



# Undertaking Cable Failure Investigations: An Introduction

Simon Sutton



# Overview

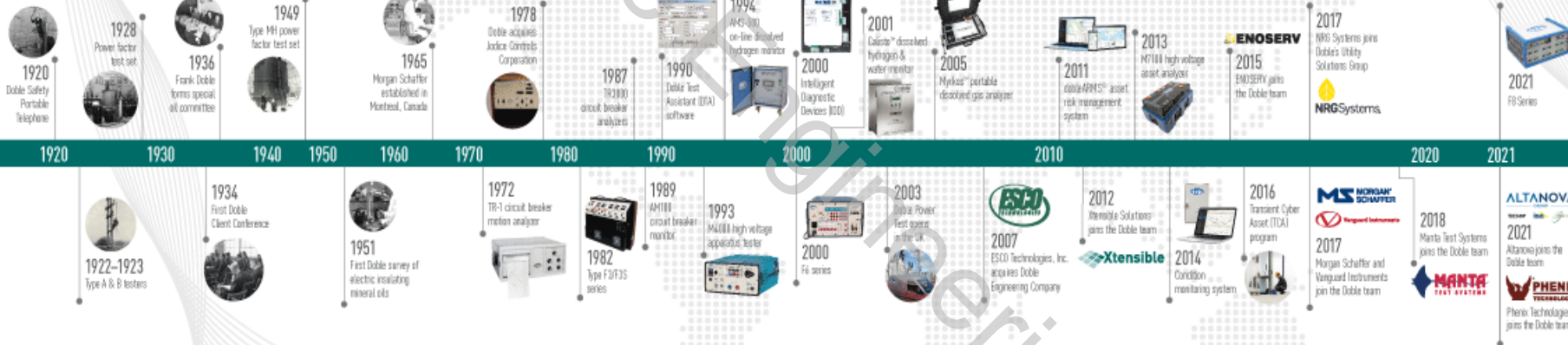
- Root cause analysis (RCA)
  - Different formalised approaches
  - The problem of using them from the point of view of the investigator
- Forensics 101
  - A starters guide to running a good investigation
- Analytical techniques to support investigations
- What you should expect in a report
- Case study
  - MV cable joint failures
  - Application of forensic techniques and tools
  - Expect the unexpected



# Doble History



## 100 YEARS OF SERVICE TO THE ELECTRIC UTILITY INDUSTRY





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**2011**  
dobleARMS® asset risk management system

**2013**  
M7100 high voltage asset analyzer



**2015**  
ENOSERV joins the Doble team



**2017**  
NRG Systems joins Doble's Utility Solutions Group



**2021**  
F8 Series

**2010**



**2007**  
ESCO Technologies, Inc. acquires Doble Engineering Company

**2012**  
Xtensible Solutions joins the Doble team



**2014**  
Condition monitoring system

**2016**  
Transient Cyber Asset (TCA) program



**2017**  
Morgan Schaffer and Vanguard Instruments join the Doble team

**2020**

**2018**  
Manta Test Systems joins the Doble team



**2021**



**2021**  
ISA & TechImp join the Doble team



Phenix Technologies joins the Doble team

# Doble Today



110

COUNTRIES



19

GLOBAL  
OFFICE  
LOCATIONS



800+  
EMPLOYEES



5,550+  
CUSTOMERS GLOBALLY



Part of ESCO  
Technologies'  
Utility Solutions  
Group

## DOBLE COMPANIES & BRANDS



# Our Solutions



## Electrical Test Equipment

Essential for day-to-day maintenance tests of electrical assets. Useful in specific phases of the asset lifecycle:

- Procure
- Operate
- Maintain
- Decommission.

## Professional Services

Diversified offer according to the electrical asset lifecycle:

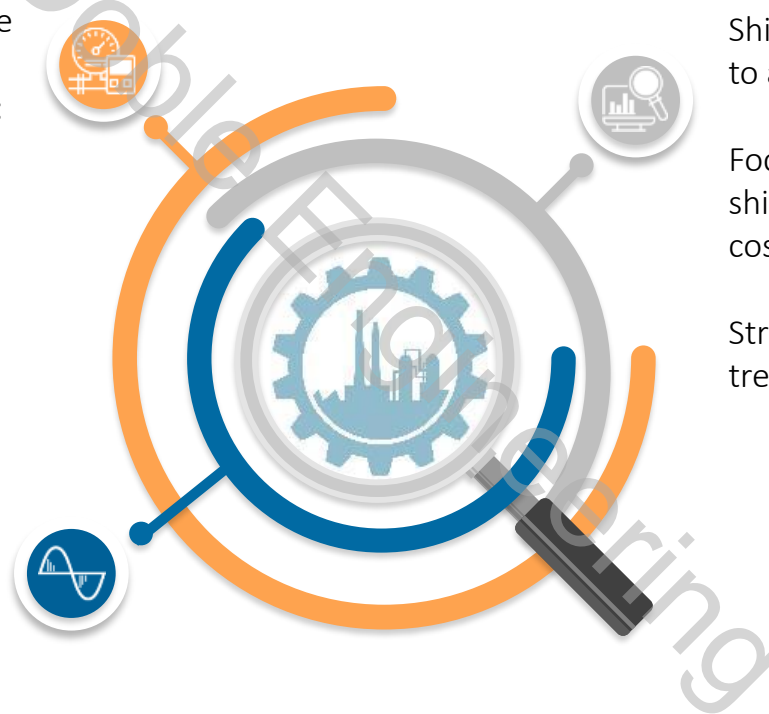
- Installation and commissioning
- Diagnostic test
- Data analysis
- Consultancy
- Training.

## Monitoring Systems

Shift from a time-based maintenance to a condition-based maintenance.

Focus on predictive maintenance and shift in focus from electric asset value cost to network outage costs.

Strong evolution of digitalization trend in the power industry.



# Services



# Forensics Introduction

- Forensics investigations are there to answer the question, “Why did it go bang?”
- Unfortunately in many cases the evidence is destroyed by the fault and we are forced into determining the most likely cause
- Forensics investigations are like jigsaw puzzles where each test reveals a little bit more of the picture.
  - Sometimes though you don’t have all the pieces!



RIP = Rest in Peace

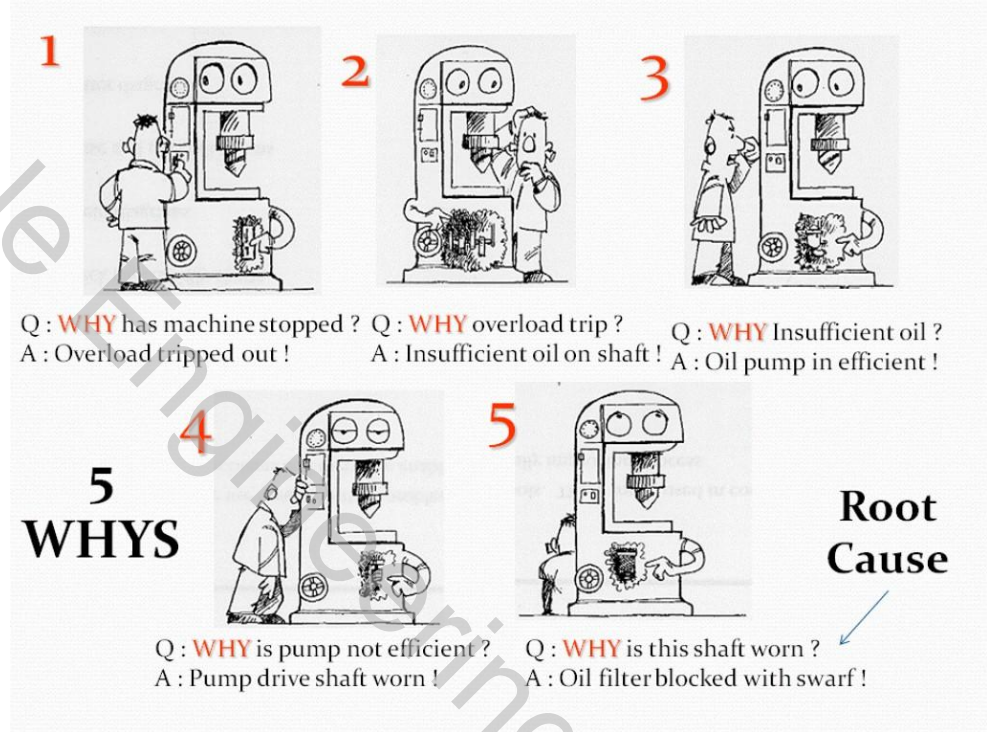


# Forensic Methodologies

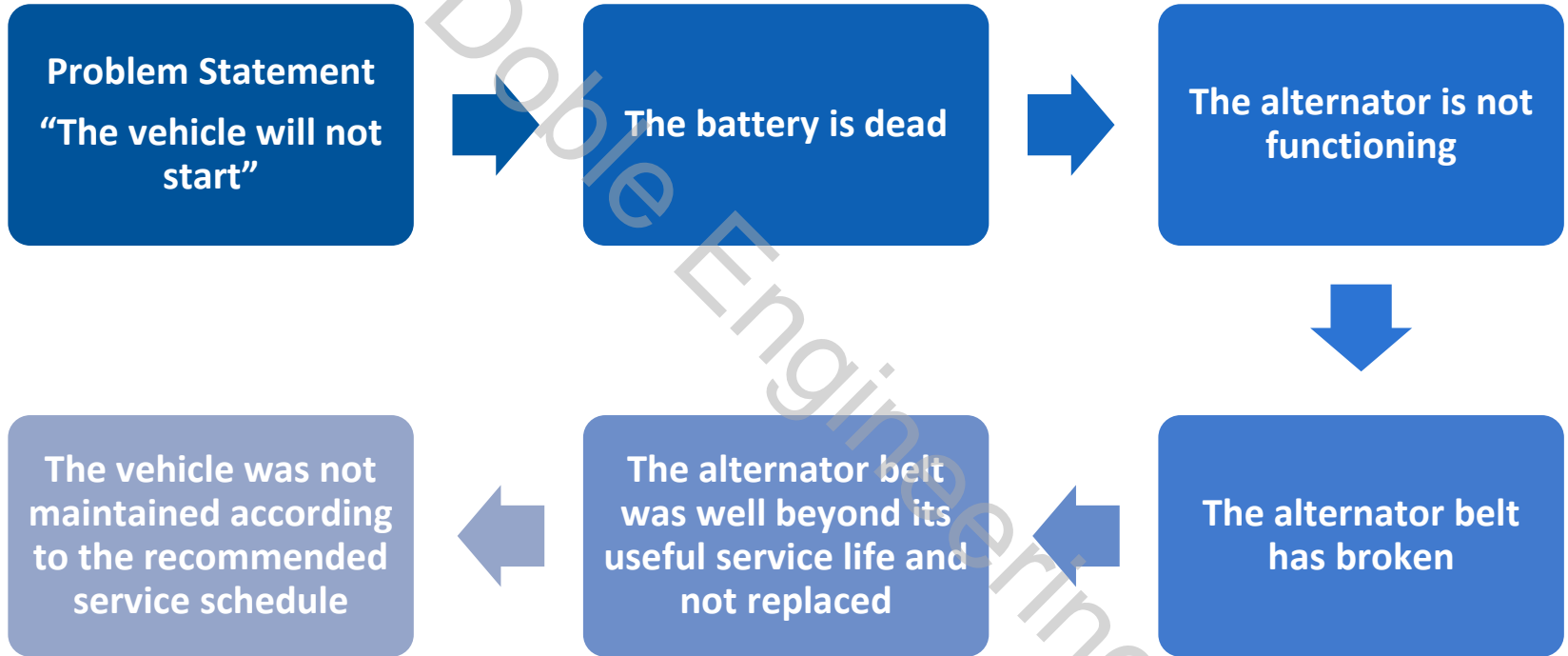
- There are a number of structured approaches to Root Cause Analysis (RCA)
  - Five Whys Analysis
  - Fishbone or Ishikawa or Cause-and-Effect Diagrams
  - Failure Mode and Effects Analysis
  - Pareto Analysis
  - And many more
- Some of the RCA approaches are aimed at systems and processes and therefore not the best choices for failure investigations

# Five Whys Analysis

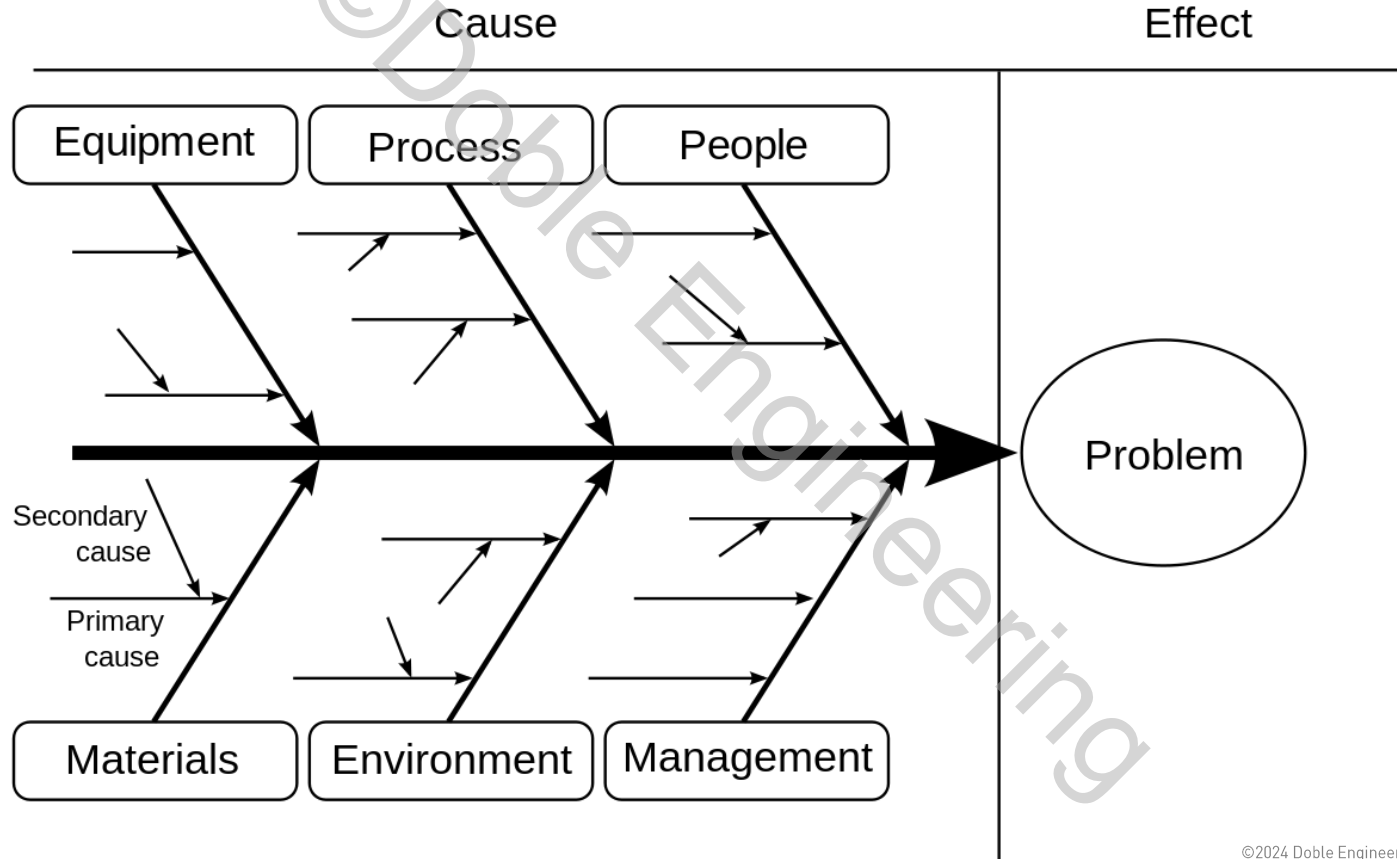
- Define the problem
- Think like a 3 year old!
- Keep asking “why”
- Don’t stop at the first obvious answer
- Keep going until you reach the root cause of the problem



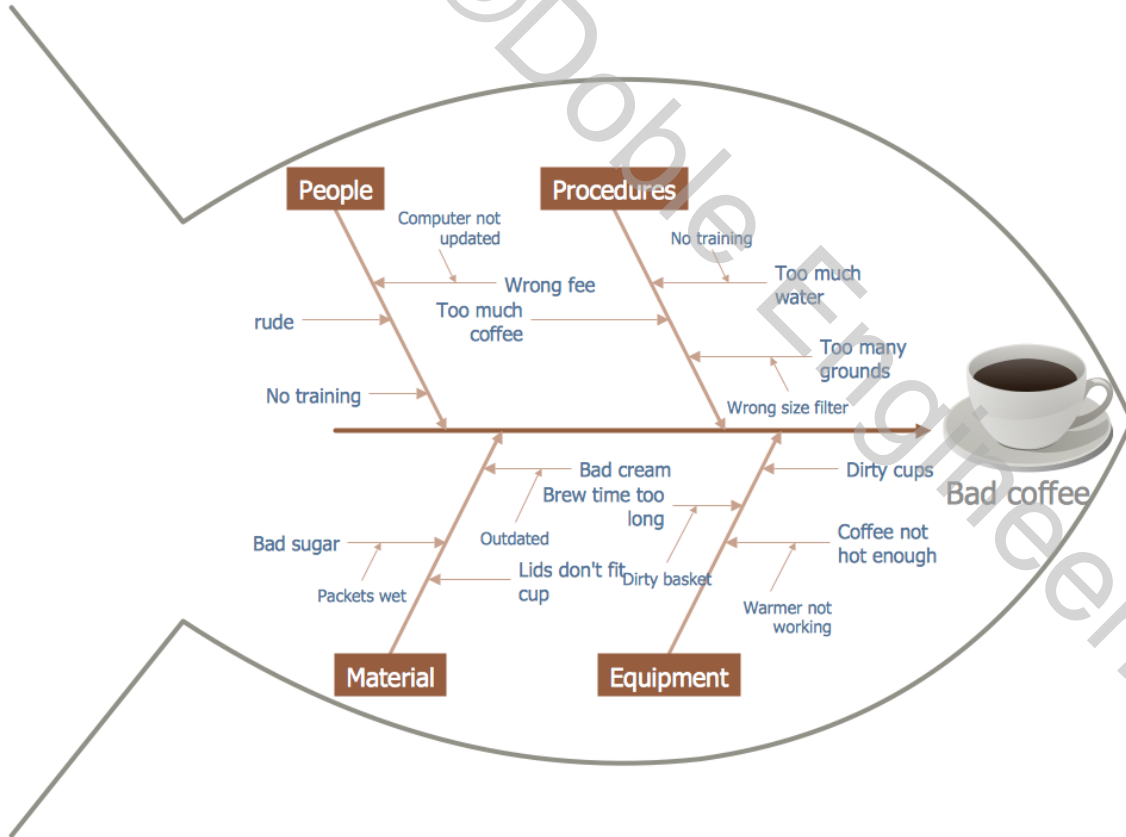
# Five Whys Analysis



# Ishikawa Diagram (Fishbone Diagram)



# Ishikawa Diagram



- Different “templates” available for different situations
  - Manufacturing (4Ms)
  - Processes (8Ps)
  - Services (5Ss)
- Captures everything but doesn't identify what is important



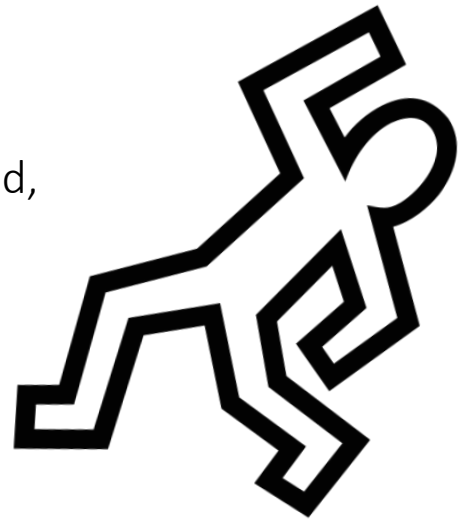
# Forensic Methodologies

- Treat these with caution, they are tools not silver bullets
  - No one method is better or worse than the others
  - Don't become shackled to a single approach
  - Remember the goal is to understand why the cable failed not prove you can follow a procedure



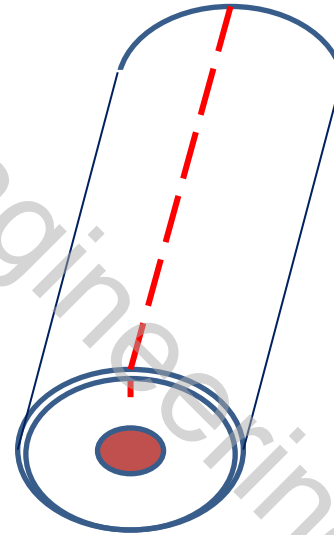
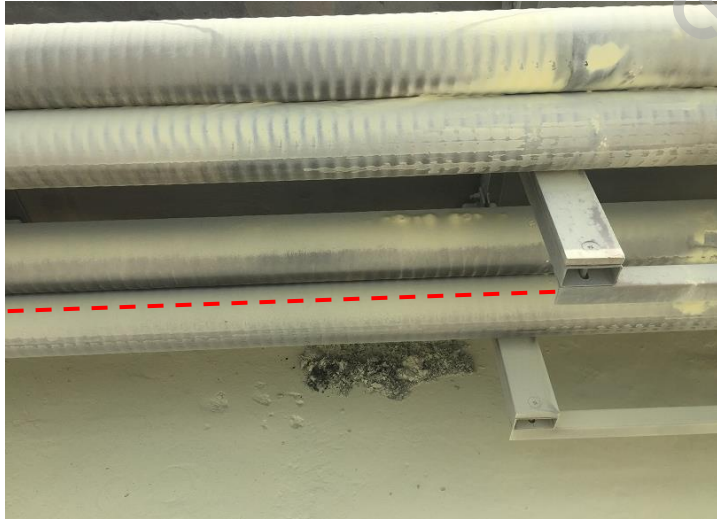
# Forensics 101

- Before doing anything, make sure the area is safe
- Before moving anything, take photos and video
  - If it's not obvious apply labels
  - Include a scale marker if you think it might help – even a hand, boot, pen etc in the photo can help
- Before moving anything, draw some sketches
  - The general layout
  - Where certain photos were taken
- Take notes



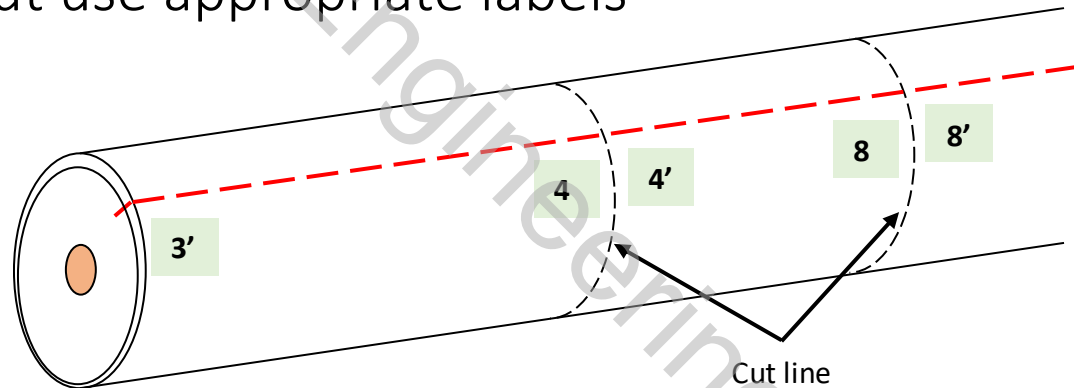
# Forensics 101

- Label everything and take notes of where it's come from
- Mark the orientation!



# Forensics – Label Everything

- Label samples so whoever looks at them knows where they have come from
  - Phase
  - Orientation - Substation A End etc
- If samples are cut use appropriate labels



# Forensic Analysis Techniques

- Common sense
  - Does it match the specification?
- Visual
  - Turning the object in your hand and letting the light reflect in different ways
- Touch
- Smell
- Visual inspection
- Stereo microscopy
- Optical microscopy
- Scanning electron microscopy (SEM)
  - Secondary electron (SE)
  - Backscatter electron (BS)
- X-ray imaging



# Forensic Analysis Techniques

- Elemental analysis – EDS, EDAX, x-ray analysis, WDS
  - Performed in an SEM
  - Good for metals and inorganic materials
  - Elemental mapping
- X-ray Fluorescence Spectroscopy (XRF)
  - Good for metal/alloy identification
  - Lab or portable
- Infra-red spectroscopy (FTIR)
  - Good for organic materials
  - Solids and liquids
  - Fingerprint, spectrum libraries
- UV-vis spectroscopy
- NIR spectroscopy
- GCMS

# Forensic Analysis Techniques

- Repeating electrical and mechanical tests from standards
  - IEC, IEEE etc
- Dimensional checks
  - Layer thicknesses
  - Concentricity
- Resistance
- Mechanical tests



# Forensic Reports

- Expect to see
  - A clear description of what happen where and when
  - List of relevant documents (not always supplied)
  - Good photographic record of the work undertaken
  - Clear description of what each test revealed
  - A discussion pulling all the evidence together and weighing the different hypotheses
  - A clear summary or conclusion
- Don't always expect a smoking gun, conclusions may be nuanced or indicate the most likely cause of failure

# Case Study – Background

- 34.5 kV 3 x 300 mm<sup>2</sup> XLPE
- In service for 4 years
- Two joint failures in 3-4 month period both in the same circuit
  - Another occurred during the course of the investigation
- Two circuits were installed on the same contract
- One faulty and one healthy cable sent
- No drawings or details of joints or cables



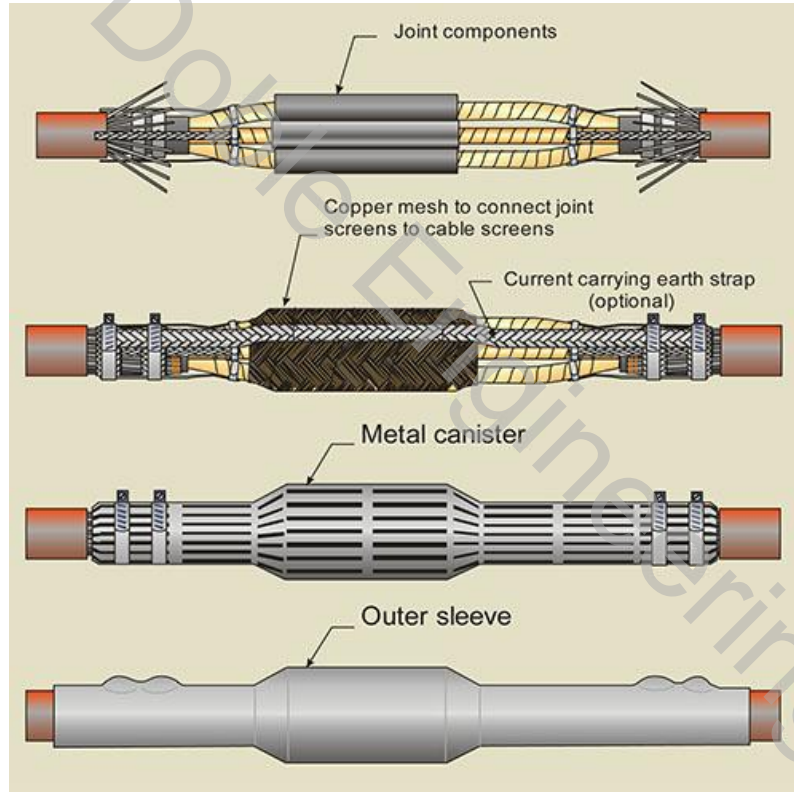
# Cable Construction

- Cables are very well protected
  - Lead sheath
  - PE jacket
  - Wire armour
- Trefoil formation
- Middle East ground conditions can be corrosive
- Petrochemical site also risks other ground contaminants

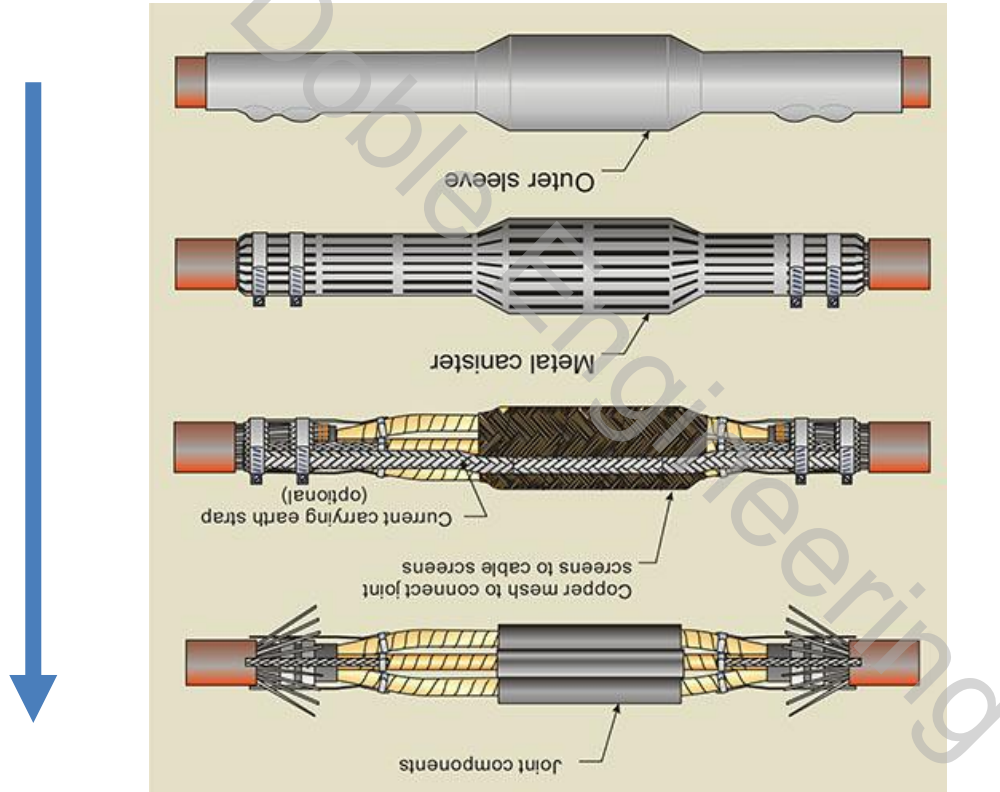




# Three Phase Joint



# Three Phase Joint

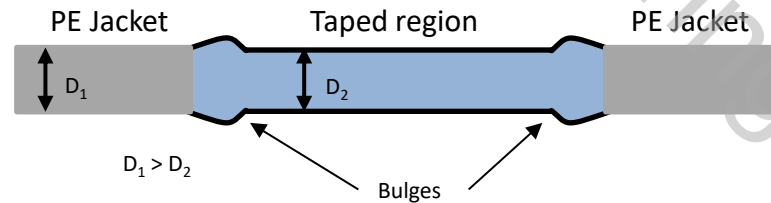
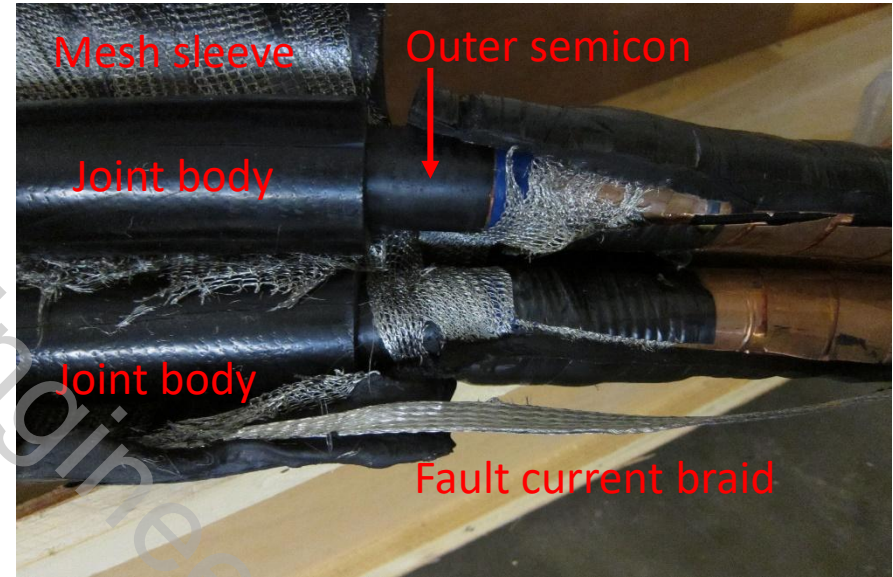
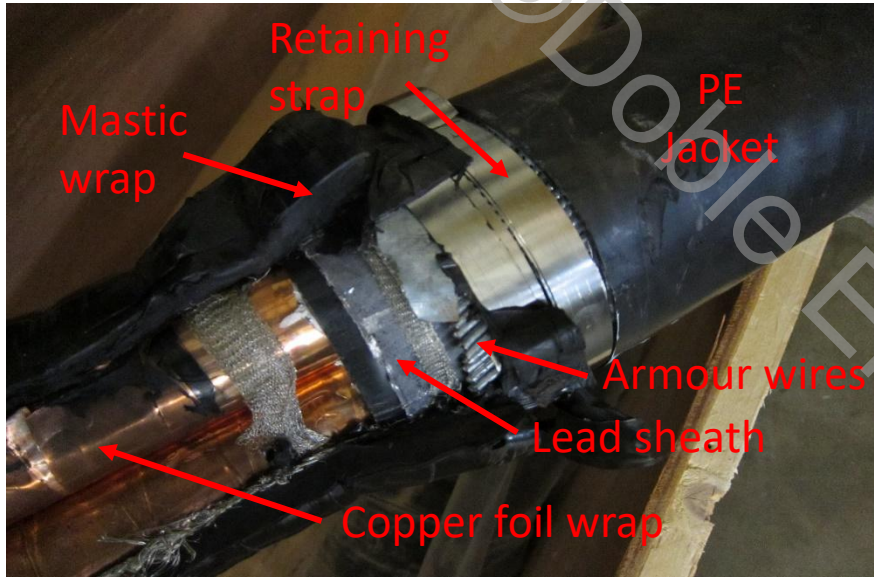


# Plan of Attack

- Start with the healthy joint
  - Learn the construction
  - If it gets damaged, it's better to damage the healthy one than the failed one
- No metallic containment
  - Fine mesh sleeve over the three joints
  - Earth continuity braid
  - Encased in heavy semi-solid putty (very hard to remove)
  - Wrapped in outer protective tapes

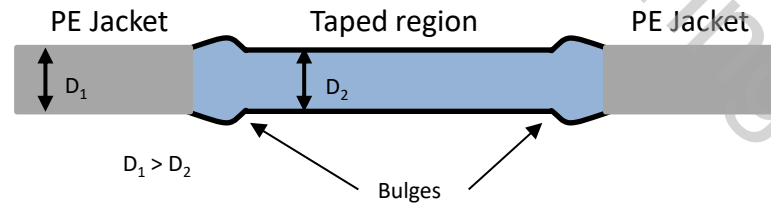
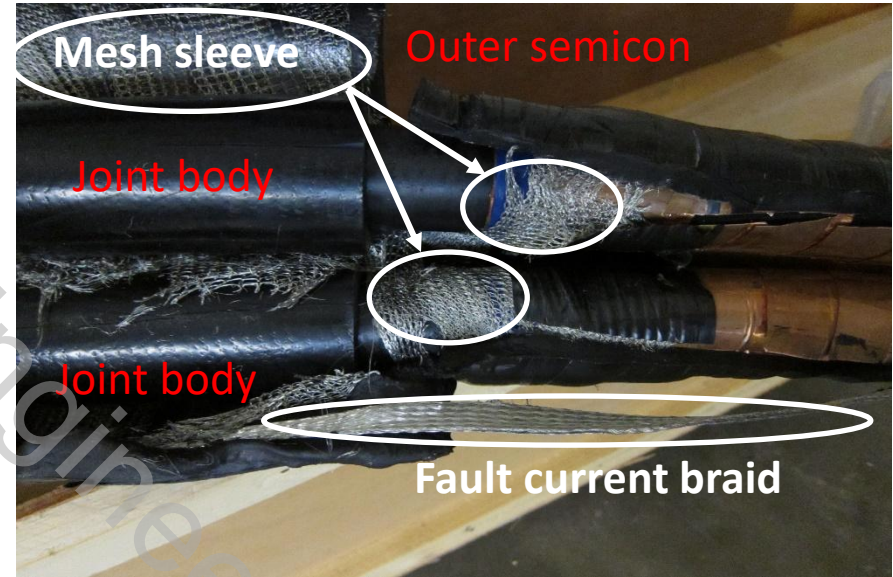
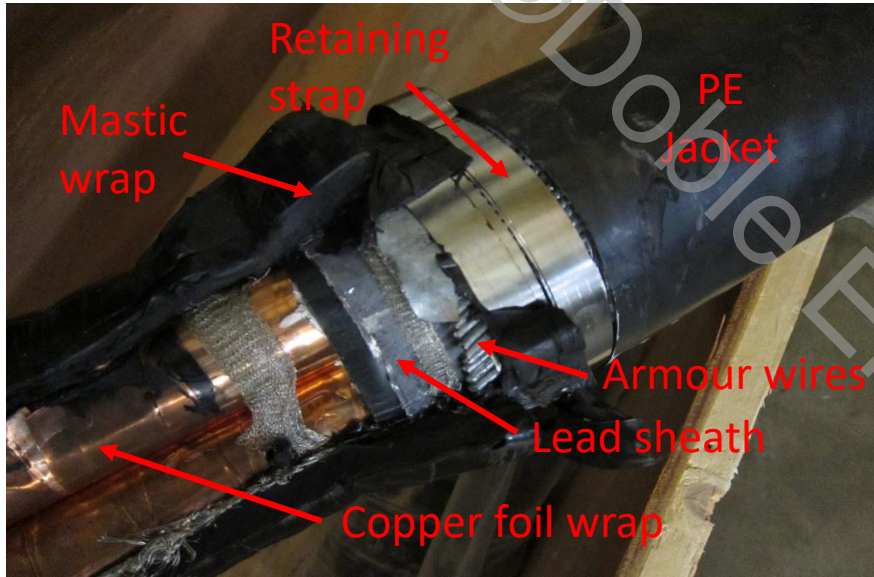


# Extracting the Joints





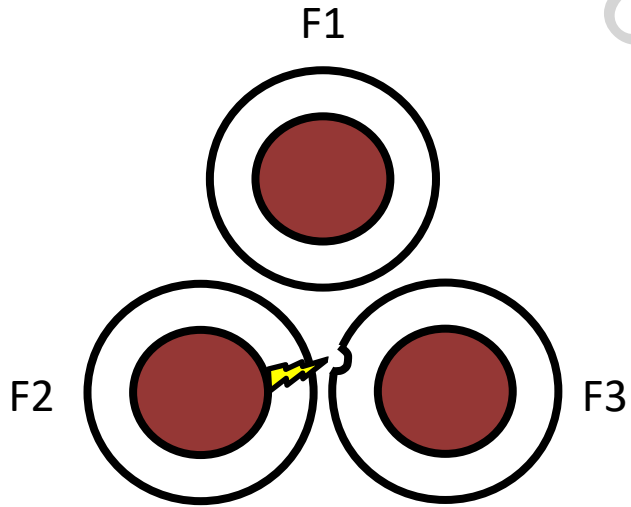
# Extracting the Joints



# Extracted Joints

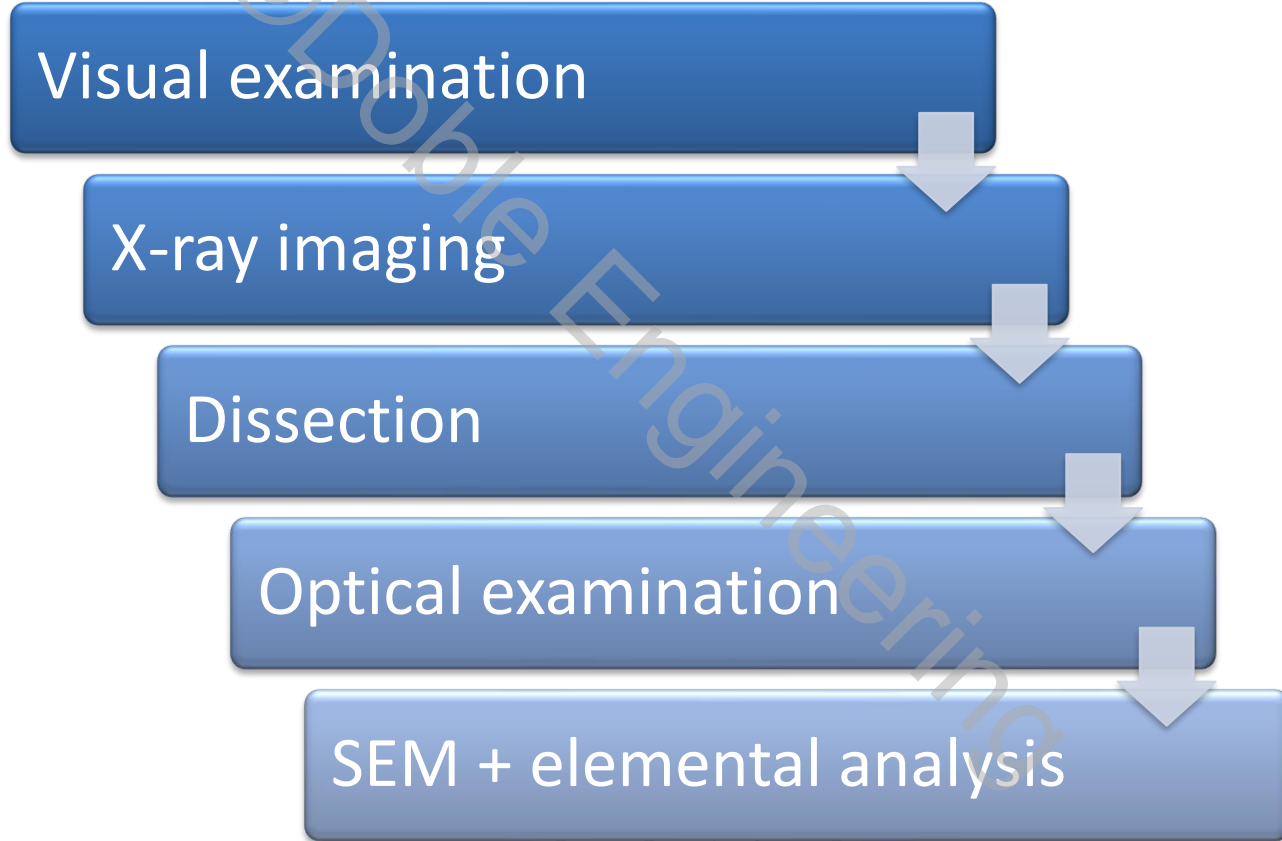


# Fault Location



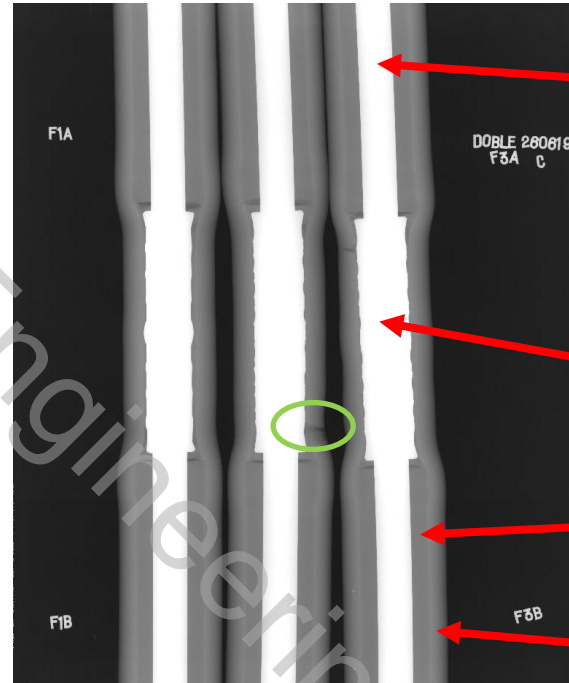


# Systematic Approach



# X-ray Imaging

- Three joints at a time were subjected to x-ray imaging
- Considered different orientations
- All three layers of the cable core are visible
- A number of features can be seen in addition to the fault path



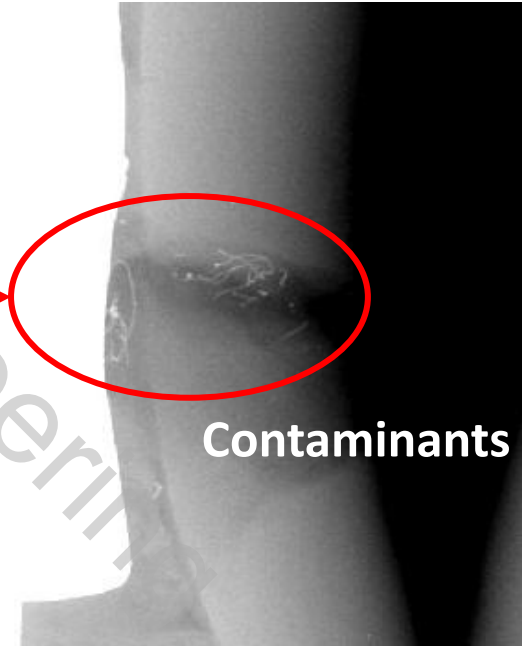
Conductor

Conductor connector

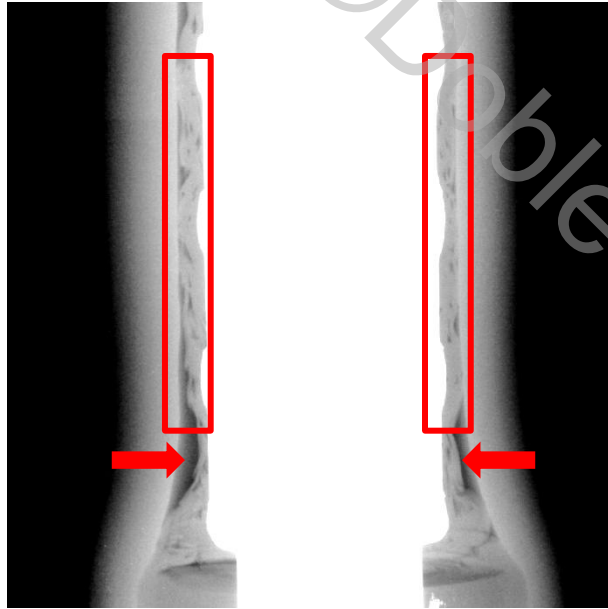
XLPE insulation

Joint body

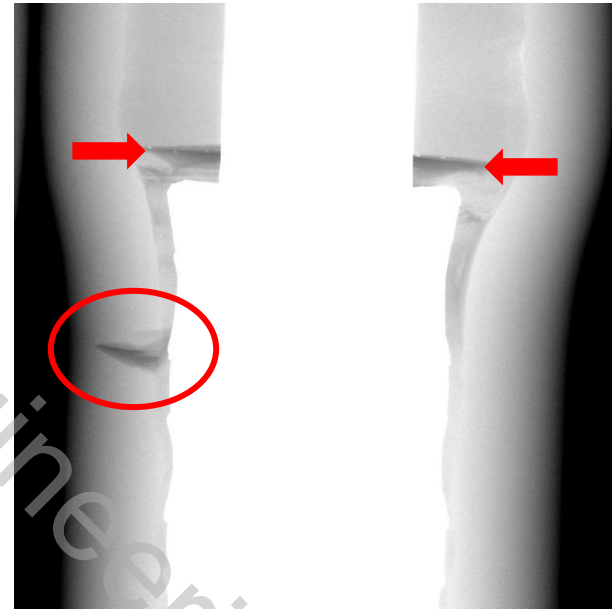
# X-ray Imaging – Fault Path



# X-ray Imaging – Other Features

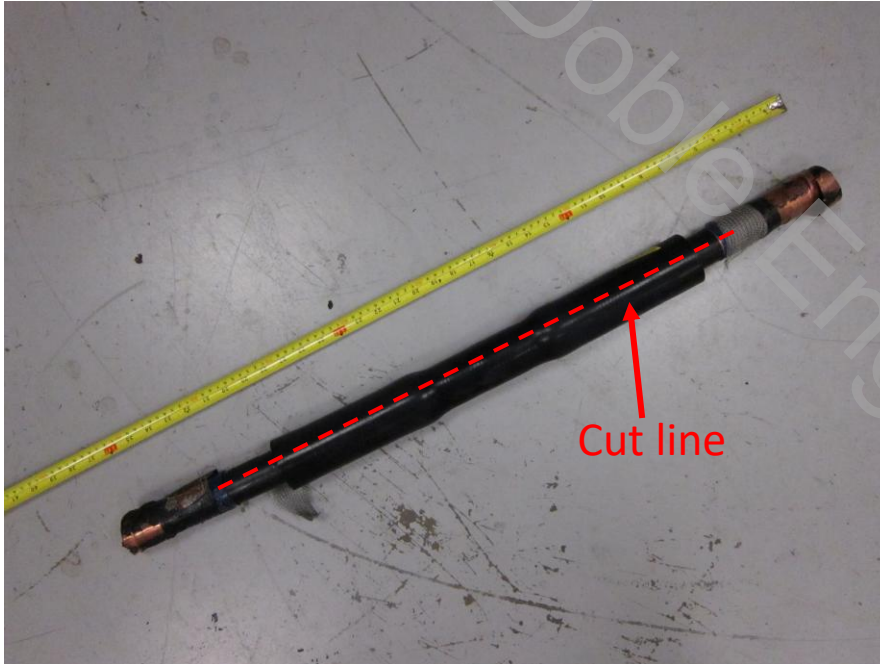


Air voids



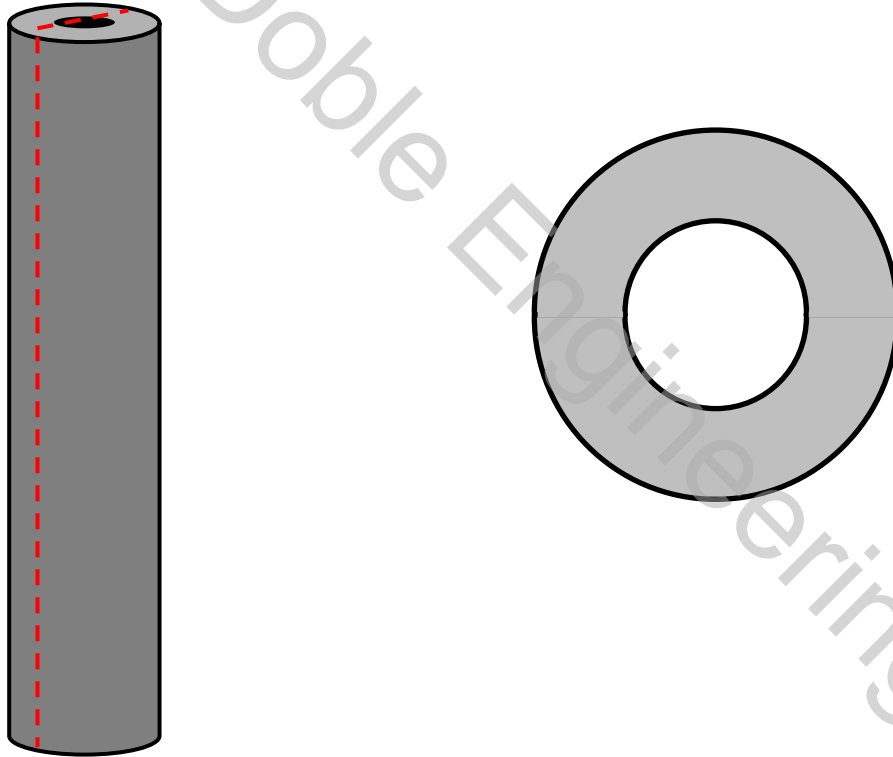
Developing fault?

# Opening the Joint

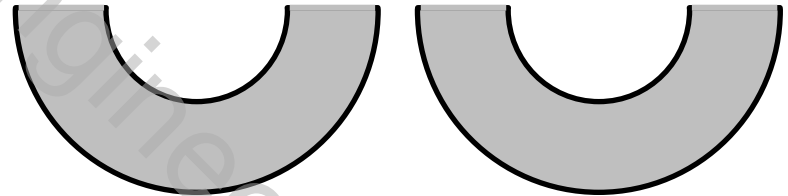
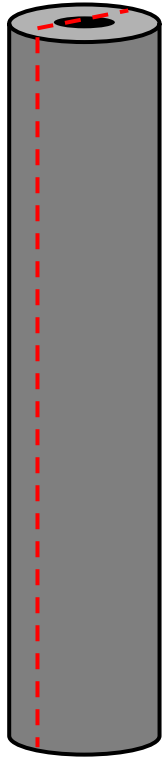


- Knowing the orientation, the identified internal features could be avoided
- Cut the silicon rubber joint body along its length
- Repeat on the other side
  - 12 o'clock and 6 o'clock
- Open the joint tube to reveal the internal surface, conductor connector and XLPE insulation

# Opening the Joint

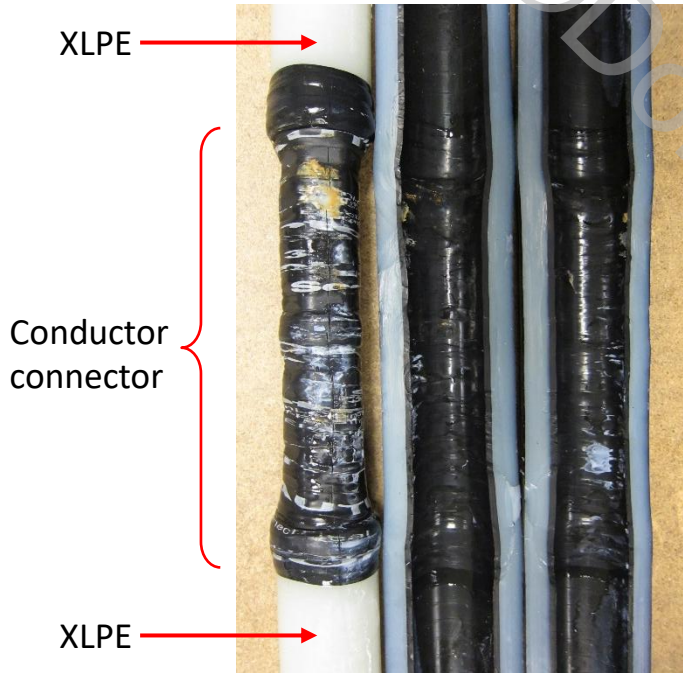


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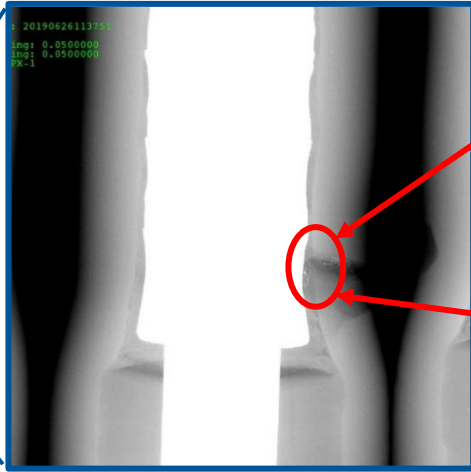
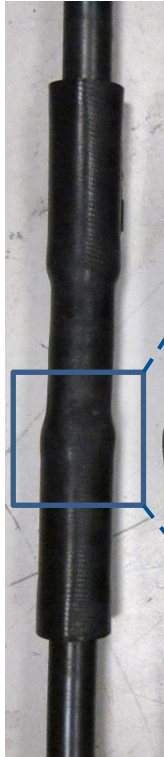




# Opening the Joints

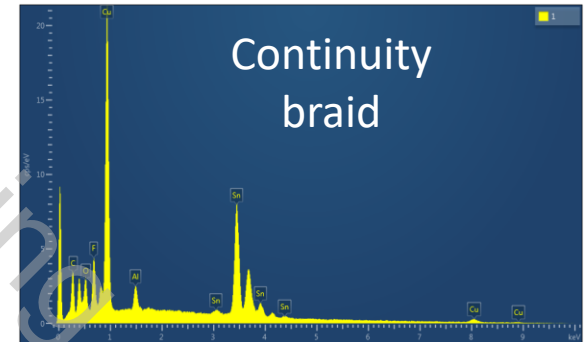
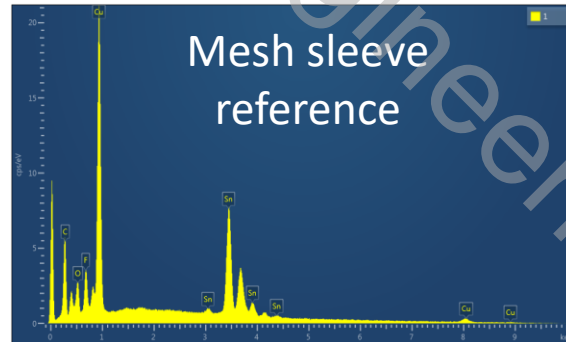
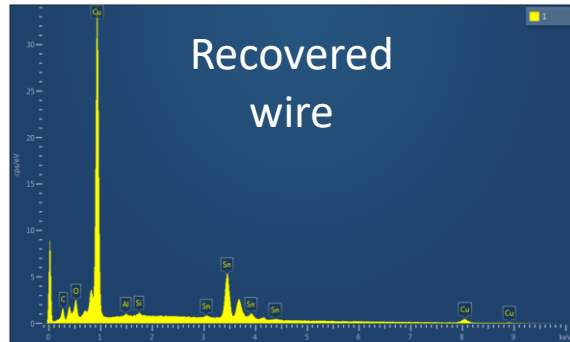
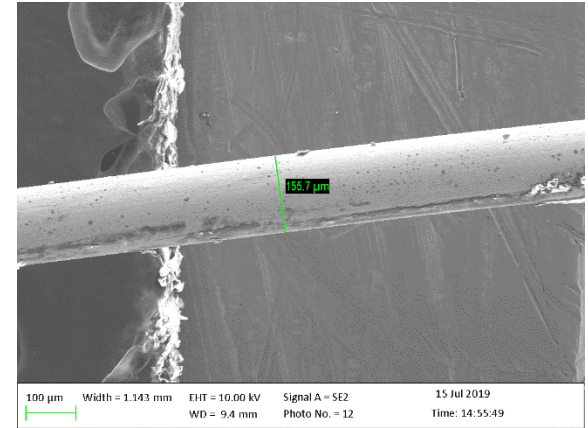
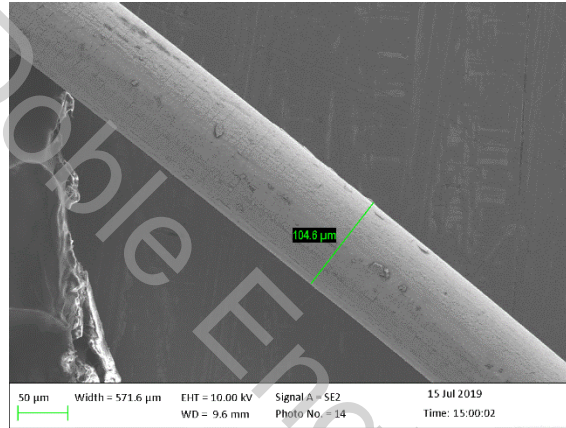
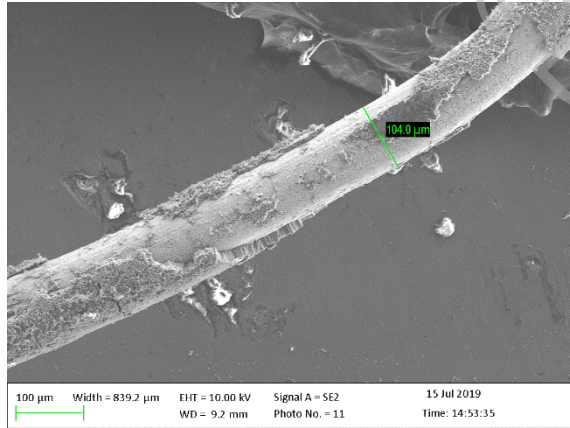


# Wires in the Fault Path



- Foreign objects:
  - In the fault channel
  - Embedded within the semicon tapes over the conductor connector
- Multiple wires
- Probably transferred from the hands of the jointer

# Identifying the Source



Diameter and elemental composition confirm the sources of the contaminants

# Five Whys

1. Why did the joint fail?
  - Breakdown to earth
2. Why did it fault?
  - There were contaminants in the tape
3. Why were there contaminants in the tanks?
  - Most likely introduced from the hands of the joiner
4. Why were there contaminants introduced?
  - Poor training and/or supervision
5. Why was this allowed to happen?
  - Poor specification and/or tender documentation

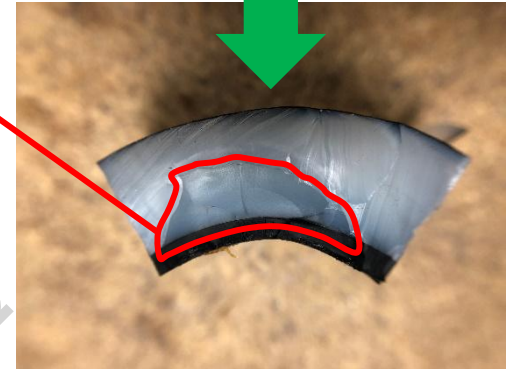
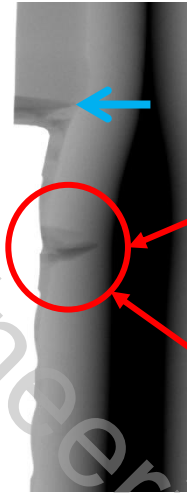
**Success!**



# More Problems – Tears in the Joint

## Body

- Tears within the silicone rubber
  - 70% through joint wall
- Rubber is under tension
- Evidence of partial discharge activity
- Potentially far more concerning as seen in all the joints to some degree



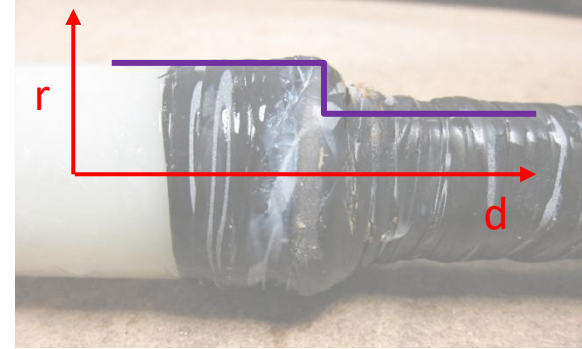
# So What Should it Look Like?

- The sharp step in the diameter creates a void and puts the silicone rubber under tension
- Manufacturers usually supply joint kits with the correct sized conductor connector



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- Manufacturers usually supply joint kits with the correct sized conductor connector
- All installed joints are at risk of failure





# Investigation Summary

- Root cause of the failure was contamination with wires from the mesh sleeve
  - This was only seen in one of the six joints examined
- More worryingly, tears and evidence of discharge activity was seen in all the joints examined
- Use of an undersized conductor connector or a failure to build up the diameter with multiple layers of semiconducting tapes is causing tension in the silicone joint body and creating voids
- All installed joints are at risk of failure

# Forensics 101 Summary



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- Applies to all failure investigations
  - Don't be shackled to a root cause analysis methodology
  - Help the investigator with the background information
  - Label, photograph, sketch everything before the slicing and dicing starts
- There are lots of analytical techniques available to help get to the root cause
  - Start simple and build up the complexity
- Don't expect a smoking gun