Applications of Computed Tomography to Evaluate Cellular Solid Interfaces

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Purpose

- Microfocus X-ray Computed Tomography (micro-CT) was utilized to investigate the interfacial cellular morphology between two closed cell rigid foams integral to the thermal protection system on The United States Space Shuttle's External Tank

- Investigate feasibility of micro-CT as a means to measure:
  - Cellular morphology
  - Void content
  - Volume of adhesive bond between polyurethane an polyisocyanurate

- Design strength models based on reliable morphological measurements made using micro-CT

Thermal Protection System Failures on the External Tank

- Popcorning of polyisocyanurate
- Polyisocyanurate failures near/at polyurethane bondlines

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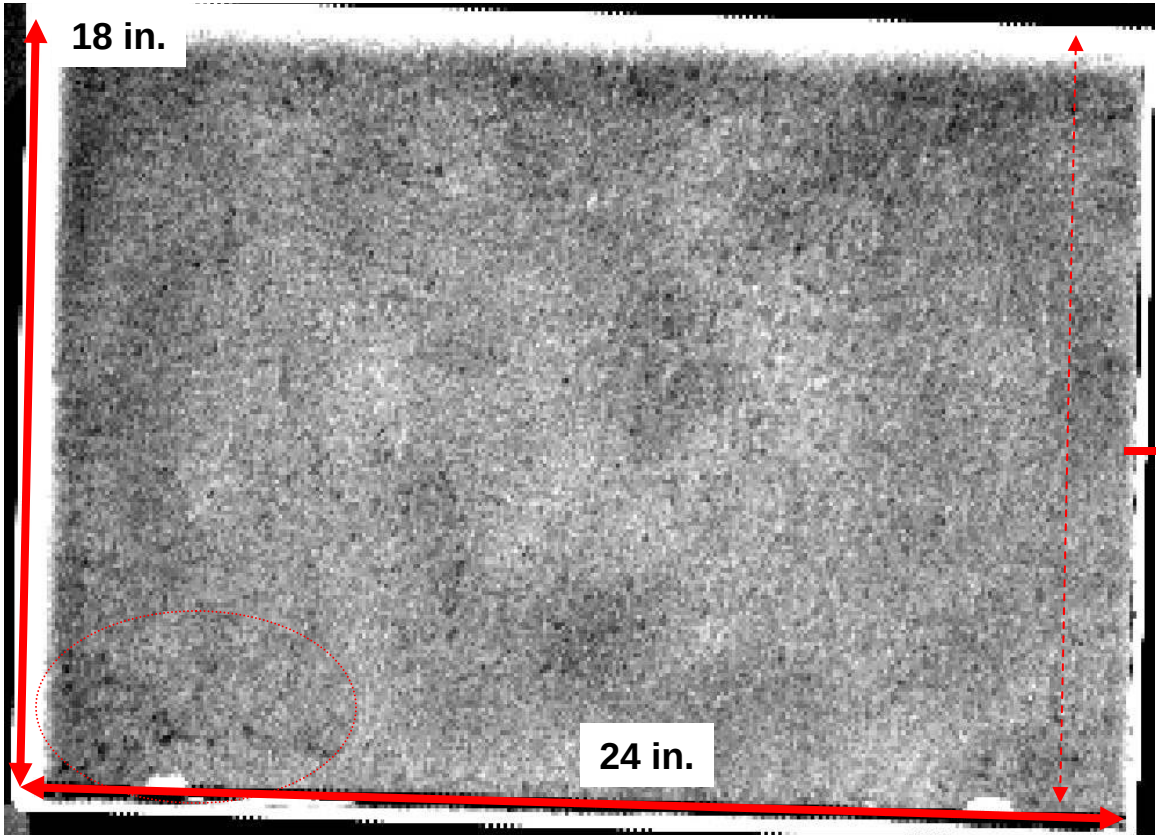
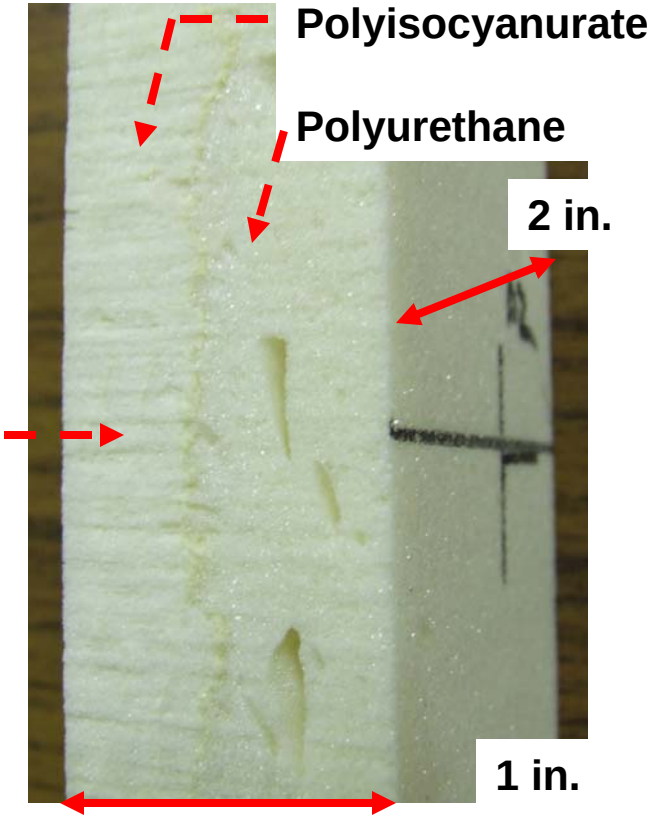
Nondestructive Testing of as Received Sample Blanks

- Initial panel size: 24 in. x 18 in.
- Selected regions machined into 2 in. wide strips





Backscatter Image of 24 in. x 18 in. panel
55kV, 20mA, 2 mm Aperture, Pixel Size = 2mm x 2mm
Exposure Time = 0.2 s/pixel, Focal Spot: 5.5 mm

Side View

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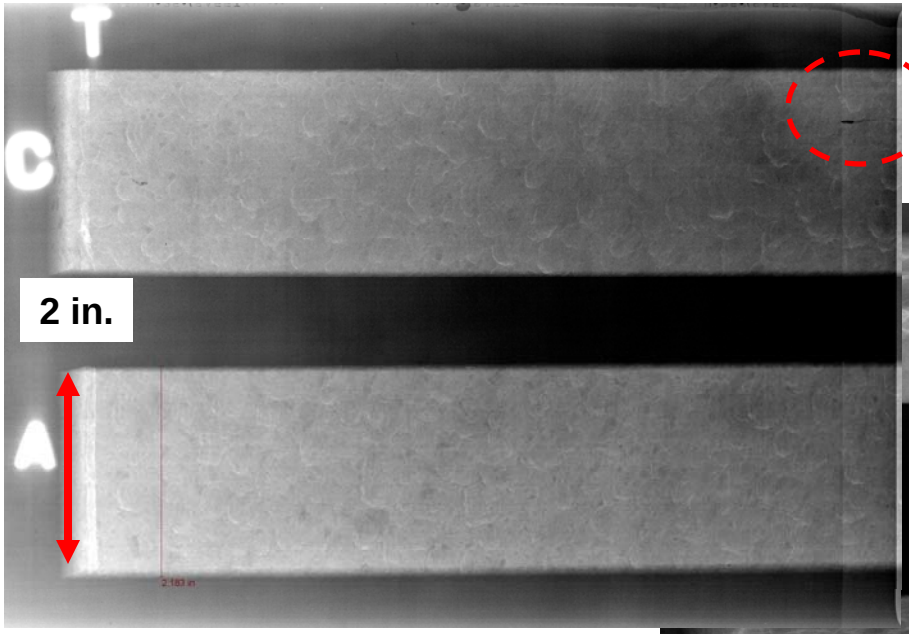
Radiography of Sample Blanks after NDE Prescreening

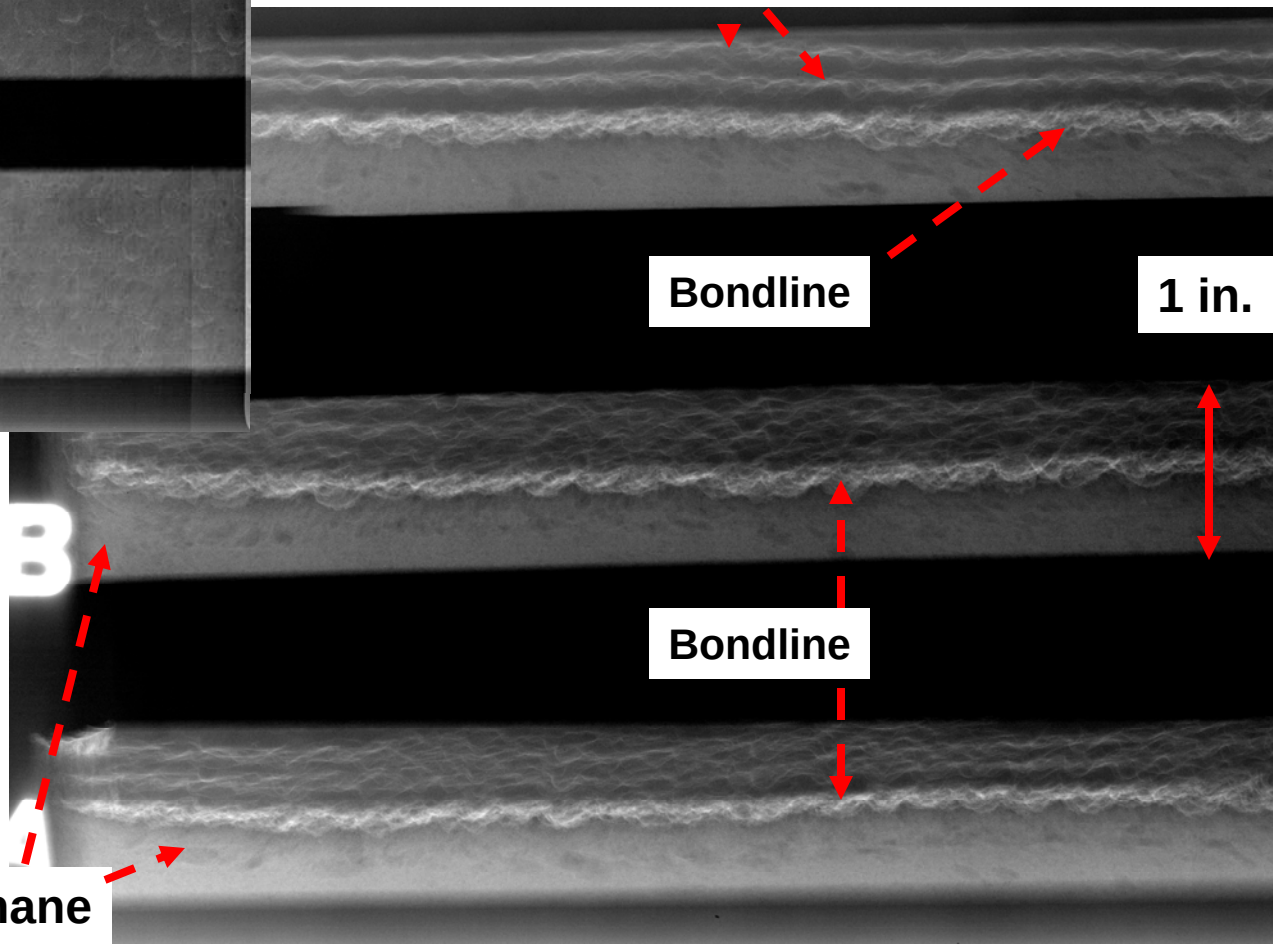


Top View

Void

Polyisocyanurate Knitlines

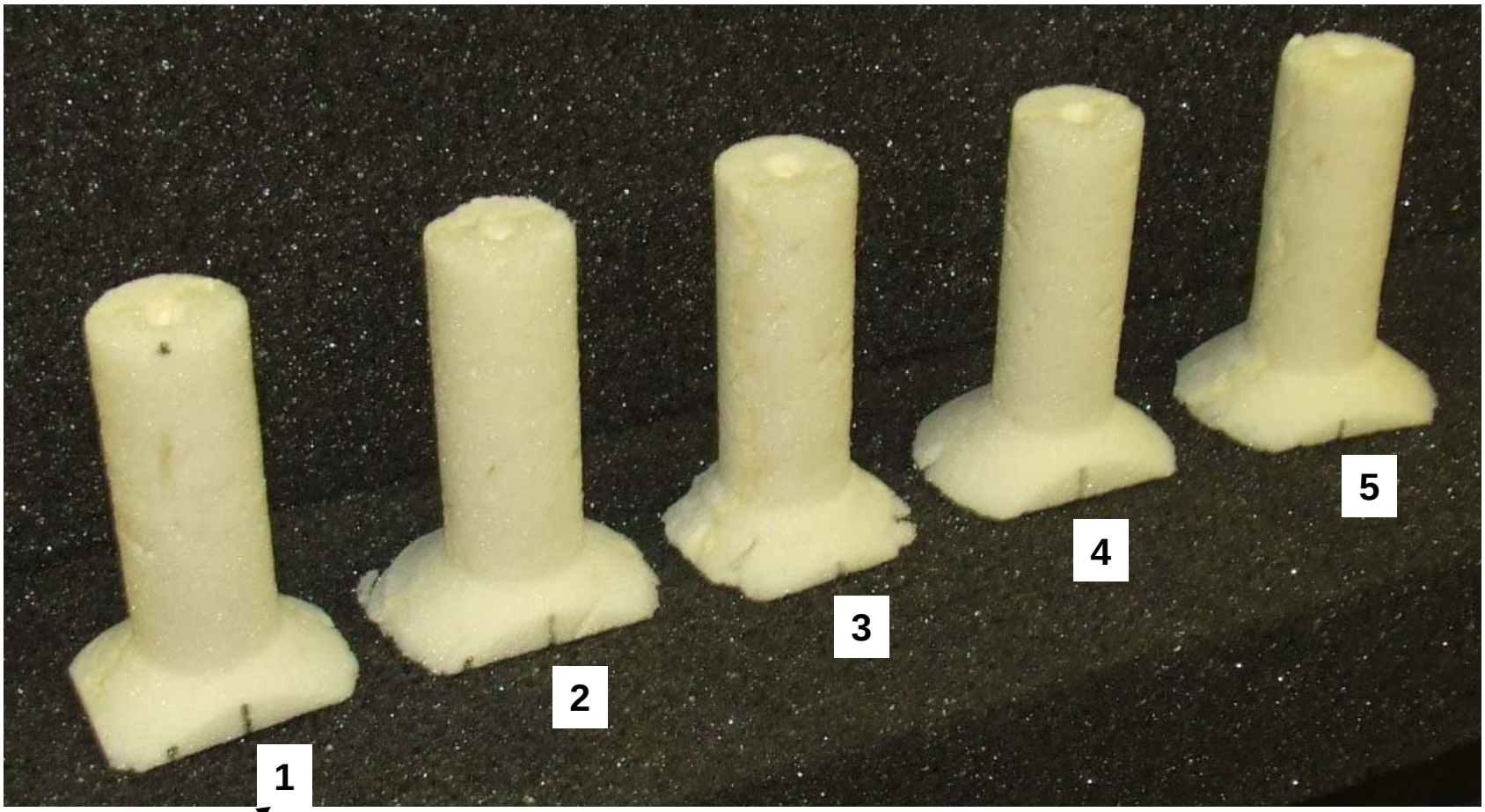
Side View



Polyurethane

160kV Philips Tube
Fuji 25 film
55 kV
6.5 mA
60 in. SFD
2.7 mins.
2.8 - 3.17 OD

Micro-CT Samples for Final NDE Prescreening



Sample ID

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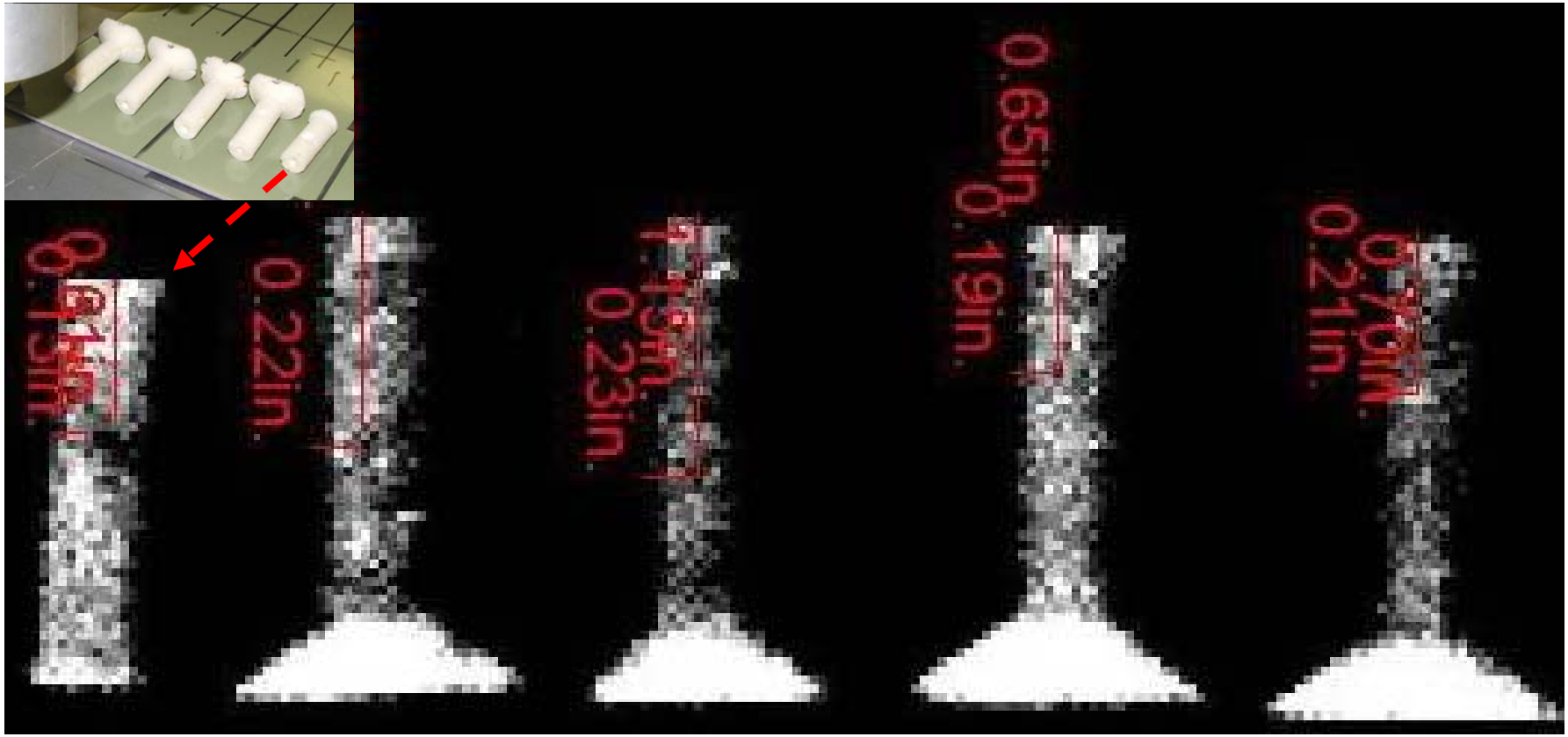
Backscatter Radiographic Image of Micro-CT Samples



- Location of selected indication was mapped for each sample prior to final machining
- Backscatter image processed using X-Ray GUI Software
- 55 kV, 20 mA, Aperture: 1 mm, Pixel Size: 1 mm x 1 mm, Focal Spot: 5.5 mm, Exposure Time: 0.2 s/pixel

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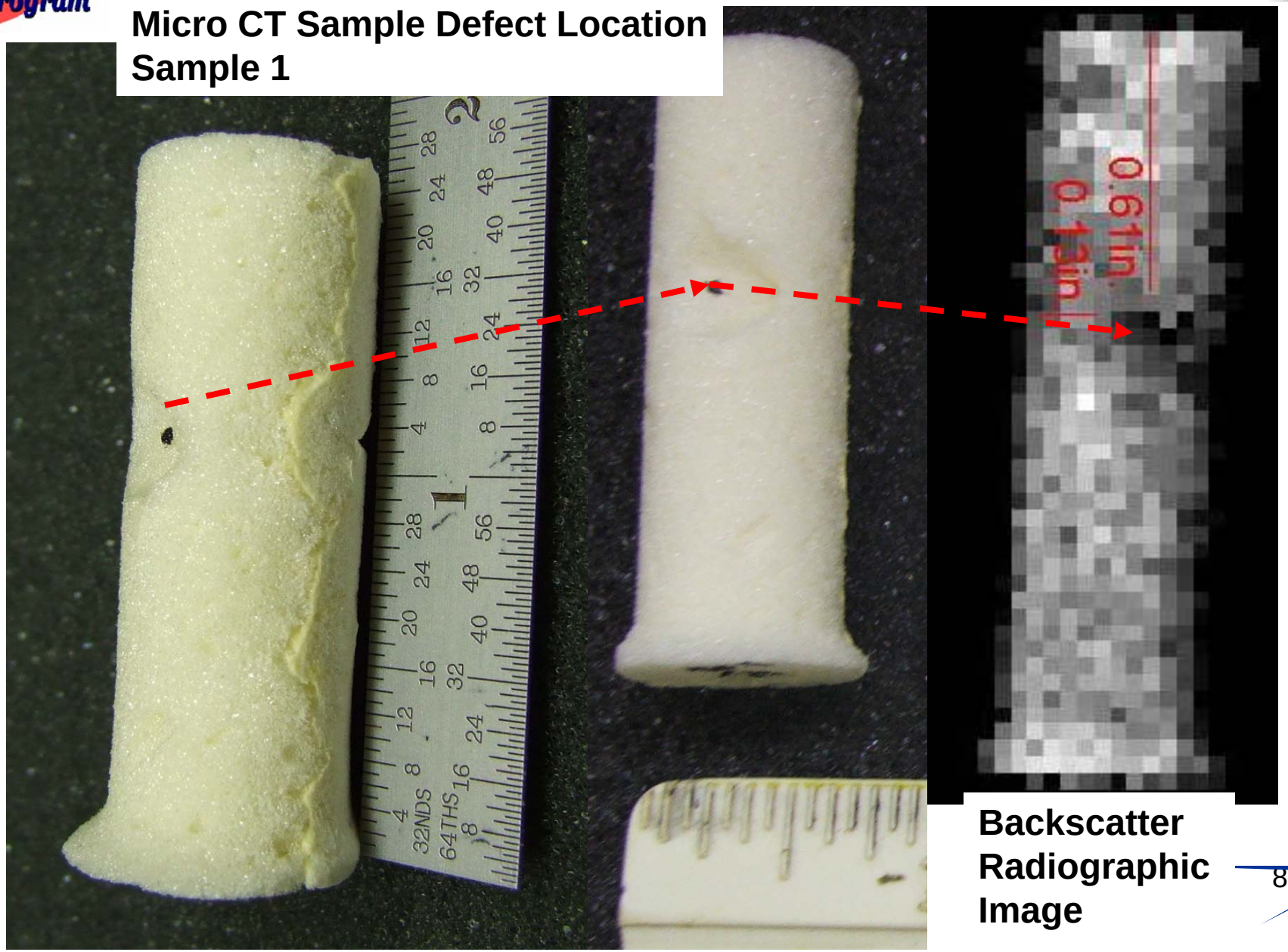
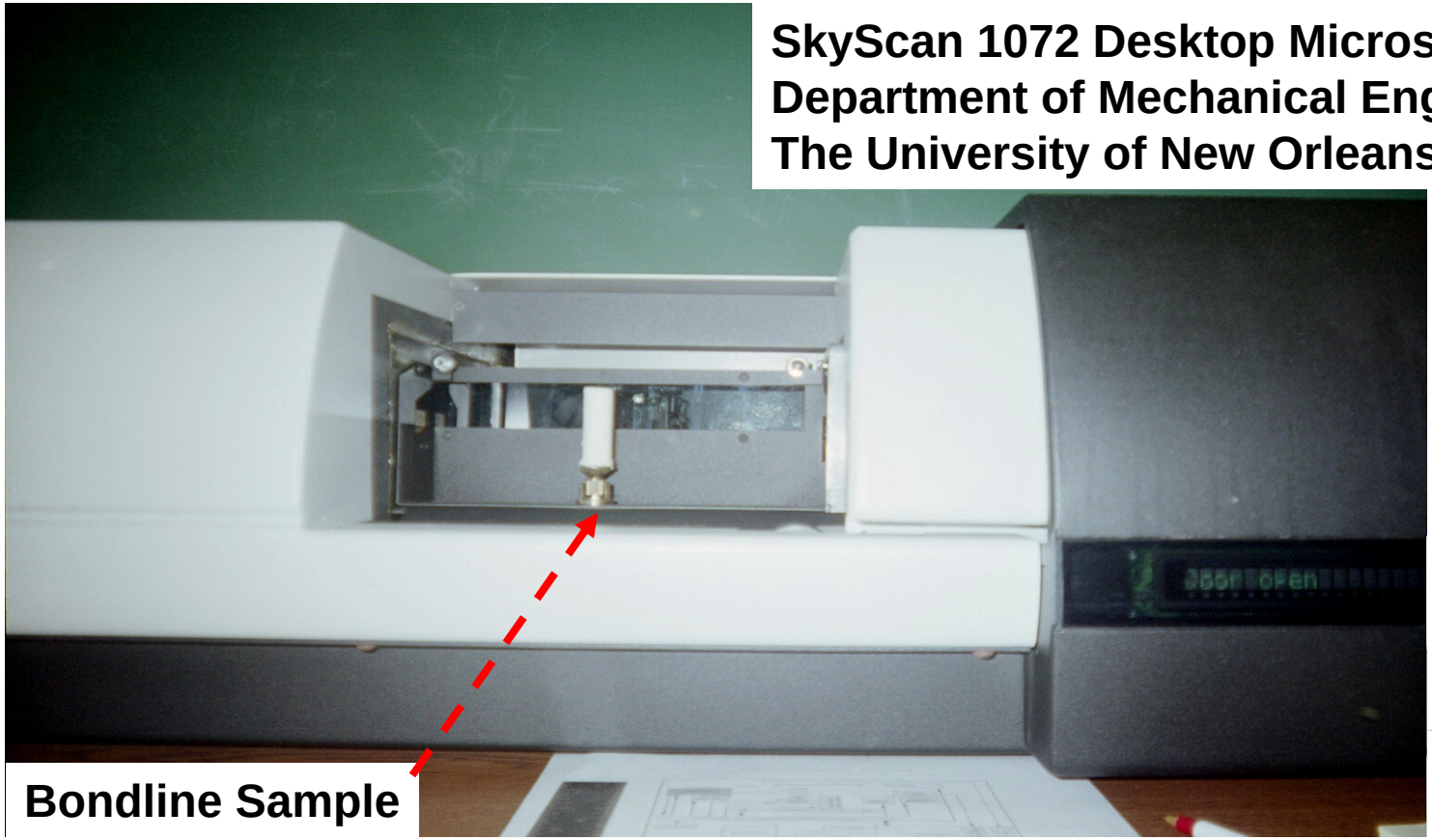
Micro CT Sample Defect Location Sample 1



Backscatter Radiographic Image

Micro-CT Test Parameters

- **100kV**
- **98 μA**
- **Mag = 14.4 x**
- **Pixel Size: 19.5 mm x 19.5 mm**



SkyScan 1072 Desktop Microscanner
Department of Mechanical Engineering
The University of New Orleans

Bondline Sample

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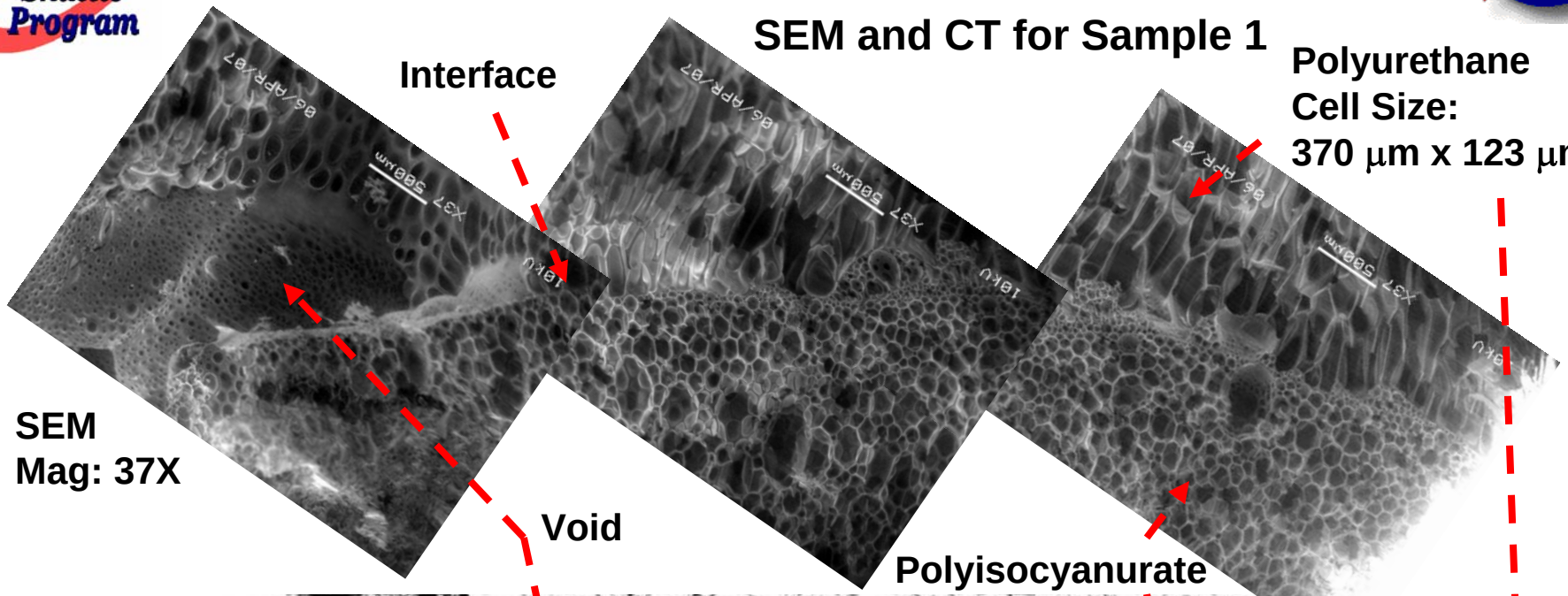
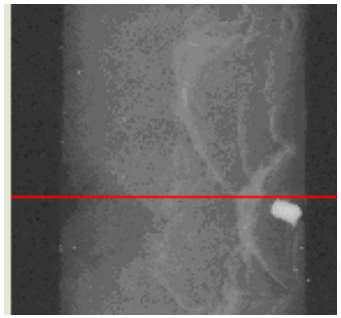
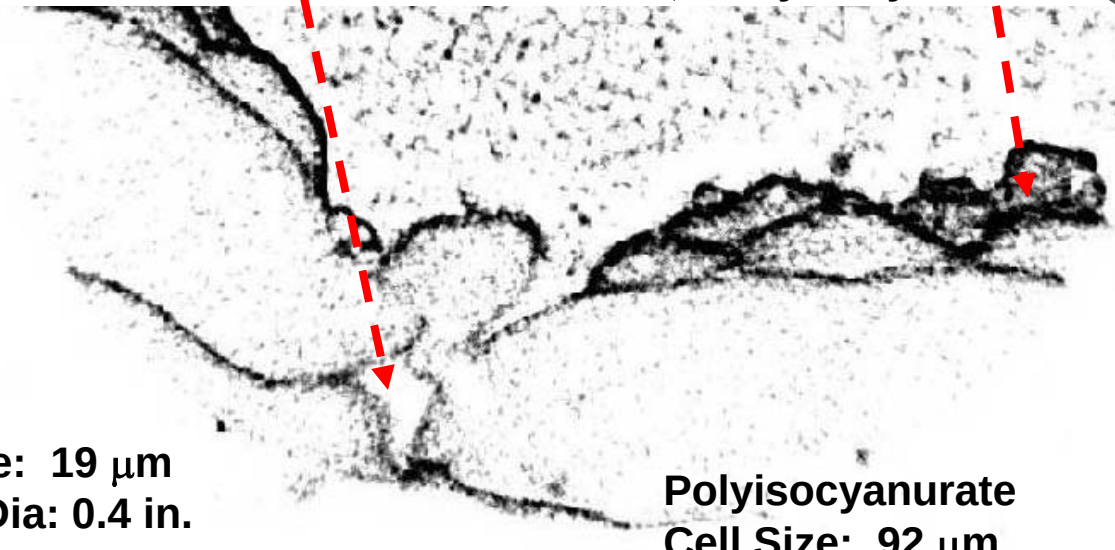
SEM and CT for Sample 1







CT
Pixel Size: 19 μm
Sample Dia: 0.4 in.

Polyisocyanurate
Cell Size: 92 μm

Void	Width (μm)	Length (μm)
A1	321	513
A2	282	667

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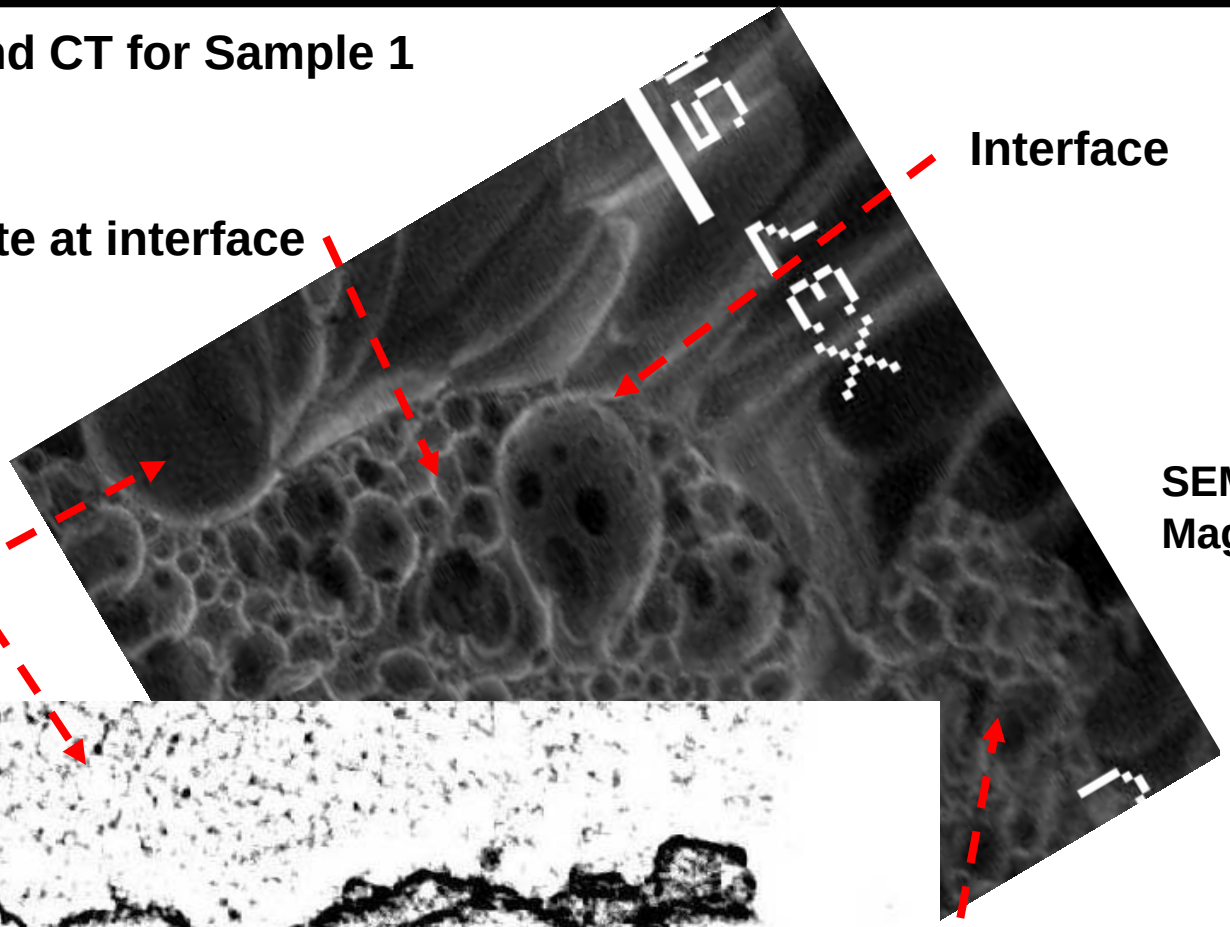
SEM and CT for Sample 1

Fine cells of
polyisocyanurate at interface

Interface



SEM
Mag: 37X

Polyurethane

Polyisocyanurate

CT
Pixel Size: 19 μm
Sample Dia: 0.4 in.

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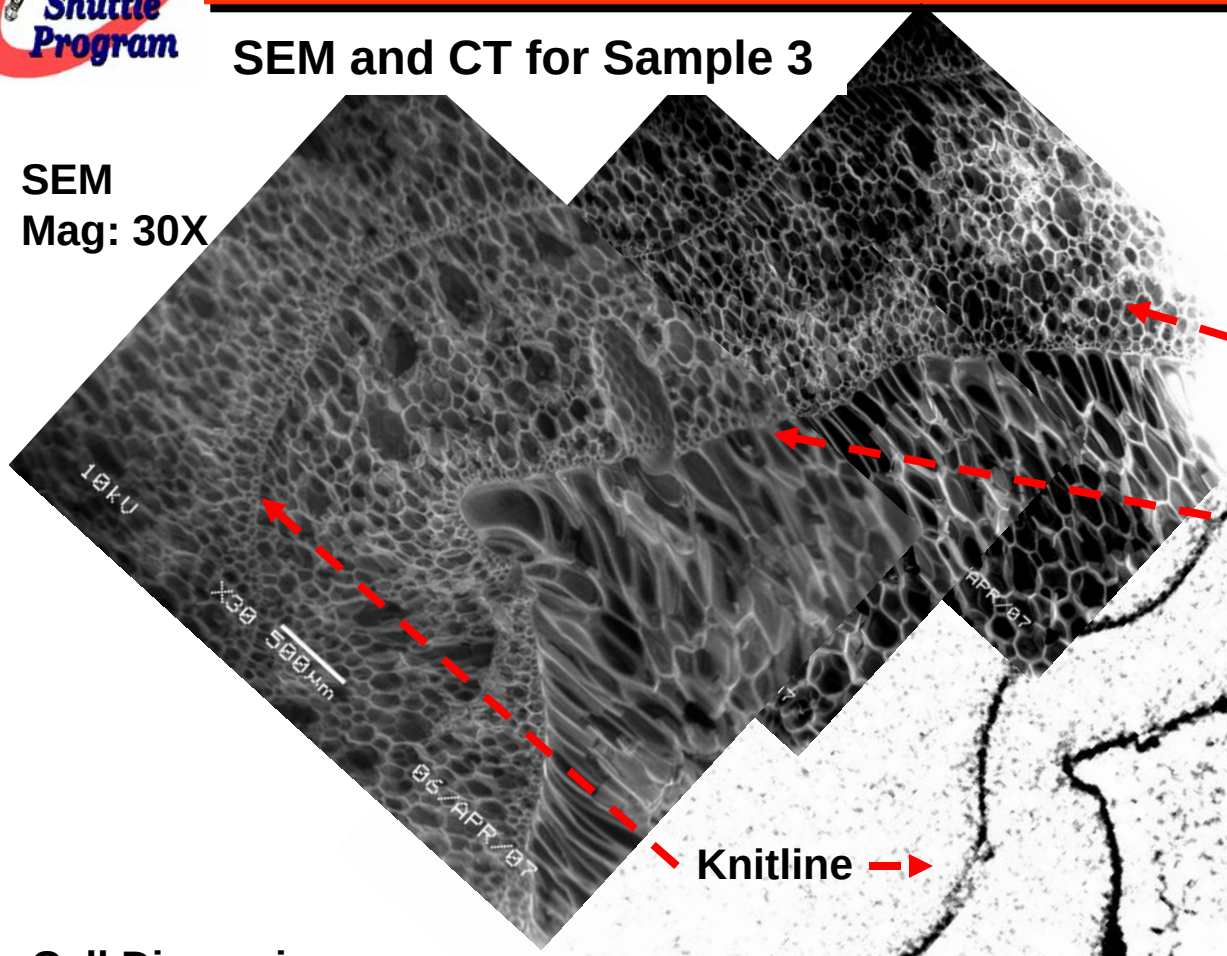
SEM and CT for Sample 3

SEM
Mag: 30X

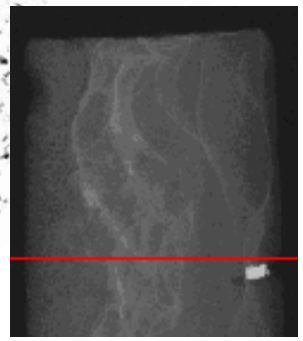


Polyisocyanurate

Interface

Polyurethane

Knitline



CT
Pixel Size: 19 µm
Sample Dia: 0.4 in.

Void Dimensions

	Average (µm)	STDEV (µm)
Major Axis	841	355
Minor Axis	416	142

Cell Dimensions Adiacent to Knitline

	Major Axis		Minor Axis	
	Average (µm)	STDEV (µm)	Average (µm)	STDEV (µm)
Polyurethane	595	202	133	15
Polyisocyanurate	122	21		

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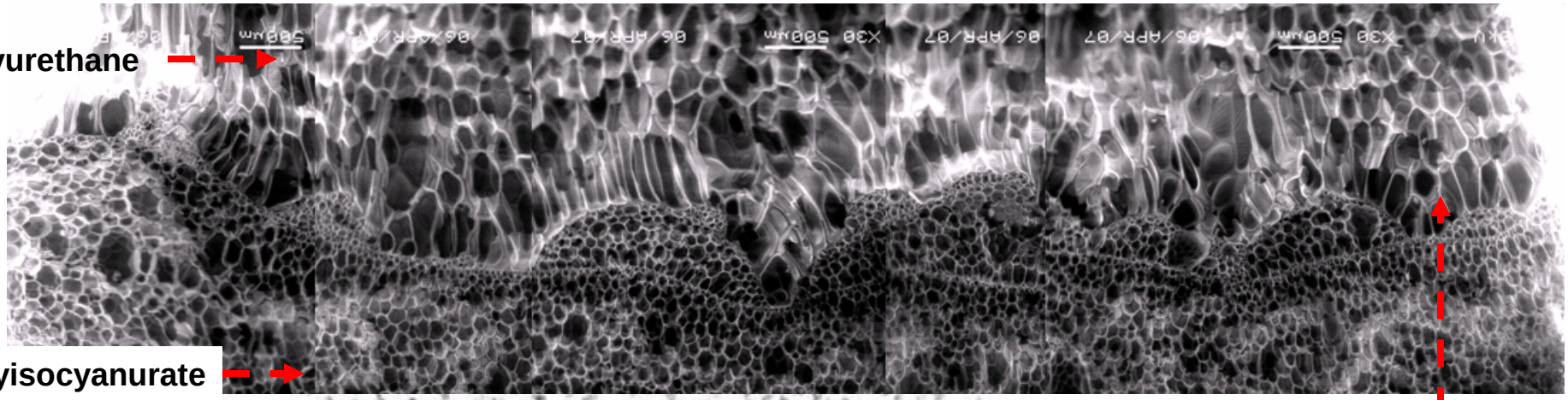
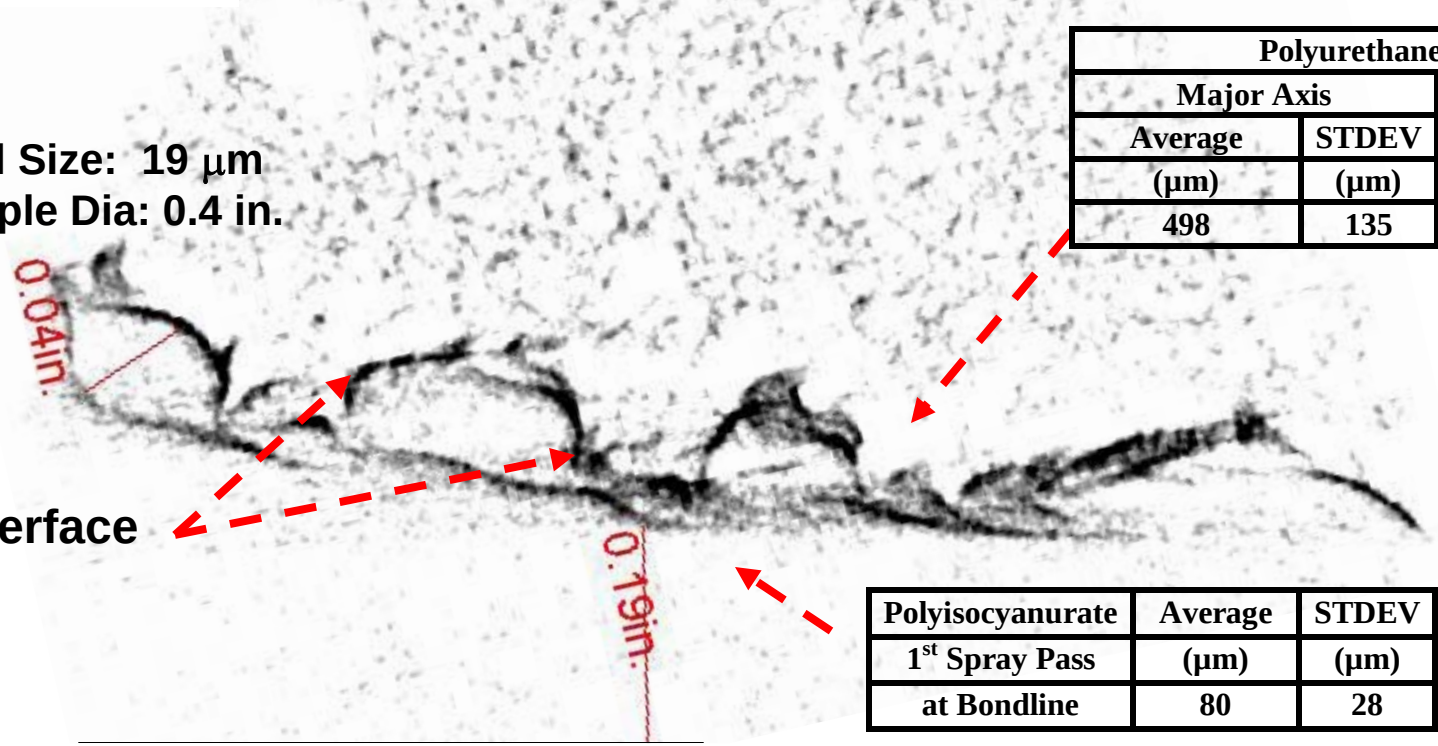
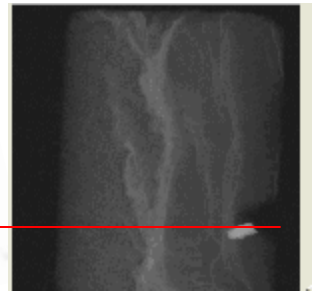
SEM and CT for Sample 5



CT
Pixel Size: 19 μm
Sample Dia: 0.4 in.



Polyurethane at Bondline			
Major Axis		Minor Axis	
Average (μm)	STDEV (μm)	Average (μm)	STDEV (μm)
498	135	148	11



Polyisocyanurate 1st Spray Pass at Bondline	Average (μm)	STDEV (μm)
	80	28

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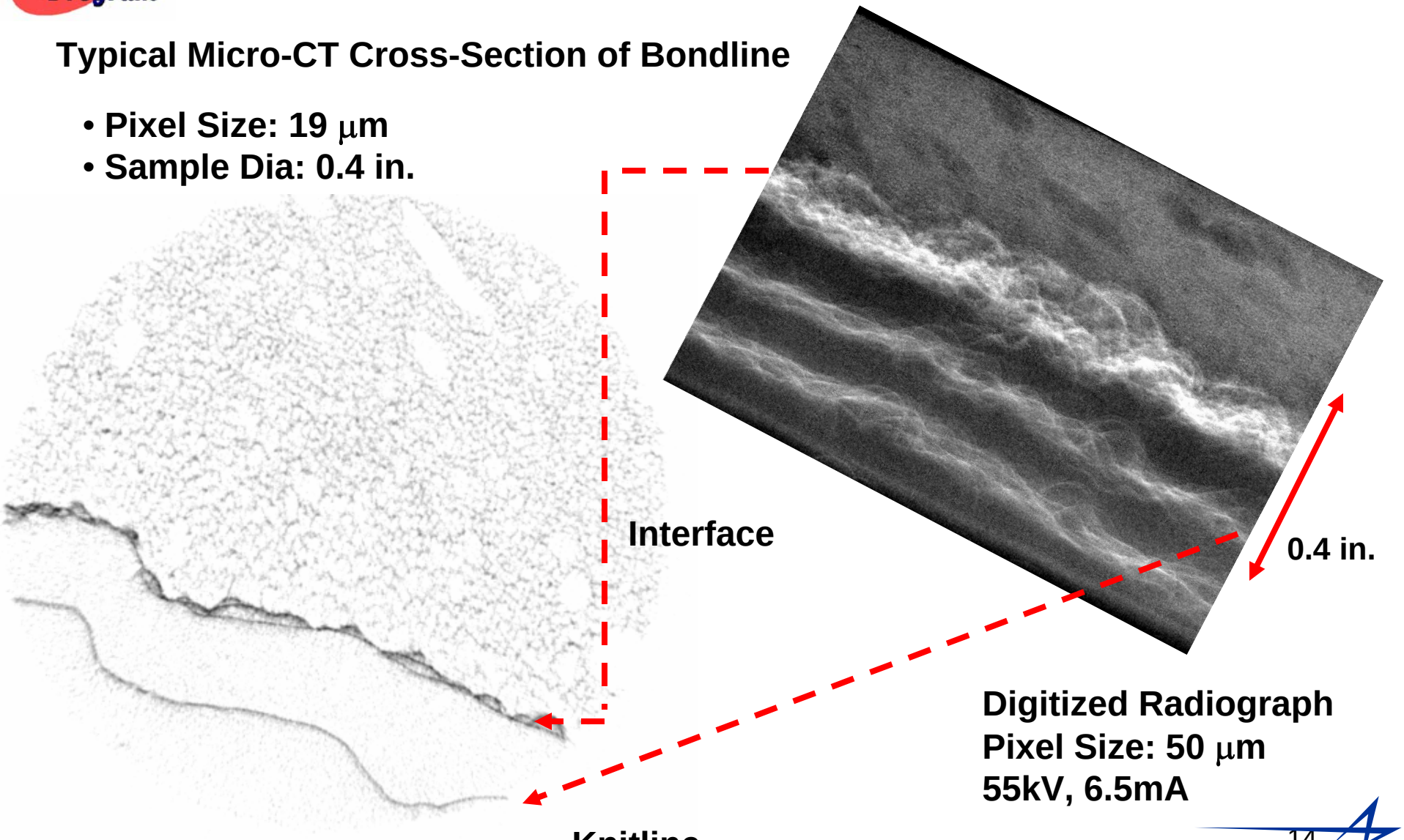
Typical Micro-CT Cross-Section of Bondline

- Pixel Size: 19 μm
- Sample Dia: 0.4 in.



Successive Micro-CT Cross-Sections

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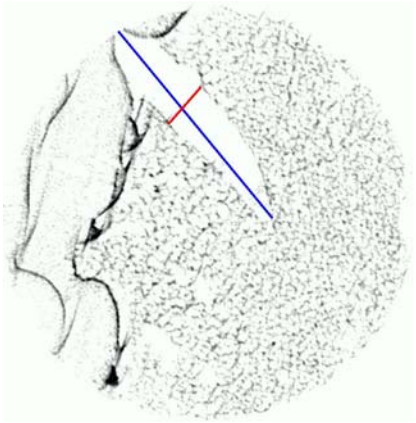
Micro-CT Cross-Section of the Largest Void Identified in Four Samples

Sample ID	Void Length (mm)	Void Length (in.)
1	8.81	0.347
2	3.24	0.128
3	3.03	0.119
4	4.54	0.179

Sample ID	Void Width (mm)	Void Width (in.)
1	1.53	0.060
2	1.56	0.061
3	1.35	0.053
4	1.60	0.062

Sample ID	Void Volume (mm^2)	Void Length ($in.^2$)
1	34.4	0.053
2	21.1	0.033
3	4.2	0.007
4	8.4	0.013

Sample 1

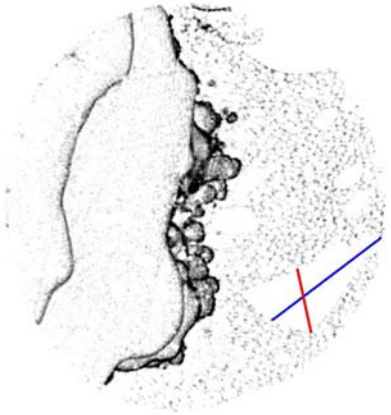


Lengths:
8.81 mm
1.53 mm

256 slices thick
(4.88 mm)

Ellipsoidal
Volume:
34.4 mm^3

Sample 2

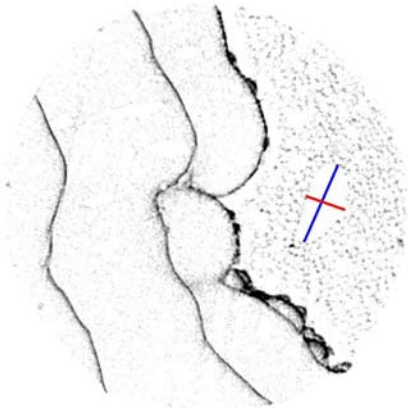


Lengths:
3.24 mm
1.56 mm

420 slices thick
(8.01 mm)

Ellipsoidal
Volume:
21.1 mm^3

Sample 3

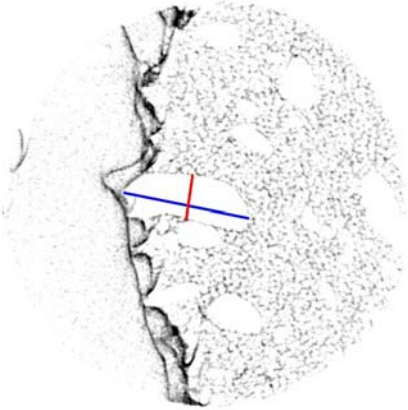


Lengths:
3.03 mm
1.35 mm

104 slices thick
(1.98 mm)

Ellipsoidal
Volume:
4.2 mm^3

Sample 4

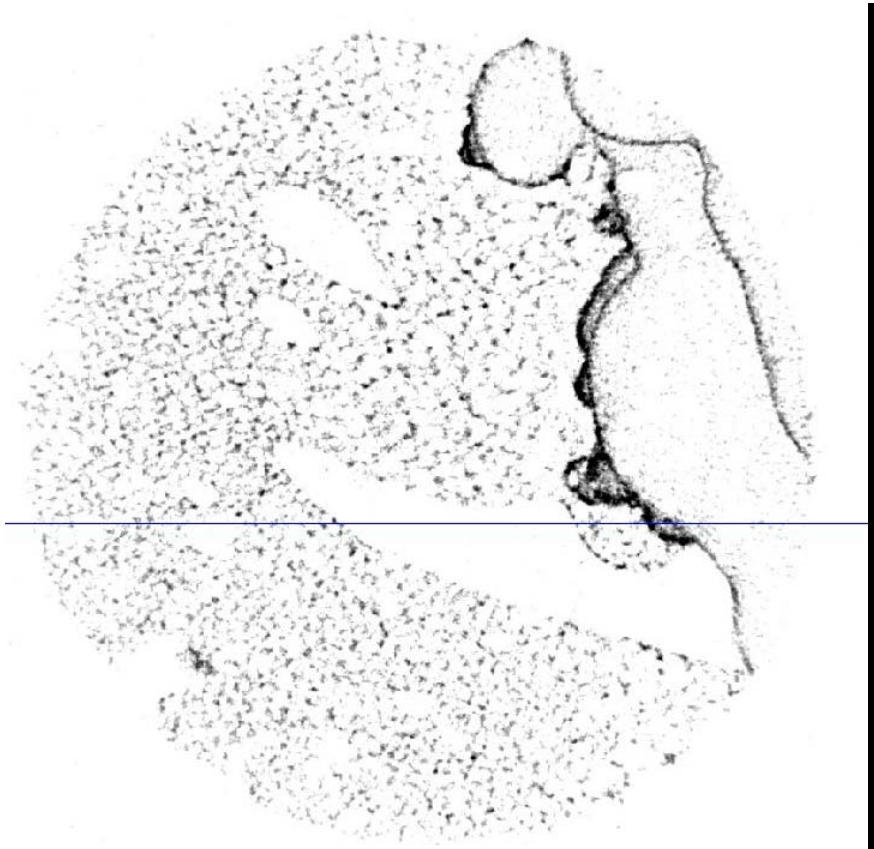


Lengths:
4.54 mm
1.60 mm

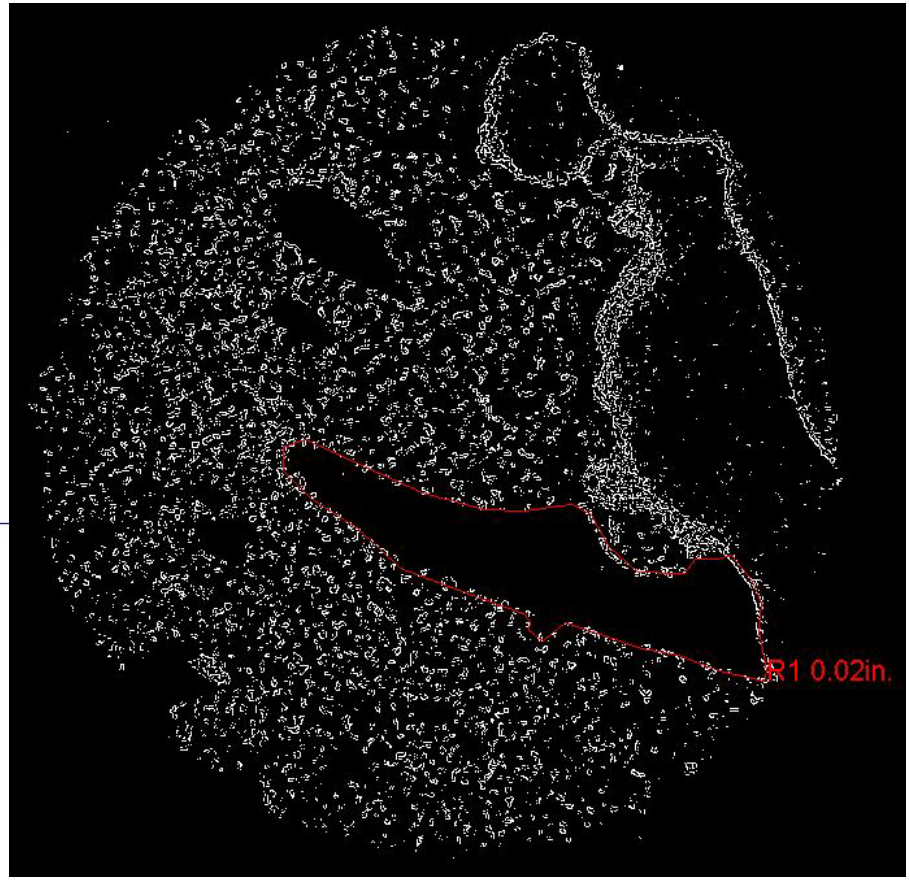
116 slices thick
(2.21 mm)

Ellipsoidal
Volume:
8.4 mm^3

2D Visualization of Micro CT Image Enhanced with X-Ray GUI



CT Bit Map



Robert's Edge Detection
with Measured Void
Area = 0.02 in.

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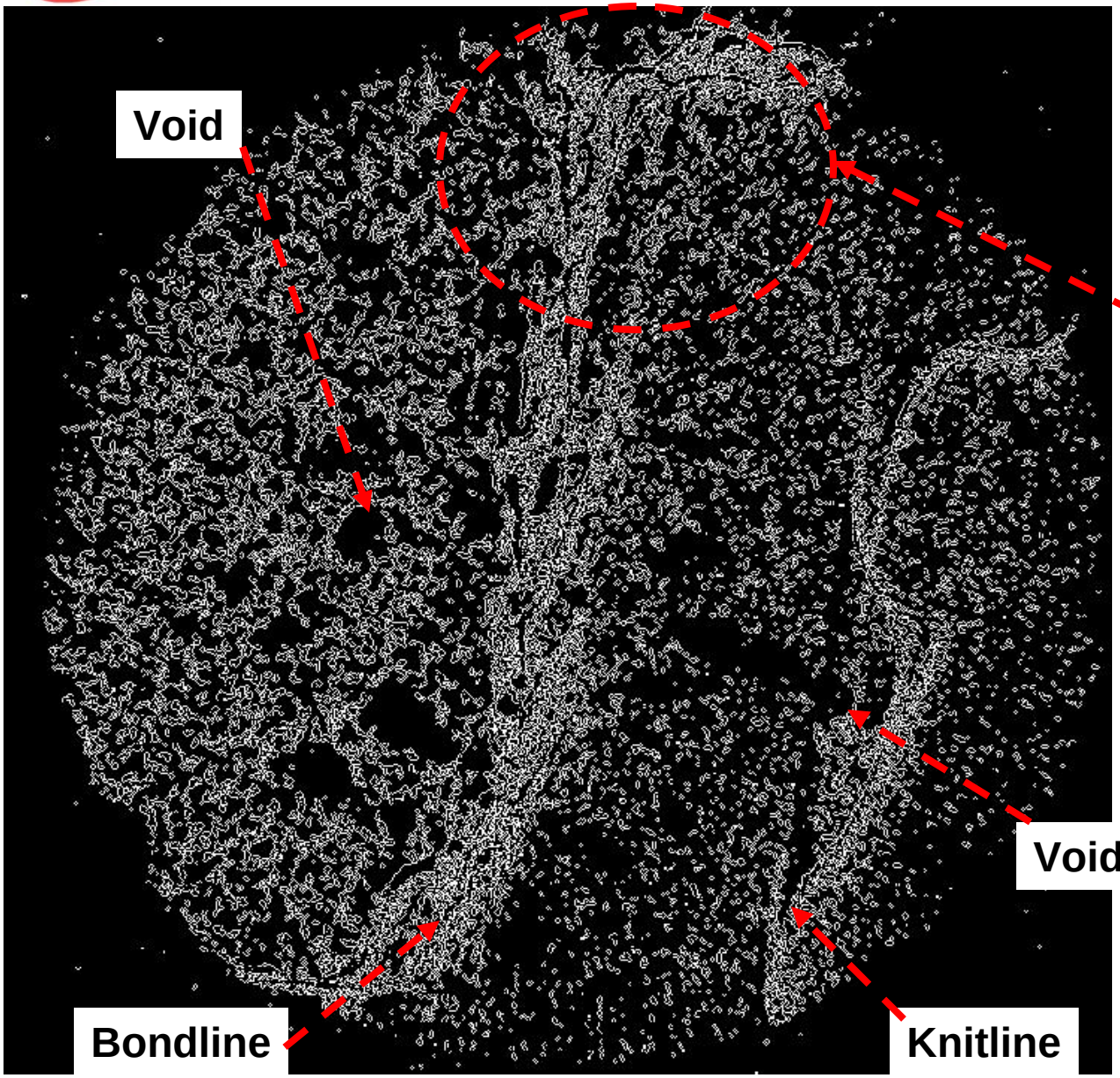
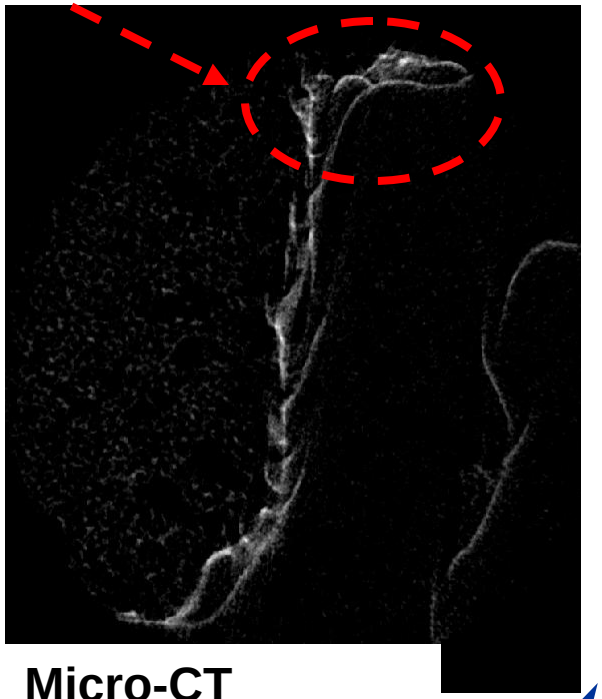


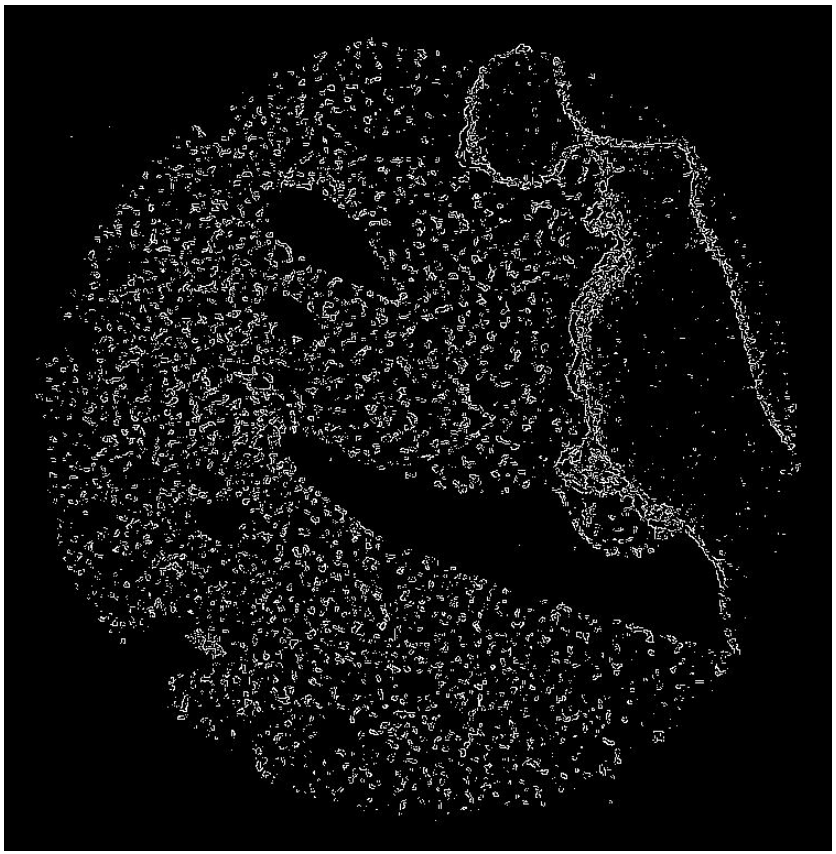
LaPlacian Edge Filter

- **Bondline and voids**
- **X-Ray GUI filtered CT bitmap**
- **Pixel Size: 19 μm**

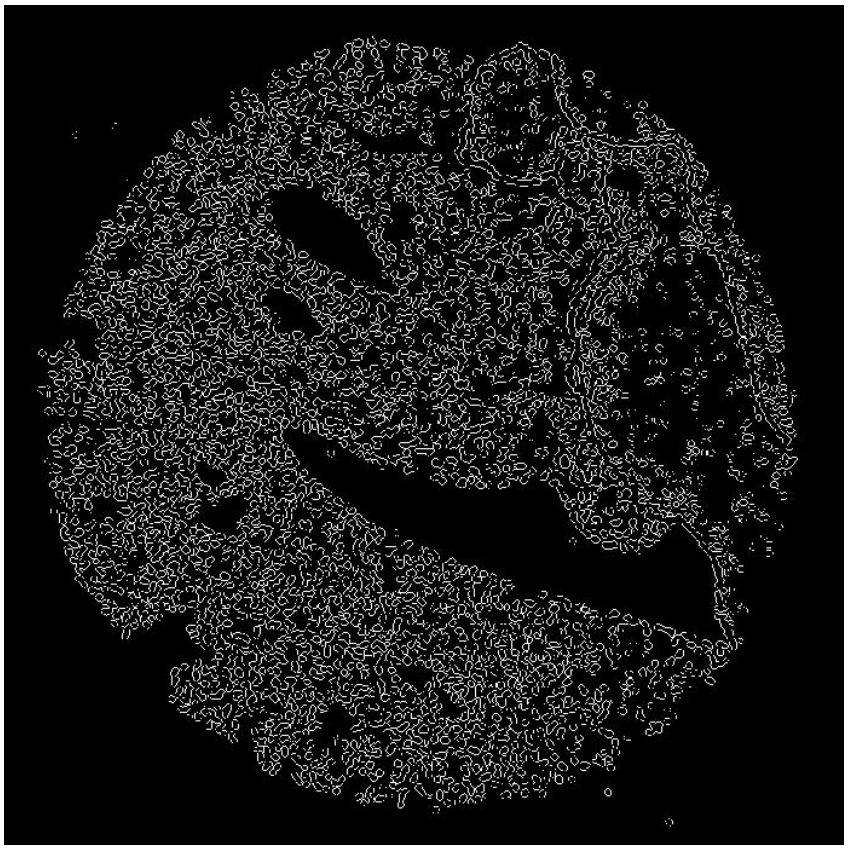


Micro-CT Image with Inverted Contrast

Edge Detection Technique Comparison for Micro CT Images

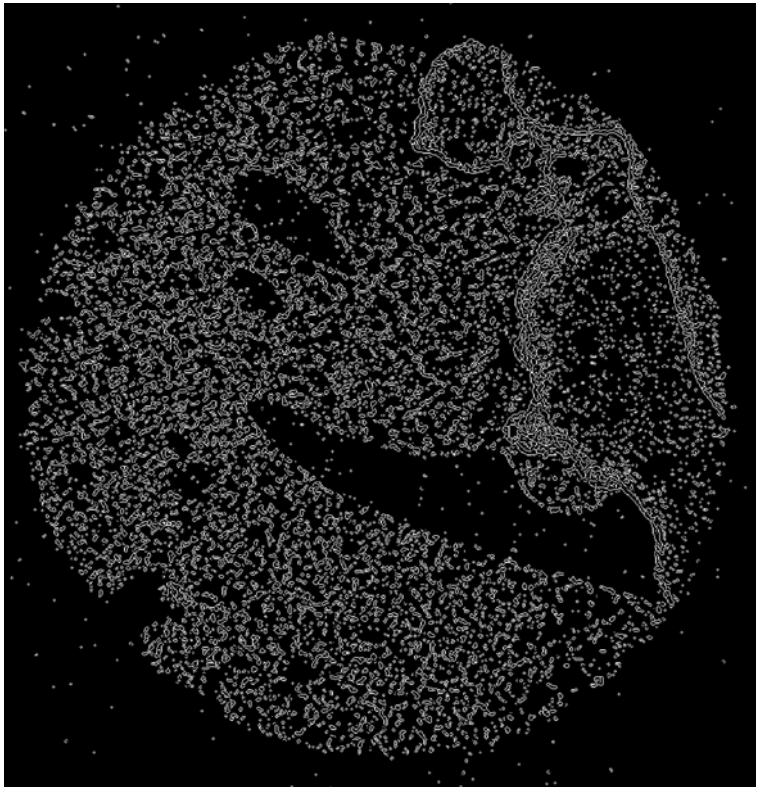


Robert's Edge Detection



LaPlacian Gaussian Edge Detection

Edge Detection Technique Comparison for Micro CT Images



Canney Edge Detection

Sobel/Prewitt Edge Detection

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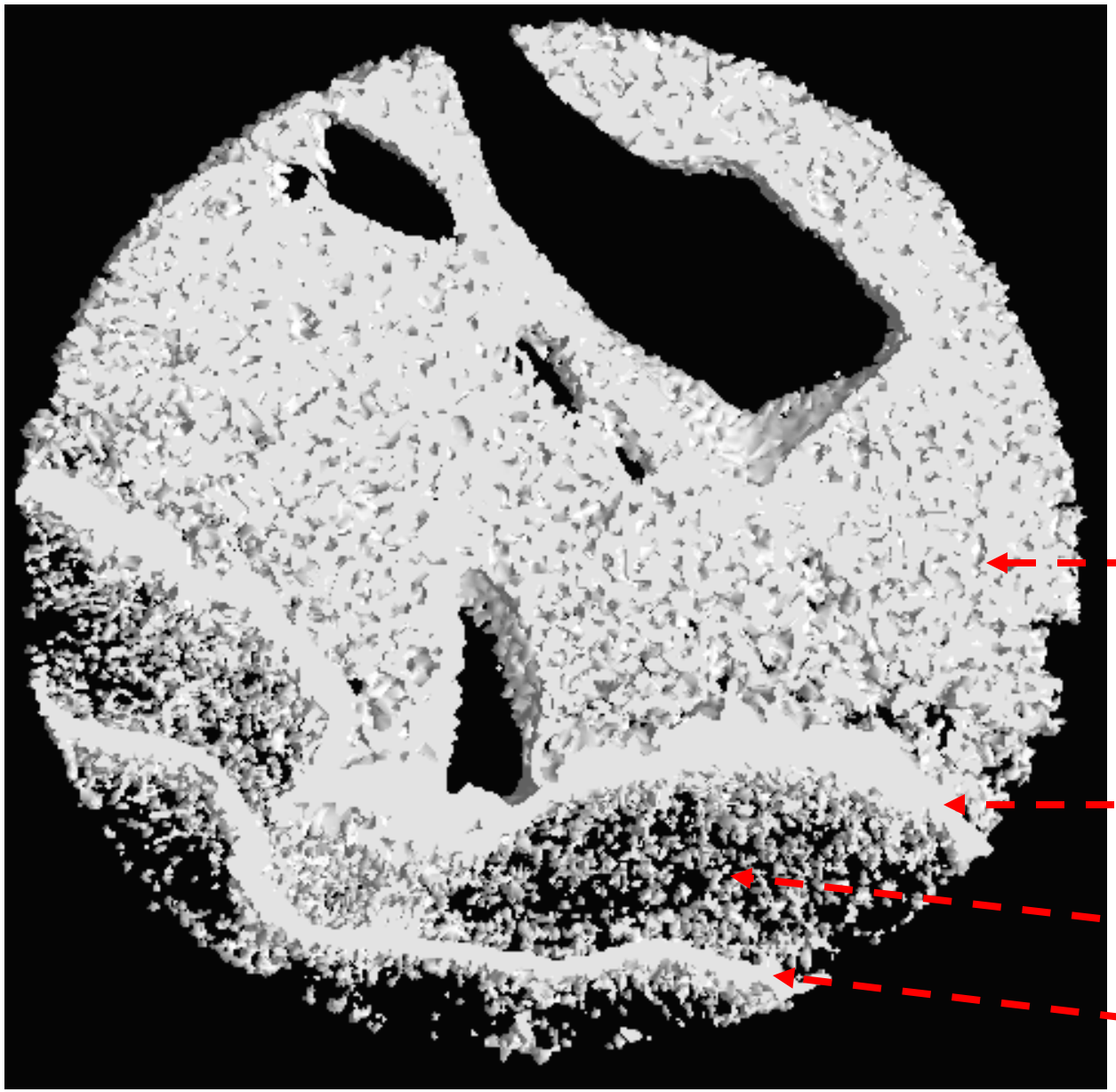

3D Visualization
with
Skyscan 3D Creator

Pixel Size: 19 μm

Polyurethane

Bondline

Polyisocyanurate

Knitline

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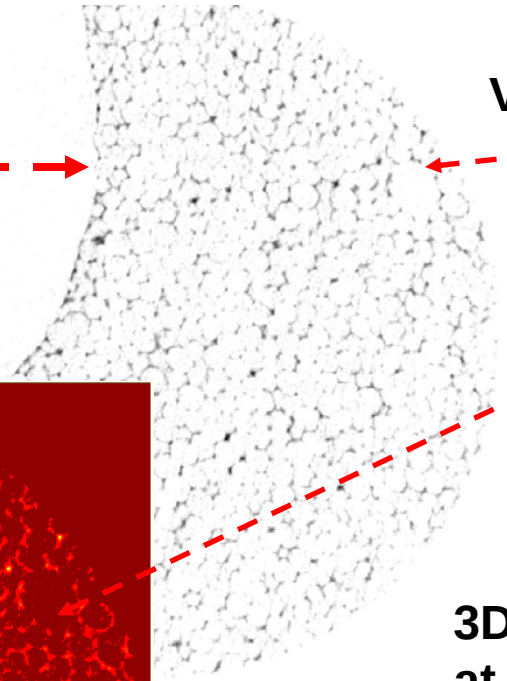
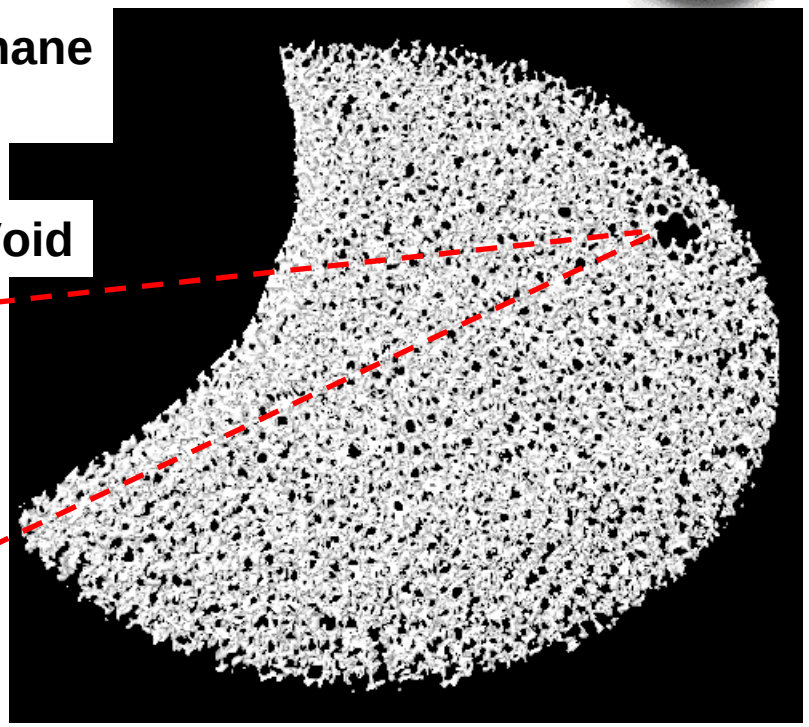
2D and 3D Visualization for Polyurethane CT Sample

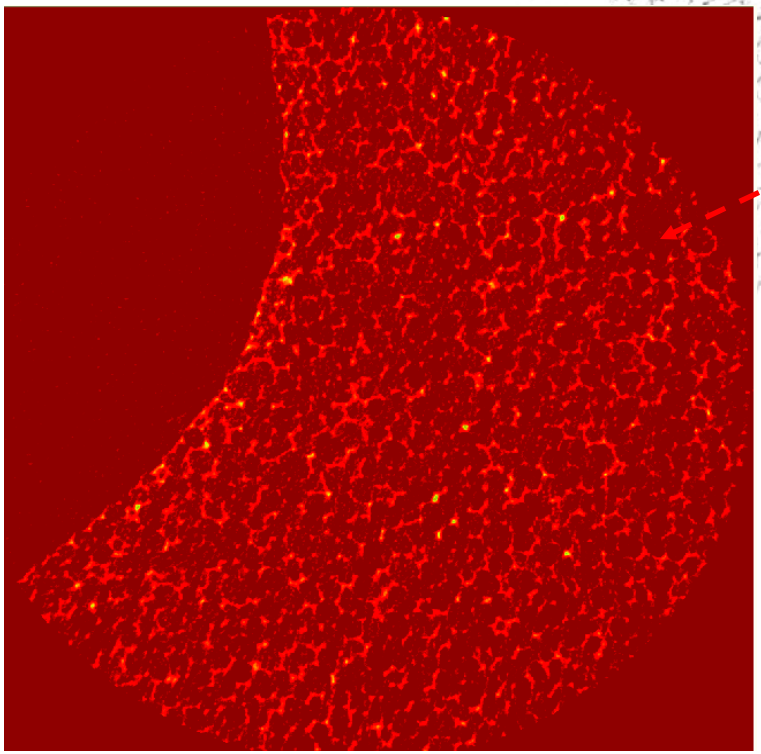
2D CT bitmap resolved using X-Ray GUI



Void

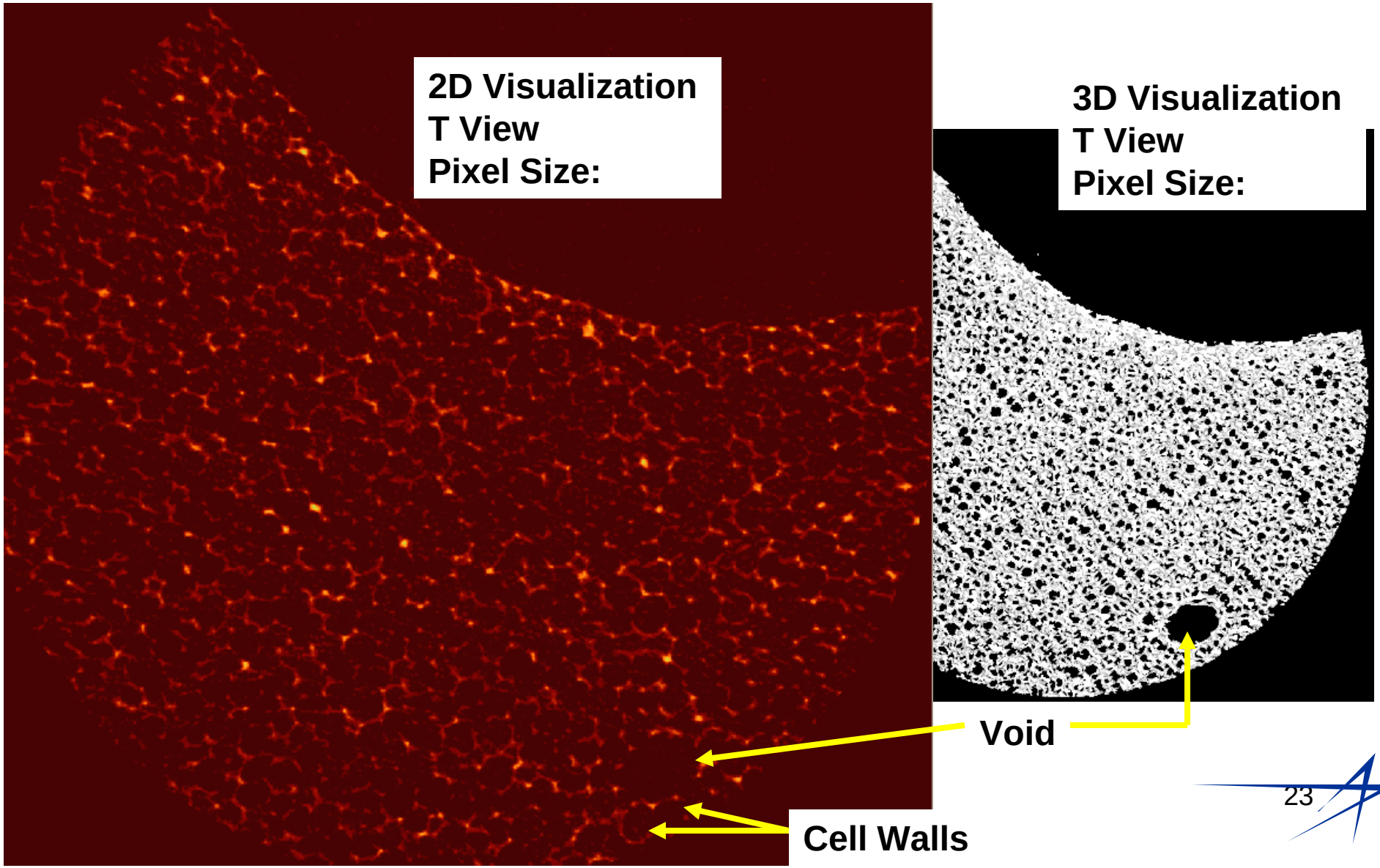


3D visualization of polyurethane at a void constructed with SKYScan 3D Creator

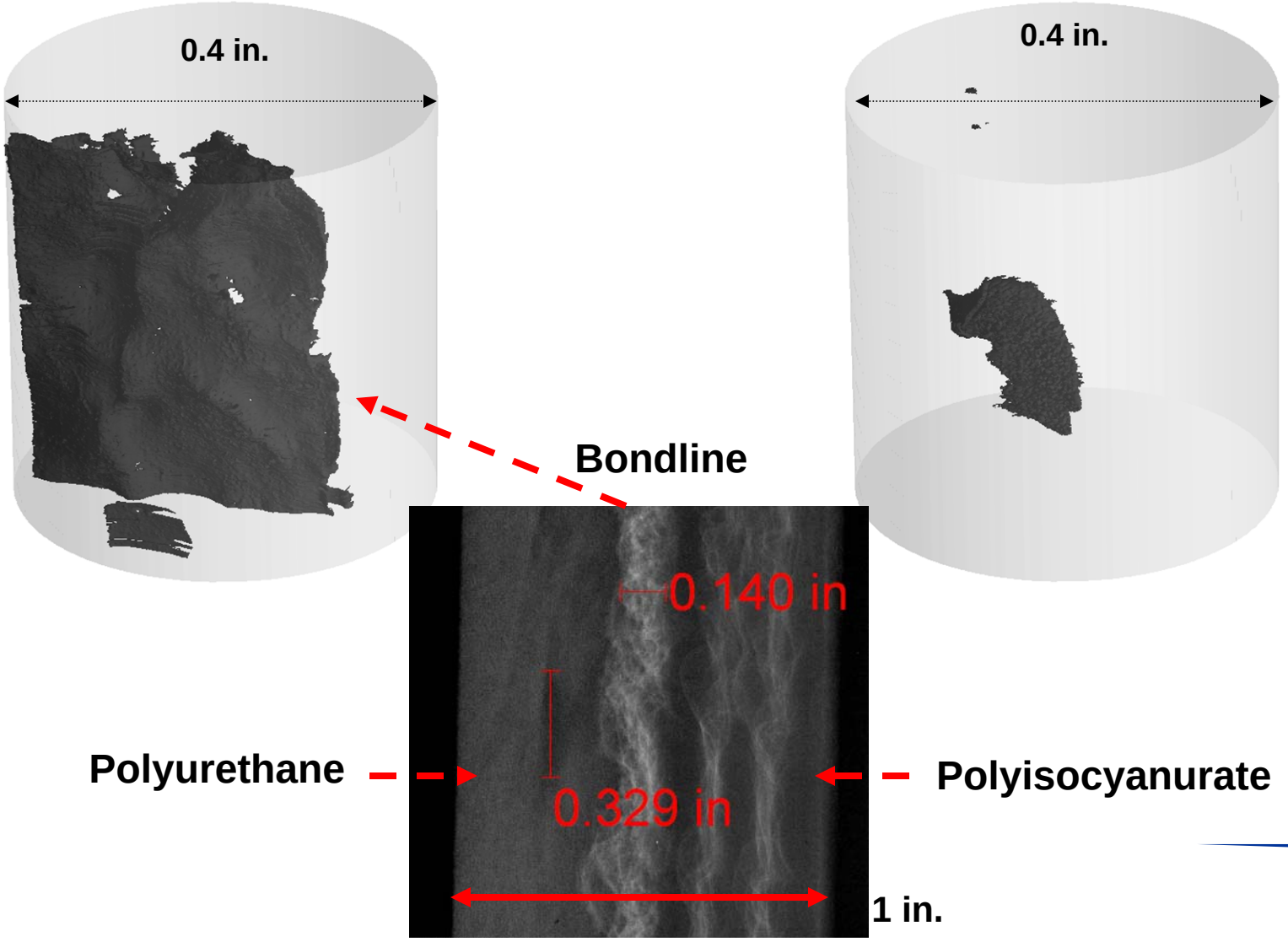


2D CT bitmap with inverted color resolved using T View

2D and 3D Visualization for Polyurethane CT Sample



2D Radiography and 3D Visualization of Bondline Interface and Void



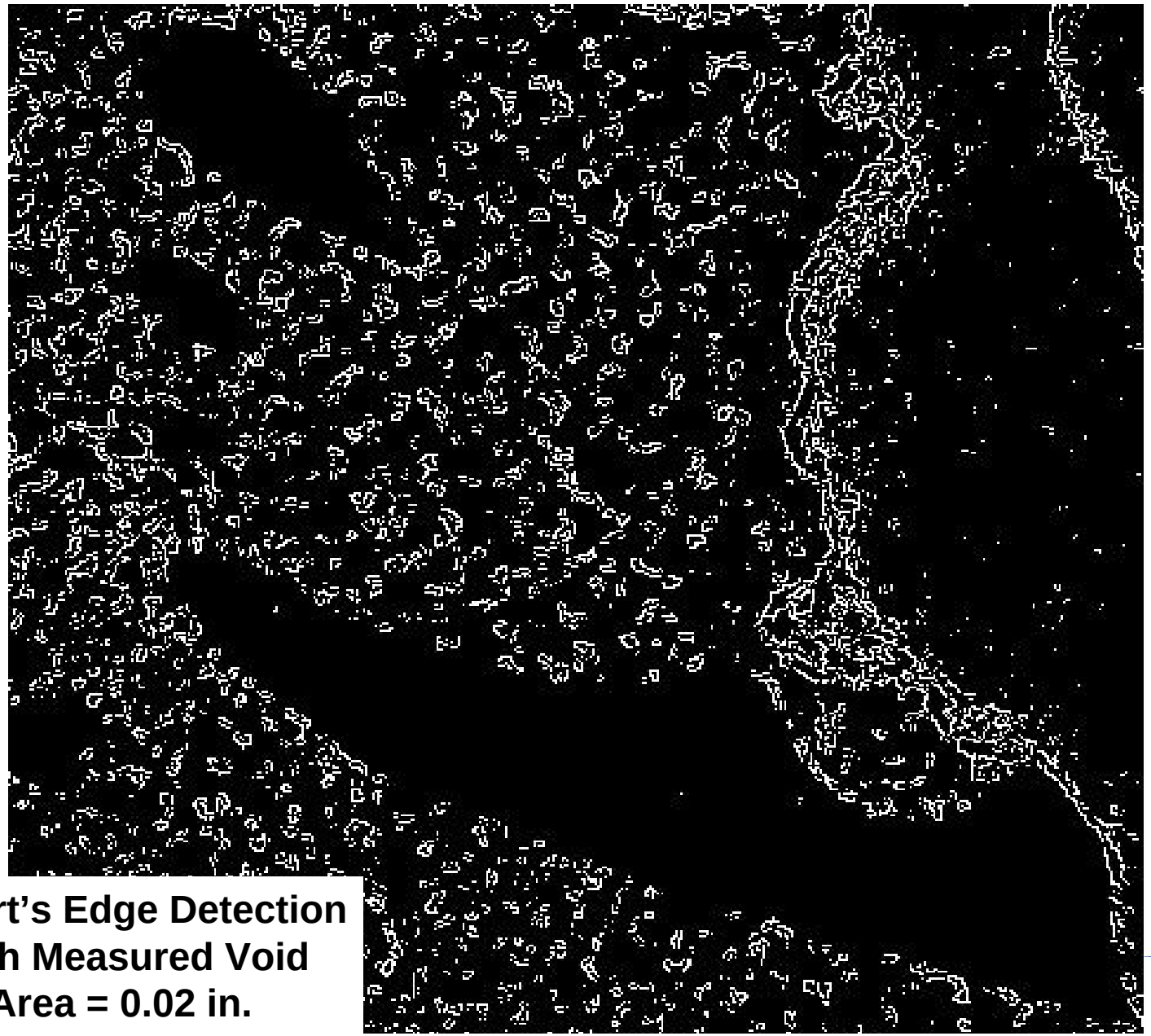
3D Visualization of Bondline Interface and Void

Conclusions

- Micro-CT provided detailed characterization of polyurethane-polyisocyanurate foams and their interfaces
- The major morphological features - foam cells, voids, knit lines, and the bondline interface were evaluated
- The features identified by micro-CT correlate well to those observed by SEM
- 3D reconstructions yielded volumetric dimensions for large voids (max ~ 30 mm)
- Internal voids and groupings of smaller cells at the bondline are concluded to be the cause of the indications noted during the NDE prescreening process

Back Up

Applications of Computed Tomography to Evaluate Cellular Solid Interfaces



Robert's Edge Detection with Measured Void Area = 0.02 in.

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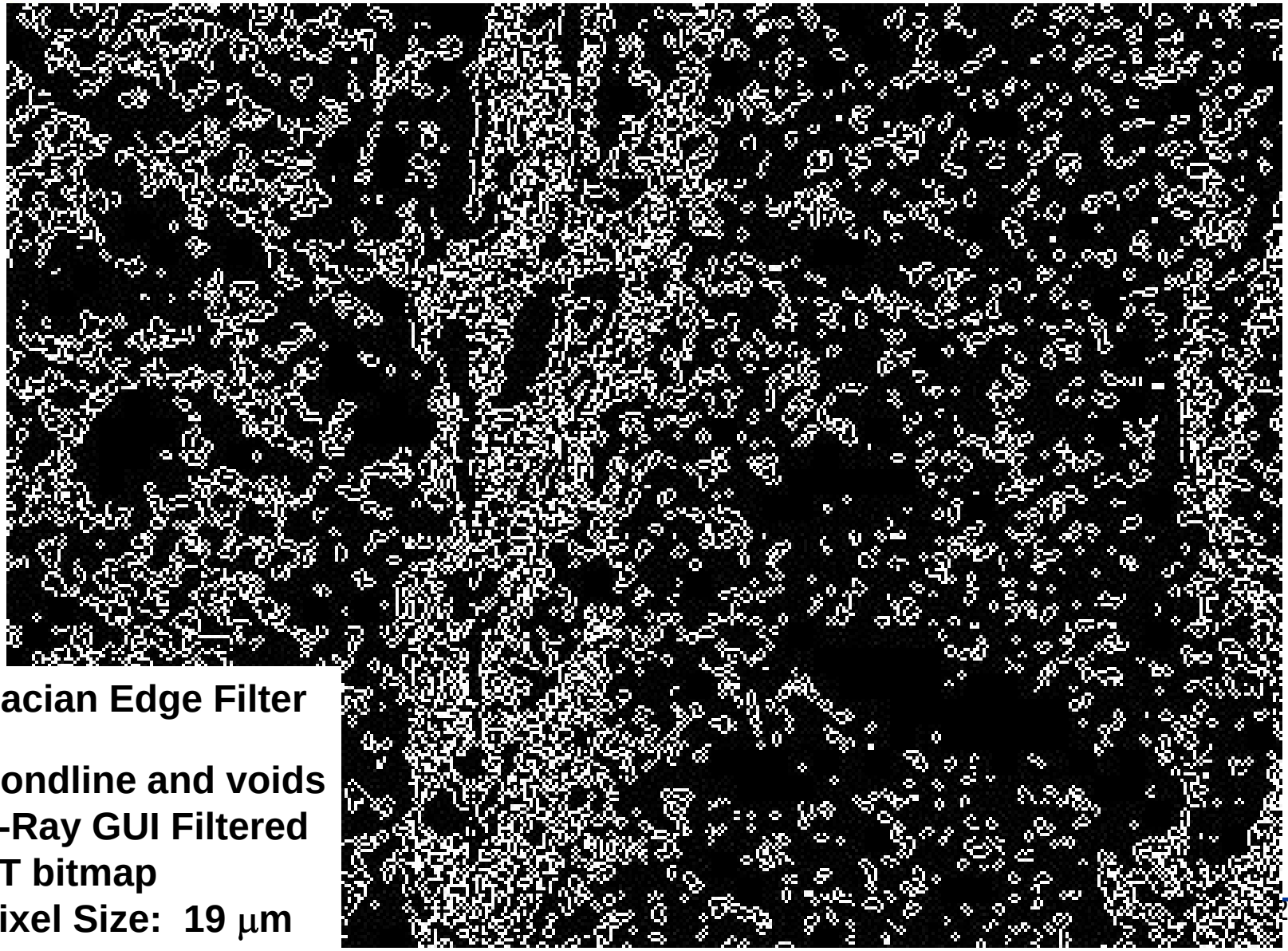

LaPlacian Edge Filter

- **Bondline and voids**
- **X-Ray GUI Filtered CT bitmap**
- **Pixel Size: 19 μm**