Reducing Hot-Section Ceramic Component Cost And Supporting EBC Development Through Development of Nondestructive Evaluation Technologies

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Presentation Outline

- Objectives
- Improving yield of high volume production ceramic rotors
  - -Approach
  - -Accomplishments (Primarily since last review 6-27-01)
  - -Collaborations
  - -Planned future work
- NDE Technology for development of EBC for monolithics
  - -Approach
  - -Accomplishments (Primarily since last review 6-27-01)
  - -Collaborations
  - -Planned future work
- Summary / Conclusion

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Objectives

- Development of nondestructive non-contact technologies for ceramic components under development for advanced, low-emission, high-efficiency microturbine and industrial gas turbines
  - Develop high-speed, low-cost, full-volume nondestructive evaluation technology to improve ceramic rotor yield - hence reduce per-part cost.
  - Develop nondestructive characterization technology for EBC coating development for monolithic and composite ceramic hot section components

NDE Technology for High Volume Large Size Monolithic Components

Approach

[Ceramic Rotors]

- Develop a high spatial resolution 3D X-ray computed tomographic imaging system
  - Work in direct cooperation with ceramic suppliers (Honeywell Ceramic Components and St. Gobain Industrial Ceramics)
  - CRADA with Perkin-Elmer/electro-optics on amorphous silicon flat panel X-ray detector
  - Cooperate with others developing flat panel cone beam 3D tomography
    - William Beaumont Hospital, Michigan
  - Utilize existing ANL facilities such as parallel architecture computers, cooperation with DOE/BES funded staff at APS
  - Target is transfer technology to end user

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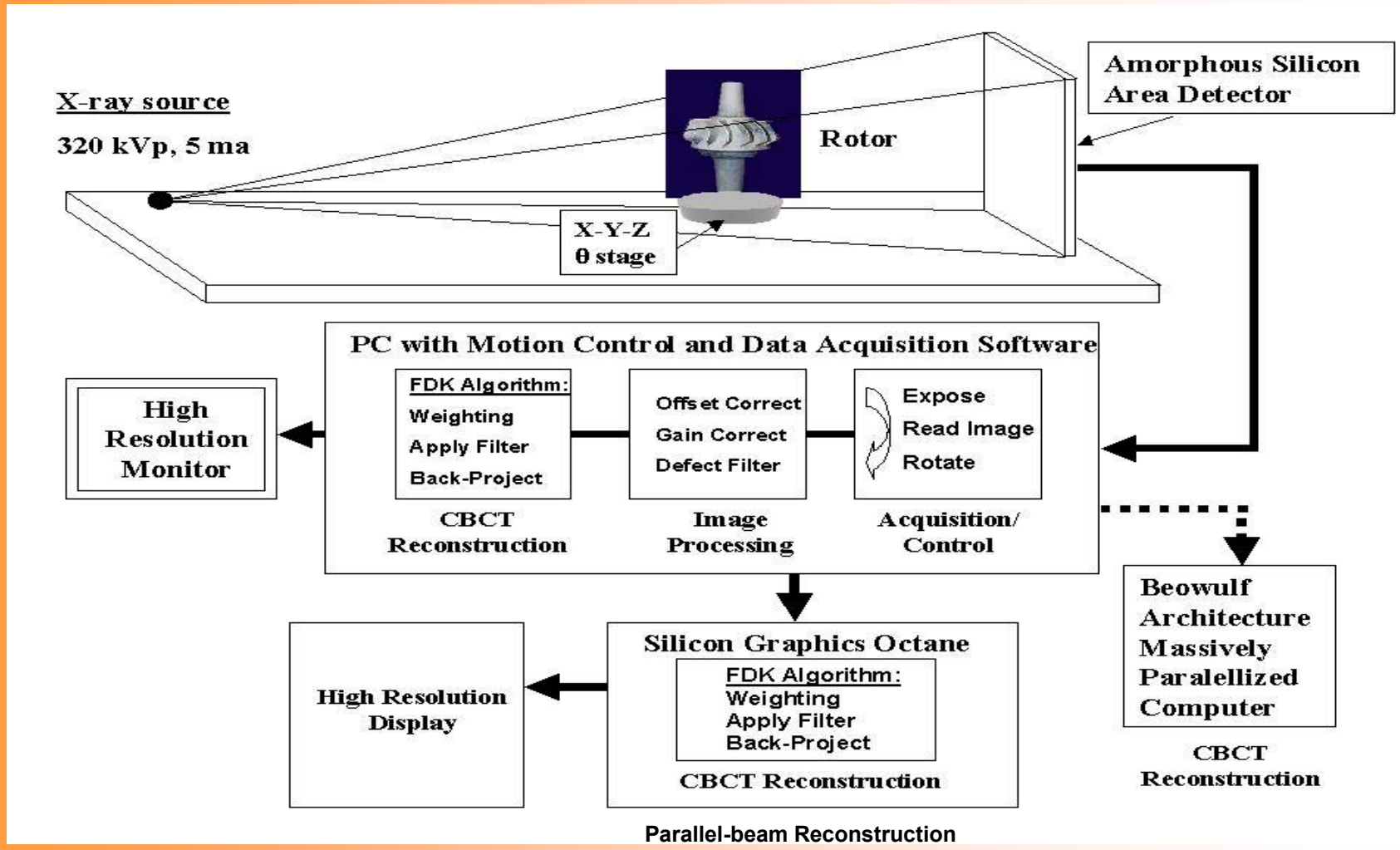
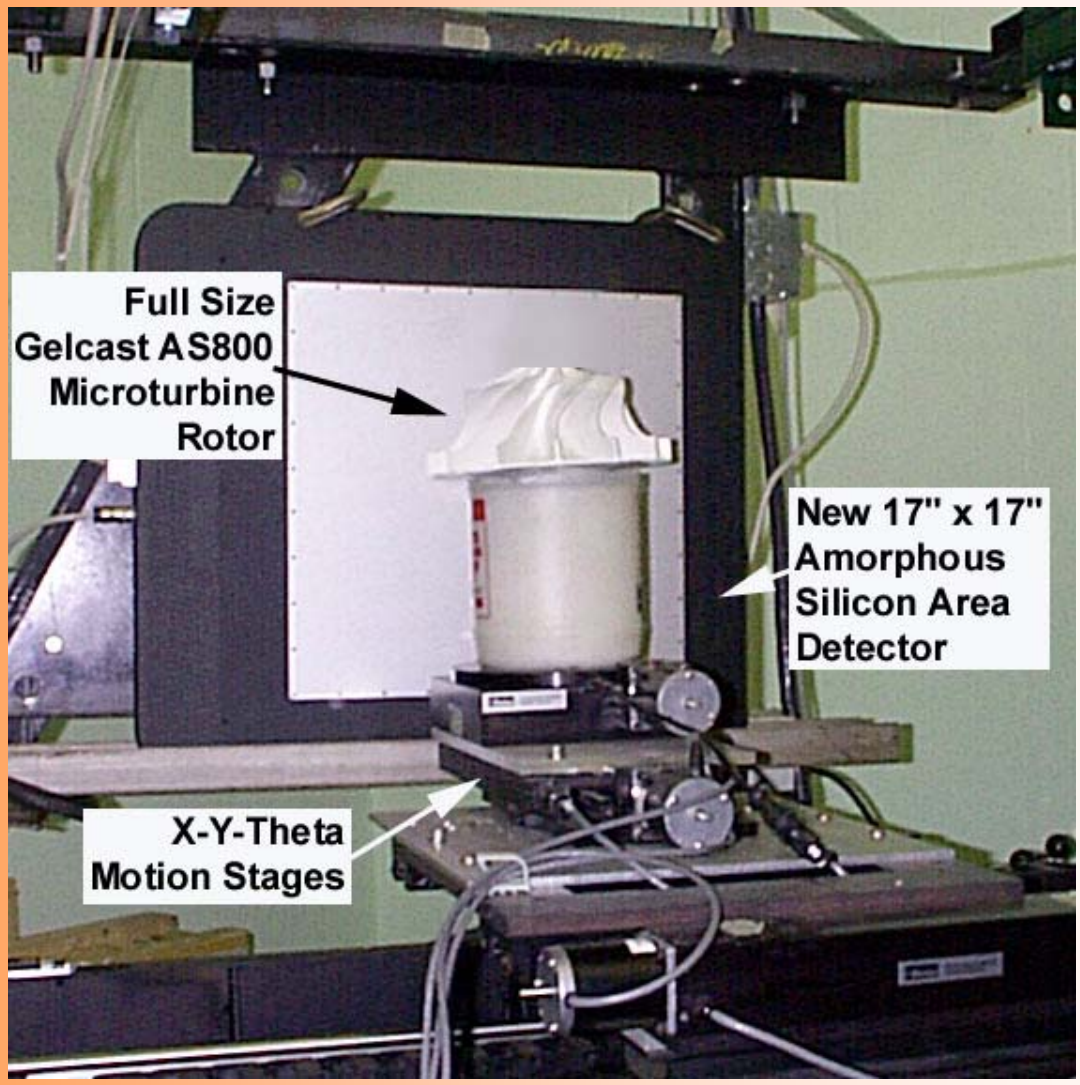
Schematic Diagram of Argonne 3D Volumetric High Speed Tomographic Imaging System



3D X-ray tomographic imaging setup with 40 cm by 40 cm amorphous silicon flat-panel detector



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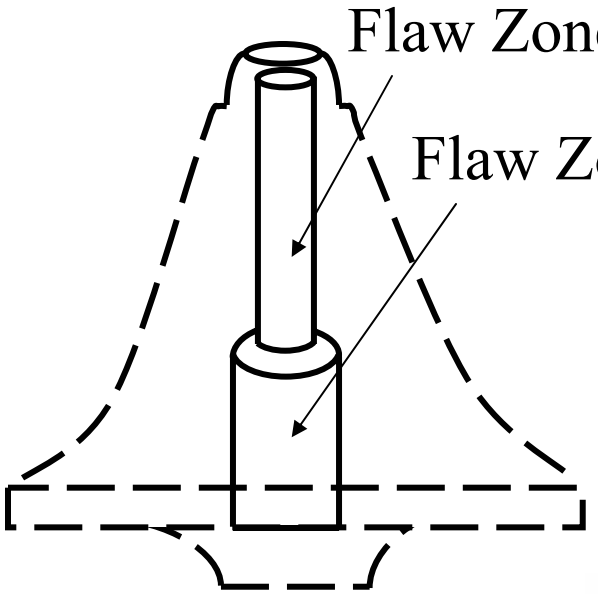
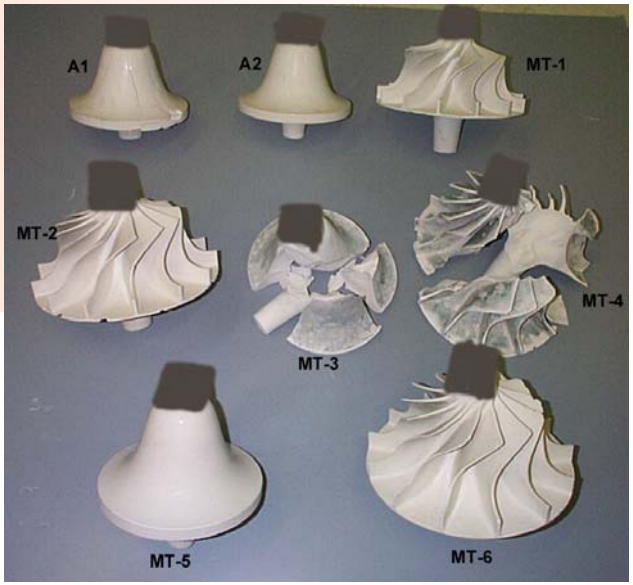
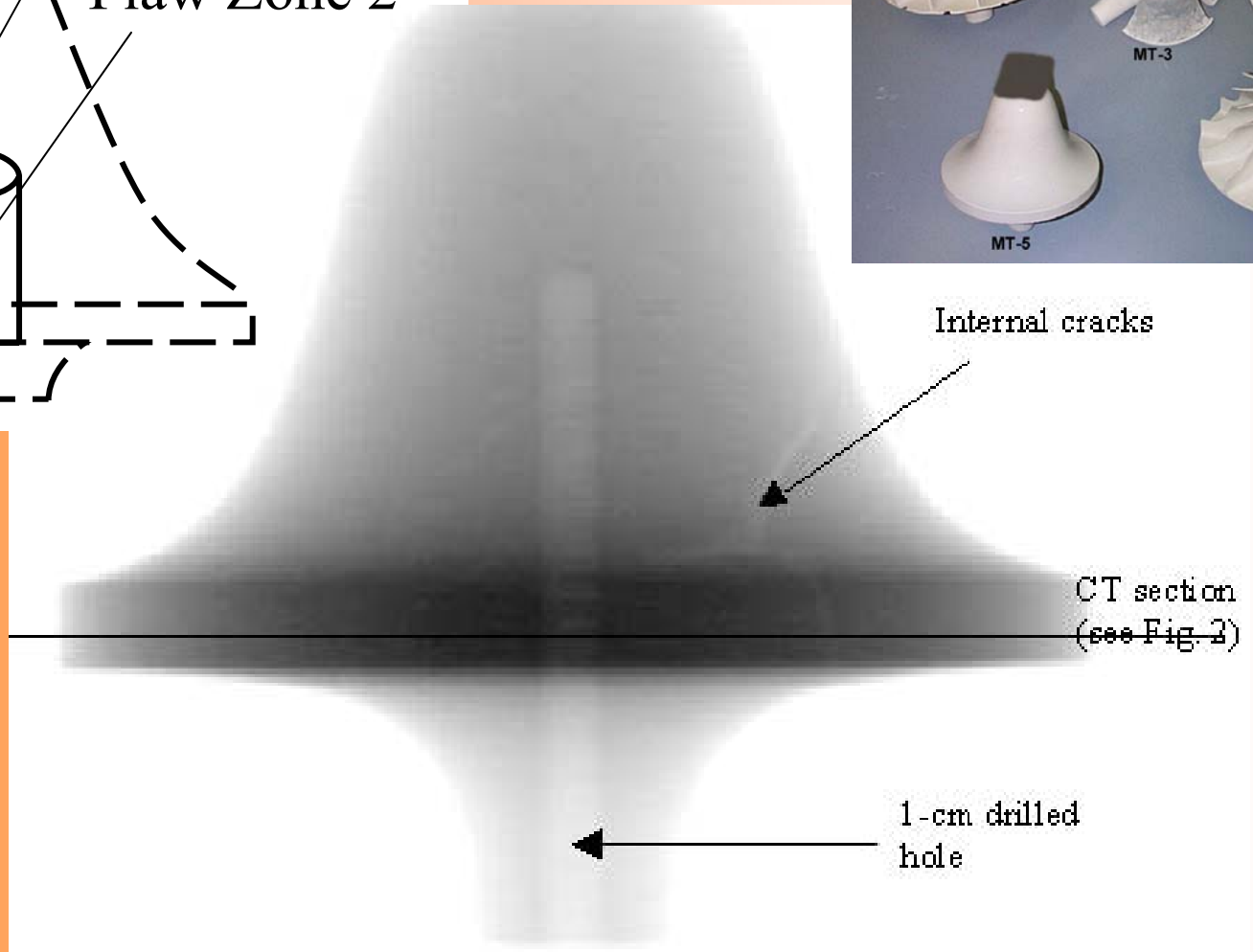
FULL-SIZED GELCAST AS 800 ROTORS USED FOR NDE/C STUDIES







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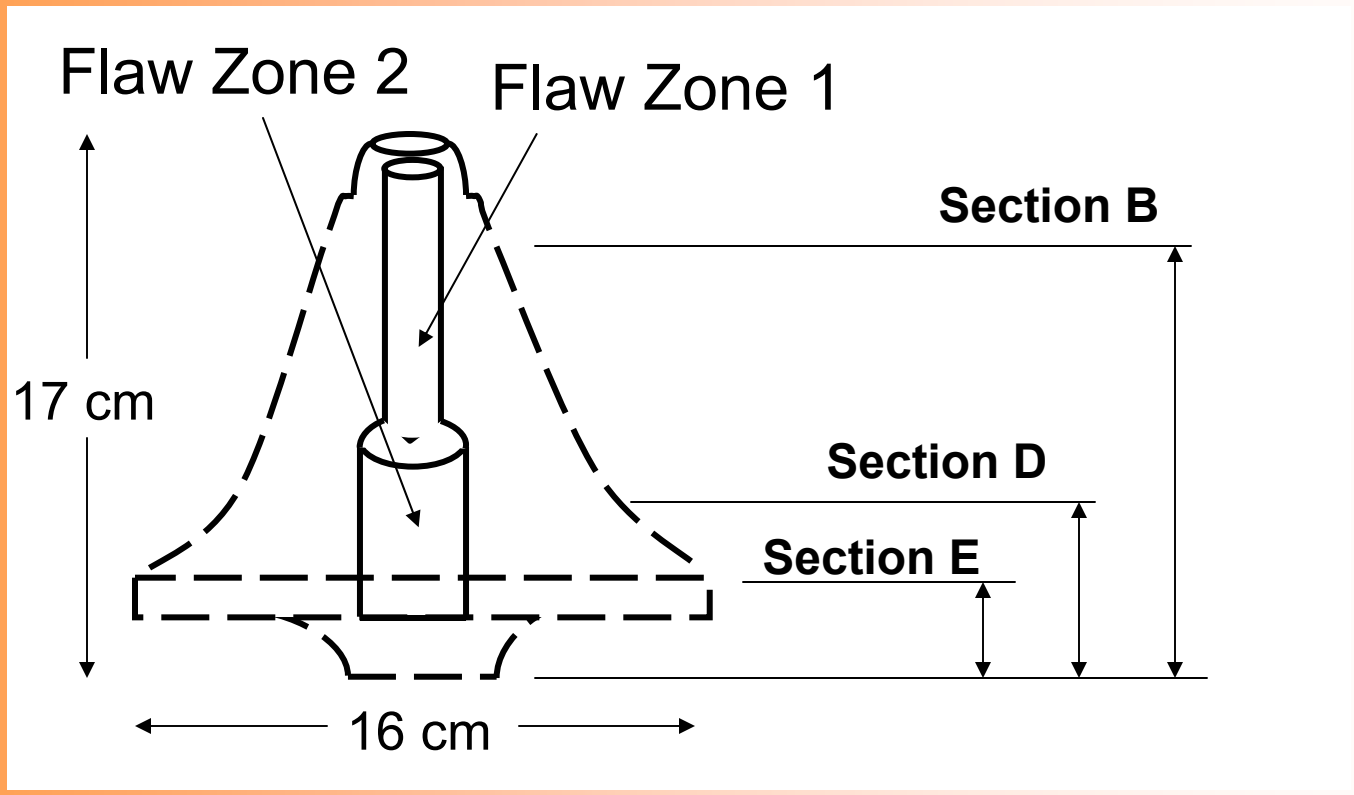
Accomplishments: 3-D High Speed X-ray Tomography

- Initial Defect -detection diagram for rotor established for steel inclusions and air-voids.
  - Current limits is mainly caused by pixel size, 400 μm of detector.
  - New 200 μm large area detector and 80 μm line detector to be received in next 3 months.
- Internal cracks in full sized rotor detected by 3 D full volume CT verified by destructive analysis.
- New Cooperative efforts started with DOE/BES/LTR with new 80 μm pixel detector

Defect-Detection Diagram Positions



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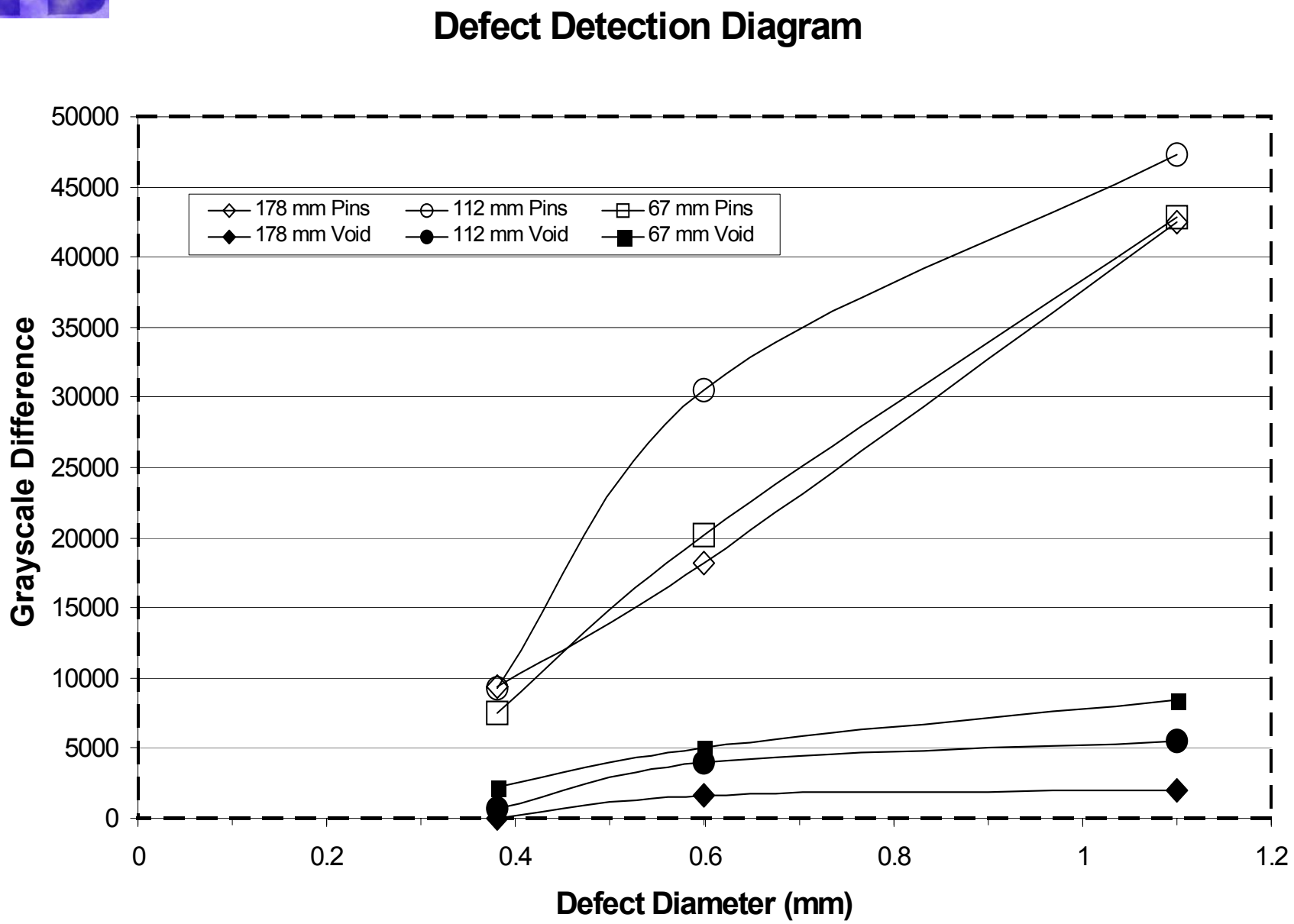
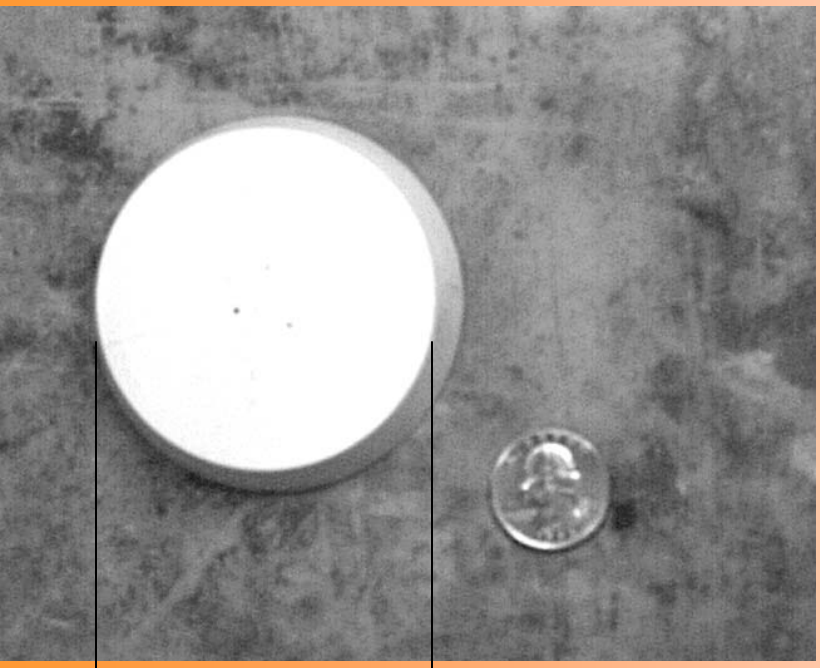
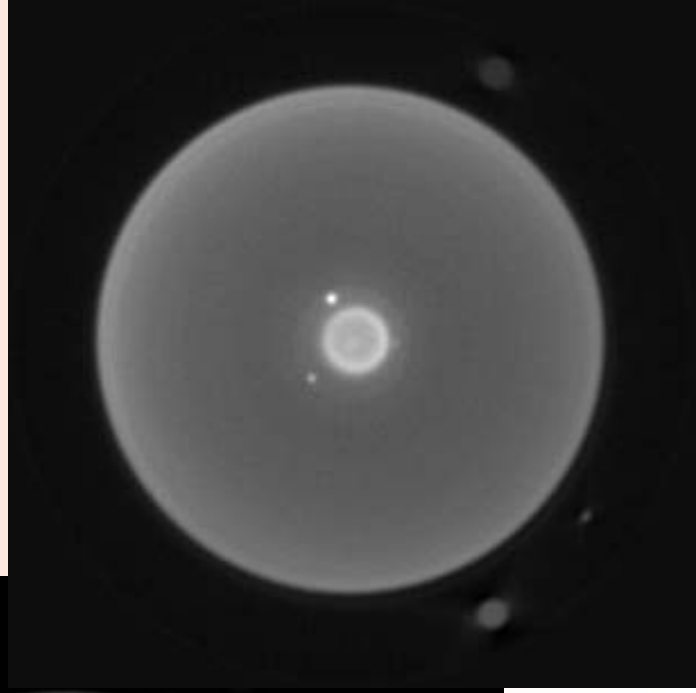
Defect-Detection Diagram

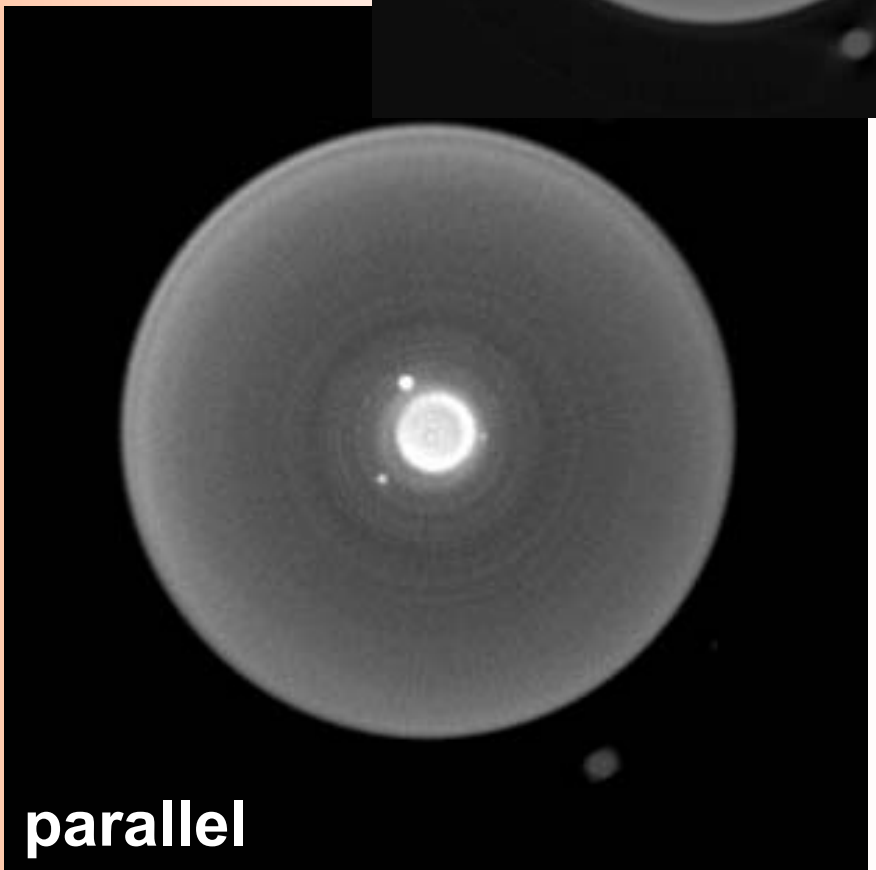


Section B
(smallest)



conebeam





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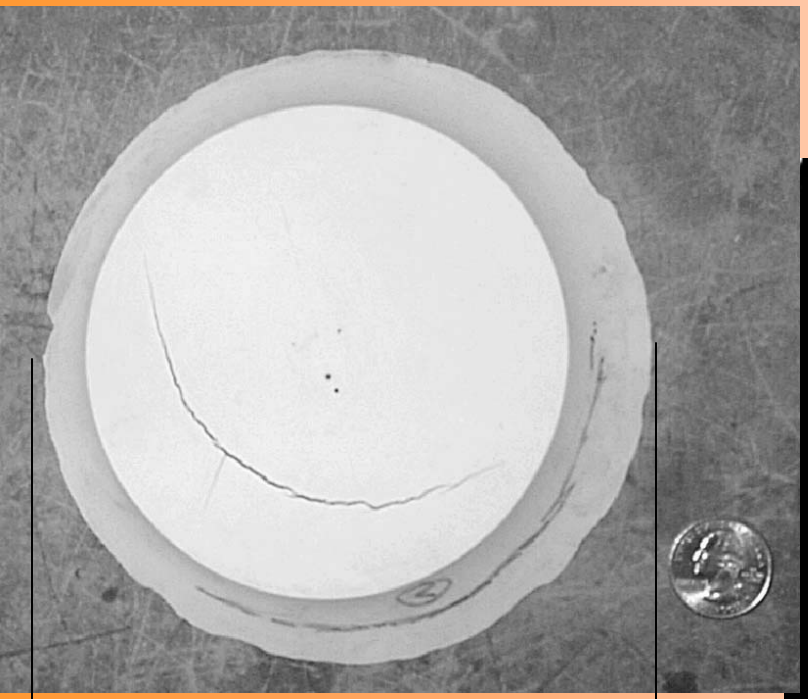
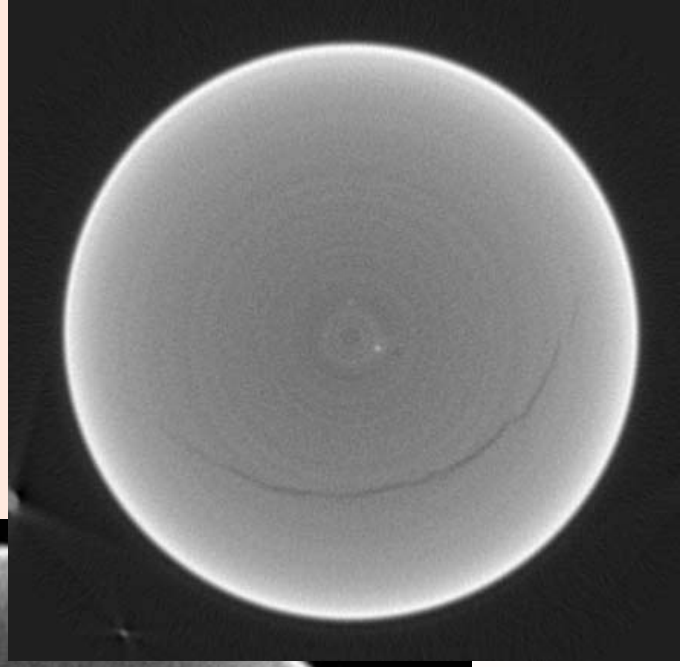
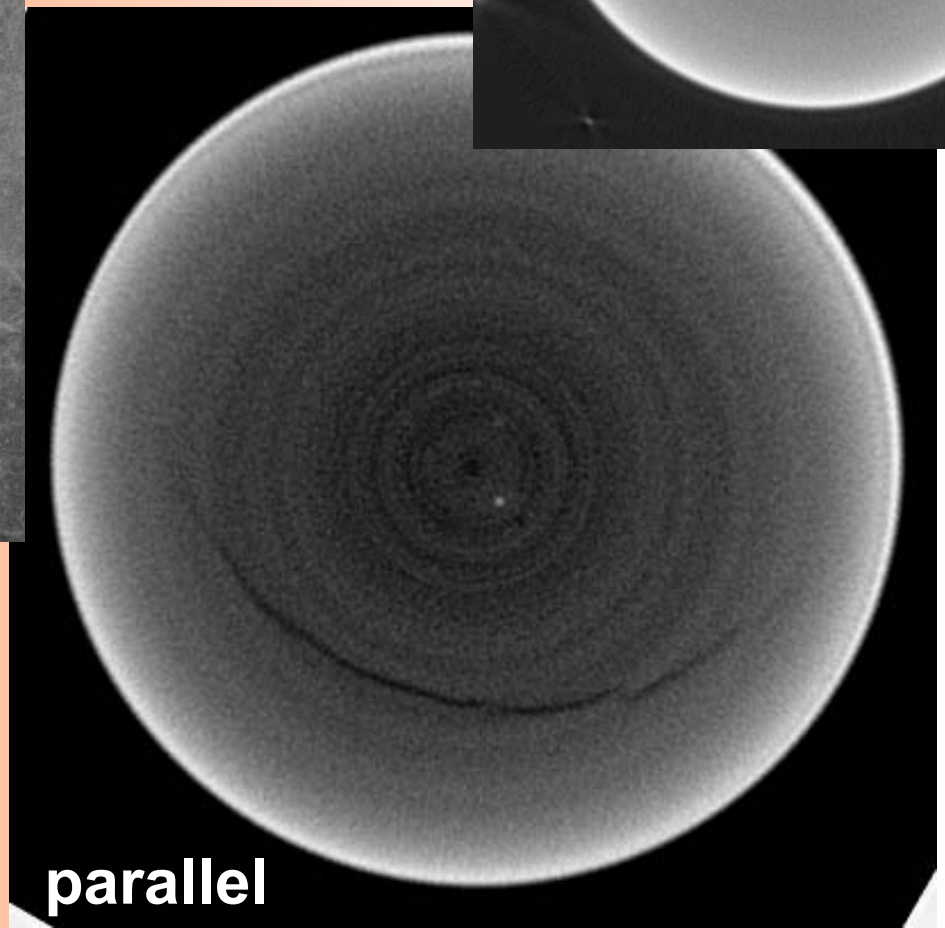
Section D
(middle)



112 mm

conebeam





parallel

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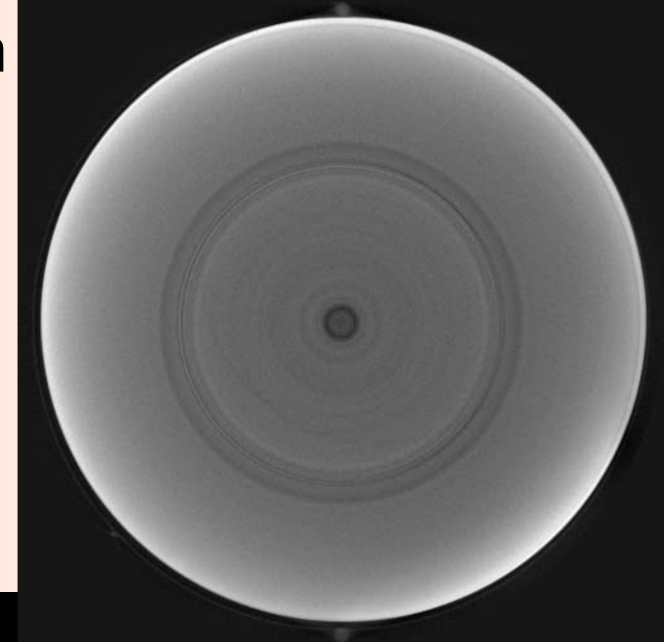
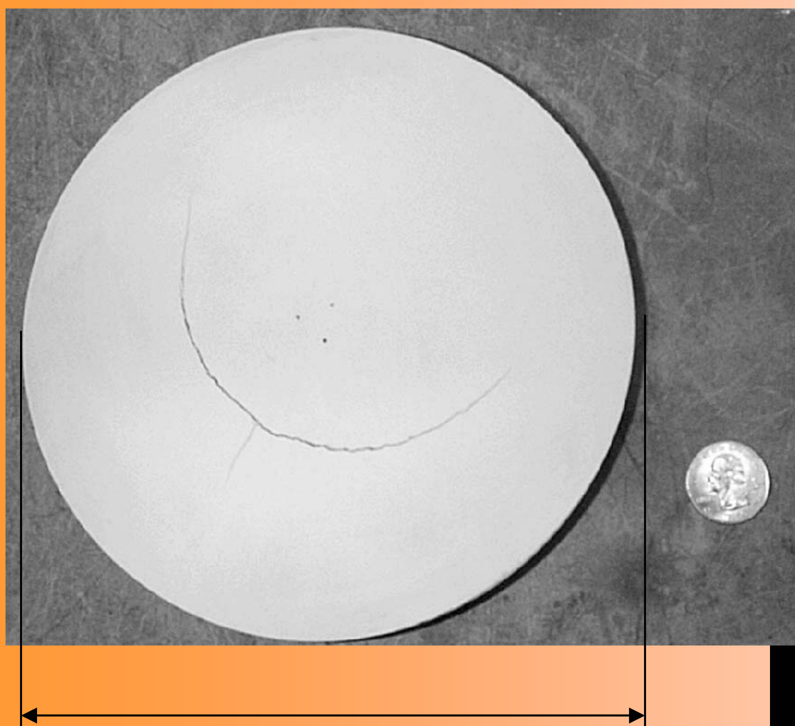
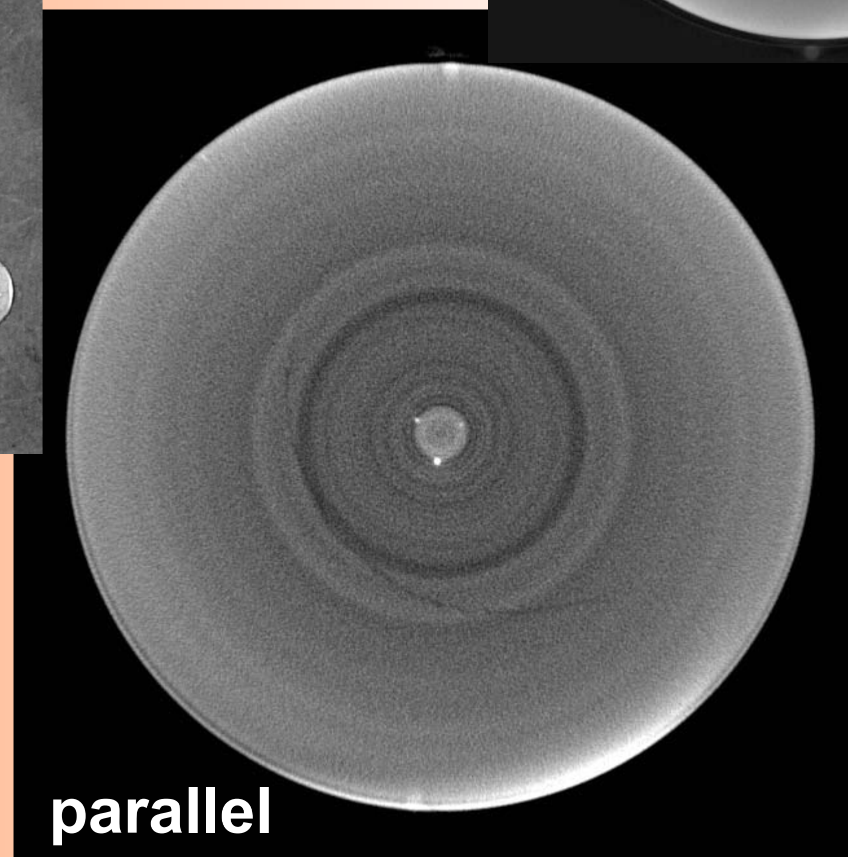
Section E
(largest)

conebeam





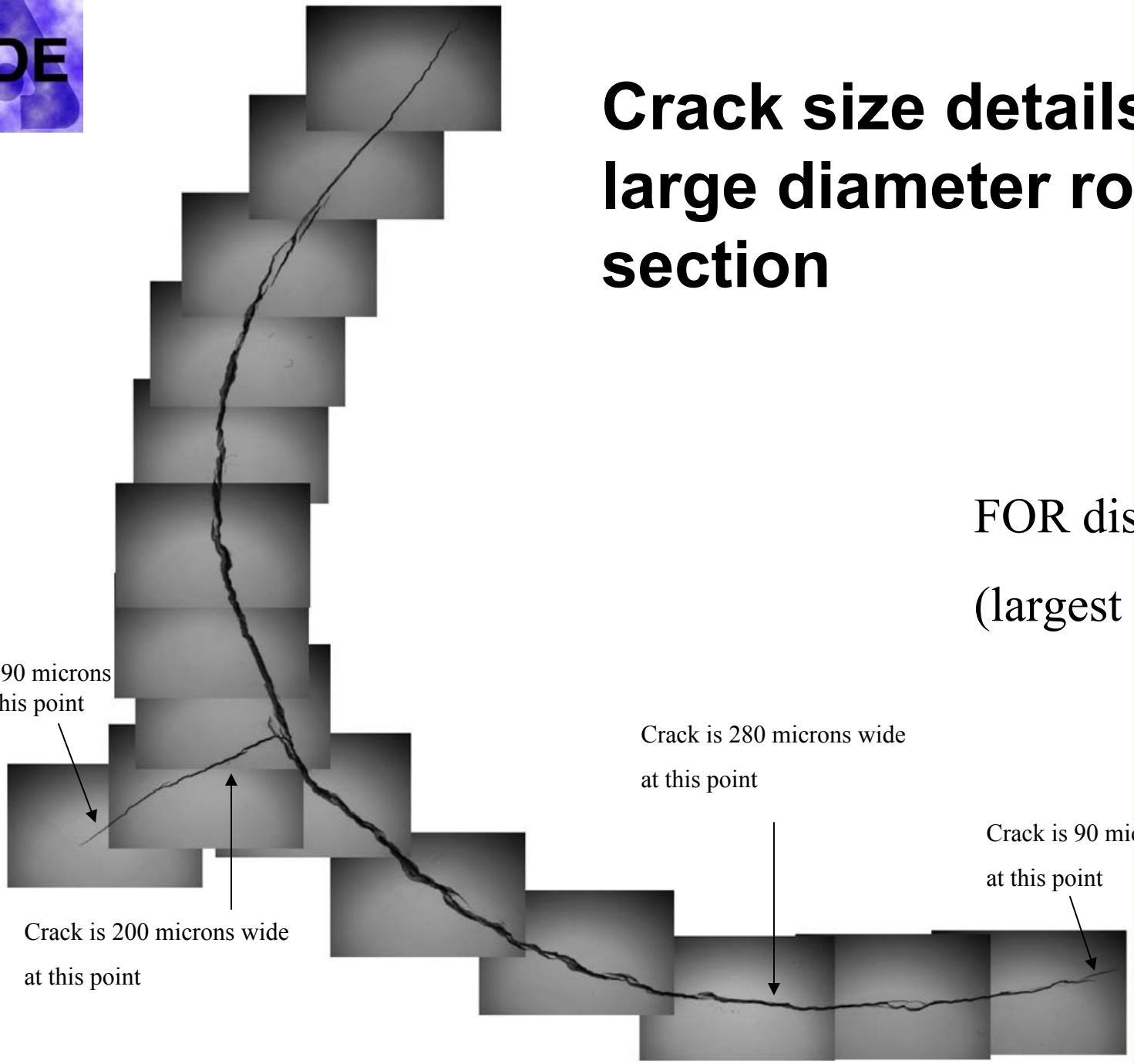
178 mm



Crack size details for large diameter rotor section

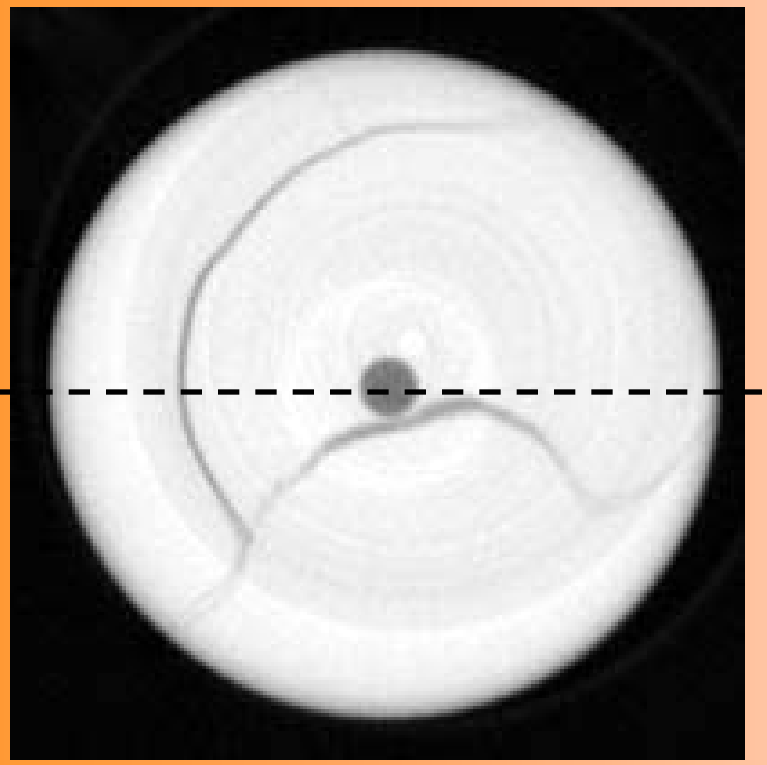
FOR disc E

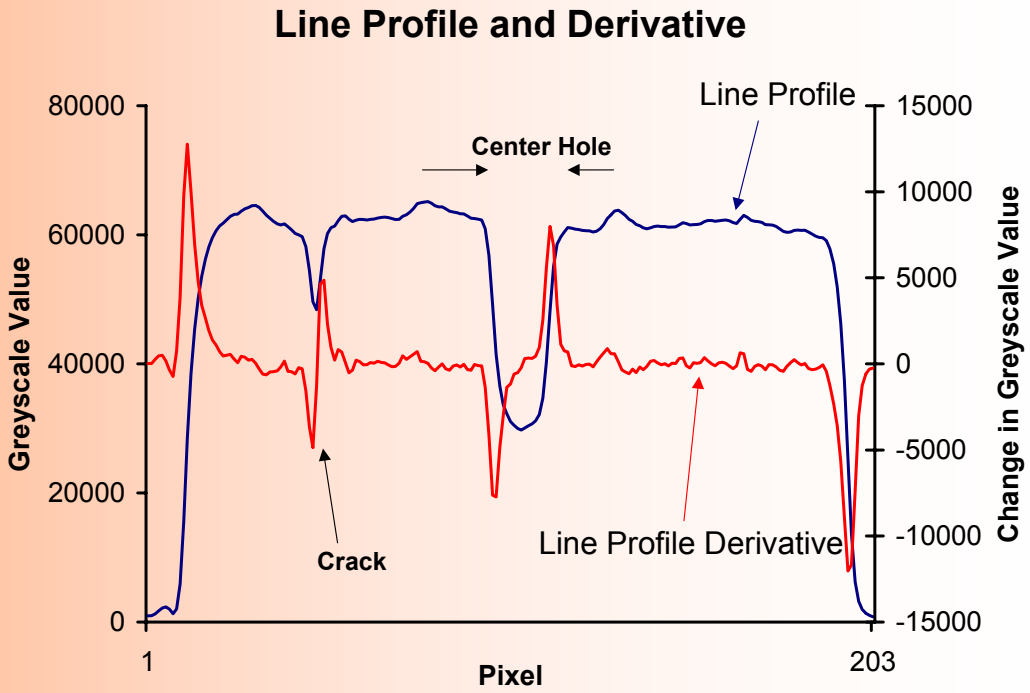
(largest disc)



Unbladed Rotor CT Slice and Line Profile

-use of derivative for edge detection





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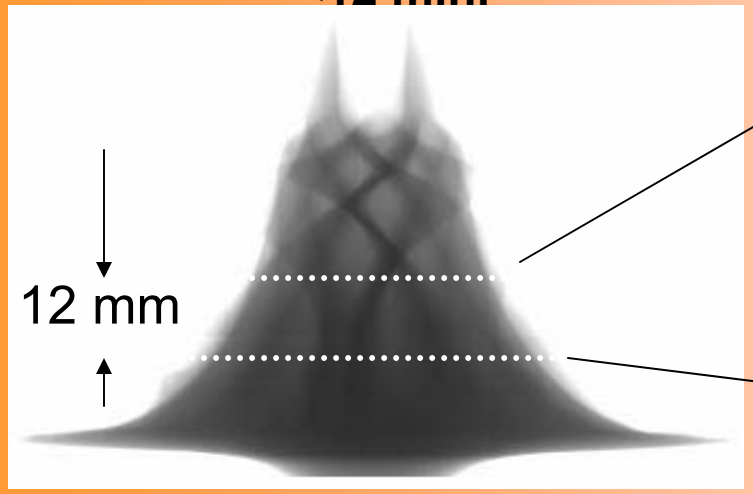
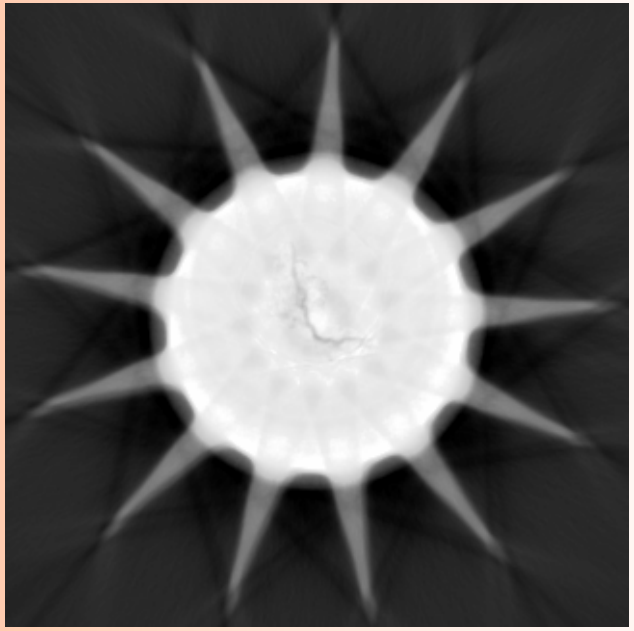
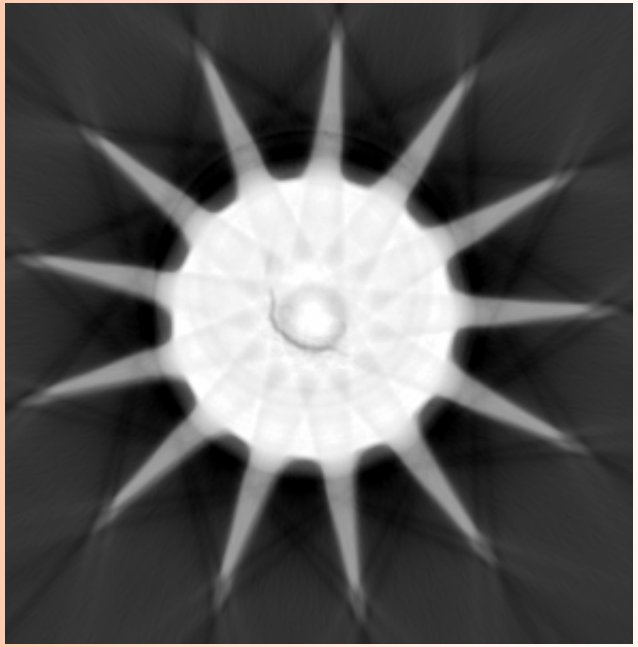
Full-size Bladed Gelcast AS800 Rotor

High-speed data acquisition < 5 min.
High-speed volumetric image reconstruction <12 min.







The crack in the rotor was found to travel 8 mm horizontally as well as 40 mm vertically.

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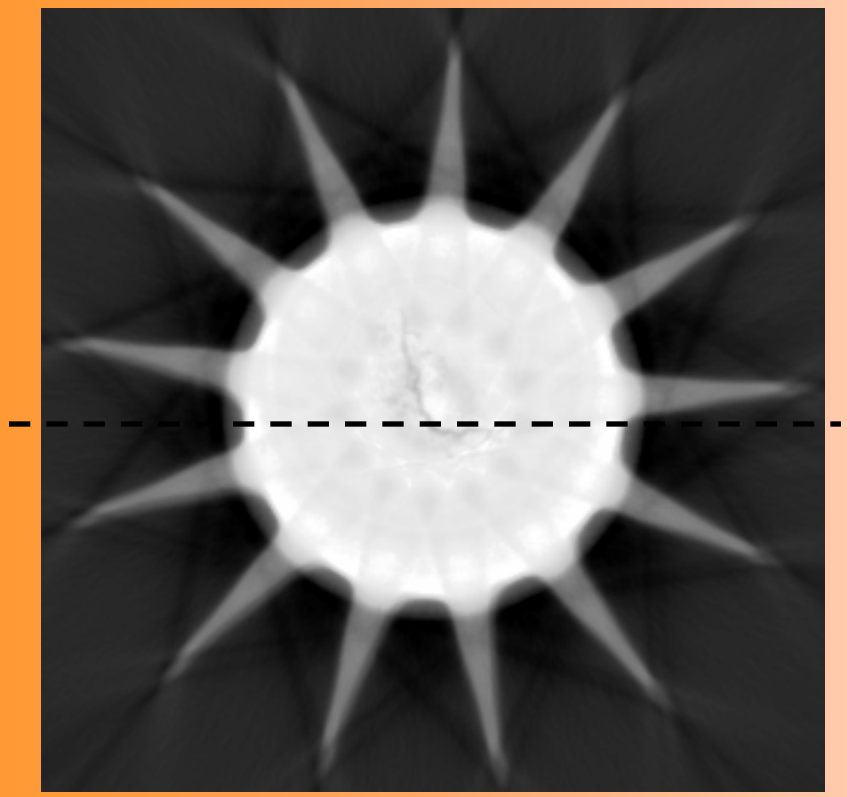
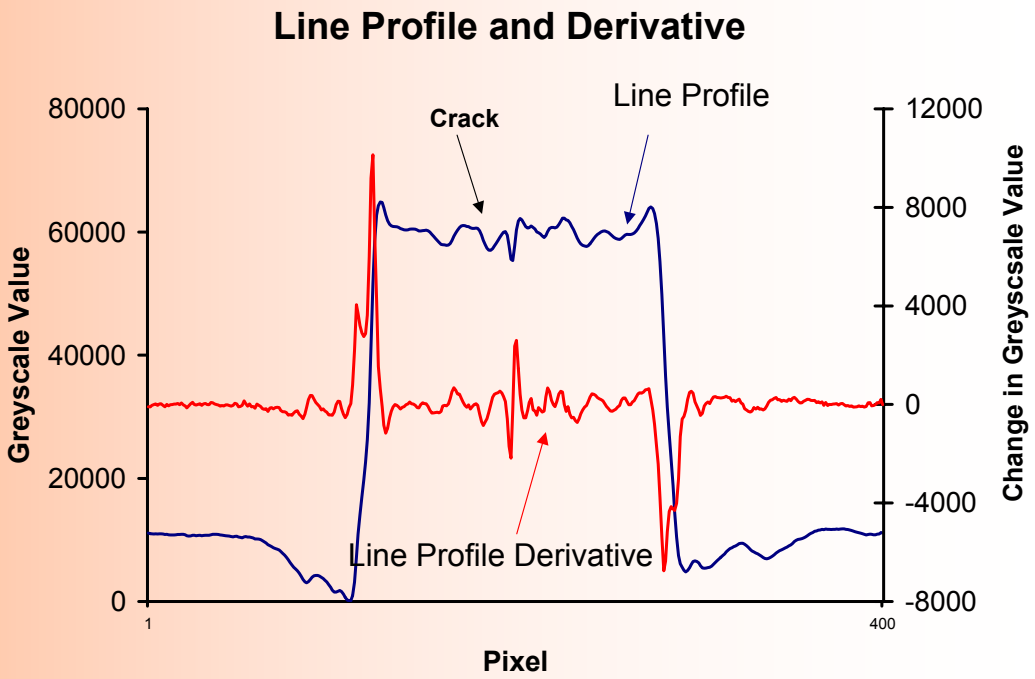
Bladed Rotor CT Slice and Line Profile





Planned Future Work

- Conduct various digital image processing studies to improve and establish probability of detection for detail-detectability curves to allow better defect size detection prediction for various part sizes
- Verify additional detected features by destructive analysis (voids, density variation , cracks)
- Install and test 200 μm pixel large area detector
- Install and test 80 μm pixel line detector
- Continue efforts on fast reconstruction with target of 800x800x800 volume in less than <7 min
- Establish best automated feature recognition digital image method to advance automation of system; i.e. stand-alone
- Continue discussions / cooperation with new industrial partners

NDE Technology for EBC's

Accomplishments: EBC's

Monolithics

- 6 monolithic AS800 vanes coated with EBC have been studied by elastic optical back-scatter NDE
- Initial destructive correlation established between back-scatter NDE data and thickness of EBC
- Free-standing EBC sample obtained and optical transmission characteristics initialed
- 6-axis articulated arm Robot installed, initial computer interface established, initial turbine vane and turbine blade CAD files transferred to robot
- First raster scan of simple flat plate done with 6-axis articulated robot arm

Accomplishments: EBC's

Composites

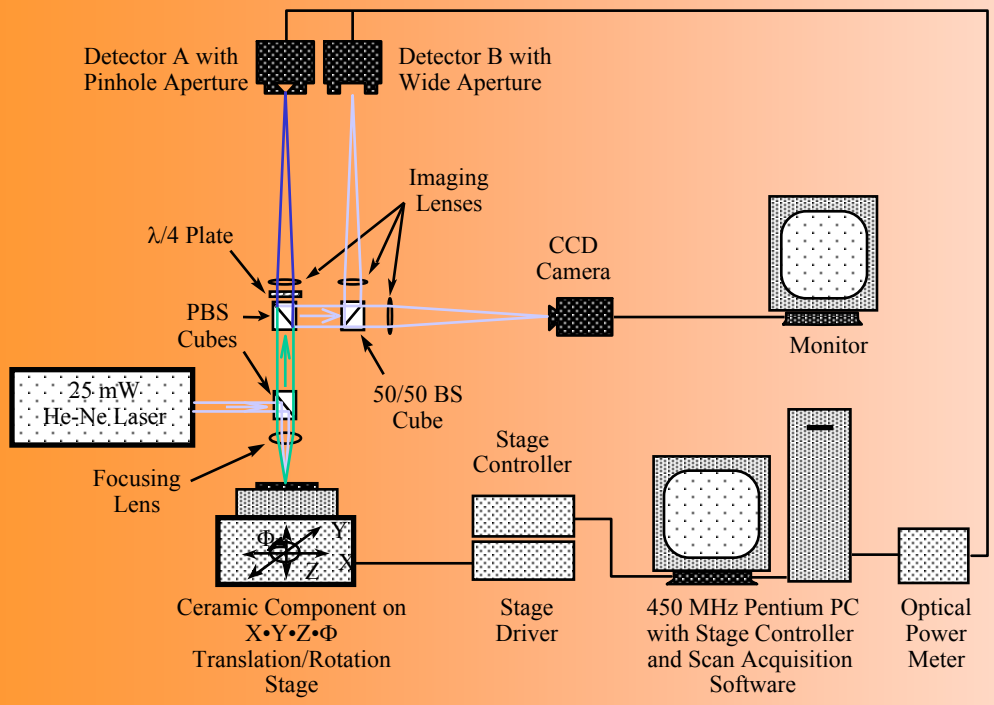
- Special set of MI SiC/SiC test samples obtained with UTRC EBC
  - delaminated
  - porosity
  - cracking
- One-sided thermal NDE acquired and analyzed for delamination
- Optical transmission characteristics established from free-standing EBC

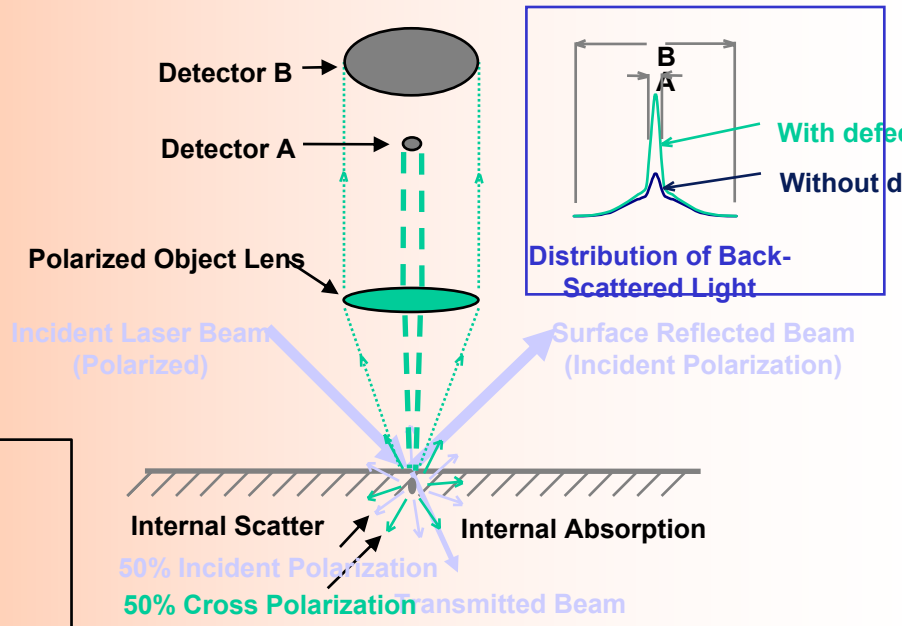
Approach
[EBC Coatings]

•Develop non-contact optical methods to verify uniform adhesion, detect disbonds, establish thickness uniformity, and size and extent of FOD.

- Work in direct cooperation with EBC developers
  - UTRC, Honeywell Ceramic Components, ORNL
- Work in direct cooperation with monolithic ceramic vendors
- Extend elastic optical scatter technology to these coatings
- Extend infrared one-sided imaging technology to these coatings
- Determine optical transmission properties of the various coating systems
- Establish methods to handle complex shapes (Robot)
- Develop analytical models to predict factors causing resulting data types
- Transfer technology to appropriate end user

Schematic of elastic optical backscatter experimental test setup





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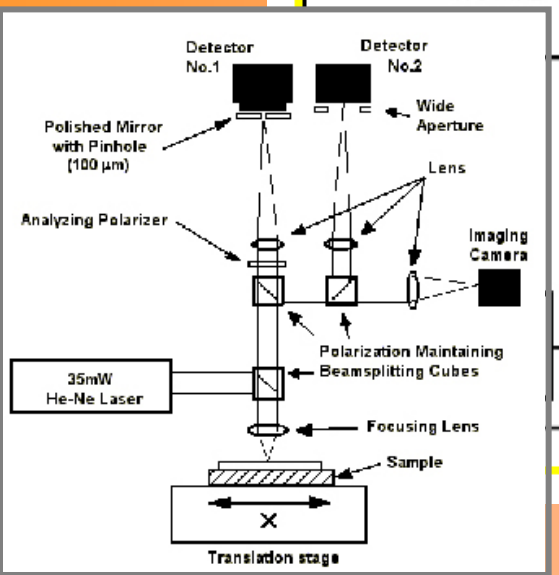
ELASTIC OPTICAL SCATTERING NDE SYSTEM



He-Ne 35mW 633nm CW

Mirror

Mirror on translation stage

Periscope Mirrors

Ti:Sapphire 50mW 700nm -1000nm CW

Argon Ion Pump 5W 488nm Pulsed

Source beam

Attenuating Beam- splitter

Half wave plate

450 MHZ PC

Polarizing Beam-Splitting cube

Polarizing Beam-Splitting cube

Focusing Lens

Detector A with 100 µm Pinhole aperture

Focusing Lens

Quarter-wave plate

Ceramic Sample on X, Y, Z Mechanized Stages

50 / 50 Beam-Splitting Cube

Focusing Lenses

Detector B

CCD Camera

Sony Display Monitor

Newport 4632 Optical Power Meter

Polarization States

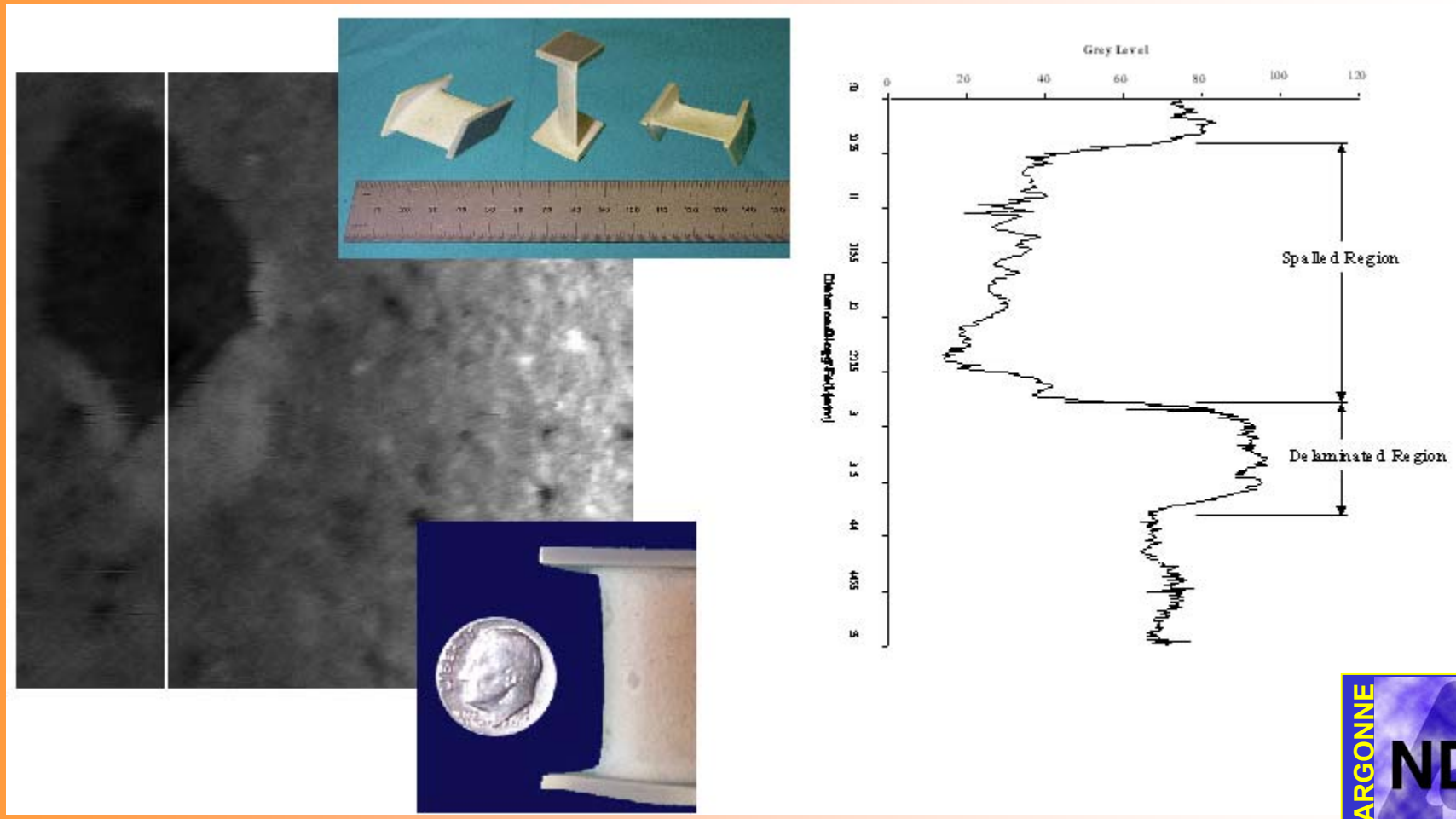
Random

Vertical

Horizontal

Elliptical

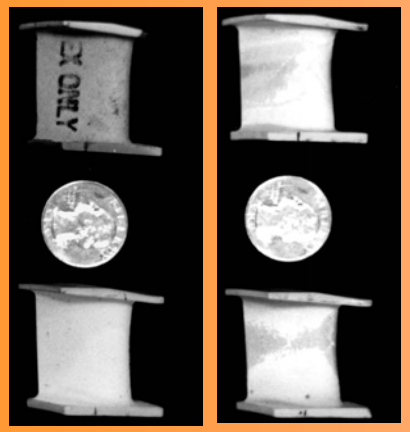
Detection of pre-spall of EBC on AS 800 vane using elastic optical scatter



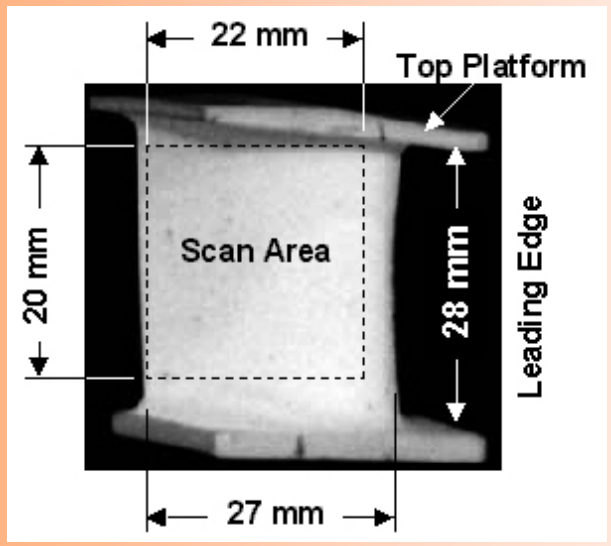
ARGONNE NDE

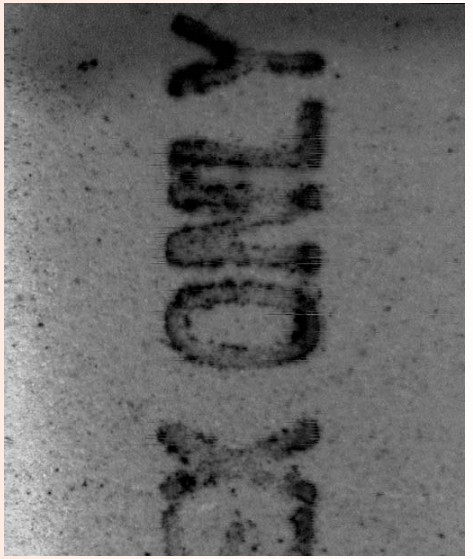
Detection of erosion of EBC on AS 800 vane using elastic optical scatter

as received 1621 hrs.



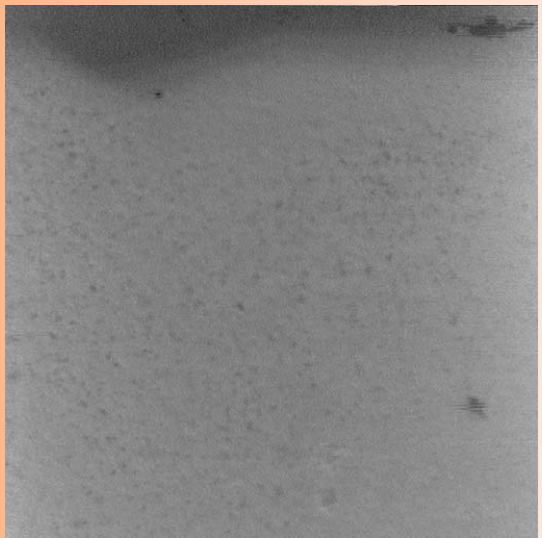
542 hrs. 1621 hrs.

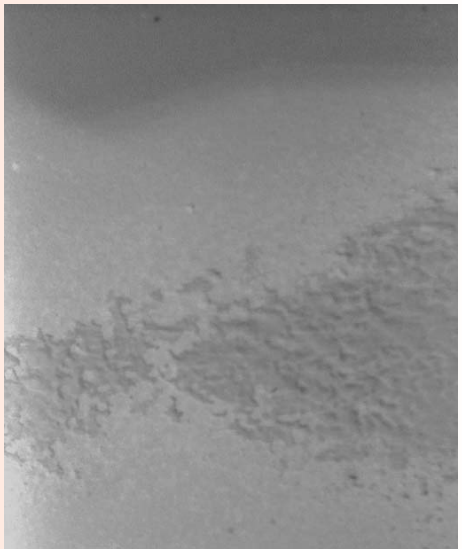




as received

542 hrs.





1621 hrs.

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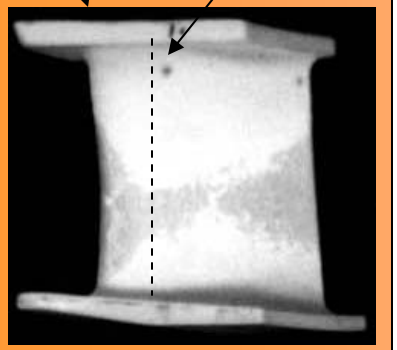
Correlation EBC thickness to elastic optical scatter intensity on AS 800 vane after 1621hrs.

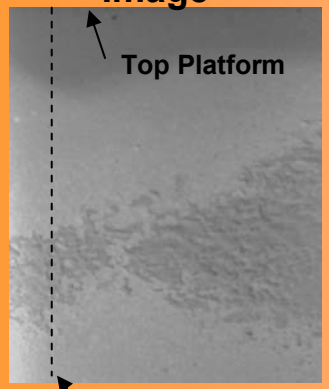
Top Platform

Optical Photo Micrograph



Photograph

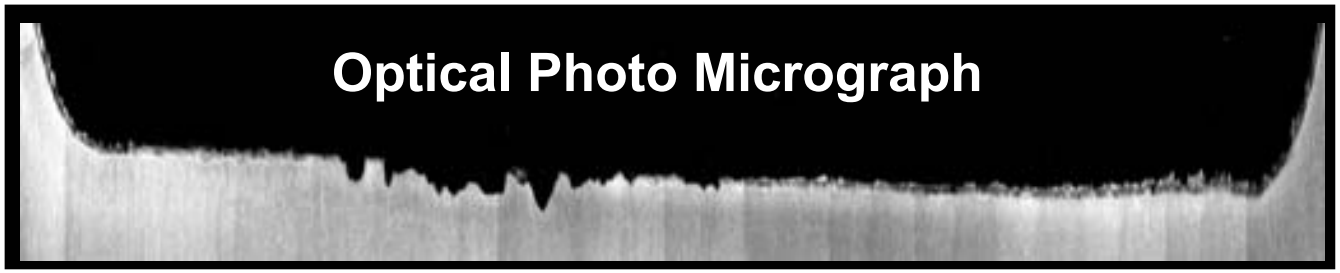
Optical Laser Scatter Image

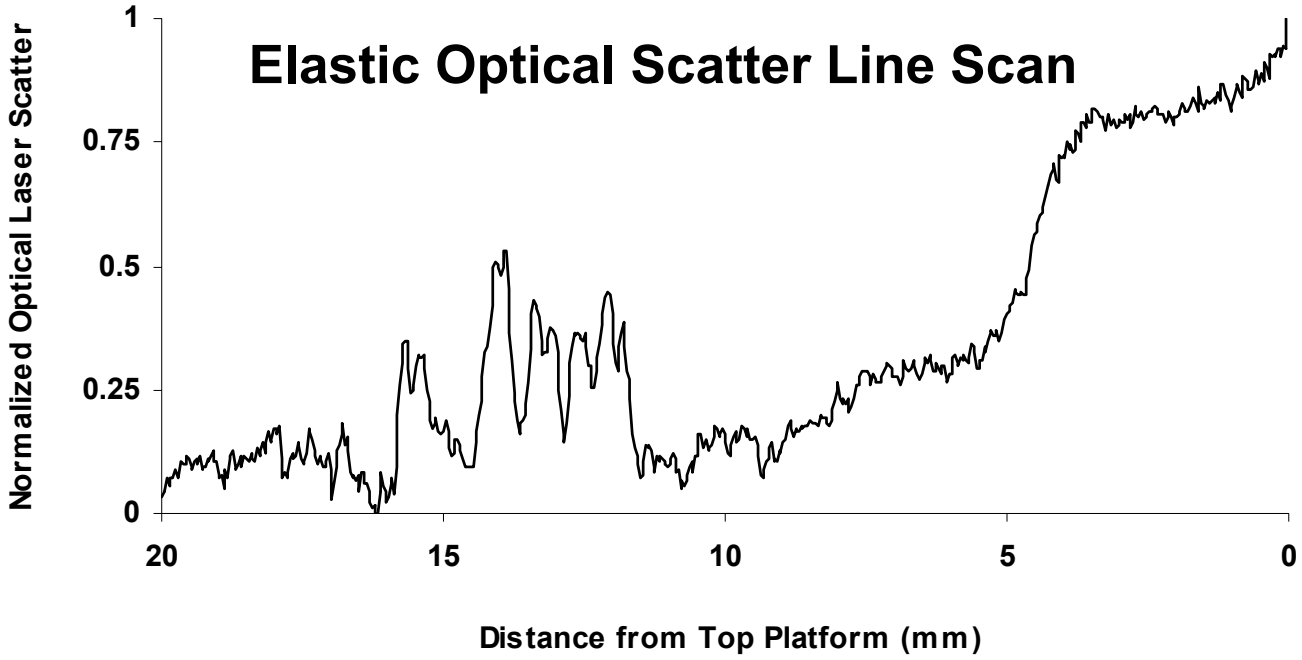


Top Platform

23 mm

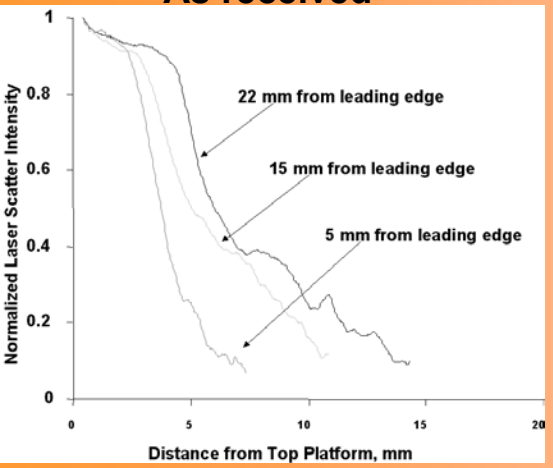
876 µm



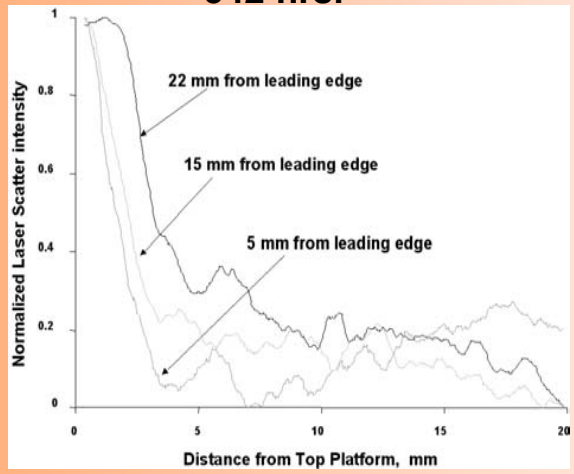


Recession of EBC thickness on AS 800 vane from elastic optical scatter intensity

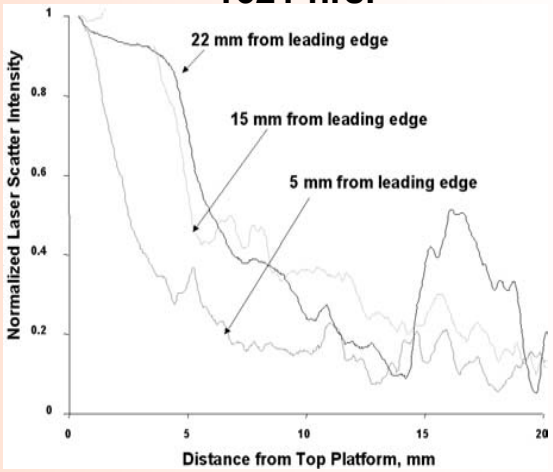
As received



542 hrs.

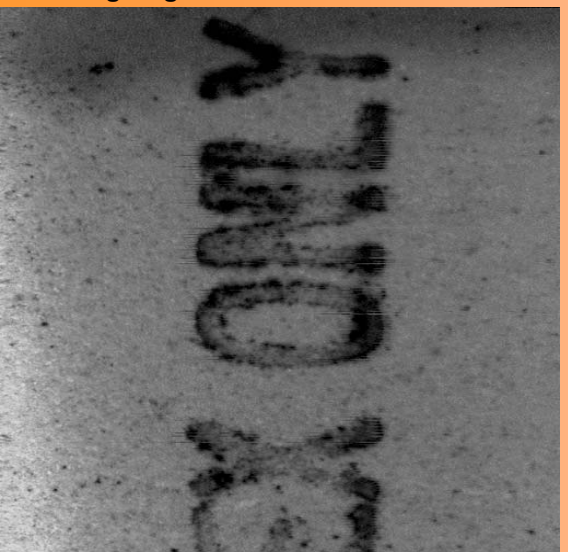


1621 hrs.

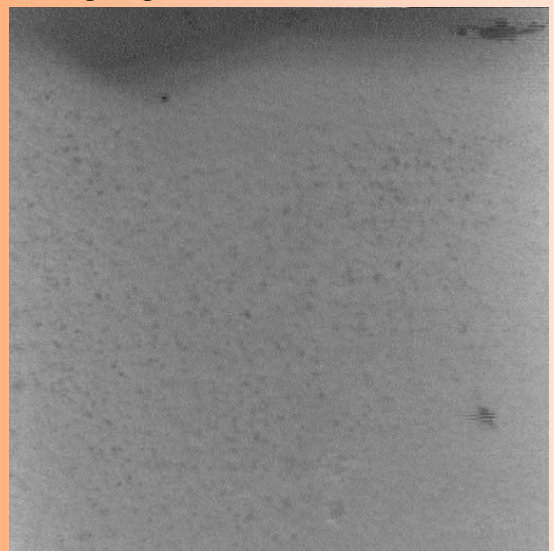


Line Plots from Laser Scans

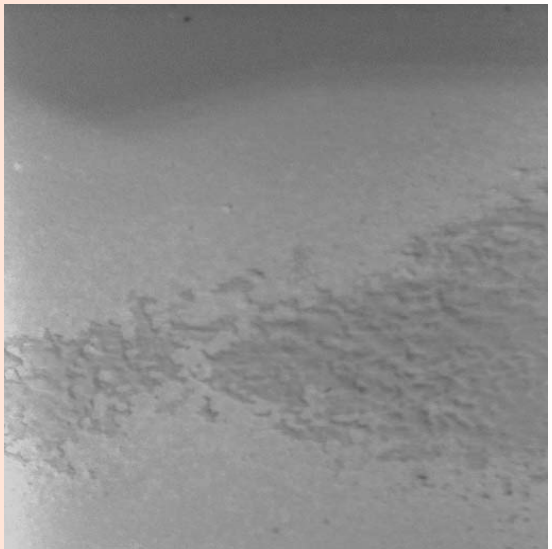
Leading Edge



Leading Edge



Leading Edge



Top Platform

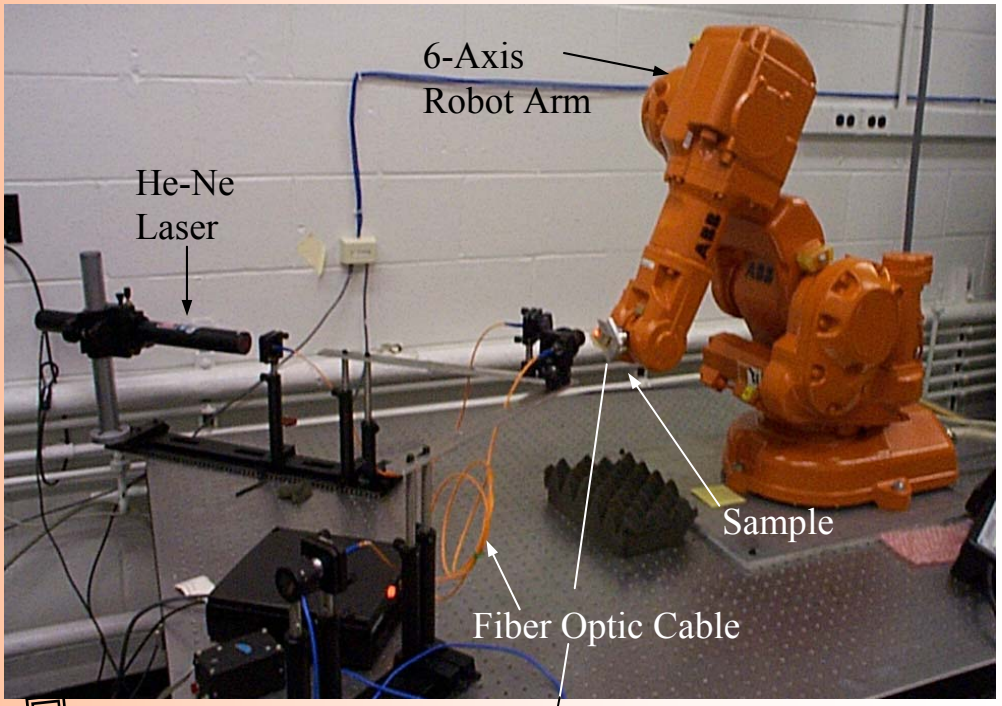
Laser Scans

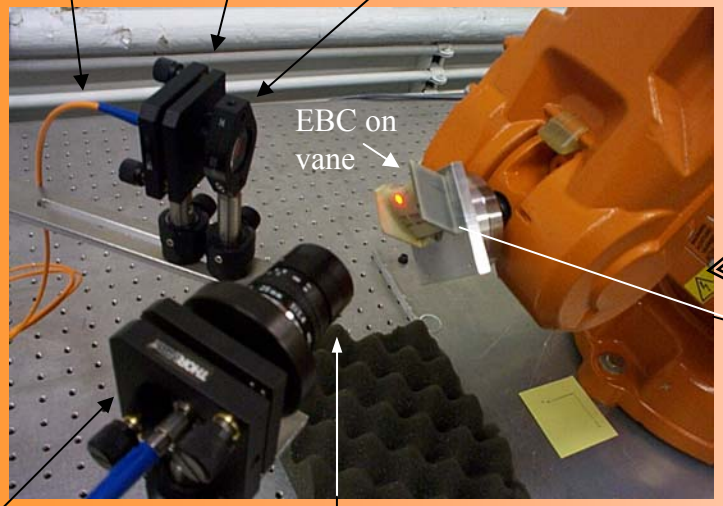
ARGONNE'S 6-AXIS COMPUTER CONTROLLED ROBOT ARM FOR NDE OF COMPLEX SHAPES

Robot Motion Characteristics

Position Repeatability = ±0.03mm

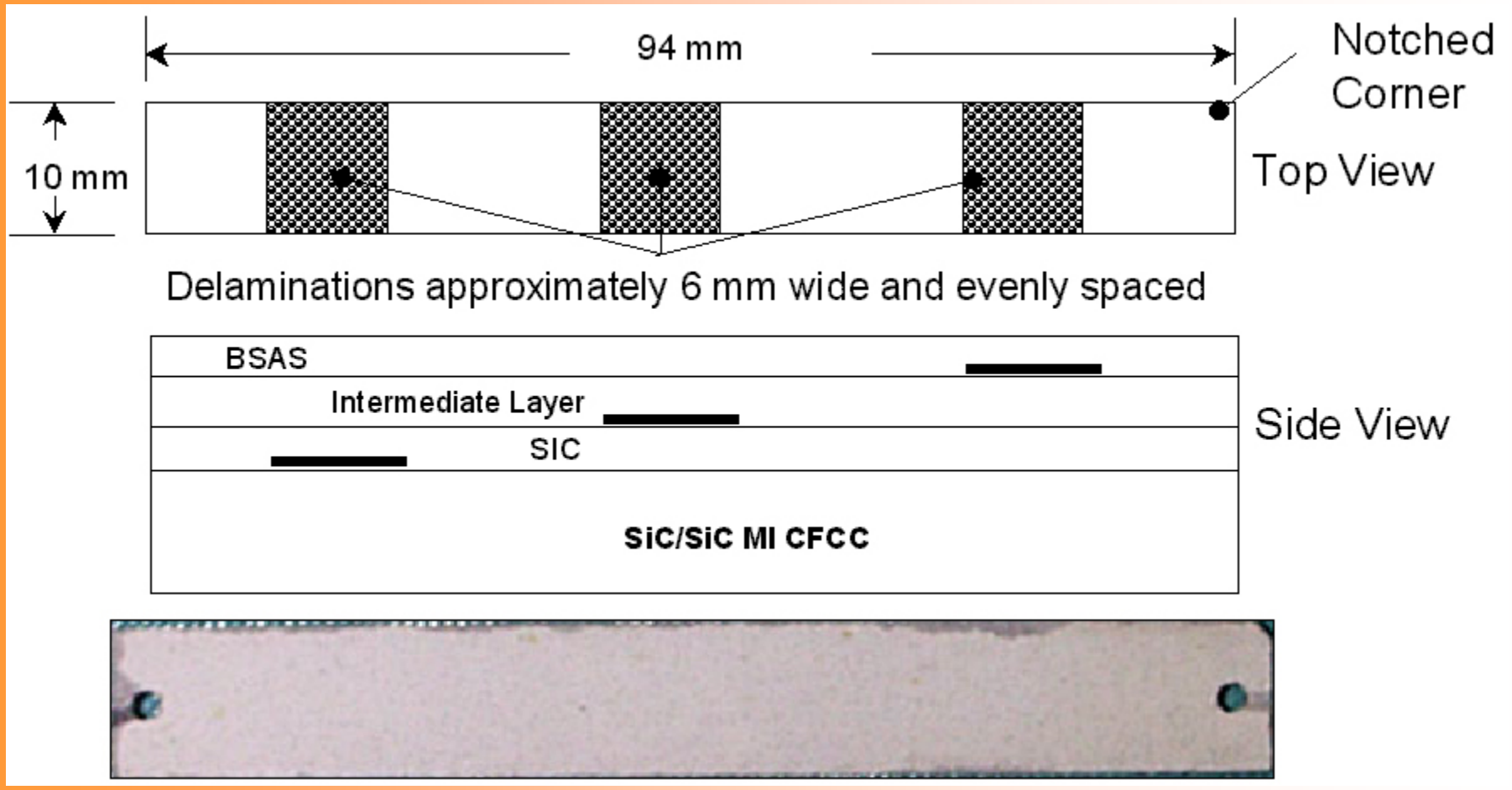
Rotational Axes Resolution = 0.01°





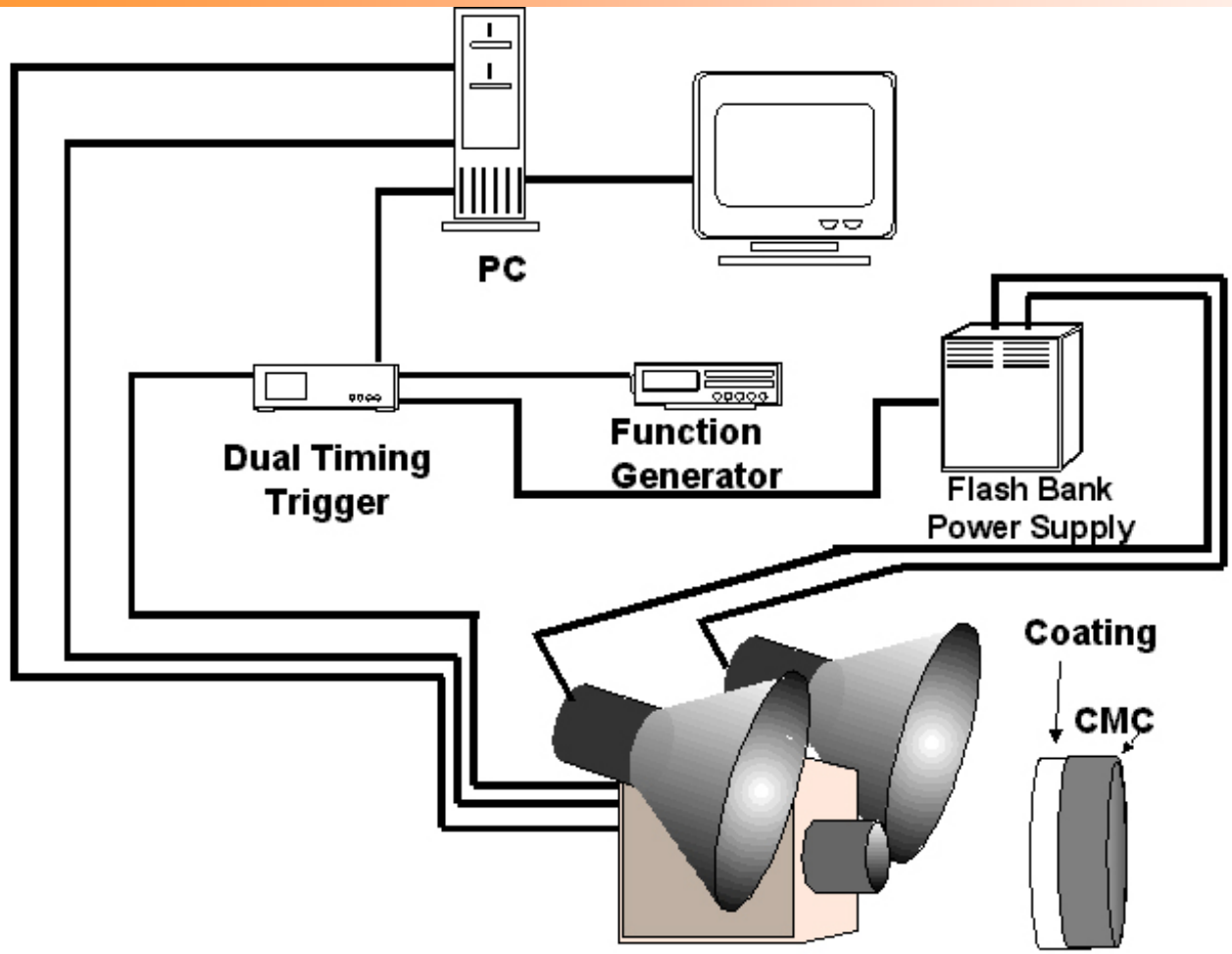
EBC SEEDED DEFECT COUPONS FOR NDE

-DELAMINATIONS-



Test Samples Provided by UTRC

THERMAL IMAGING NDE EXPERIMENTAL APPARATUS

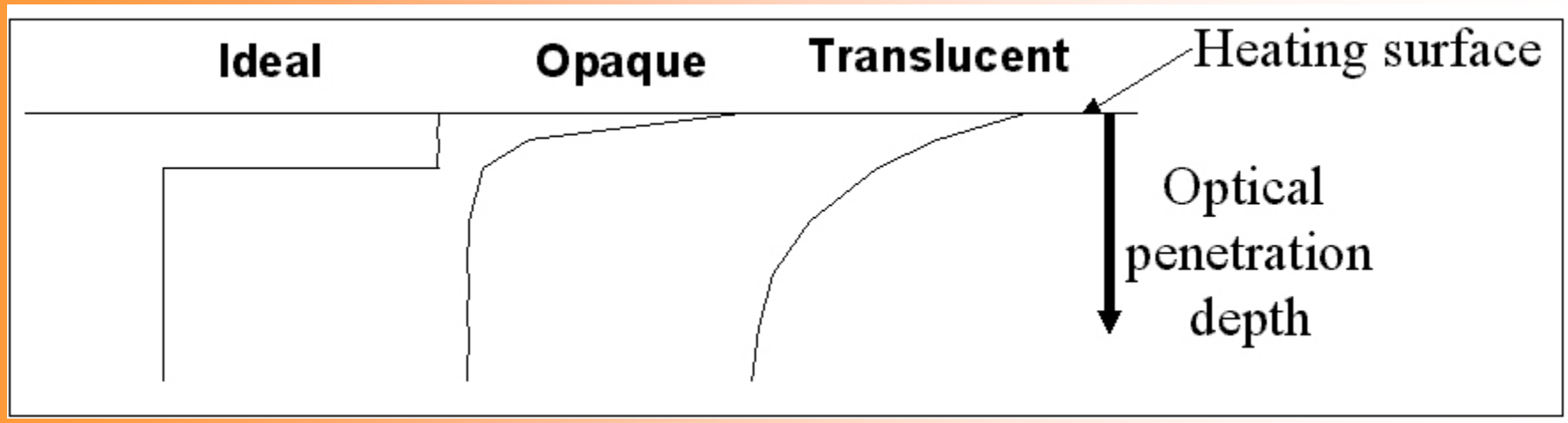


Detector

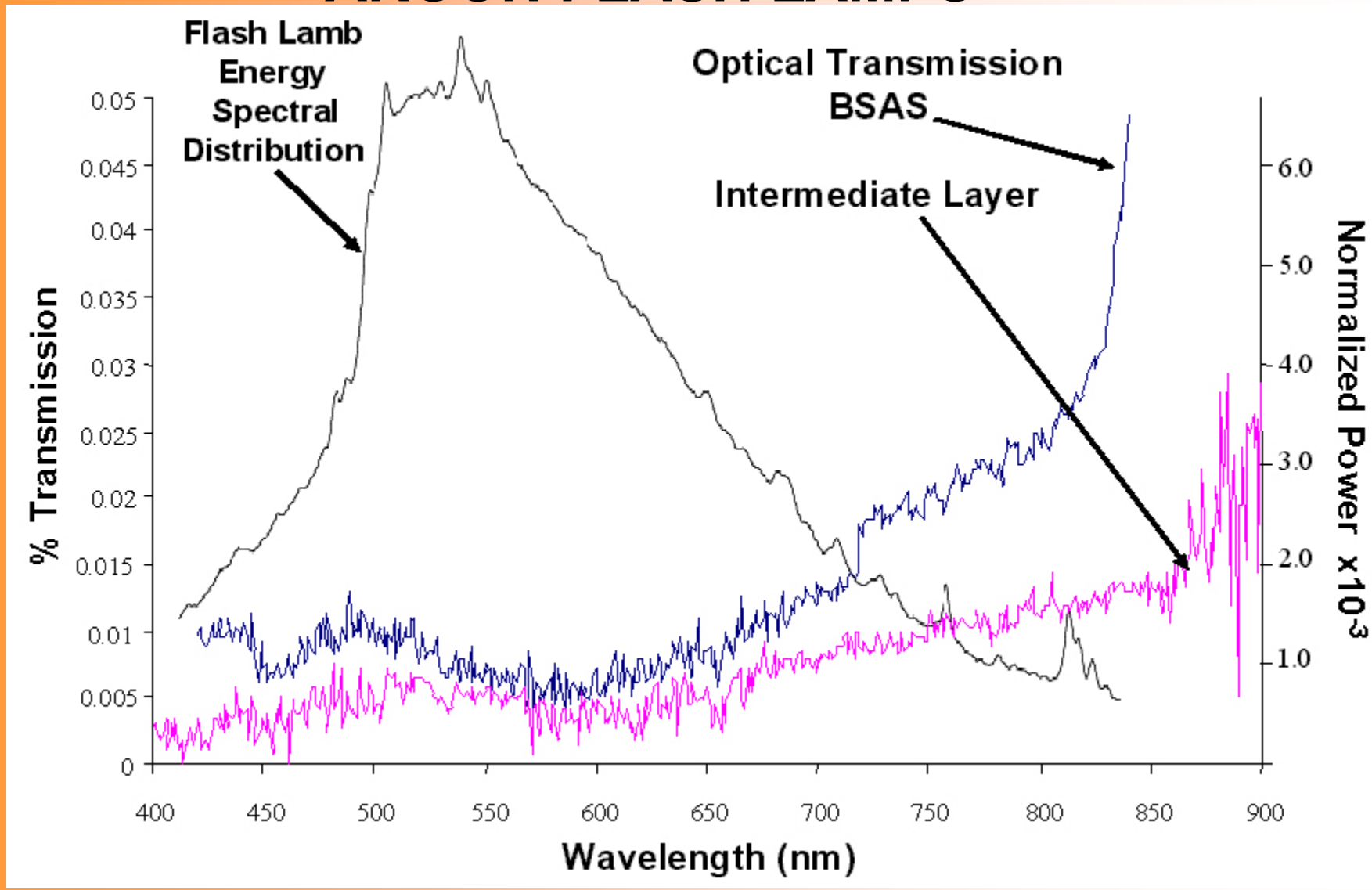
- 256x256, InSb, 200 mm
- 12-bit dynamic range
- Full window frame rate to 120 Hz
- 64x64 window frame rate to 1900 Hz.
- Typical flash pulse width approx. 6.0 ms

EFFECT OF OPTICAL PROPERTIES

- Parker's theory of the surface temperature decay assumes material is heated with a step heating pulse whose penetration depth is negligible
- This assumption is appropriate for optically opaque materials
- Absorption depth cannot be considered negligible for translucent materials and introduces volumetric heating



OPTICAL SPECTRAL ENERGY DISTRIBUTIONS OF ARGON FLASH LAMPS



ONE SIDED THERMAL IMAGING OF SEEDED COUPON

closest to surface

.1 sec

.2 sec

.3 sec

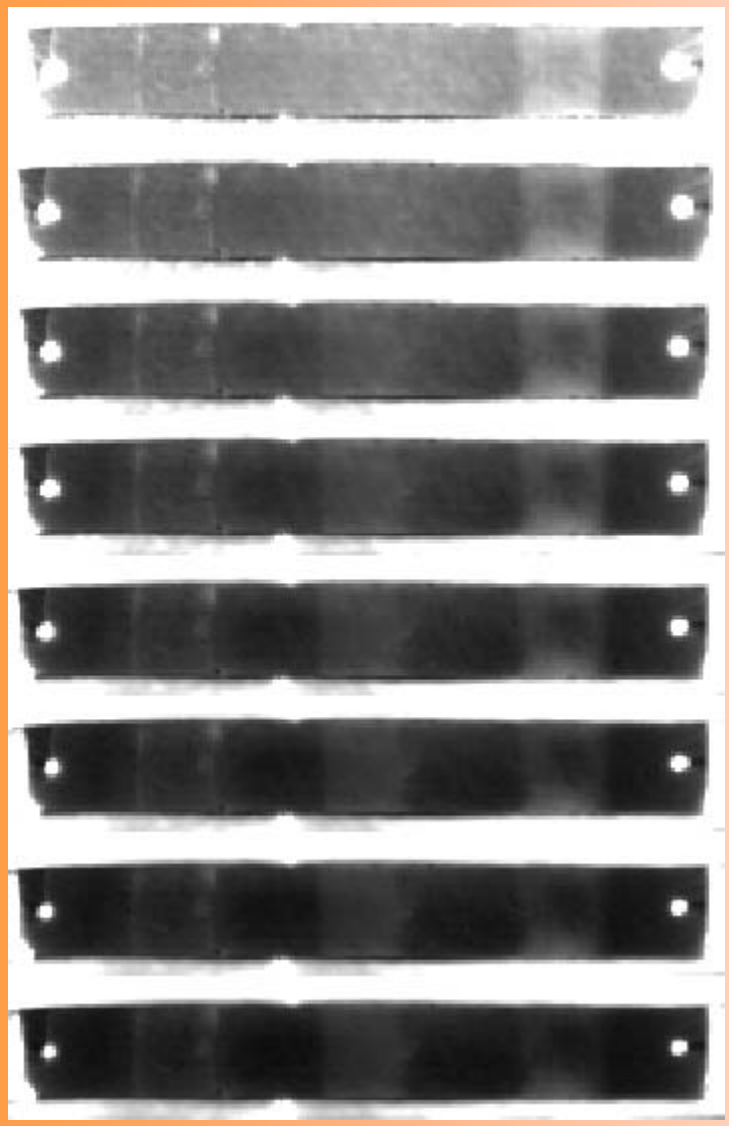
.4 sec

.5 sec

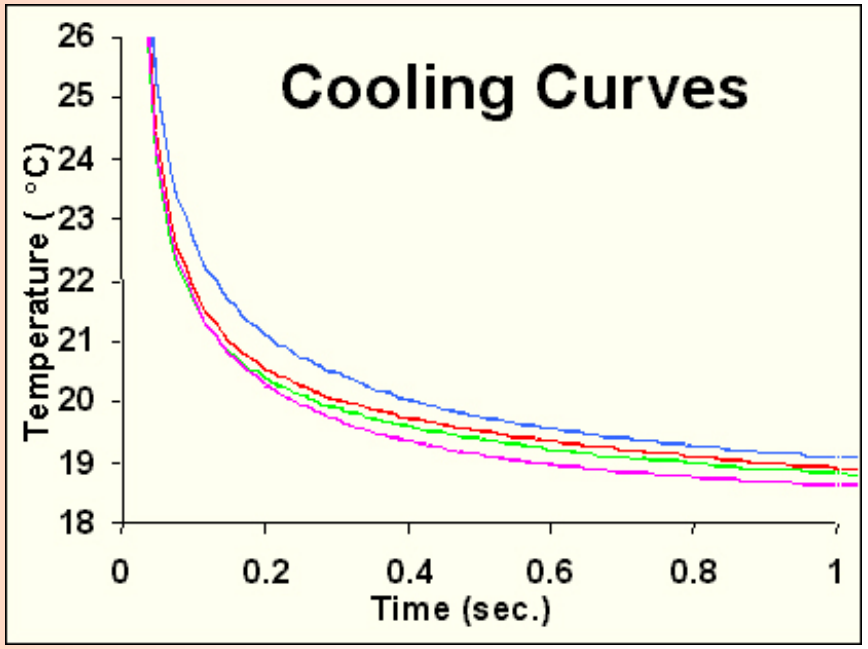
.6 sec

.7 sec

.8 sec



Diffusivity Map



If volumetric heating was significant, seeded delamination would be indistinguishable from non-flawed regions

Future Plans for EBC

Monolthics

- Examine correlation's of NDE data on Rolls-Royce/Allison EBC test specimens with additional destructive analysis
- Determine effects of other EBC systems, specimens from UTRC, on the NDE response signals
- Conduct limited impact damage test, examine specimen (AS800/Honeywell EBC) with laser scatter data, and one-sided thermal imaging
- Establish optical transmission characteristics of free-standing EBC (Honeywell and perhaps UTRC)

Composites

- Conduct one-sided NDE studies of special test samples of MI SiC/SiC with UTRC EBC [BSAS/mixed]
- Obtain new set of MI SiC/SiC samples with SAS/mixed EBC
- Conduct optical transmission characteristics of SAS and SAS/mixed

Summary/Conclusions

- Have demonstrated a technology which may reduce ceramic rotor cost through improved yields via full volume 3D X-ray imaging. This is well under way
- Results of full volume 3D CT suggest detection of < 400 um features in rotor up to 23cm in diameter
- 3D CT data also allows dimensional data but accuracy not yet established
- Automation of 3D X-ray image data via use of automated feature detection will be pursued in next 12 months
- Elastic optical laser scattering and thermal imaging technology is under development to characterize EBC coatings for uniform thickness, detecting and sizing delaminated regions, estimating size and extent of FOD
- Elastic optical laser scattering appears to provide a fast and accurate means to monitor coating thickness on of EBCs
- One-sided thermal imaging while full field and fast, currently seems less sensitive to features
- Extensive cooperation has been established with many partners

Summary/Conclusions

- Selected, purchased, installed, and initially tested 6-axis articulated arm robot in order to handle complex shapes like blades and vanes
- One-sided thermal imaging while full field and fast, currently seems less sensitive to features
- Extensive cooperation for all aspects of this project has been established with many partners