SOUTHWEST GAS CORPORATION

Failure Analysis as a Part of System Integrity

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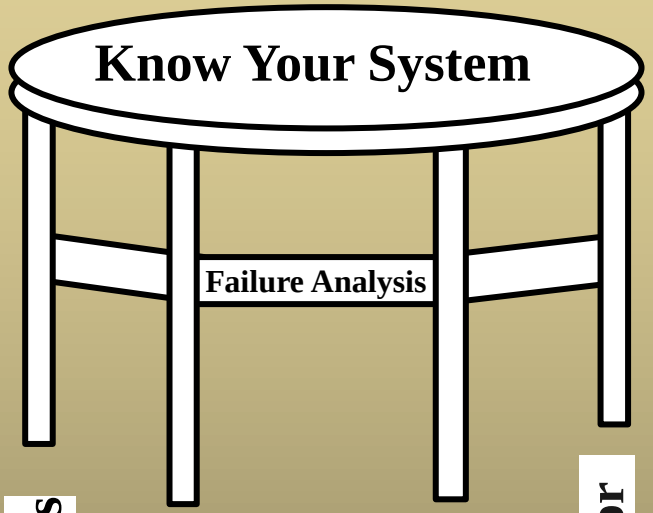
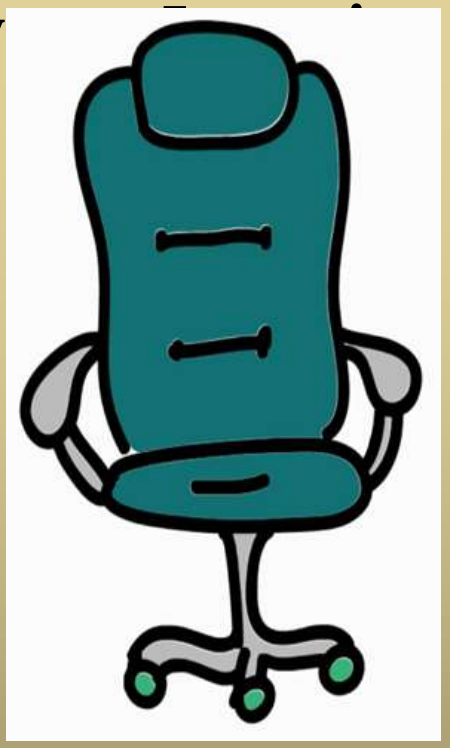
Department: Engineering Staff - System Integrity

I terial Investigations into Sy
(7 Elements of DIMP)





Periodic Evaluation and Improvement

Identify Threats

Evaluate & Rank Risks

Identify & Implement Risk Countermeasures

Measure Performance, Monitor Results & Evaluate Effectiveness

Report Results

Know Your Infrastructure

- Materials
- Type of construction
- Operating conditions
- Relevant factors within surroundings
- Utilize best information available to make decisions about what is in the system
- Update information as new or better data becomes available
- Be Creative and Innovative

- **All the above Elements have linkage with Failure Analysis at the front end and for determining cause.**

Things to Consider

- **Global** - does the threat exist throughout the system?
- **Local** - is it limited to a certain geographic region or material type?
- **Relevance** – create threat sub-categories for granularity and refinement.
- **Identify elements** that help define or eliminate a threat.

Establish threat parameters

49 CFR 192.617, Investigation of failures. states:

"Each operator shall establish procedures for analyzing accidents and failures,

including the selection of samples of the failed facility or equipment for laboratory examination, where appropriate,

for the purpose of determining the cause of the failure and minimizing the possibility of a recurrence."

This is the seed for conducting Failure Analysis and the development of our Lab.

Failure Analysis as a Part of System Integrity

- Our Lab is equipped with the analytical tools necessary to:
  - Inspect
  - Evaluate
  - Characterize components & assemblies

Characterize

Many Types of Labs

What is a Lab?

Failure Analysis as a Part of System Integrity

Failure Analysis as a Part of System Integrity

- While the term "**Failure**" exists in the DOT code, this term is rarely used in our lab.
- This **connotation is negative** to the degree it's **misleading** and implies a greater impact than may actually exist.
- We refer to our (failure) analysis as a **Material Investigation (MI)**.

Failure Analysis as a Part of System Integrity

- When more specific details are required, we will use behavior-specific vernacular:
  - Crack
  - Pull-out
  - Worn O-ring
  - Substandard Material

ANALYTICAL PHASES*

I. VISUAL INSPECTION
II. PHYSICAL CHARACTERIZATION
III. NONDESTRUCTIVE TESTING
IV. DATA ANALYSIS
V. PROCESS OF ELIMINATION
VI. DISASSEMBLY
VII. HIGHER ORDER CHARACTERIZATION

* NOT MUTUALLY INCLUSIVE

Analytical Limitations

A Material Investigation can be no better than:

- Information Provided Surrounding the Sample
- Quality of the Sample

Phase I: Visual Inspection

- **First Step** - review all accompanying or available information.
- **Second Step** - complete visual inspection of the sample in the as-received condition.

Note:

Potential **impacts & sensitivity** will dictate the degree of photo documentation throughout.

Visual Inspection (Continued)…

- During visual inspection, we document all physical characteristics and identify:
  - ***Anomalies*** - existence of a peculiarity or abnormality but having no effect on the sample.
  - ***Discontinuities*** - imperfection or anomaly **but** within an applicable standard.
  - ***Defects*** - discontinuity exceeding an applicable standard.

Visual Inspection

Macro Inspection –

- Visual inspection of objects that can be seen with the naked eye magnified 2.25X-5X their original size.
- Typically performed with the assistance of a 5-8 Diopter circular magnification light.

Phase II - Physical Characterization

To characterize the sample by its:

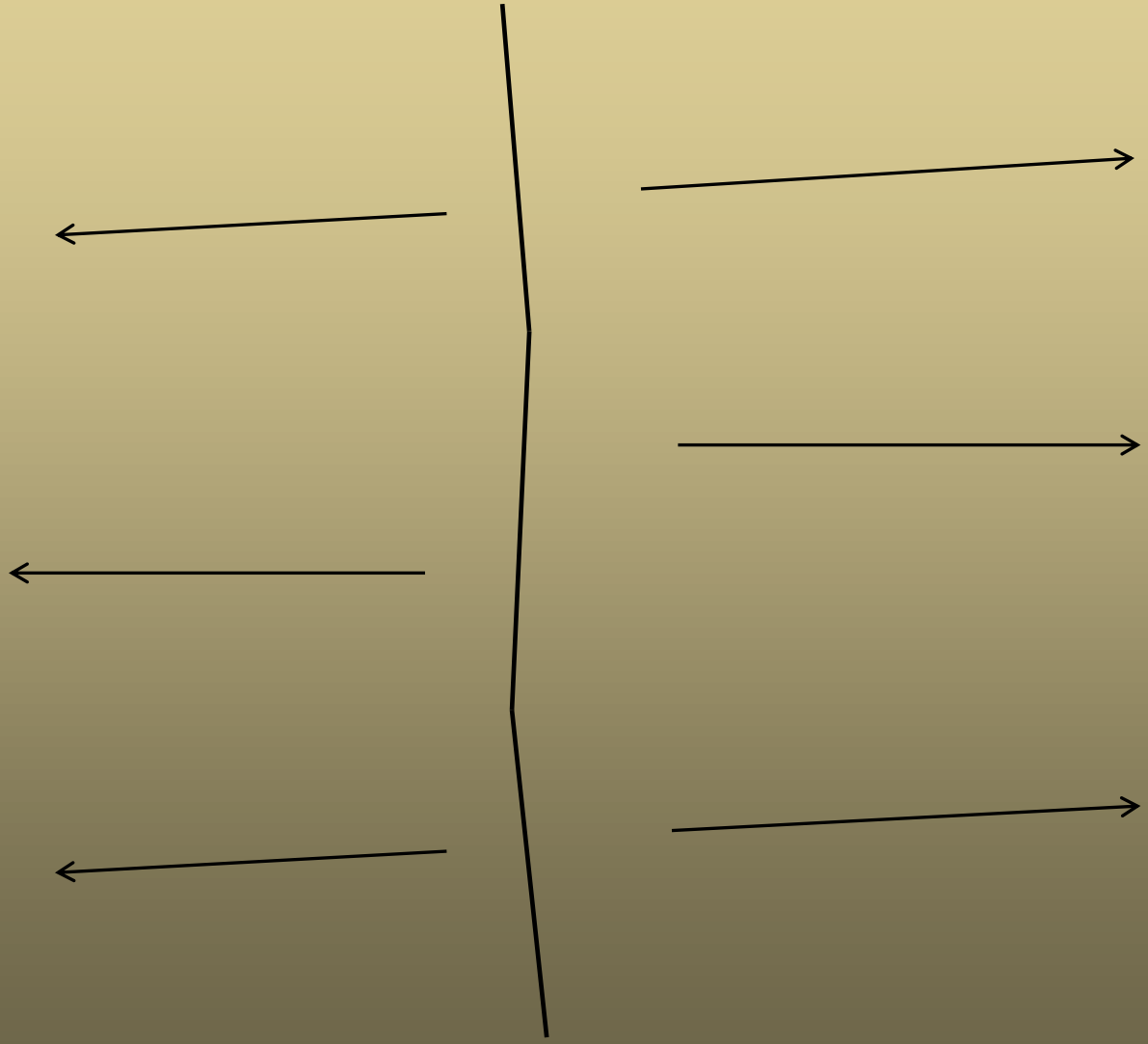
- Dimensions
- Discontinuities or Defects.

Failure Analysis as a Part of System Integrity

- **Dimensional stability** – quantifying the sample for conformance to a manufacturing or finished product standard.

Failure Analysis Short-Course

Lesson 1

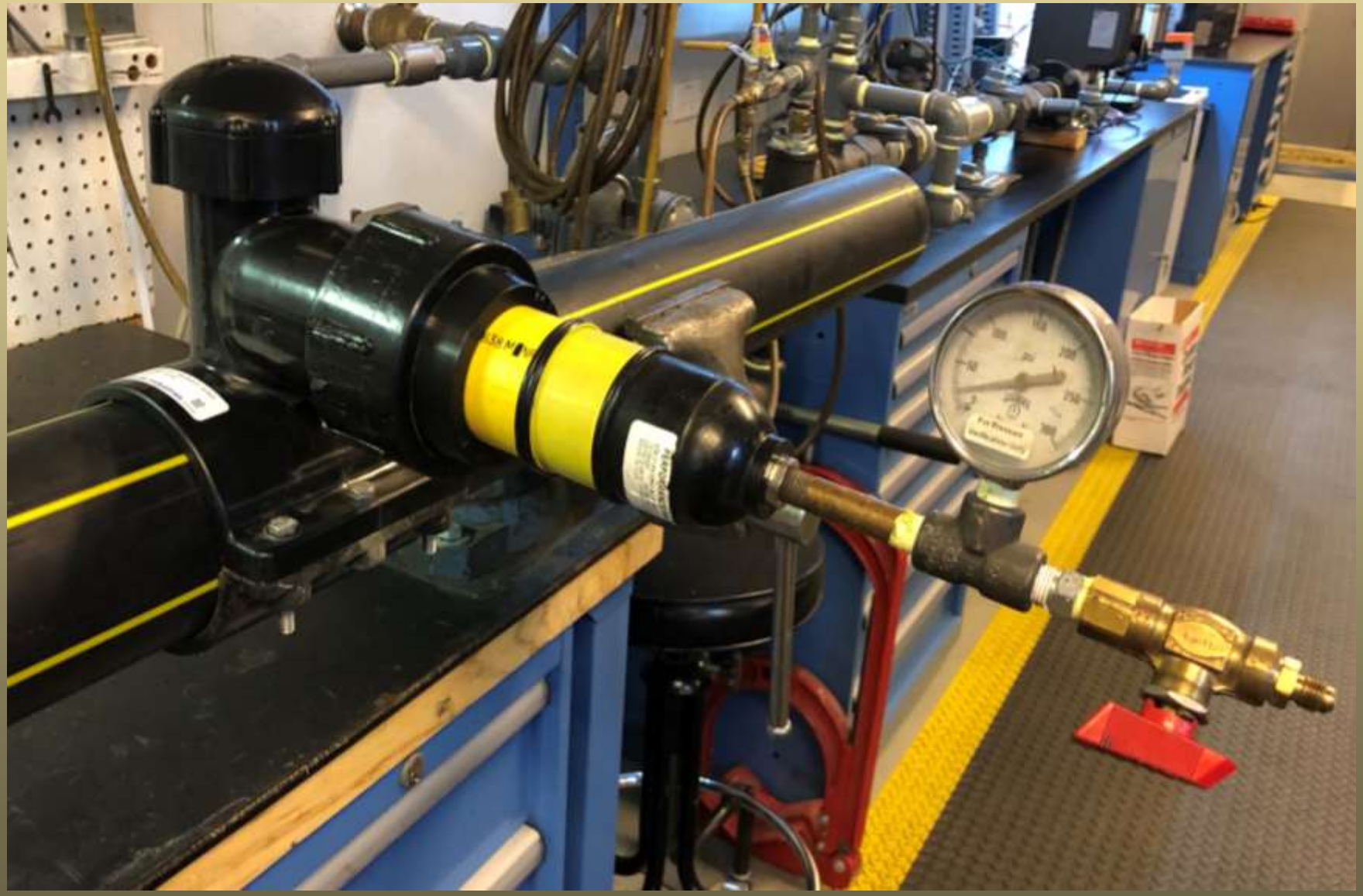


Phase III – Nondestructive Testing (NDT)

Pressure Testing

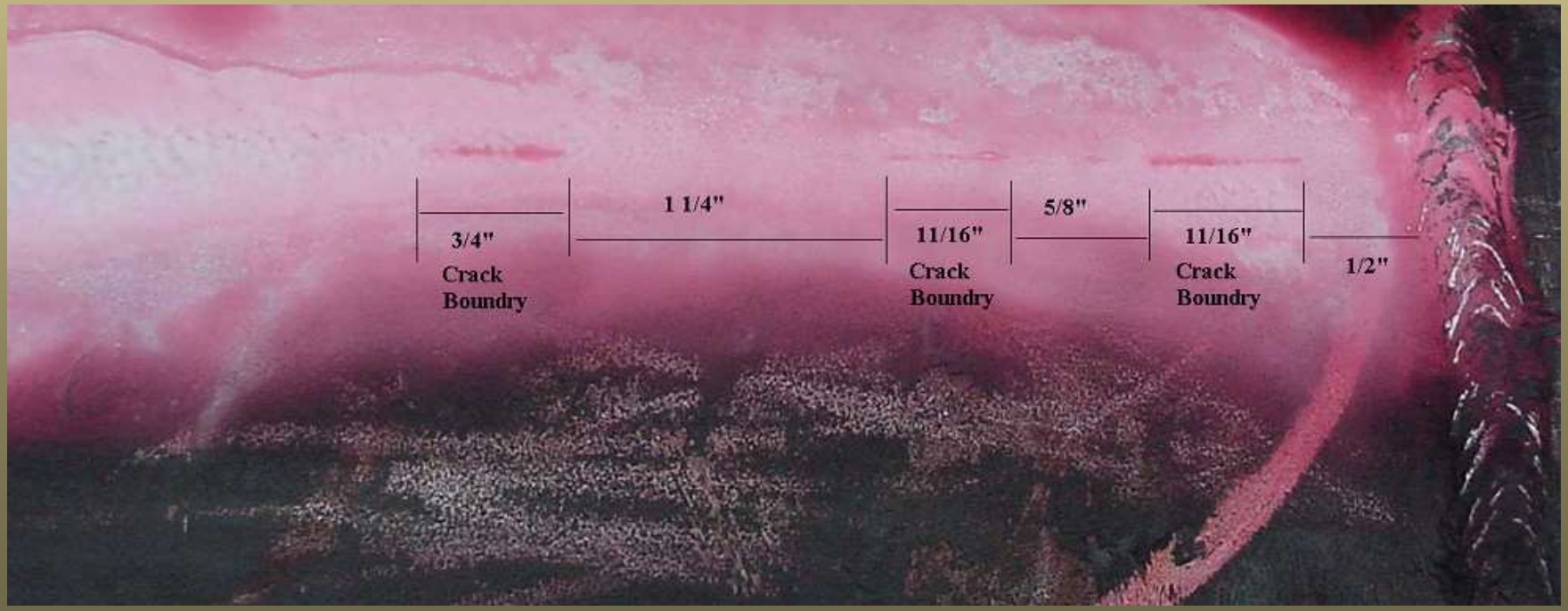
- **Approximates** the in-situ condition.
  - Limitations replicating the condition regarding loading, temperature and the medium.
  - Therefore, effects such as a **leak and its pathway** may not always recur.
  - Still an effective tool in qualitatively identifying the parameters of a leak pathway and its intensity.

Failure Analysis as a Part of System Integrity



Phase III - NDT (continued…)

1. Dye Penetrant – look for surface discontinuities on plastic or steel.



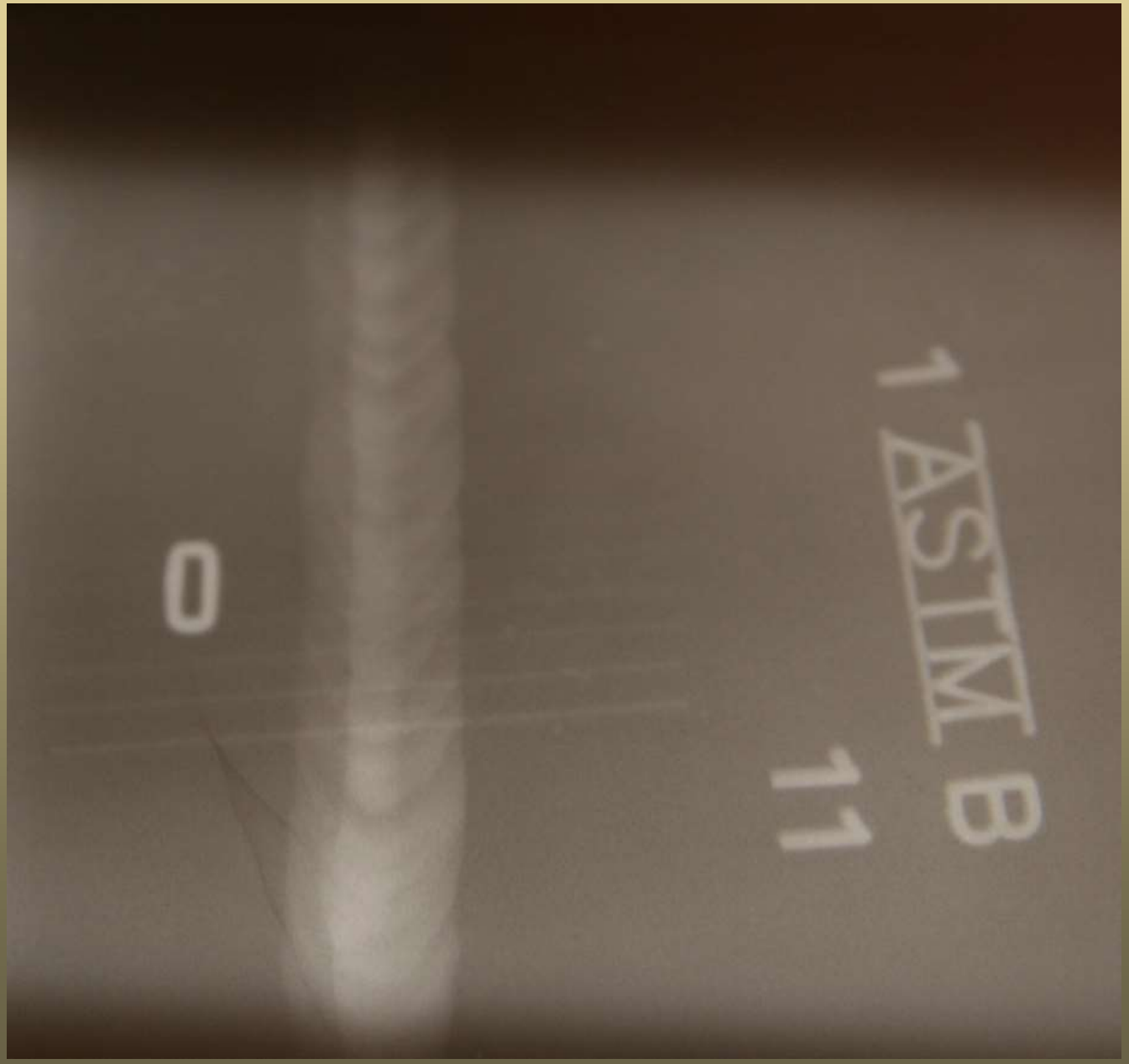
Phase III - NDT (continued…)

2. Magnetic Particle - surface to slightly subsurface discontinuities, on steel samples, with AC/DC wet and dry inspection.

Failure Analysis as a Part of System Integrity

Failure Analysis as a Part of System Integrity

Failure Analysis as a Part of System Integrity



Phase III - NDT (continued…)

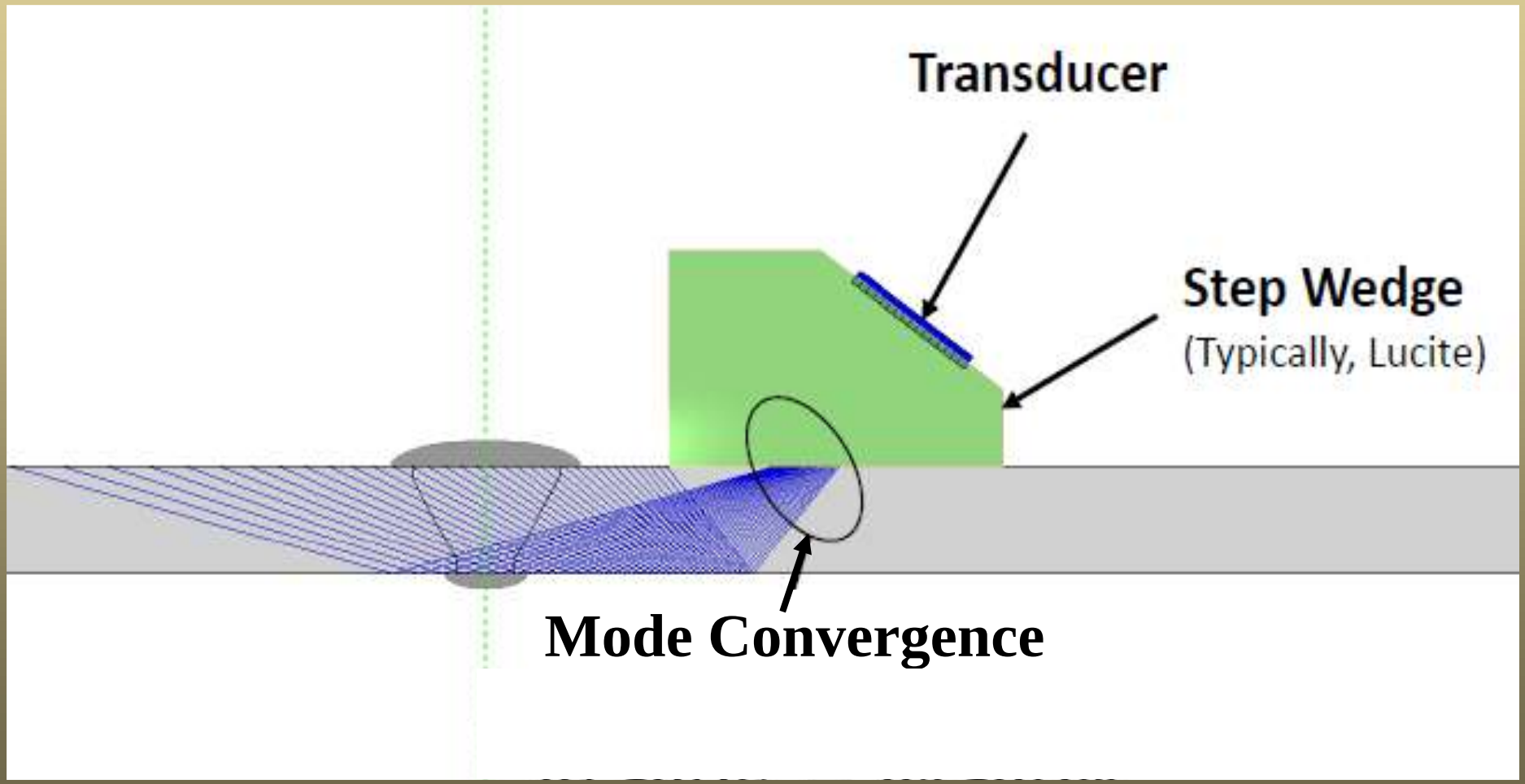
3. Longitudinal Wave Ultrasonics –
   Cross-sectional analysis of steels or plastics:

   - Measure the thickness of any material but **limited with regards to quantifying** a discontinuity's 3-D shape.

   - Can identify the depth of voids, separations and discontinuities aligning **relatively perpendicular to the transducer orientation**.

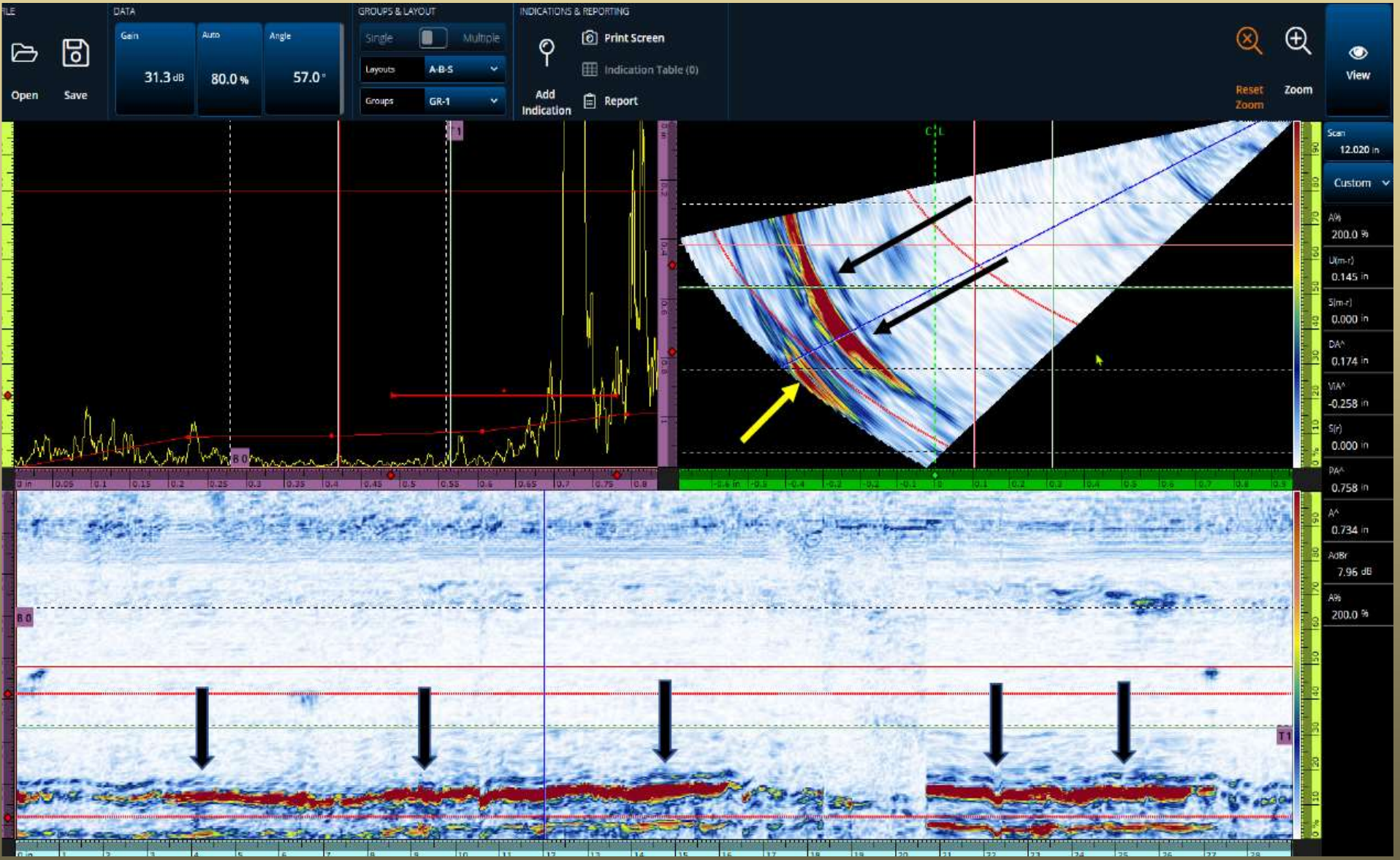
Longitudinal Wave Ultrasonics

Phased Array Ultrasonic Testing (PAUT)



WT
280
WT

S-SCAN PAUT


FILE
Open
Save
DATA
Gain
31.3 dB
Auto
80.0 %
Angle
57.0 °
GROUPS & LAYOUT
Single
Multiple
Layouts
A-B-S
Groups
GR-1
INDICATIONS & REPORTING
Add Indication
Print Screen
Indication Table (0)
Report
Reset Zoom
Zoom
View
Scan
12.020 in
Custom
A%
200.0 %
D(m-r)
0.145 in
S(m-r)
0.000 in
DA^
0.174 in
VIA^
-0.258 in
S(r)
0.000 in
DA^
0.758 in
A^
0.734 in
AdBr
7.96 dB
A%
200.0 %

Phase III - NDT (continued…)

Borescope

- 40X Magnification
- .001” Scaling Accuracy

Phase IV - Data Analysis

- Enter all data from Phases I – III into database or data management system.

Material Investigations

Manage Material Investigation

Location Information

WR Number *

Address

Division *

District *

City

State

WR Date

Date Received

Date Entered

Failure Date

Problem

Disposition

Cancel/Return

Add MI Record +

Manufacturer Information

Manufacturer

Model

Lesson 2

OQPJQ Number

Phase IV - Data Analysis

- Search for prior occurrences or similarities in our database.
- Match the characteristics of our preliminary visual analysis and NDT with past history.

Failure Analysis as a Part of System Integrity

- Sir Arthur Conan Doyle's fictional detective, Sherlock Holmes stated…

- "*when you have eliminated the impossible, whatever remains, however improbable, must be the truth"* (The Sign of the Four)

Phase V - Process of Elimination

Narrow the field of considerations

By removing any impossibilities

V - Process of Elimination (continued…)

- Identify Phenomena **inherent to a material or manufacturing process or from specific vintages** that can be dismissed by establishing the manufacturer and production dates.
- Many discontinuities or defects are **only indigenous to the manufacturing process itself.**
- **Characteristics of a discontinuity or defect (geometry)**
  - Linear or circular - eliminate various possibilities relative to the orientation of the prevailing stress creating the discontinuity or defect.

V - Process of Elimination (continued…)

Use **Visual Inspection** to eliminate impossibilities simply by **establishing discontinuity locations and features:**

- I.D vs. O.D.
- Certain phenomena can only occur in a joint or fitting.
- Impingement - mutually inclusive event with an object capable of creating a point load and leaving an impression.
- Blunt forces (shovel, digging bar…) - are eliminated if a mechanical edge or mechanical impression is not present.

Phase VI – Disassembly:

- Requires compromising the *as-received* condition
- Autopsy

➢ Method of **disassembly is dictated by the information from the prior steps** and the physical presentation.

Phase VI – Disassembly (Continued…)

1. Comparative Analysis

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Phase VI– Disassembly (Continued…)

2. Reverse Engineering Analysis

- Systematically dismantling and examining a fitting or component.
- Reveal the details of its design, manufacture & function.

Phase VI – Disassembly (Continued…)

3. Sequential Disassembly

Disassembling a fitting or component when an exemplar or reverse engineering is not needed.

Phase VI – Disassembly (Continued…)

4. Destructive Disassembly (Tool Time)

- Cutting, slicing or sawing a fitting or component.
- Sometimes, easiest access to an area of interest.
- Needed to characterize or examine the assembly.

Failure Analysis as a Part of System Integrity

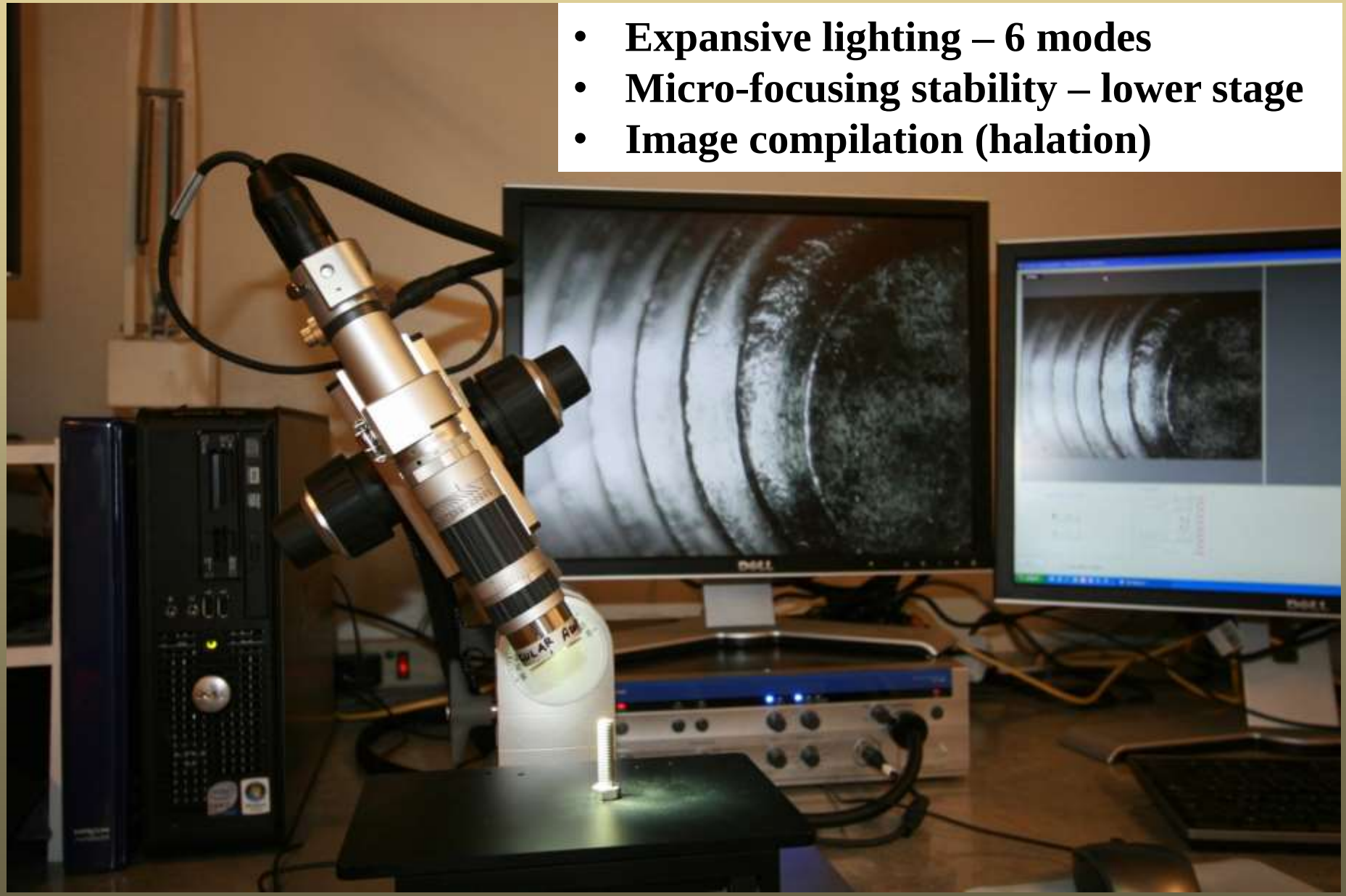
Failure Analysis as a Part of System Integrity

- Often, disassembly will reveal the cause
- Just as often, the cause is still not clear.

Phase VII: Higher Order Characterization

3D Digital Video Microscope

3D Digital Video Microscopy

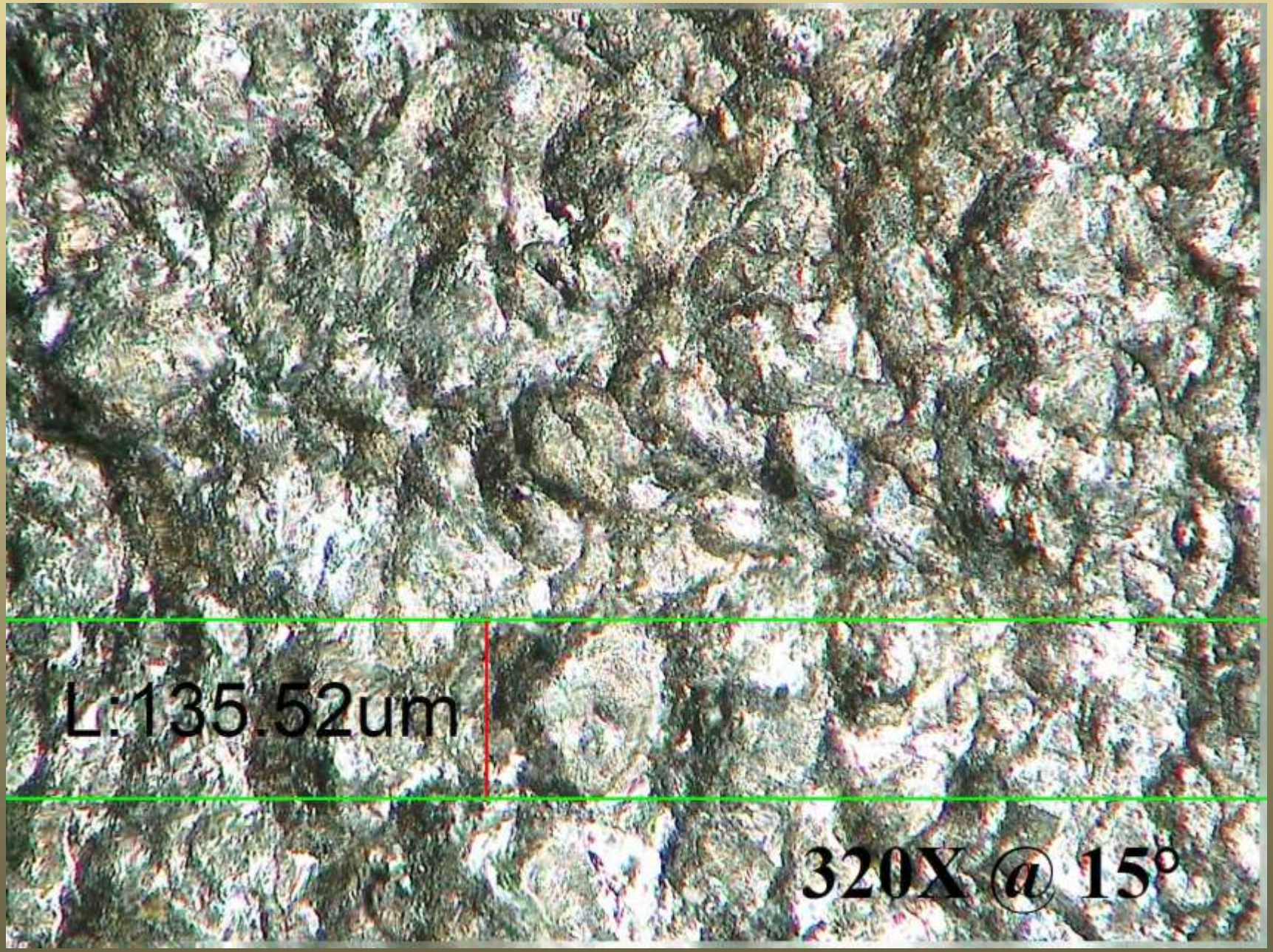


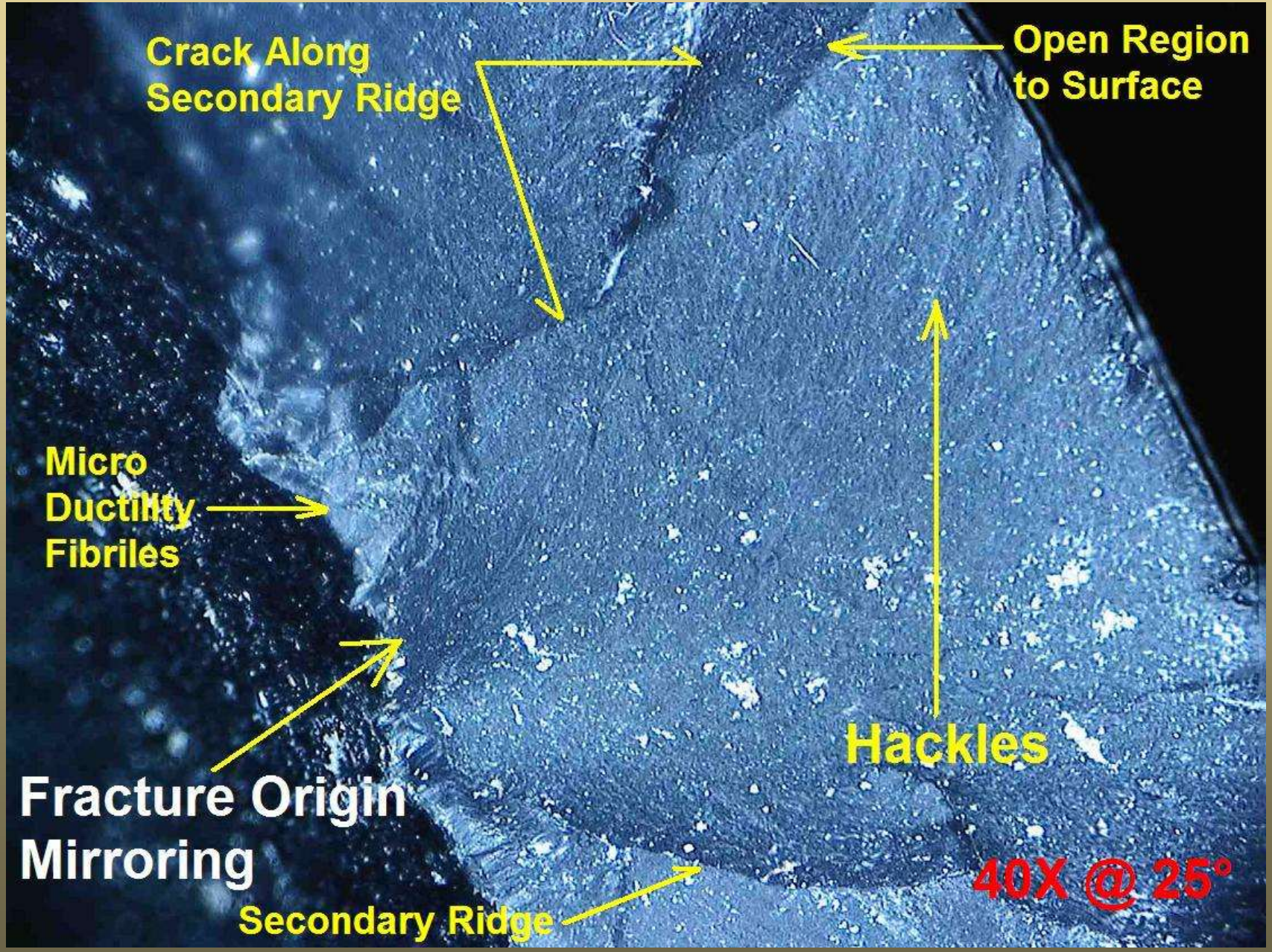
- **Expansive lighting – 6 modes**
- **Micro-focusing stability – lower stage**
- **Image compilation (halation)**

3-D Microscopy

Unique Features

- Frame can tilt up to 90°
- Lens & Fuselage adaptors - up to 7000X
- Expansive lighting – 6 modes
- Micro-focusing stability – lower stage
- Image compilation (halation)

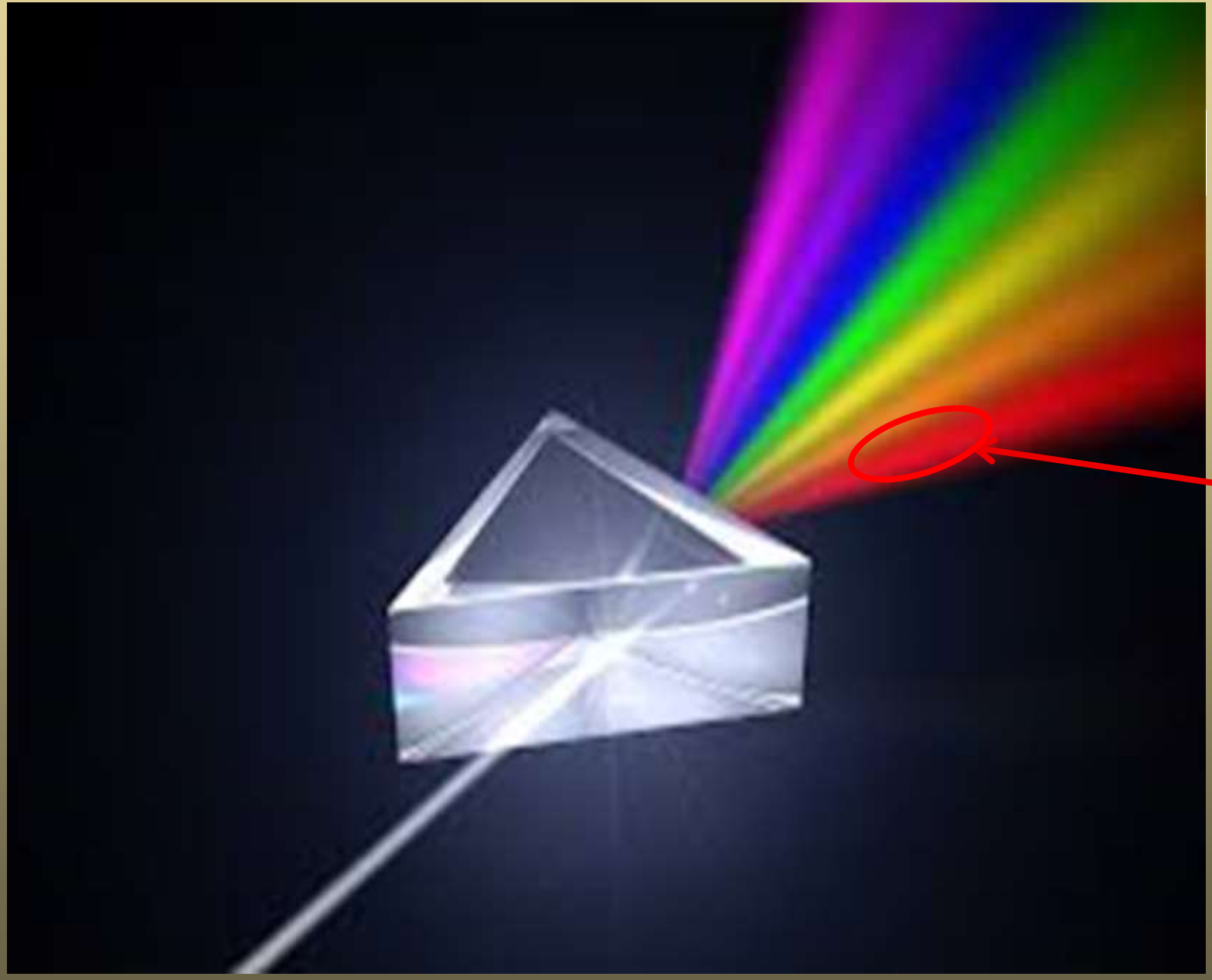

L:135.52um
320X @ 15°


Crack Along
Secondary Ridge
Open Region
to Surface
Micro
Ductility
Fibriles
Hackles
Fracture Origin
Mirroring
Secondary Ridge
40X @ 25°

Higher Order Characterization (Continued…)

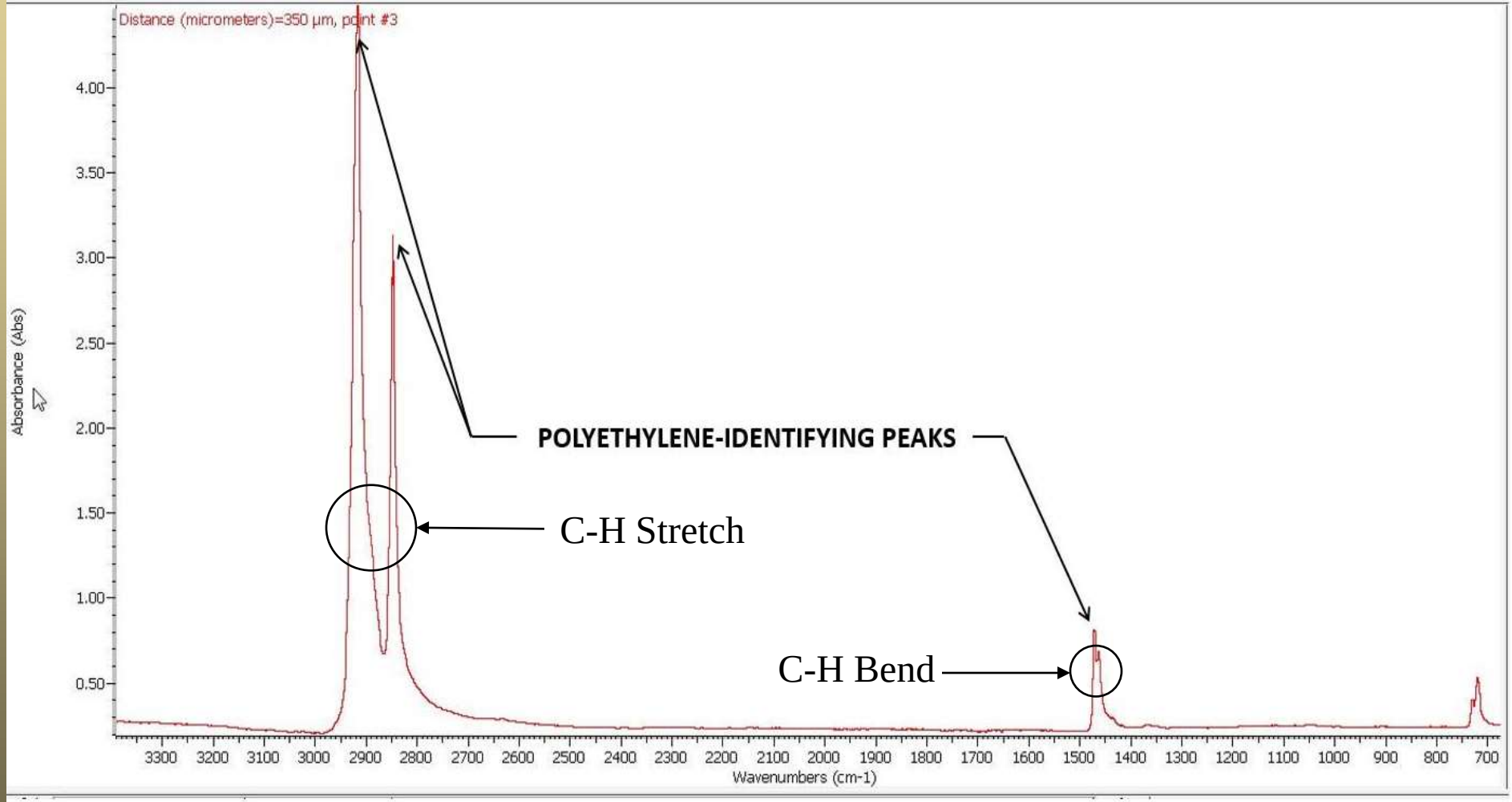
- Fourier Transform Infrared Spectroscopy (FTIR)
- Differential Scanning Calorimeter (DSC)
- Oxidative Induction Time (OIT)
- Scanning Electron Microscopy (SEM)
- Energy Dispersive X-Ray Spectroscopy (EDX)
- Optical Emission Spectroscopy (OES)
- Laser Microscope
- Nano-Scanning Laser Microscope
- Pennsylvania Edge Notch Test (PENT)
- Stress Rupture Tank (SRT)
- Charpy V-Notch (CVN)
- Tensile Test – Steel & Plastic
- Flow Bench

Fourier Transform Infrared Spectrometer (FTIR)



ν_1
symmetric stret
ν_2
bend
x
z

NORMAL POLYETHYLENE FTIR SPECTRUM



Differential Scanning Calorimeter (DSC)

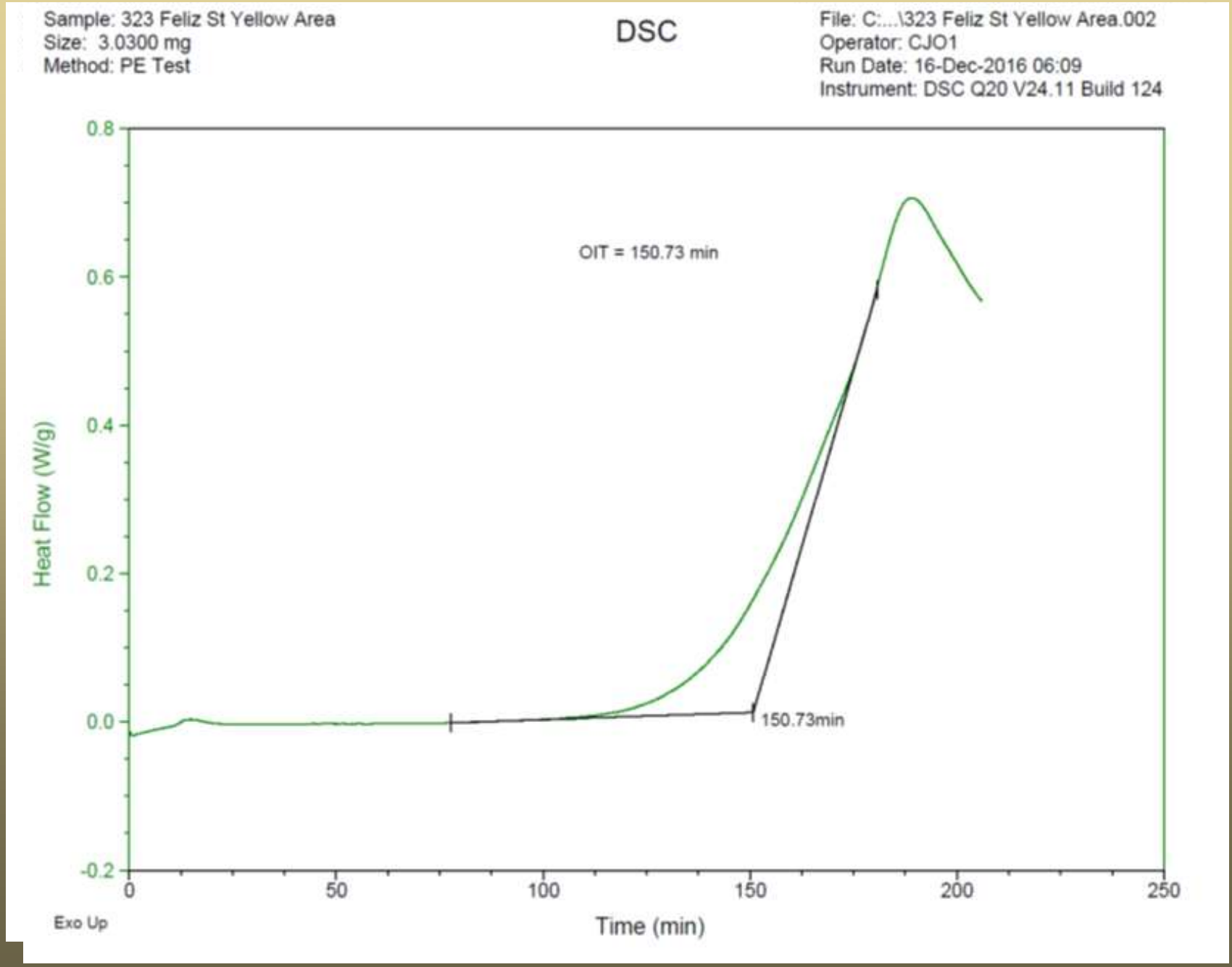
Provides polymer melt information:

Internal Reaction

- Temperature history
- Melt Point
- Process cooling rate
  - % Crystalline vs. % Amorphous

External Reaction

- Oxidative induction time (OIT) -
  - Polymer's resistance to oxidation


Sample: 323 Feliz St Yellow Area
Size: 3.0300 mg
Method: PE Test
DSC
File: C:...\323 Feliz St Yellow Area.002
Operator: CJO1
Run Date: 16-Dec-2016 06:09
Instrument: DSC Q20 V24.11 Build 124
OIT = 150.73 min
150.73min
Heat Flow (W/g)
0.8
0.6
0.4
0.2
0.0
-0.2
0
50
100
150
200
250
Time (min)
Exo Up

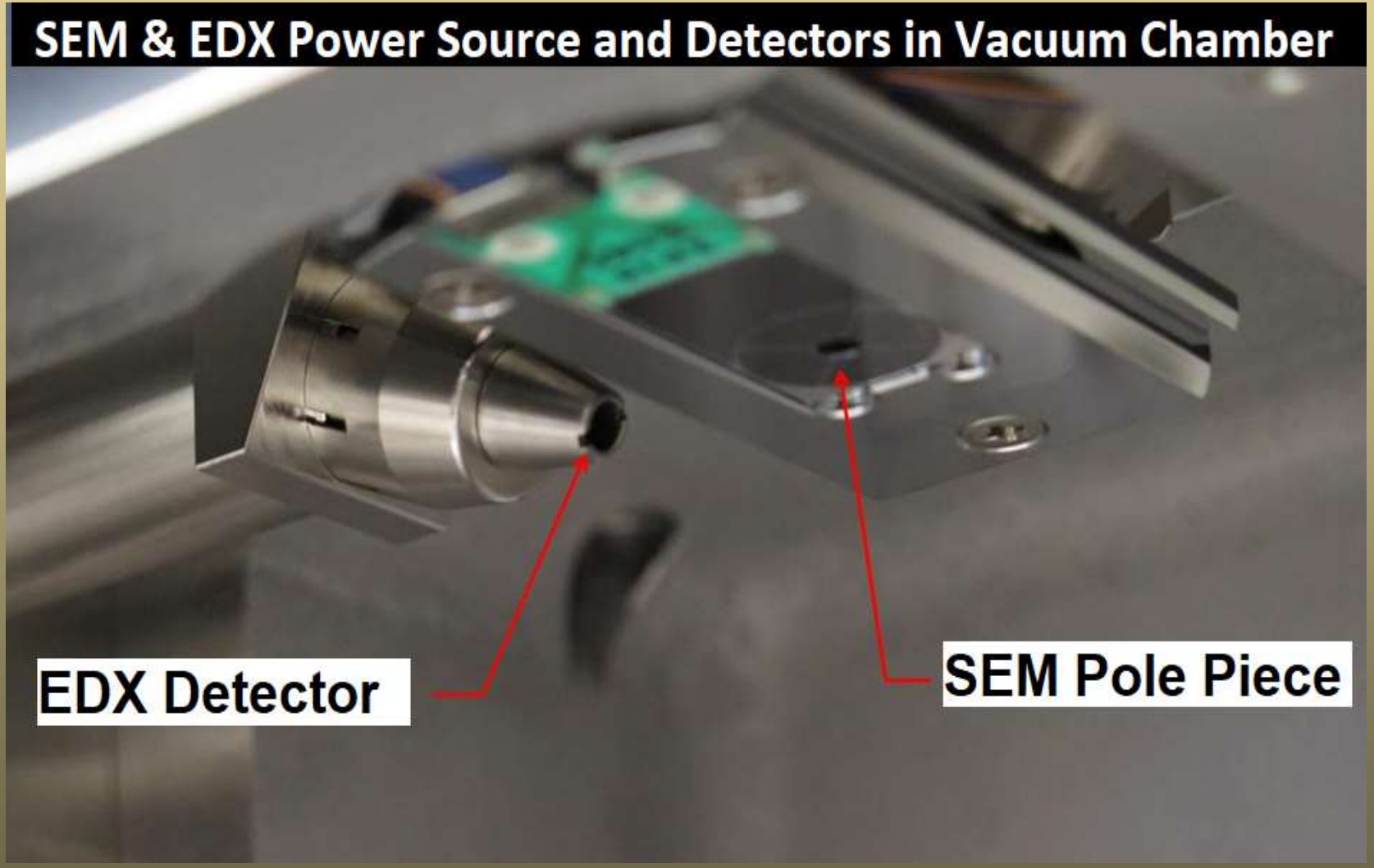
Scanning Electron Microscope (SEM)

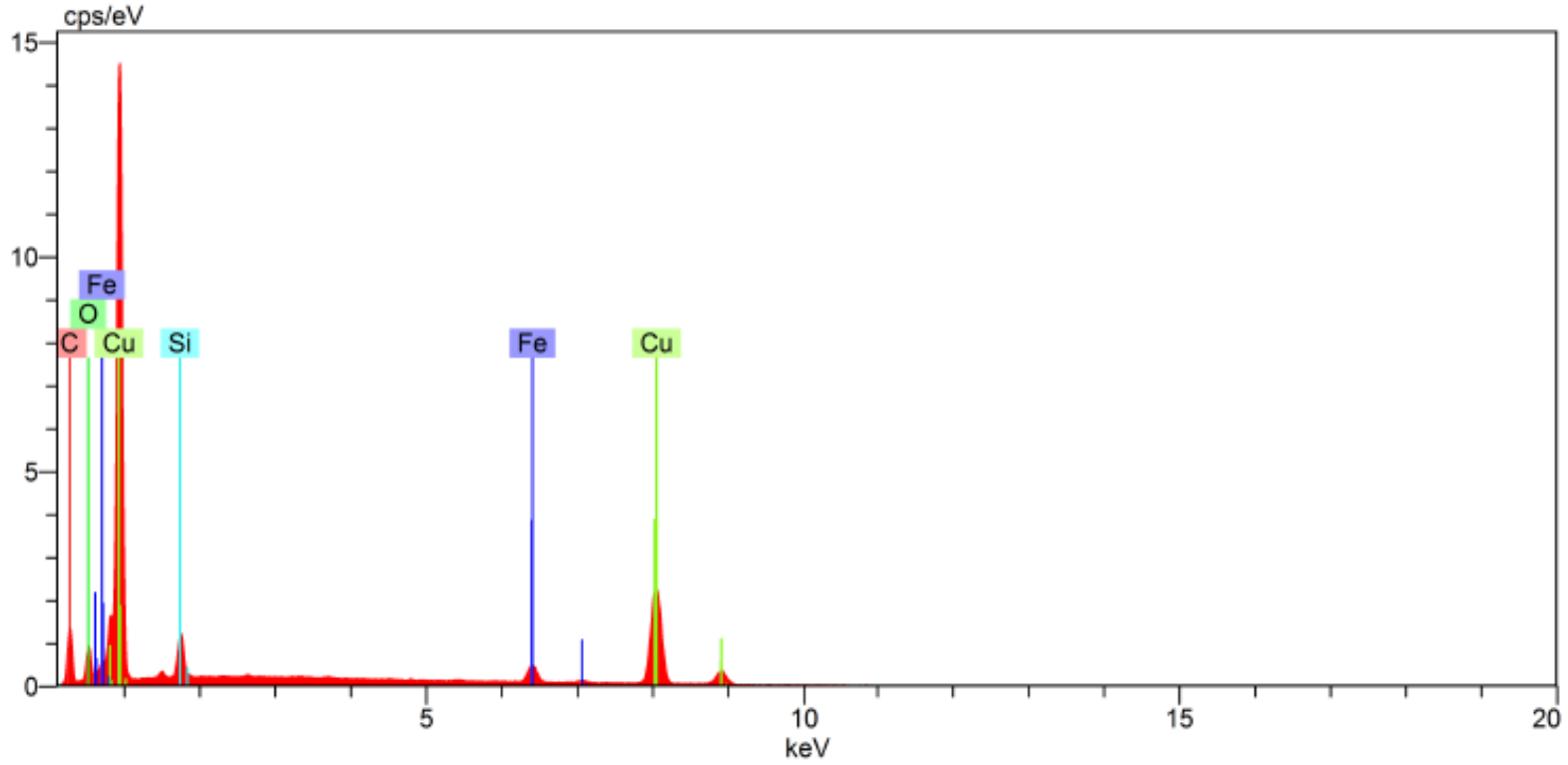
SEM

- Up 80,000X magnification
- Up to 2.75 inches in diameter x 2 inches thick
- High resolution image-capture

EDX = Energy Dispersive X-Ray Spectrometer

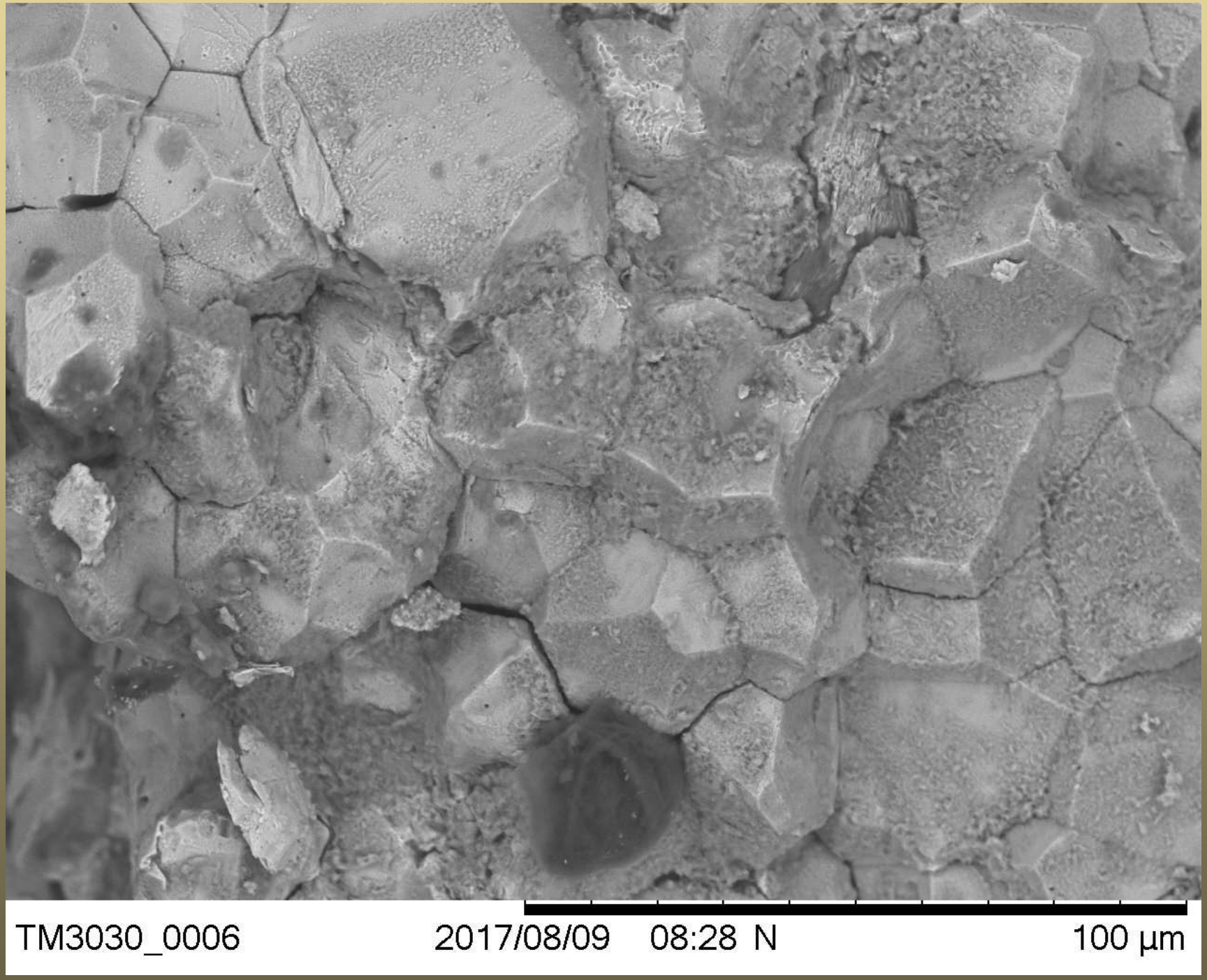
- Able to identify elements boron (5) – americium (95).

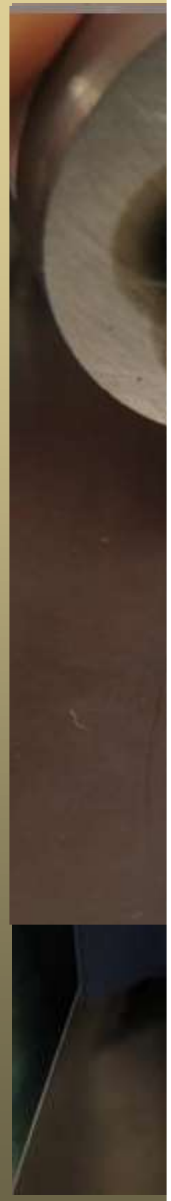

SEM & EDX Power Source and Detectors in Vacuum Chamber
EDX Detector
SEM Pole Piece



Map Date:09/25/2015 3:28:46 PM HV:23.6kV Puls th.:4.15kcps

El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
C	6	K-series	24.29	37.66	60.47	2.9
Cu	29	K-series	22.82	35.39	10.74	0.6
O	8	K-series	13.97	21.67	26.12	1.7
Fe	26	K-series	1.81	2.81	0.97	0.1
Si	14	K-series	1.60	2.48	1.70	0.1
		Total:	64.49	100.00	100.00	


TM3030_0006
2017/08/09 08:28 N
100 µm



Sample:	Kleiss - CAP - Lot 1K180124	Material:	Method:	Fe 100
Furnace No:		Heat No:	Order No:	
Analysis Time:	2019-04-04 07:48:25	User:	Unit:	%

	C	Si	Mn	P	S
Ø	0.442	0.202	0.557	0.012	0.0085

	Cr	Mo	Ni	Cu	Al
Ø	0.132	0.019	0.102	0.292	0.025

	As	B	Bi	Ce	Co
Ø	0.011	0.0004	<0.0025	0.0039	0.0092

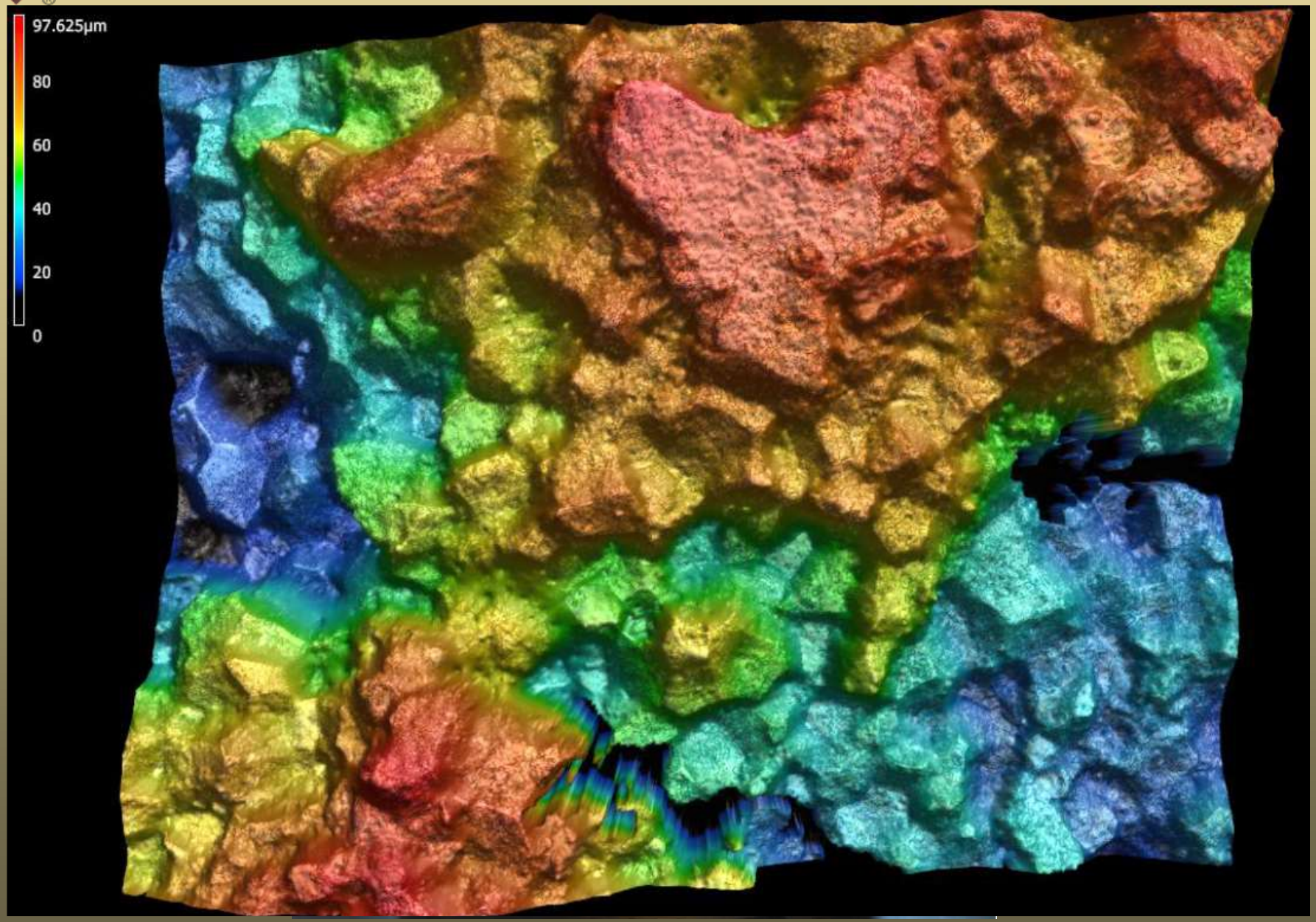
	Mg	Nb	Pb	Sb	Sn
Ø	0.0007	0.0079	0.0044	0.0075	0.014

	Ta	La	Ti	V	W
Ø	<0.02	0.002	0.036	0.0019	<0.005

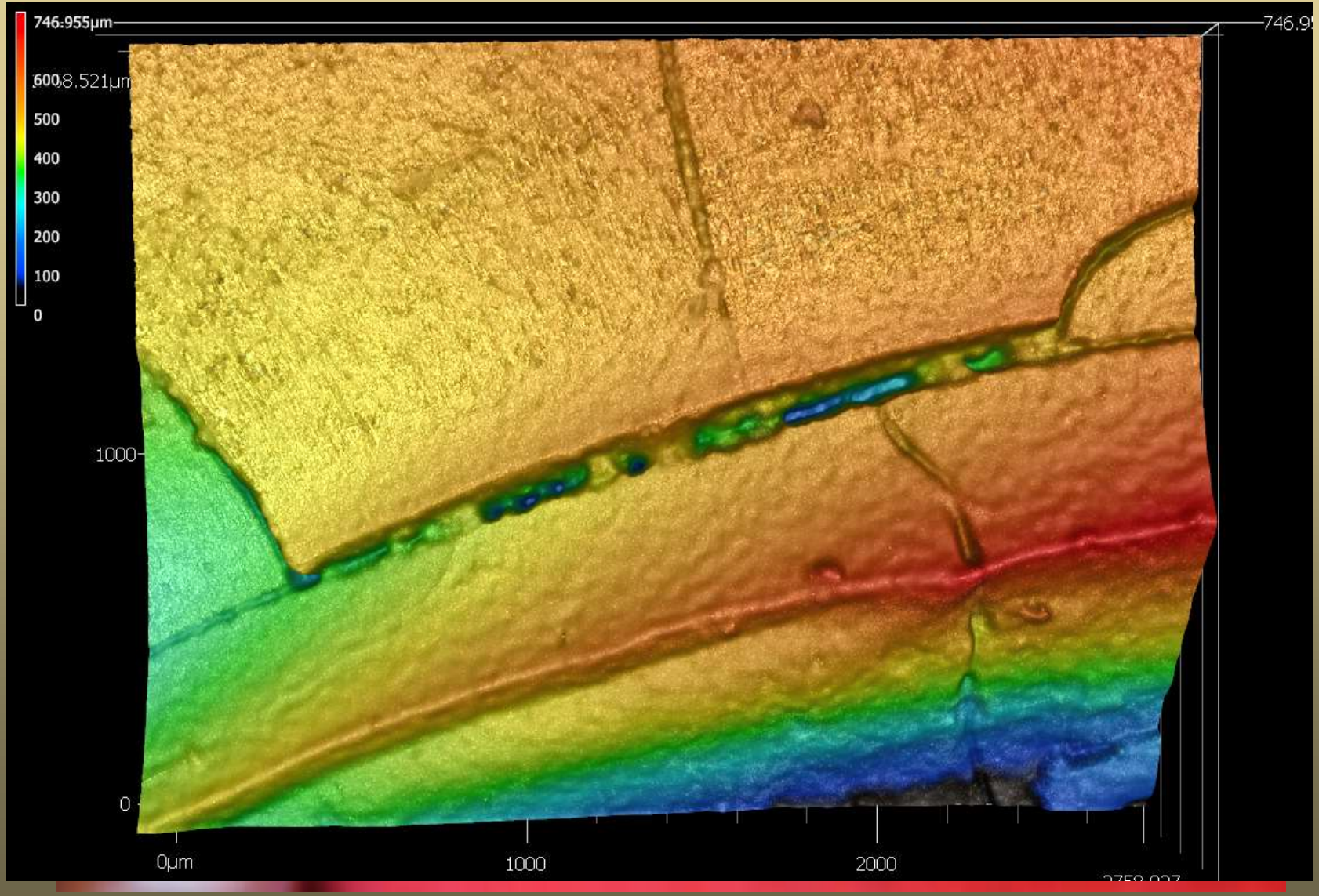
	Zn	Zr	Se	N	Ca
Ø	0.012	<0.0005	<0.001	0.011	0.0011

	Te	Fe	CE(IIW)	Pcm
Ø	<0.001	98.08	0.592	0.503

Laser Microscope



Laser Microscope (Continued…)



Once the above phases of analysis are concluded:

- Most often, a clear cause is established.
- Almost Always, it's the simplest explanation.

Occam's Razor - nature prefers simplicity and tends to follow the path of least resistance.

Principle of Parsimony –

fewest leaps of logic.

Questions & Answers

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Trepanation (Trepanning)

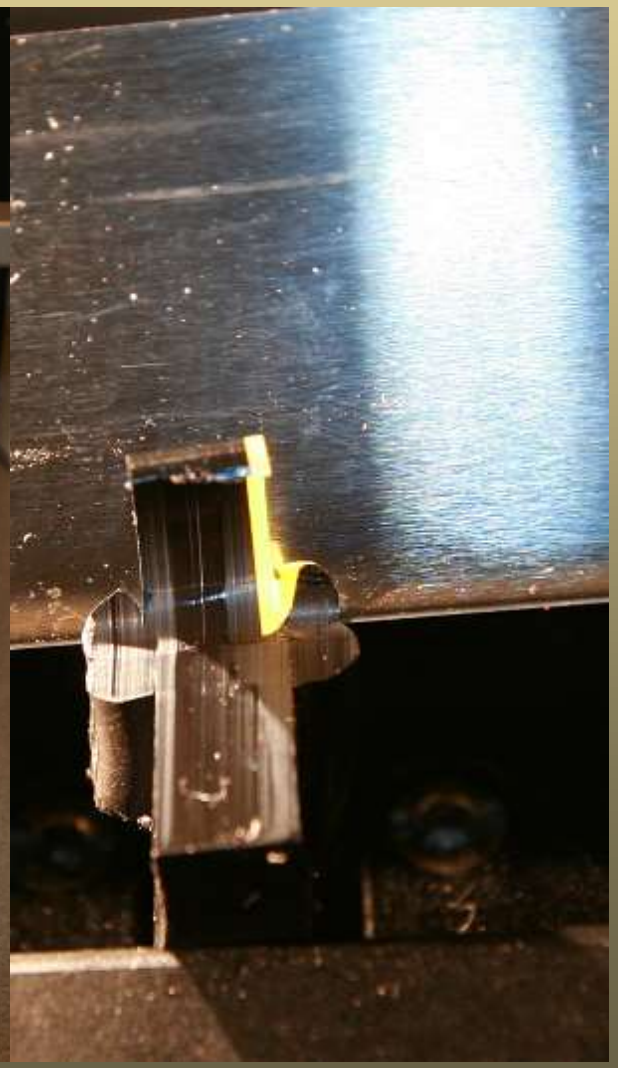
- Removing a square, rectangular or circular sample.
- Determine soundness or for additional testing.

Liquid Nitrogen –

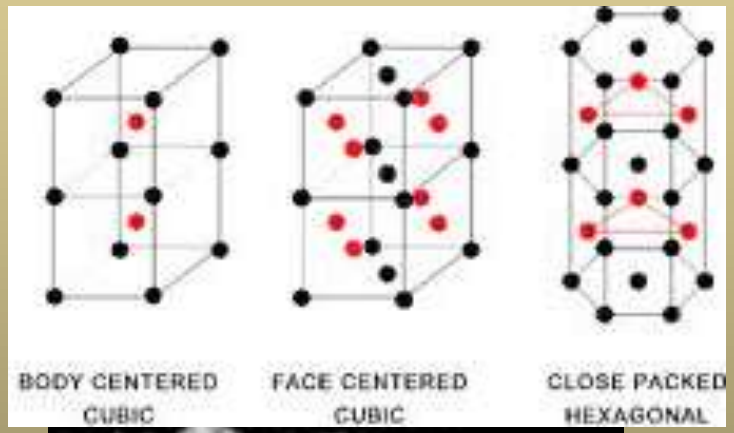
- Freeze and open a discontinuity or defect.
- Useful for cracks or to expose a fracture surface.

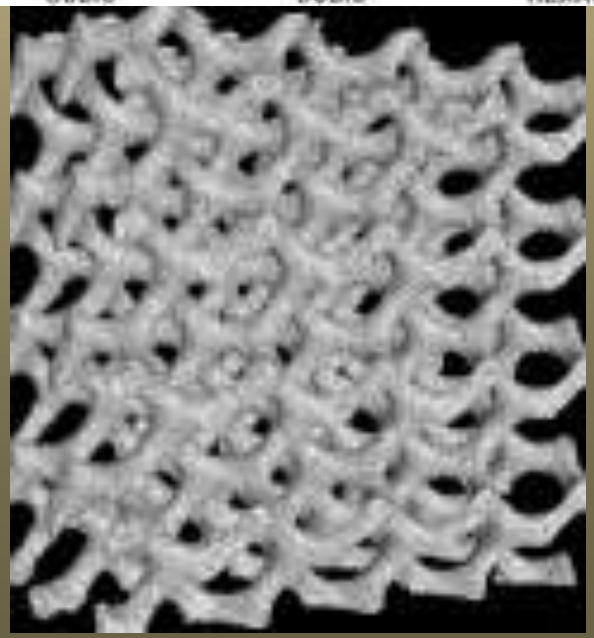
Failure Analysis as a Part of System Integrity

- **Microtomography** – instrument that cuts thin slices of a sample from 1-60 μm (.001 - .060 mm)

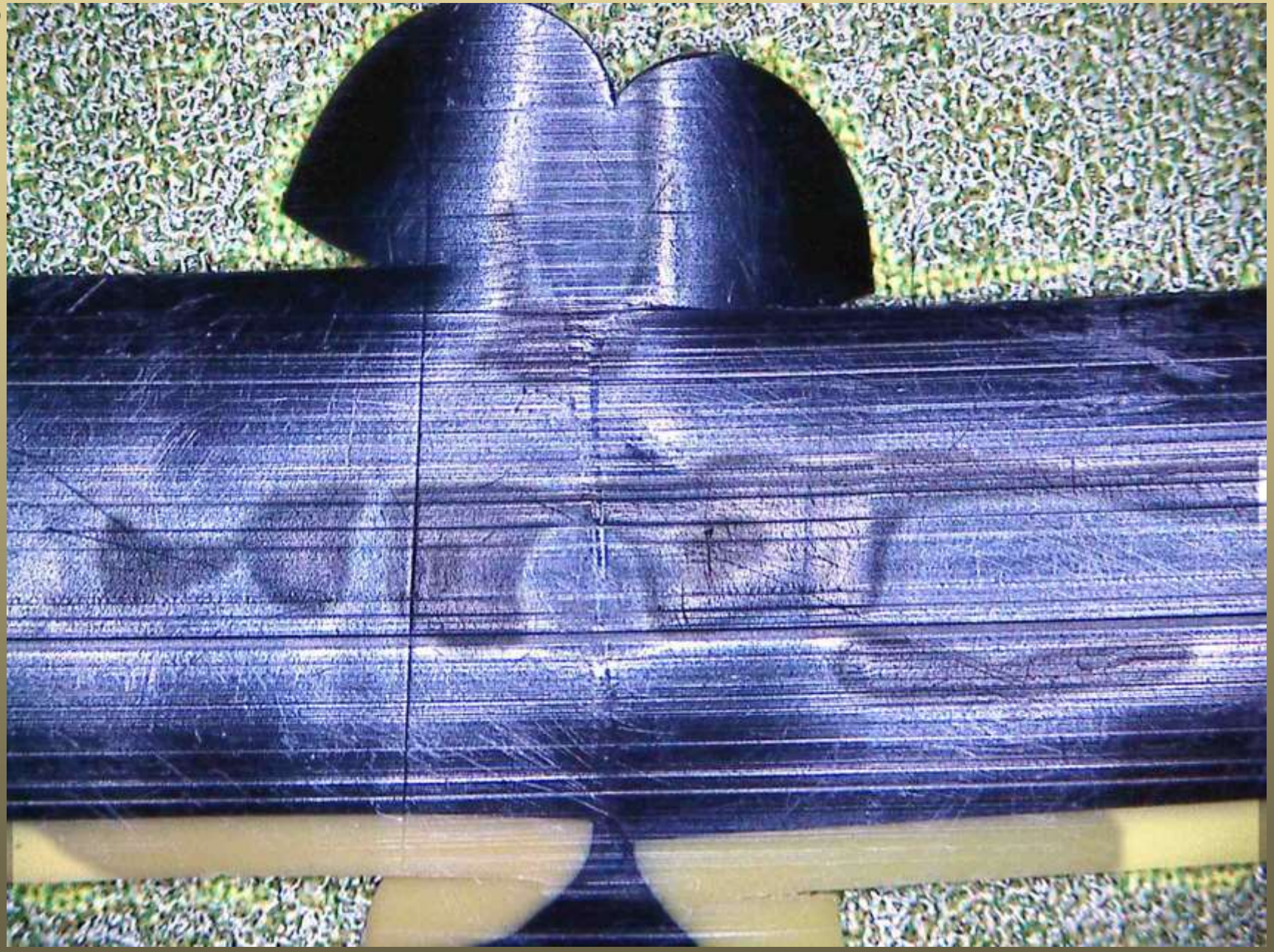


Steel - Symmetric Crystal Lattices





Plastic – Asymmetric Viscoelastic Structure

Birefringent

Failure Analysis as a Part of System Integrity