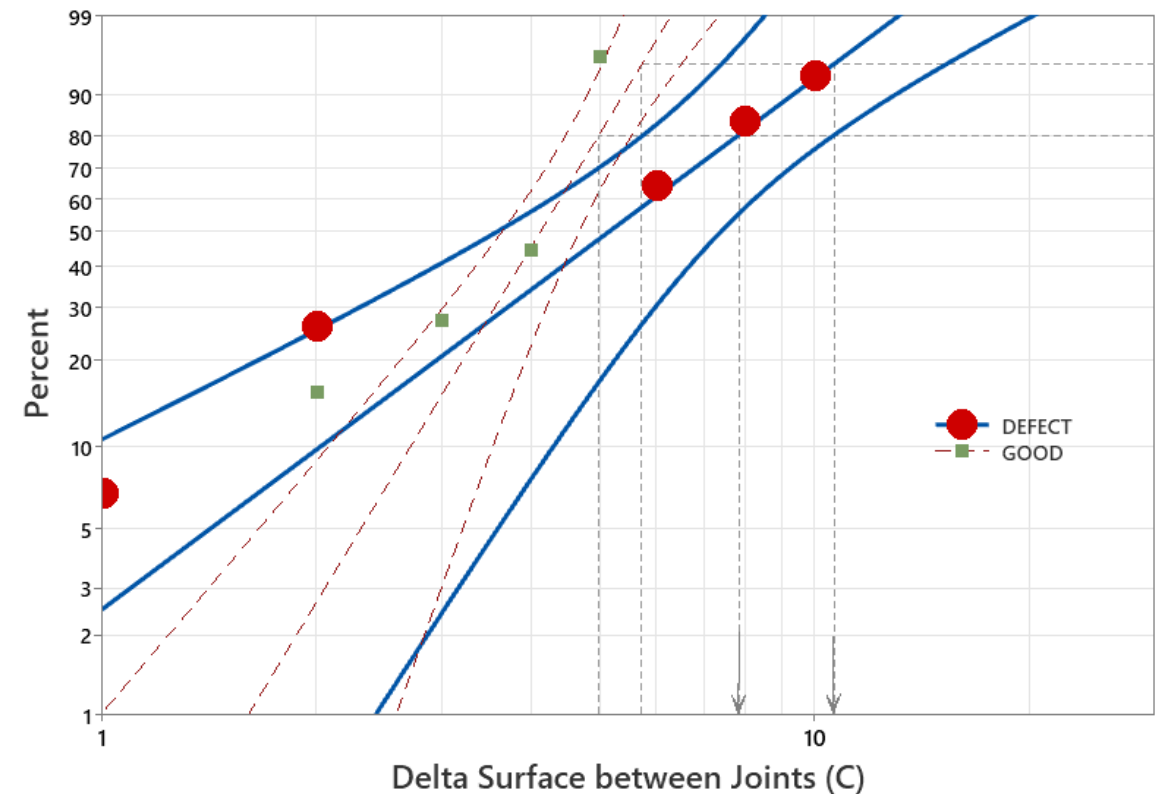
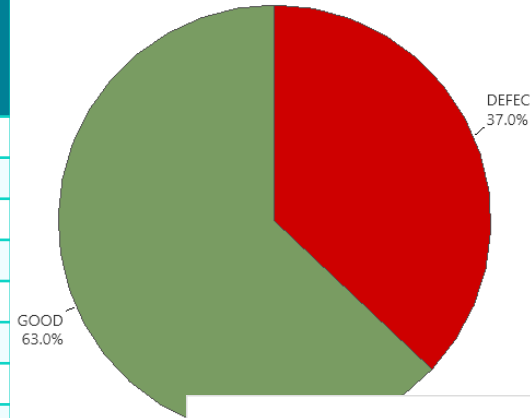
Comparison

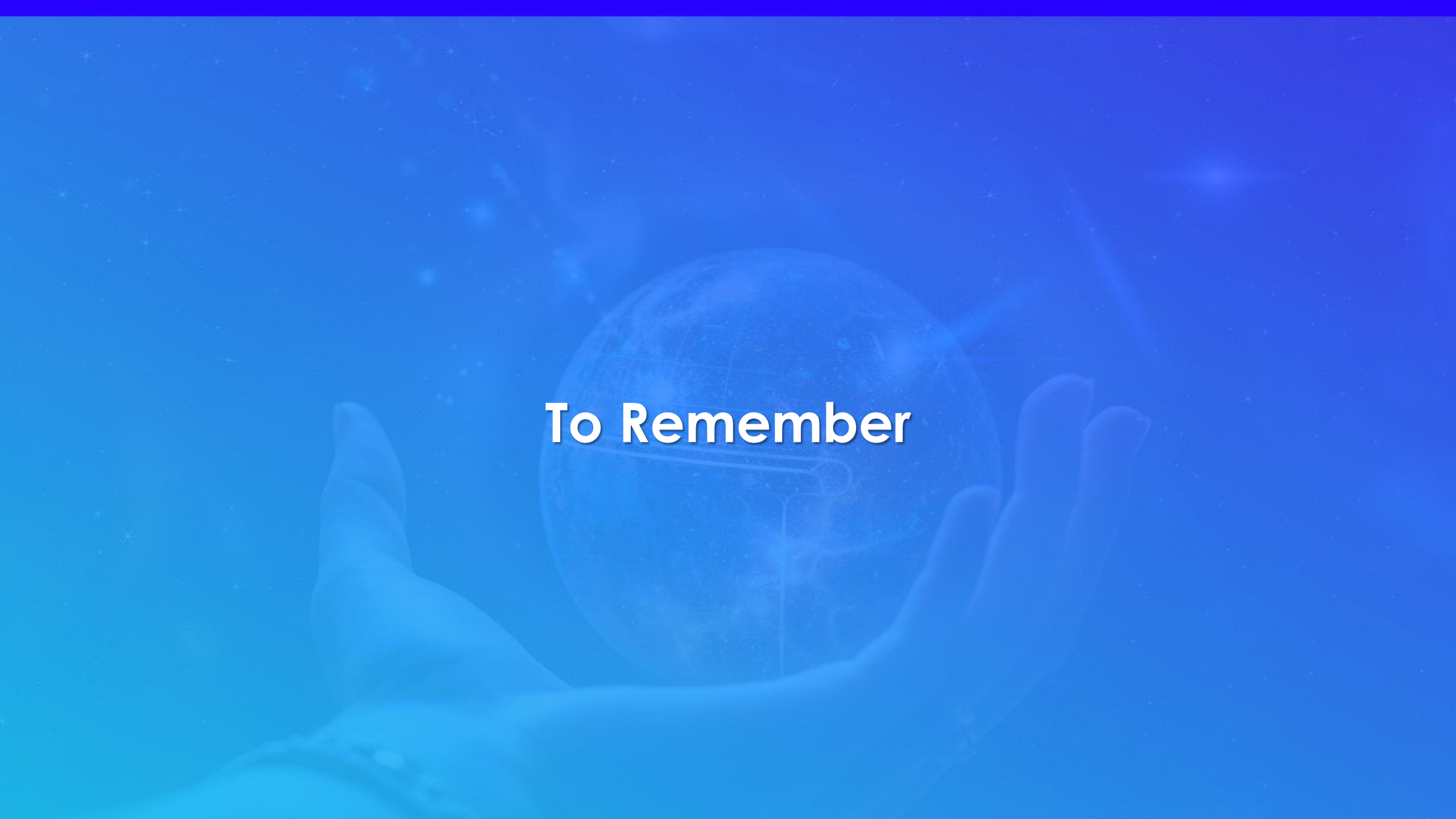
Construct test groups with known “good” and known “defective”



Surface Temperature Comparison – equilibrium

Phase A No Defect [°C]	Phase B No Defect [°C]	Phase C Defects Present [°C]	Temperature Range [°C]
69	64	65	5
69	64	66	5
69	64	70	6
69	69	65	4
69	69	66	3
69	69	70	1
64	69	65	5
64	69	66	5
64	69	70	6
73	72	75	2
73	72	71	2
73	72	81	8
73	76	75	3
73	76	71	5
73	76	81	8
71	76	75	5
71	76	71	5
71	76	81	10
74	69	72	5
74	69	72	5
74	69	75	6
74	73	72	2
74	73	72	2
74	73	75	2
69	73	72	4
69	73	72	4
69	73	75	6





To Remember

Points

1. Shearbolt resistances generally low & different between designs
2. Connector performance on Cu different to Al
3. ΔT 's can be large
4. ΔT 's vary between joints - body Thermal Resistance
5. Arc / fire taping will complicate
6. ΔT 's depend on time / current / temperature – repeat measurements
7. T_{IR} typically overestimates the surface temperature of joints
8. T_{IR} comparisons should be made between the same component types
9. If temperature or temperature difference is large - there is a concern
10. Diagnoses **require more information** than just the IR image
 1. Loading history required
 2. Type of joint

Nigel Hampton has more than 35 years of experience in the MV, HV & EHV cable field at BICC in the United Kingdom, Borealis in Sweden, NEETRAC, UL Solutions and currently EPRI in the United States. He has been active in the international community of CIGRE participating in WG's on Space Charge, Water Tree Diagnostics, HVDC Testing and most recently as the US representative on the Reliability Analysis Group for HV & EHV. Nigel currently Chairs IEEE400.0 Field Testing Techniques and IEEE400.2 Field Testing using VLF Sources. Nigel has served as the Technical Advisor to the AEIC Cable Engineering Committee since 2008.

His current research interests include: Extruded MVDC, VLF Diagnostics, Cable System Ageing, Forensics, HV & EHV Cable Systems.