



**PSCCMW  
Galveston  
2002**

# **Development of NDE Technology for Environmental Barrier Coatings and Residual Life Estimation**

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# OUTLINE

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- Results of NDE: EBCs for SiC/SiC
- Results of NDE: Pre-spall detection of TBC's
- Outline of new Effort for NDE of oxide/oxides
- Concluding Remarks



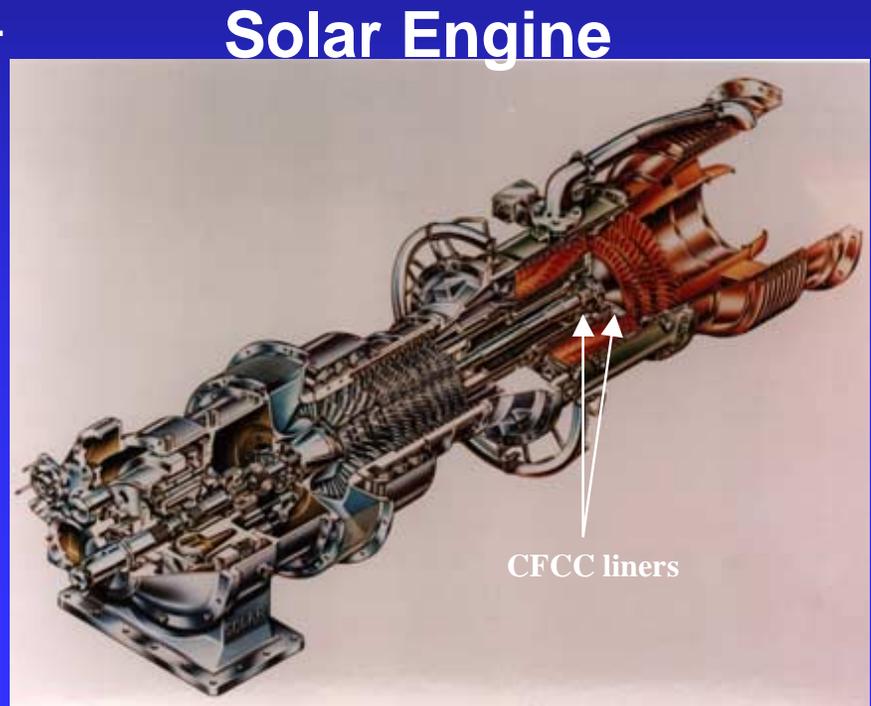
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# EBC on SiC/SiC

**Objective:** Can NDE technology provide pre-spall detection and track accumulated damage on EBC coated ceramic composites for turbine combustors



**Solar Combustor**

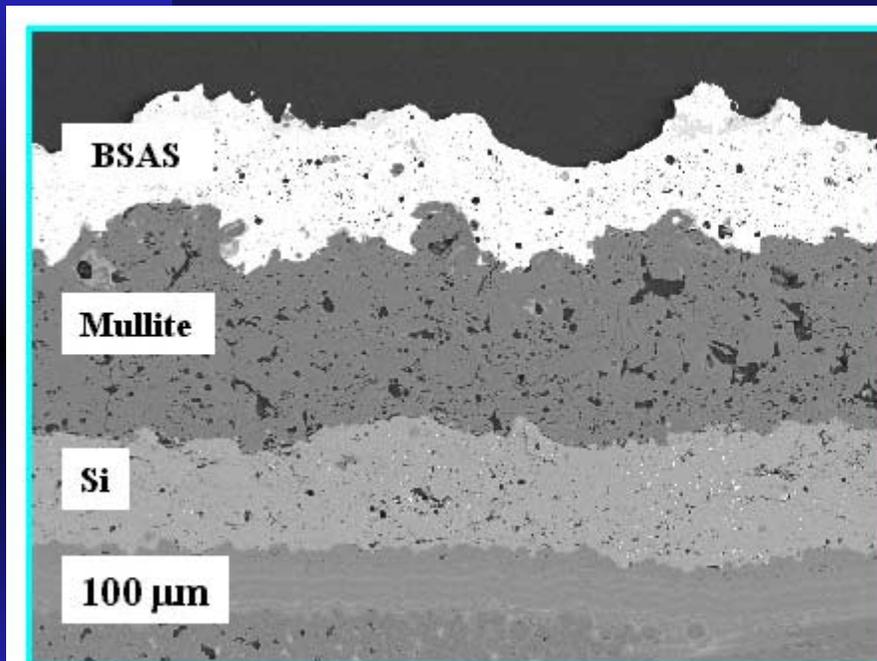


**Solar Engine**

# MICROSTRUCTURE OF EBC AS DEPOSITED ON MI SIC/SIC COMPOSITE

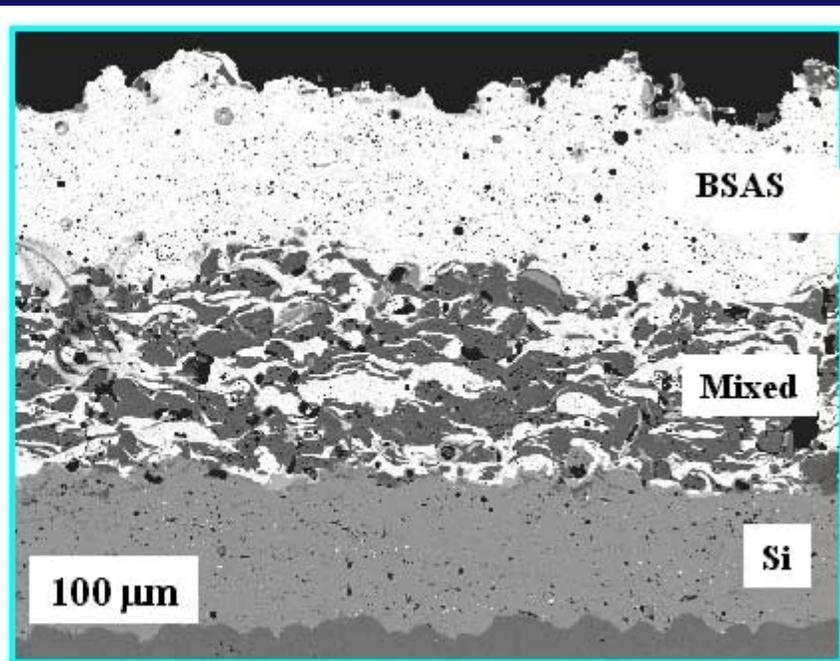
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Plasma sprayed coatings consist of two layers on a Si bond coat and CVD SiC seal coat



“Dual layer” Mullite/BSAS

Currently on Inner Liner at Texaco



“Mixed layer” (Mullite+BSAS)/BSAS

Currently on Outer Liner at Texaco  
and on both liners at Malden Mills



# NDE APPROACHES AT ANL

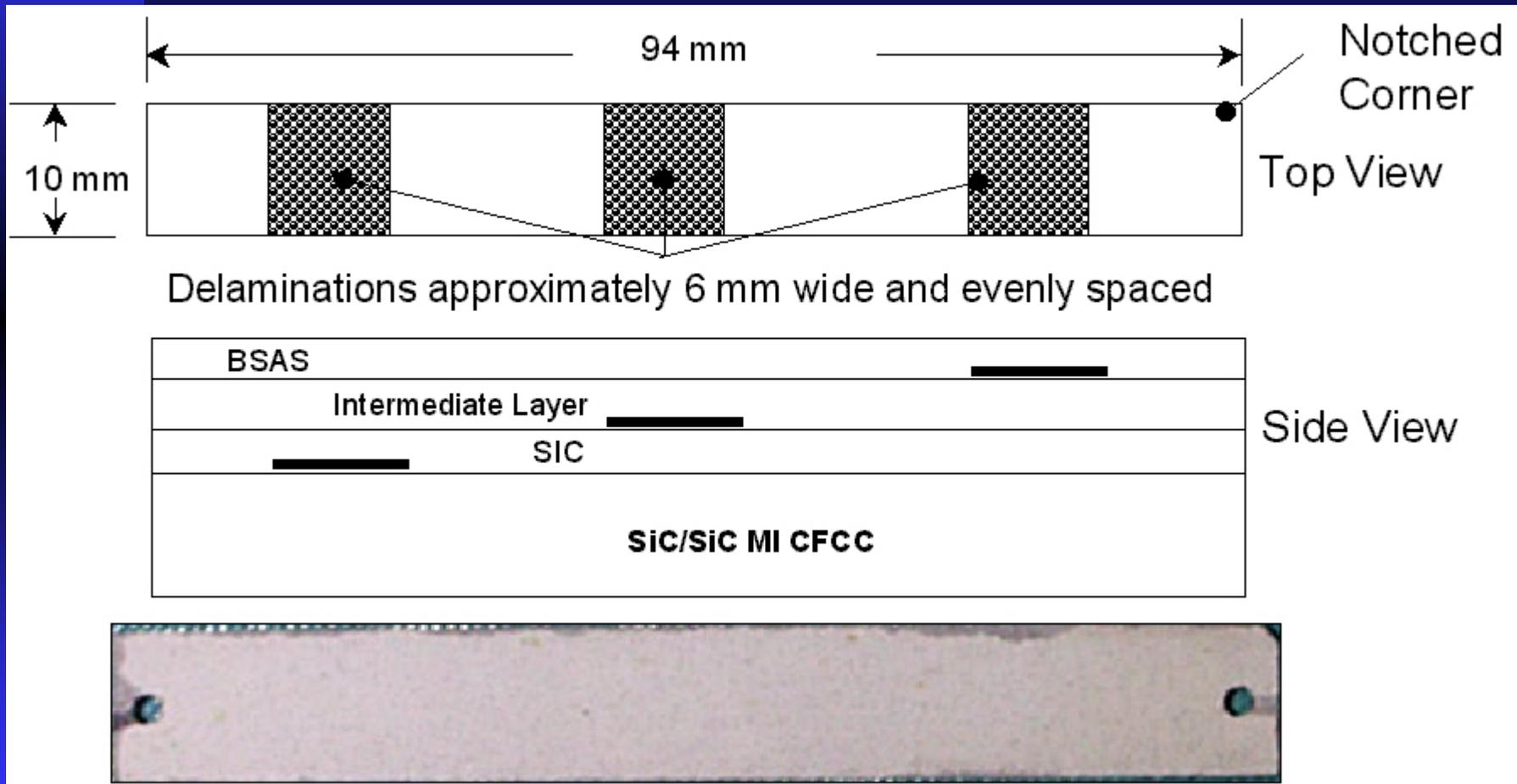
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- **Spectrally tuned flash infrared imaging**
  - ◆ through transmission
  - ◆ one-sided
- **Air-coupled ultrasonics**
  - ◆ through transmission
  - ◆ one-sided



# EBC SEEDED DEFECT COUPONS FOR NDE -DELAMINATIONS-

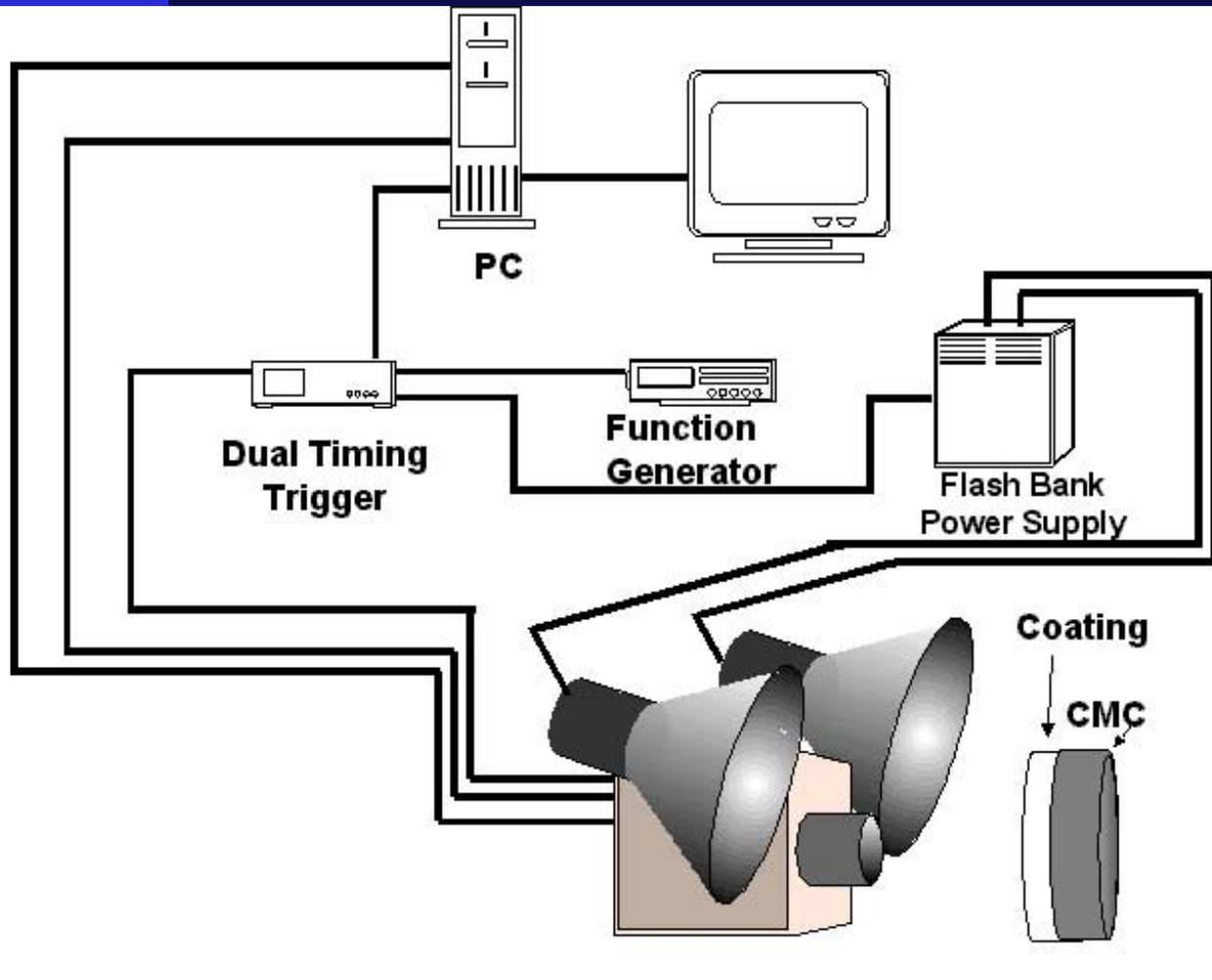
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Test Samples Provided by UTRC

# THERMAL IMAGING NDE EXPERIMENTAL APPARATUS

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## Detector

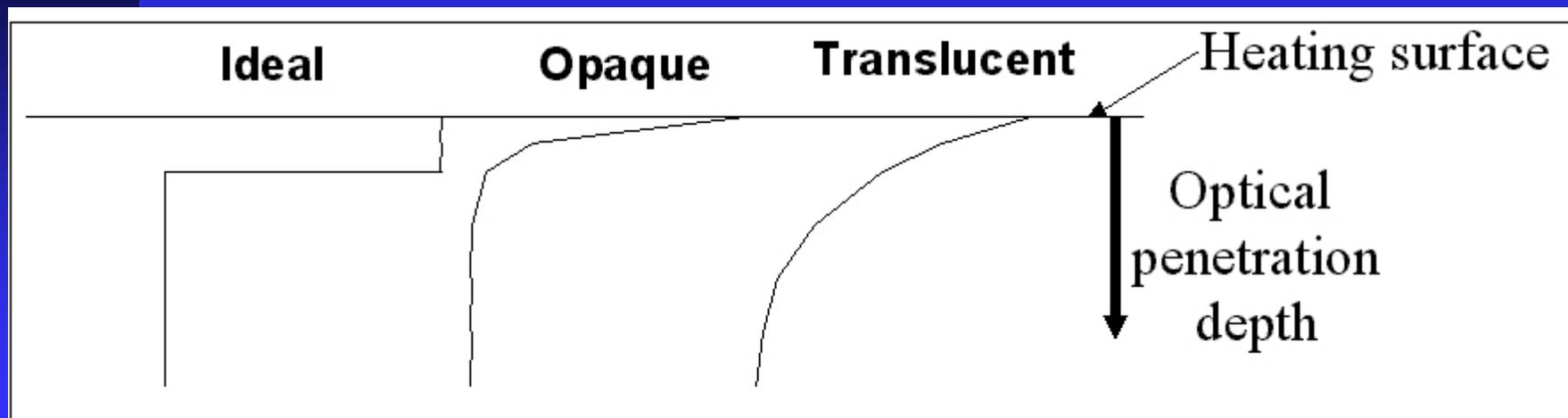
- 256x256, InSb, 200 mm
- 12-bit dynamic range
- Full window frame rate to 120 Hz
- 64x64 window frame rate to 1900 Hz.
- Typical flash pulse width approx. 6.0 ms



# EFFECT OF OPTICAL PROPERTIES

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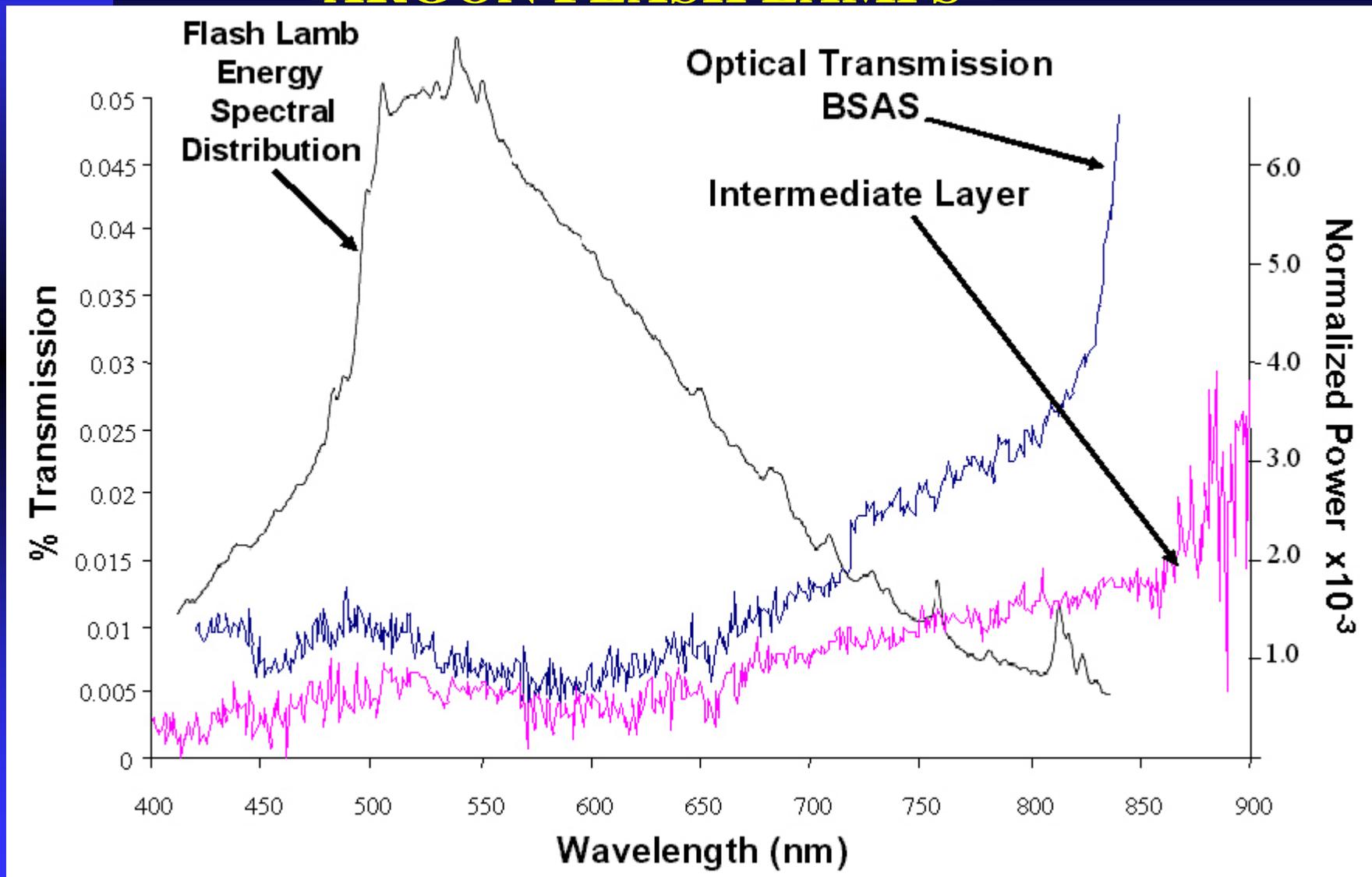
- Parker's theory of the surface temperature decay assumes material is heated with a step heating pulse whose penetration depth is negligible
- This assumption is appropriate for optically opaque materials
- Absorption depth cannot be considered negligible for translucent materials and introduces volumetric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





# OPTICAL SPECTRAL ENERGY DISTRIBUTIONS OF ARGON FLASH LAMPS

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# ONE SIDED THERMAL IMAGING OF SEEDED COUPON

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closest to surface →

.1 sec



.2 sec



.3 sec



.4 sec



.5 sec



.6 sec



.7 sec

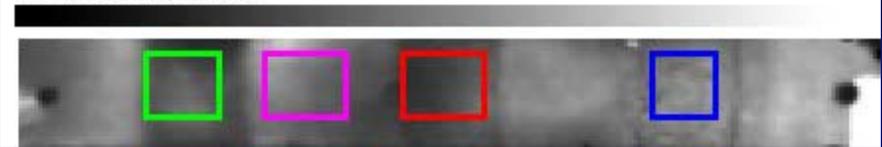


.8 sec

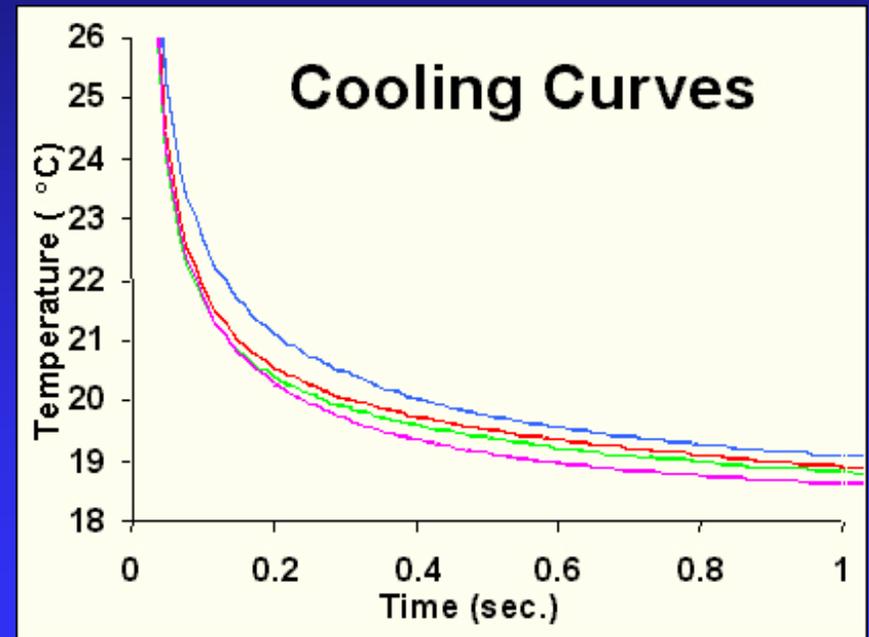


Lower Temperature

Higher Temperature



Diffusivity Map

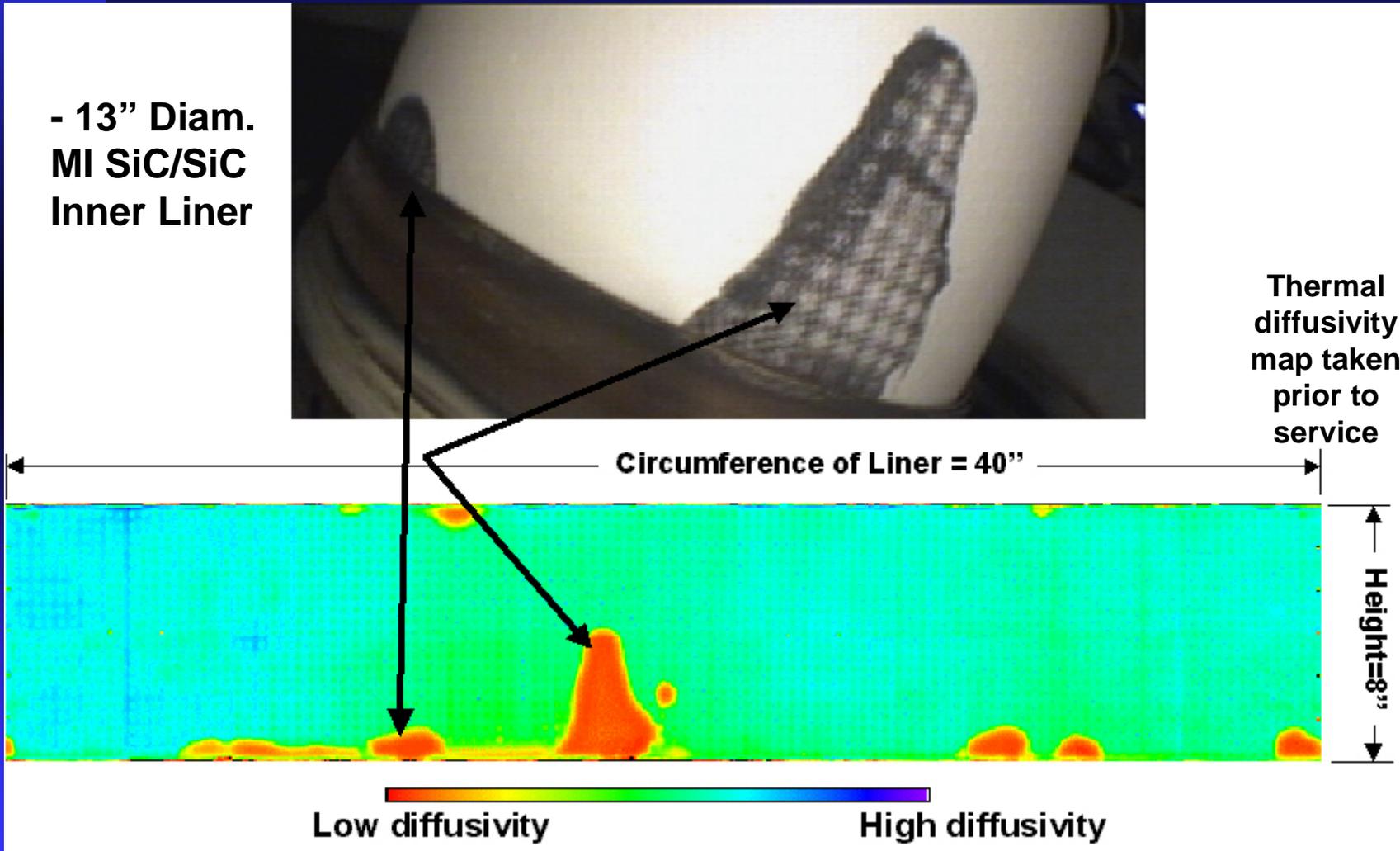


If volumetric heating was significant, seeded delamination would be indistinguishable from non-flawed regions Argonne National Laboratory



# CORRELATION OF NDE PREDICTED DAMAGE WITH BOROSCOPE OBSERVATION FOR EBC LINER

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# SPALLATION OF EBC COATED LINER

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4533  
hours



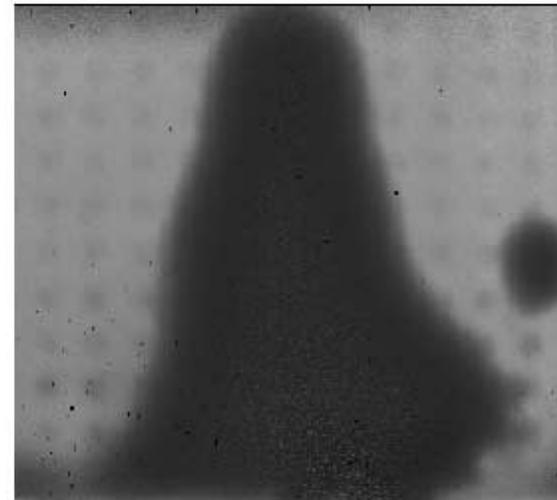
7317  
hours



14,000  
hours



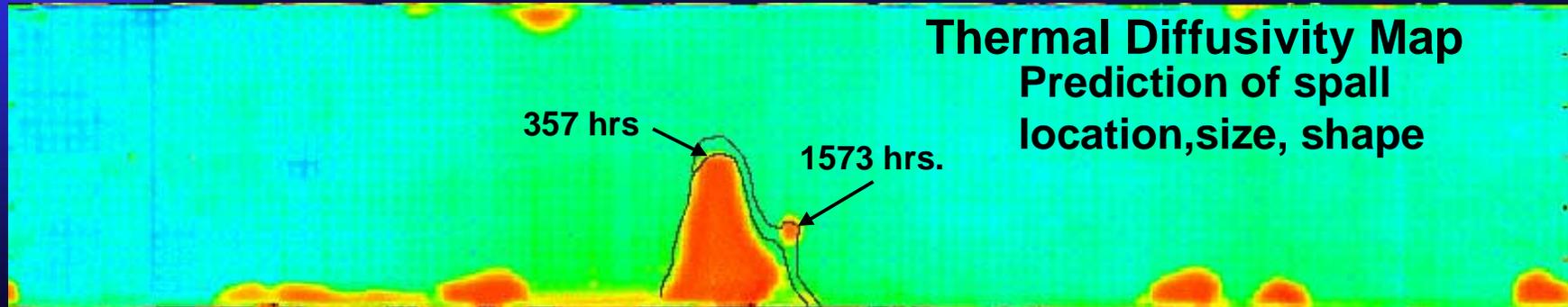
Thermal  
Diffusivity  
Map



Boroscope Images Courtesy of Solar Turbines

Argonne National Laboratory

# NDE PREDICTED SPALL



357 hrs.

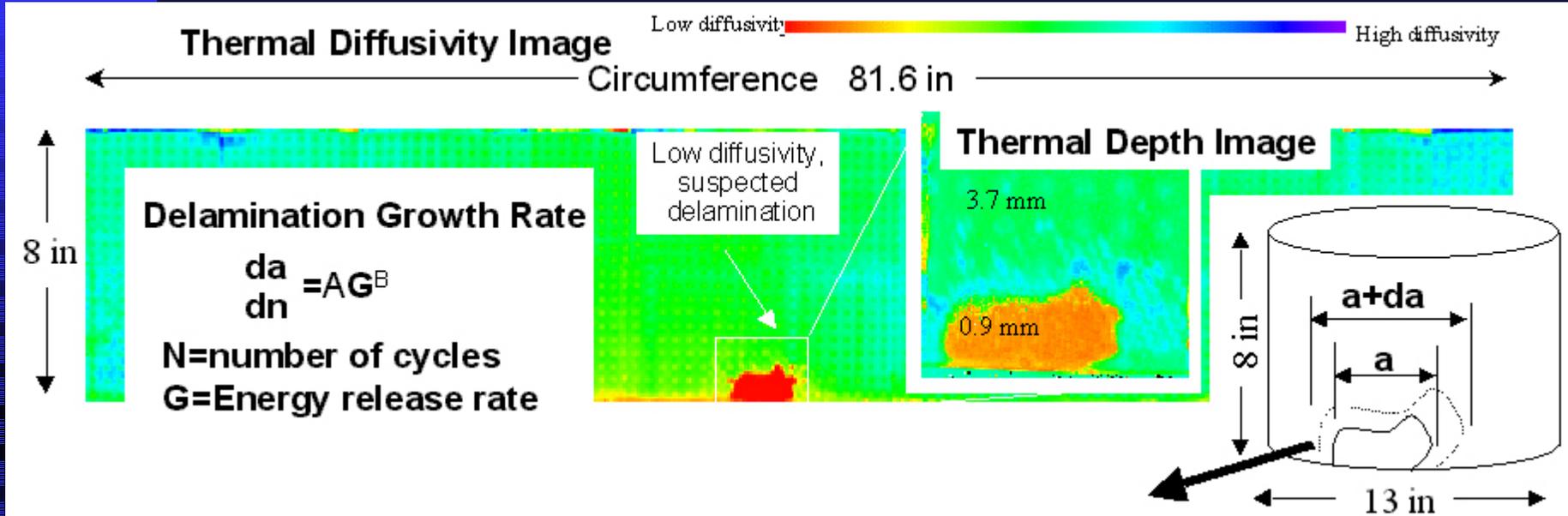
Boroscope  
Images



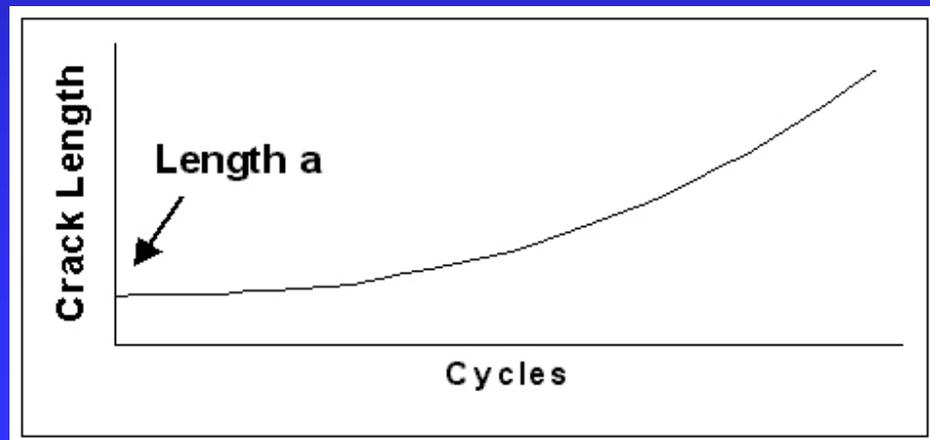
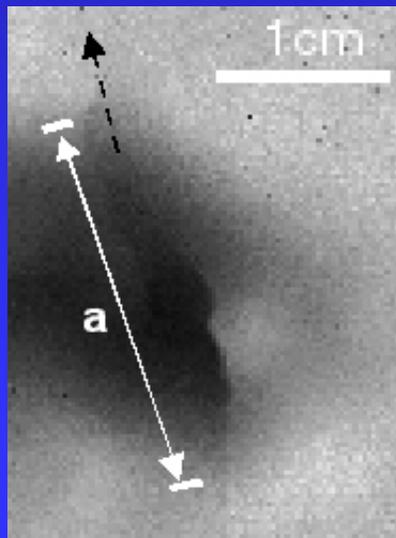
1573 hrs.



# Large Flaw Characterization



Predicted Crack Growth Rate





## NDE STATUS: EBC

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- **Only APS BSAS top coat studied to date**
  - ◆ **with two different interlayers**
    - ◆ **BSAS/Mullite**
    - ◆ **Mullite**
- **Proper spectral luminescence flash with one-sided infrared imaging at frame rates  $> 500$  Hz has demonstrated detection of pre-spall**
- **Present air-coupled ultrasound system not as discriminating for delam detection of these systems**



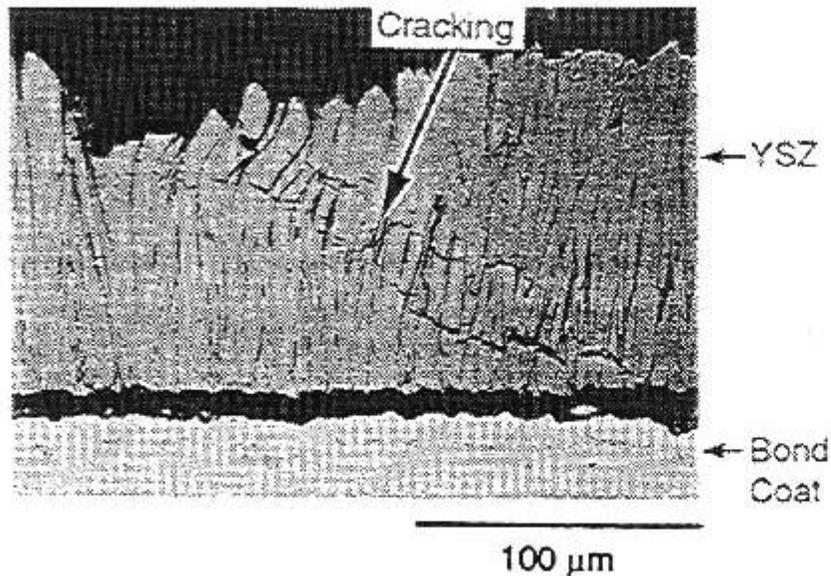
# **NDE FOR TBC CONDITION AT ENGINE SHUT DOWN**

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- **Determine size of potential pre-spall regions**
- **Determine size of any areas affected by FOD**
- **Determine extent of cracking caused by TMF**
- **Can NDE data be coupled to appropriate residual life models**

# EXAMPLES OF DIFFERENT TYPES DAMAGE/DEFECTS FOD, SURFACE CRACKS

## FOD

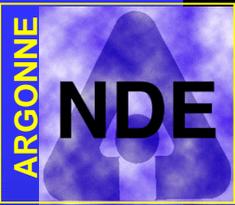


Micrograph of TBC Showing  
Cracking Due to Particle  
Impact Damage

## CRACKS

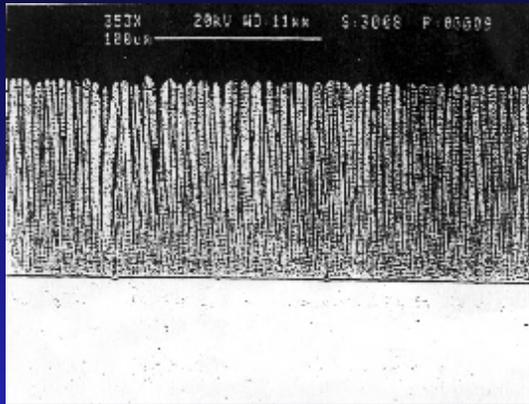


EB-PVD Yttria Stabilized Zirconia Coated  
Blade Showing Coating Distress and  
Cracking Near Trailing Edge

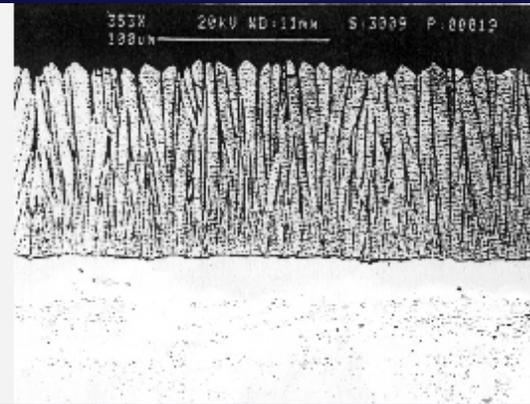


# EFFECT OF BOND COAT SURFACE TEXTURE ON EB-PVD MICROSTRUCTURE

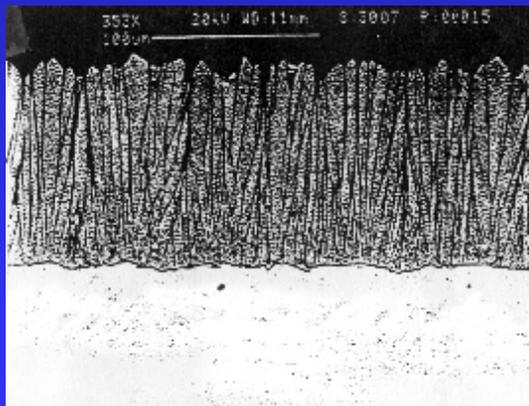
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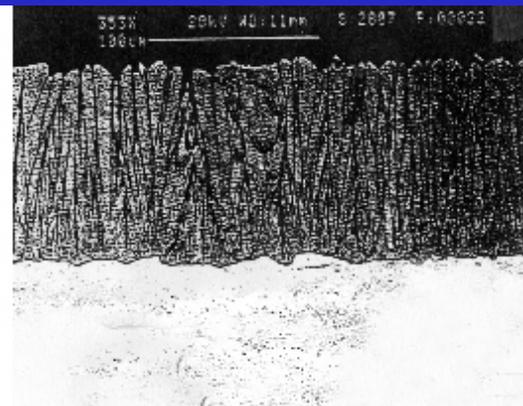
Polished



220 Grit



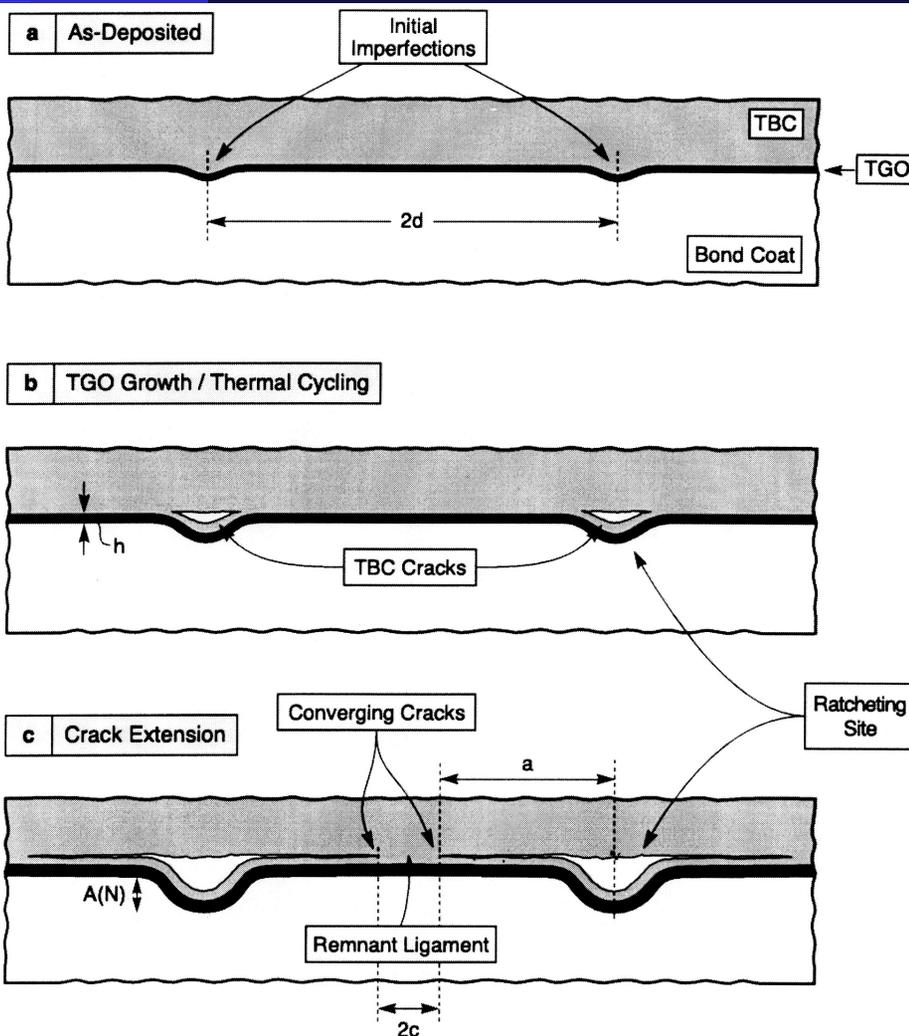
80 Grit



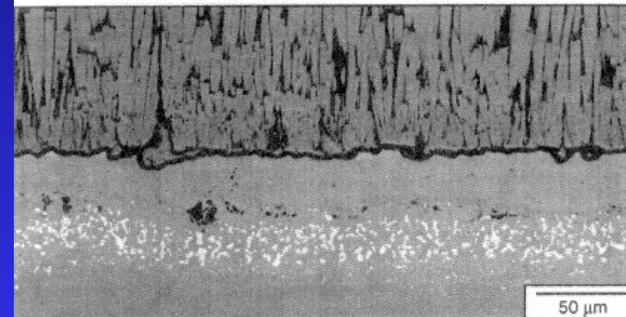
54 Grit

From: Rignet, et al  
at NASA conf.  
Pub. 3312, 1995

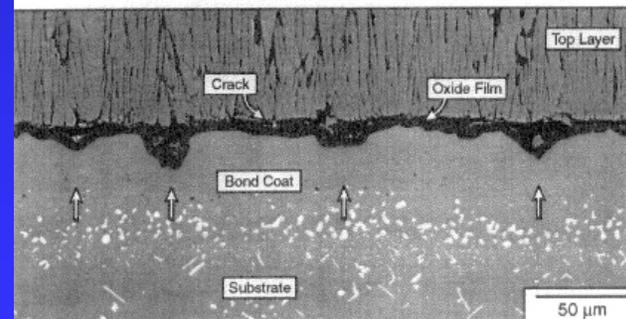
# MECHANICS OF SPALLATION OF TBC -ONE THEORY



As Received



80 Cycles



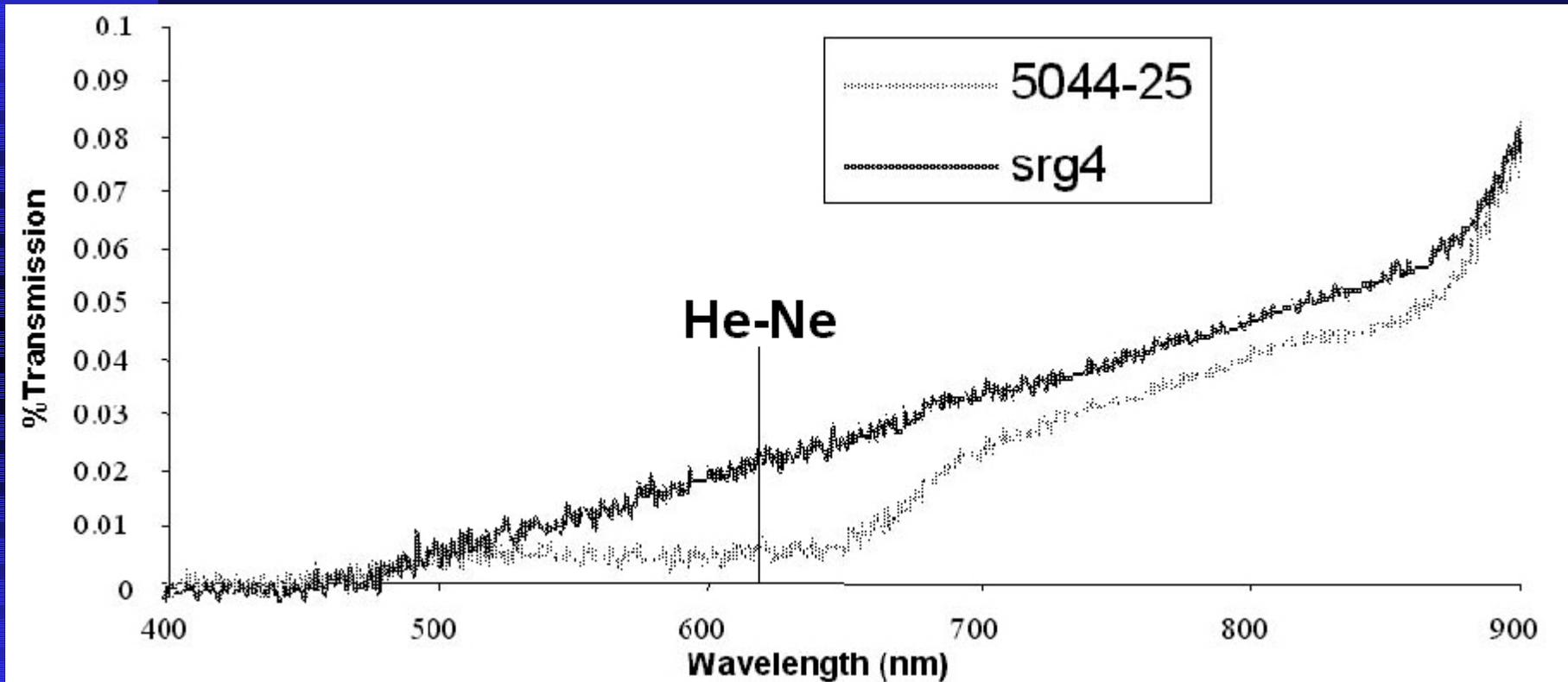
180 Cycles

After: Evens et. al, Princeton

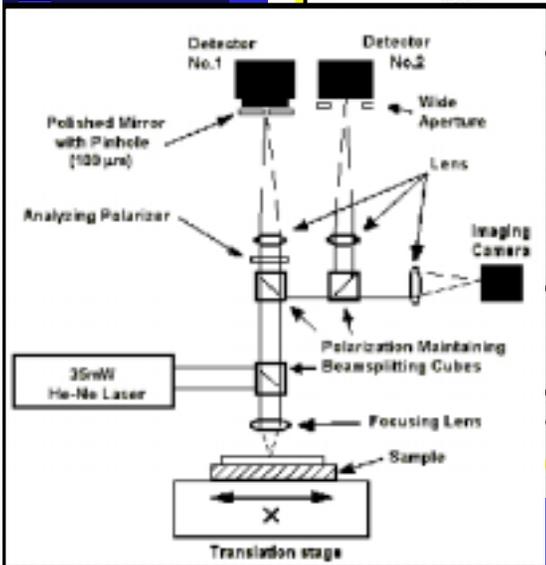
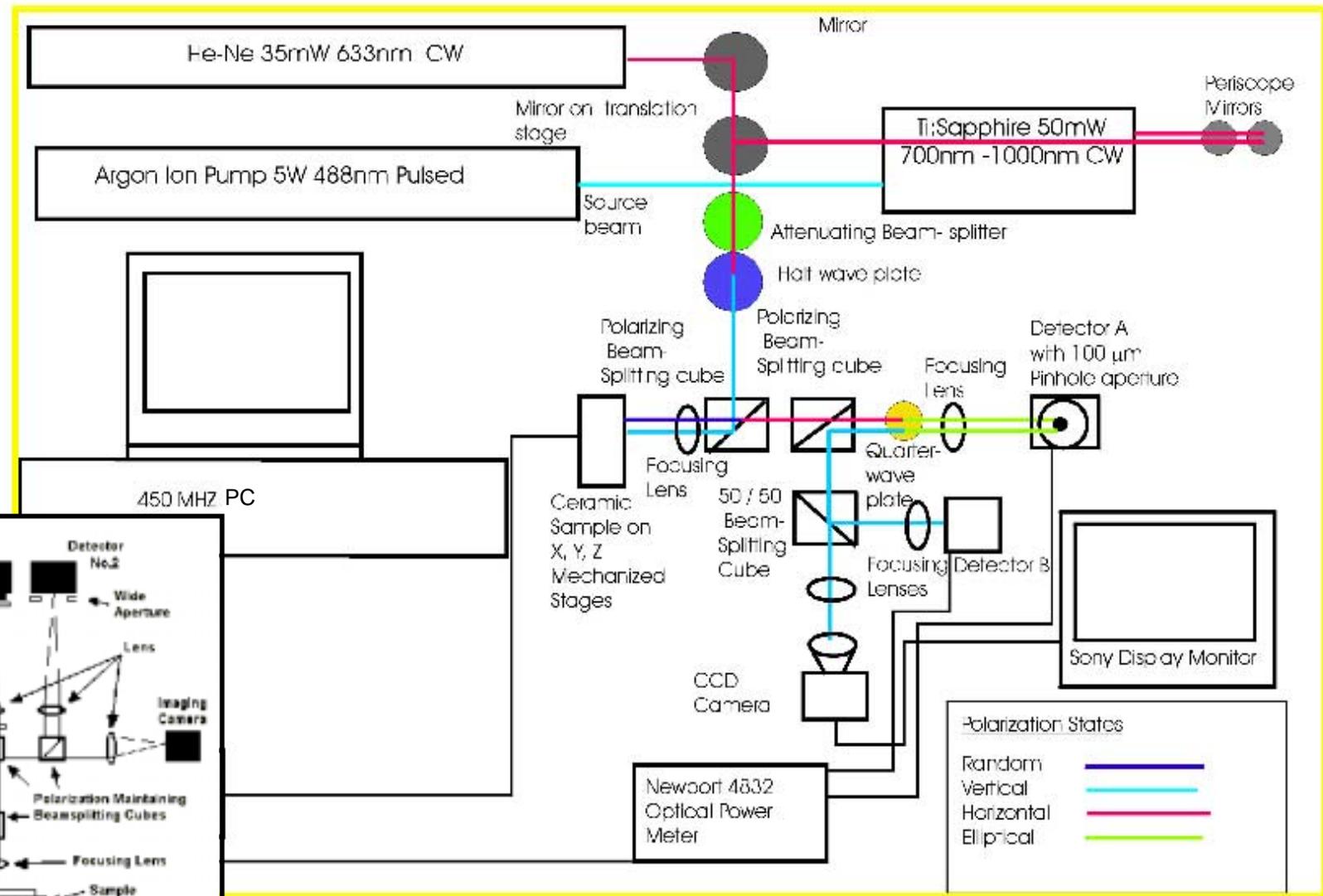


# Optical Transmission Characteristics of EB-PVD 7YSZ Coating

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# ELASTIC OPTICAL SCATTERING NDE SYSTEM



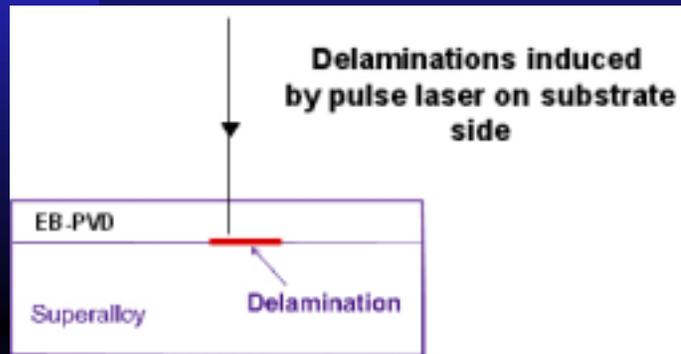


# Elastic Optical Scatter Detection of Induced Delaminations

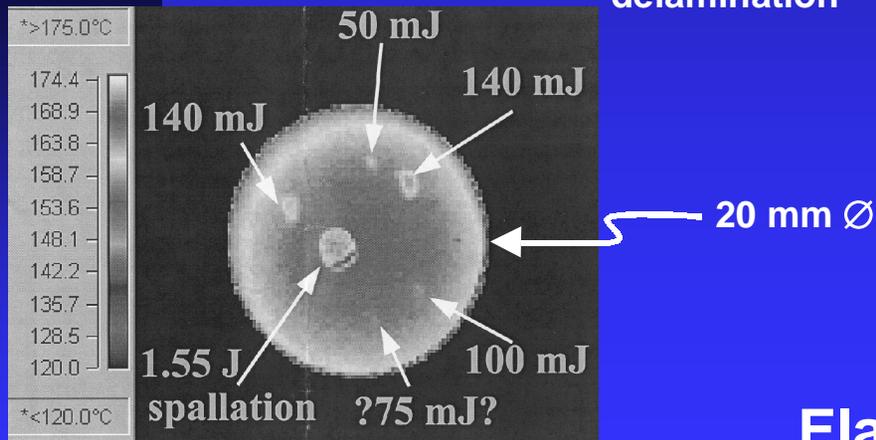
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(Sample provided by D. Clarke, UC-SB)

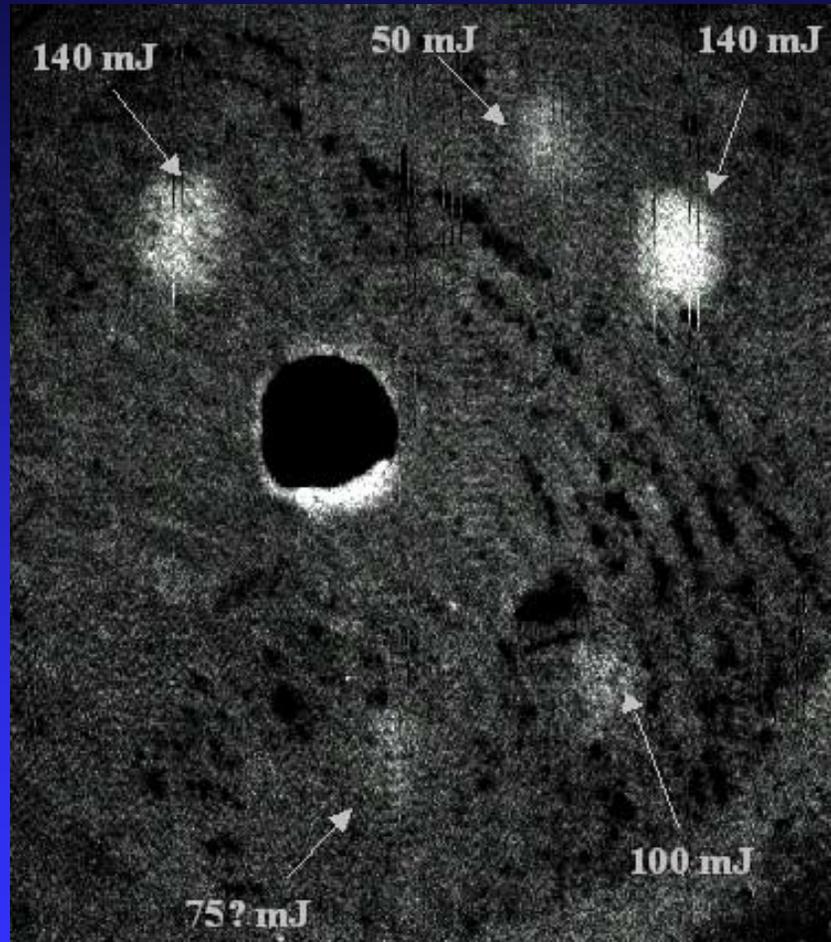
EB-PVD - No bond coat



← Laser Pulse for delamination



Thermal Image Reveals Regions of Interface Delaminations Produced By Laser Pulse. Courtesy of JRC-Petten



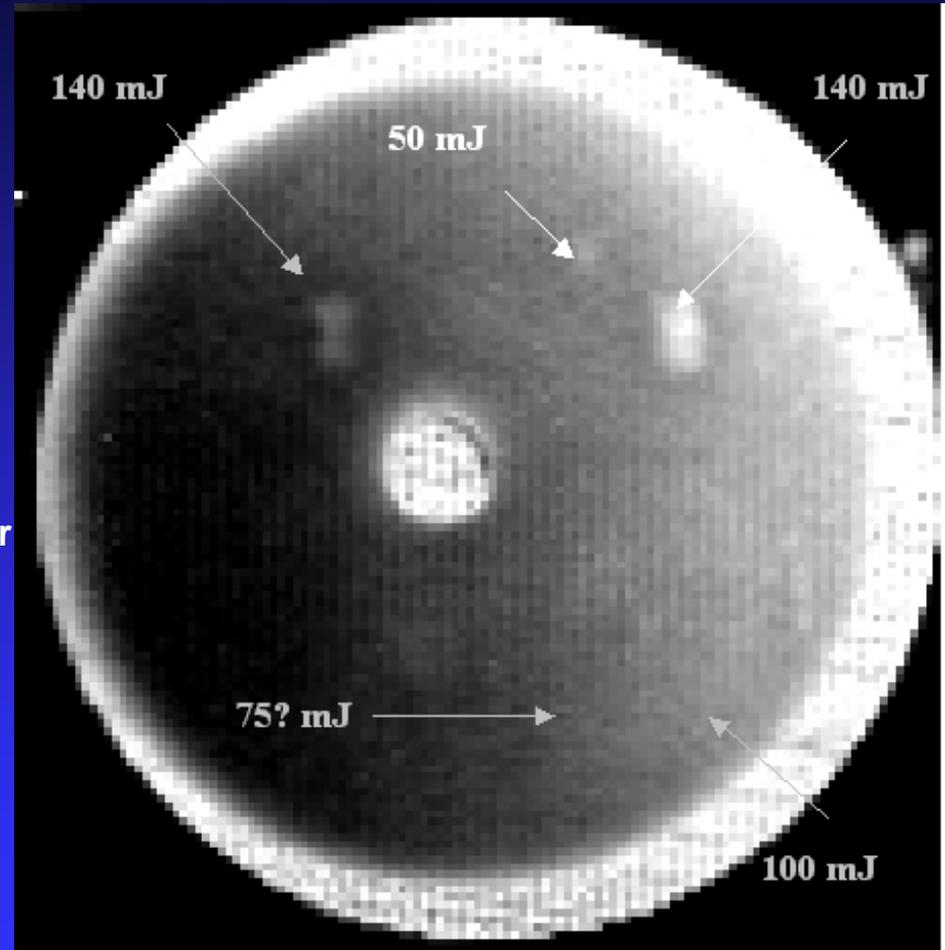
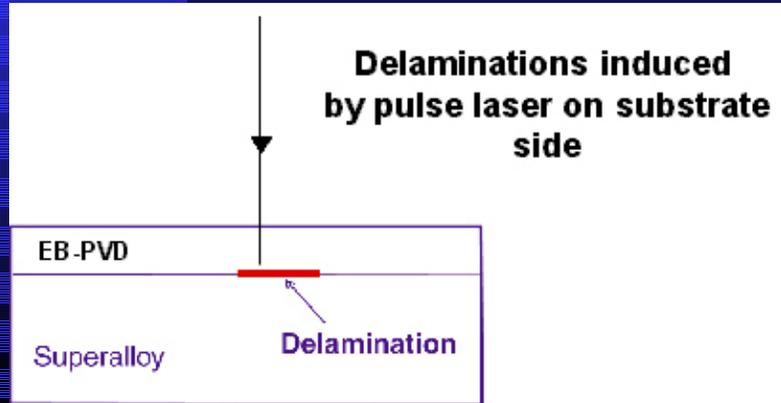
Elastic Optical Scatter Image Data  
 $\lambda=0.6328 \mu\text{m}$ , Scan Step =  $10\mu\text{m}$



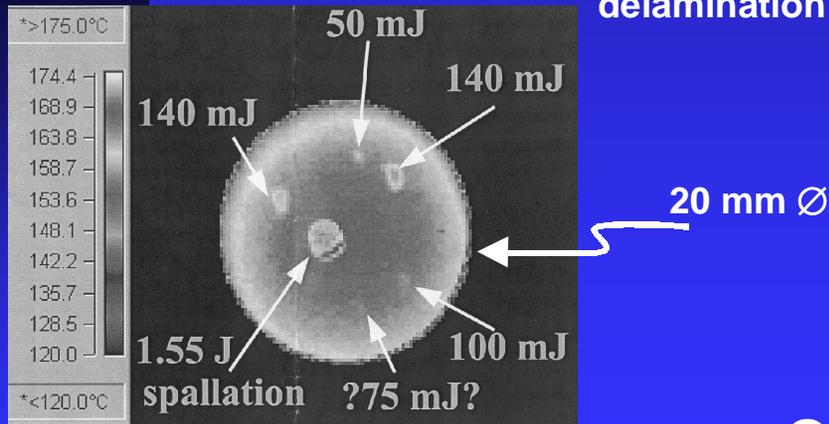
# ONE-SIDED THERMAL FLASH NDE DETECTION OF INDUCED DELAMINATIONS

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EB-PVD - No bond coat



← Laser Pulse for delamination



## One-Sided flash Time-Dependent Surface Temperature Image

Thermal Image Reveals Regions of  
Interface Delaminations Produced  
By Laser Pulse. Courtesy of JRC-Petten

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# Scanning Laser Ultrasound C-scan of EB-PVD Defect Sample

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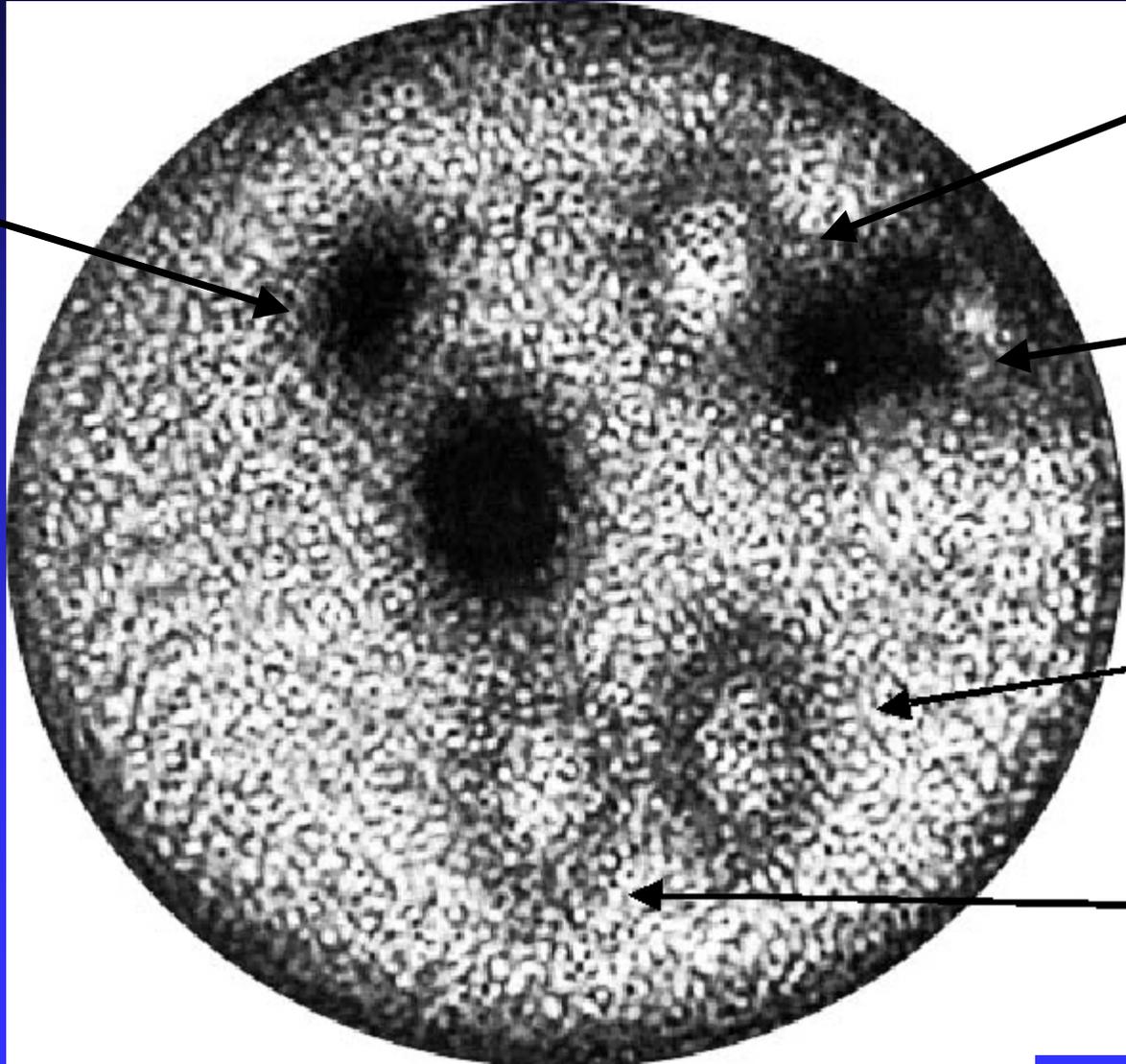
140 mJ

50 mJ

140 mJ

100 mJ

75 mJ

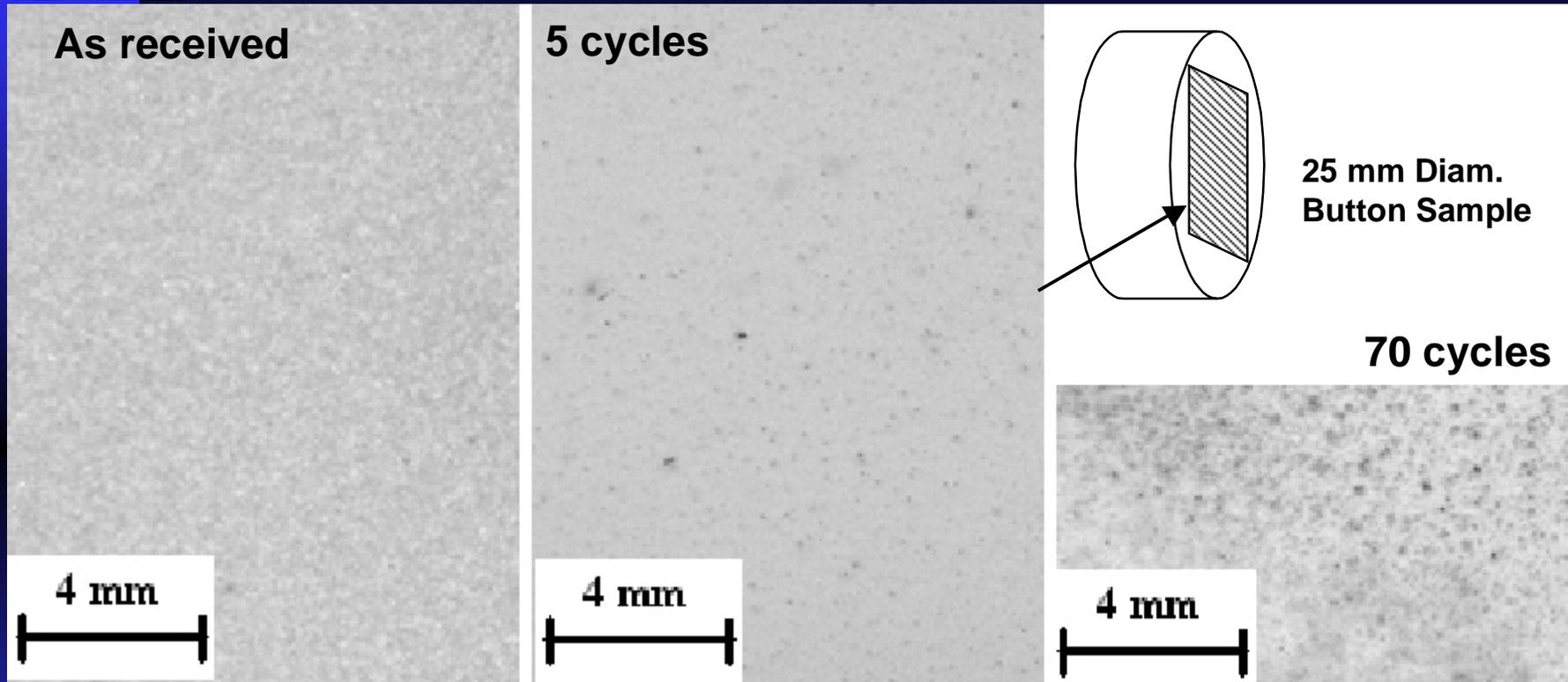


Data Obtained  
at Lasson  
Technologies



# LASER SCATTER NDE DATA FROM THERMALLY CYCLED EB-PVD TBC

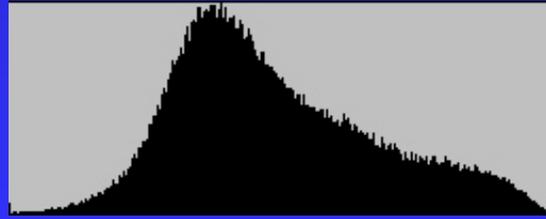
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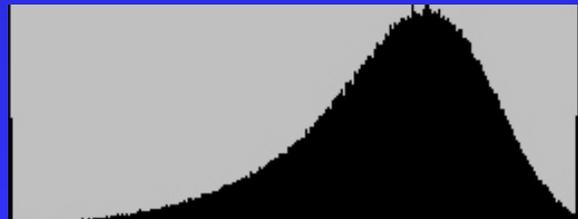
Pixel Count



Grey Scale



Grey Scale



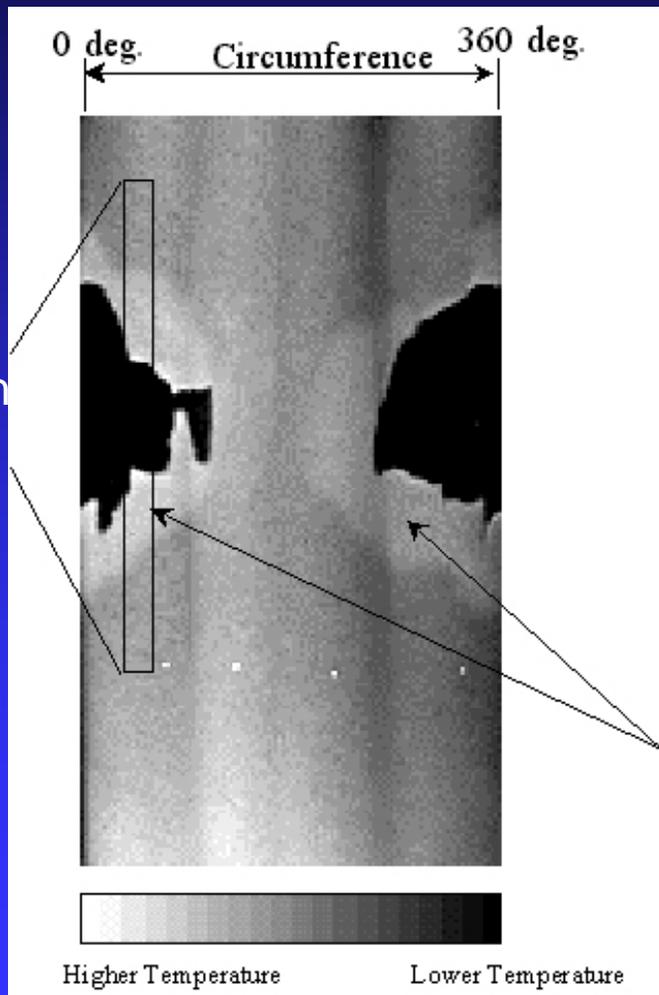
Grey Scale



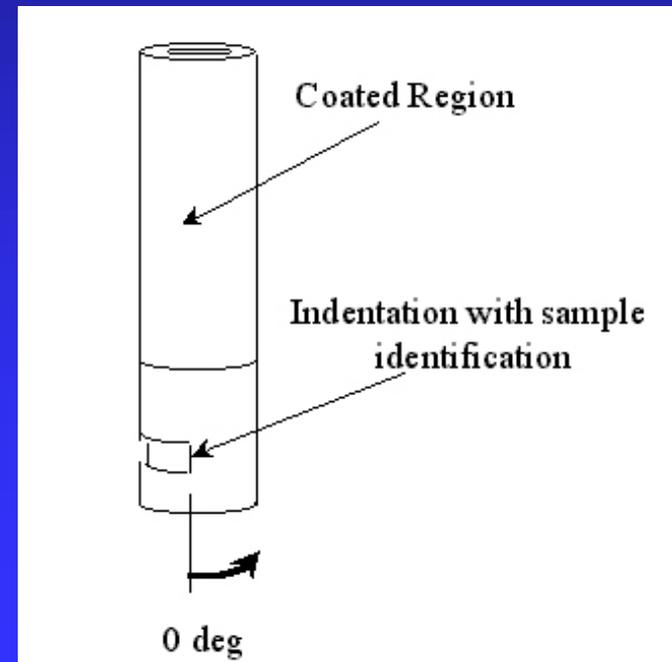
# TBC-AIR PLASMA SPRAY ONE-SIDED THERMAL DELAMINATION DETECTION

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## Thermal Image



## Experimental Setup



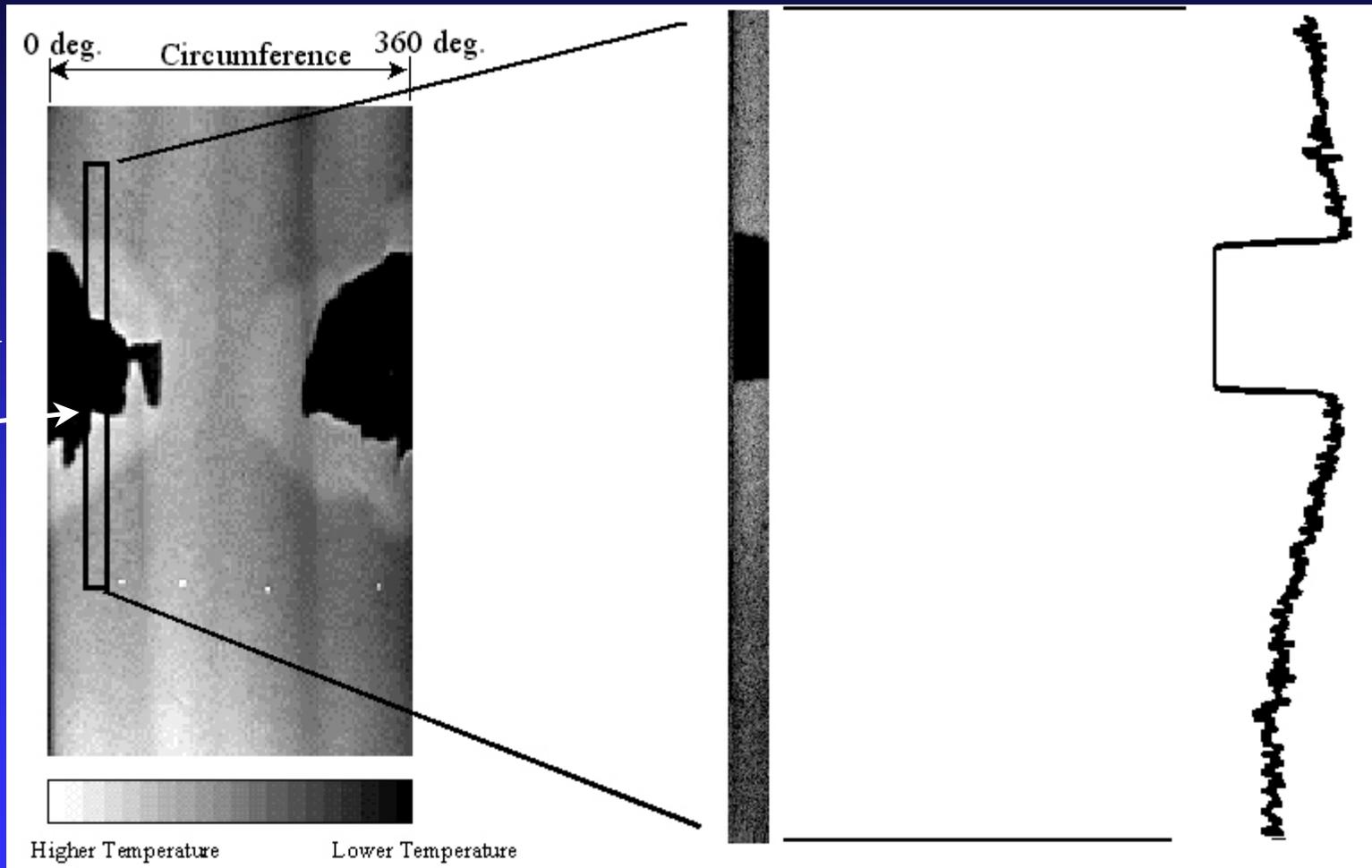


# EFFECT OF DELAMINATION ON ELASTIC SCATTER DATA

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## APS TBC

Laser Scanned Region



Front-Flash Image

Laser Scatter Image

Line plot of  
Laser Scan Data



## **NDE Status: TBC**

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- **Use of polarized back-scattering scanning laser technology has demonstrated detection of induced debonds for EB-PVD**
- **Applicability to APS TBC also has been shown**
- **Correlation's of PBSSL data to pre-spall seems possible if failure mechanism, with periodic TBC/bond-coat topography, holds to be true**



# NEW EFFORTS TO ADDRESS OXIDE/OXIDE WITH EBC



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## ■ Objectives

- ◆ Establish NDE methods and protocols that allow reliable detection of:
  - ◆ delamination within oxide/oxide CMC
  - ◆ delaminations between oxide-based EBC and oxide/oxide CMC
  - ◆ crack patterns, crack depth, and crack densities of EBCs
  - ◆ degradation of thermal properties of EBC from in-service use
- ◆ Establish if NDE measured properties (e.g. elastic modulus) can be used as a part of a predictor for remaining useful life

## ■ Collaborating Partners

- ◆ Siemens-Westinghouse Power Systems
- ◆ COI Ceramics, Inc.



# APPROACH



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## ■ Detection

- ◆ Conduct tests with “seeded-defects” Alumina/720 oxide/oxide composite specimen without EBC. Various delamination to be inserted at different depths. Filament wound as well as 2-D cloth lay-up. [Note: It is intended to examine Aluminosilicate/N720 as well]
- ◆ Conduct NDE studies of special EBC-coated seeded-defect samples of Alumina/N720 as well as a limited NDE study of EBC-coated Aluminosilicate/N720
- ◆ Study Combustor Liners and other Turbine components



## **NDE TECHNOLOGIES TO BE EXPLORED**



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- **Detection of delams with:**
  - ◆ **Air-coupled ultrasound with New Low-noise system**
  - ◆ **Fast, high resolution X-ray tomography using new CMOS-based detector**
  - ◆ **non-EBC coated oxide/oxide with one-sided Infrared. [Thermal capacity of EBC is very high]**
- **Crack patterns detection with Holography**
- **Crack density with guided plate waves**
- **Others**



# APPROACH



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## ■ Residual Life

- ◆ Establish effects of N720 fiber architecture on NDE elastic modulus measurements
- ◆ Utilize samples that have been damaged by:
  - ◆ thermal shock
  - ◆ impact
  - ◆ cyclic fatigue
- ◆ Correlate elastic modulus measured by NDE with residual strength of Alumina/N720
- ◆ See if “knock-down” factor data from NDE, can be coupled to FEA code, e.g. GENOA, that would predict remaining useful life at specific set of load conditions

## ■ Time Frame: 3 years



# SUMMARY

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## ■ NDE technology for EBCs

- ◆ Demonstrated pre-spall detection of BSAS EBC on MI SiC/SiC

## ■ NDE technology for TBCs

- ◆ Preliminary efforts suggest correlations between polarized laser back-scatter and TBC/bond coat topography for EB-PVD.
  - ◆ Does TBC/Bond Coat Topography  $\Rightarrow$  Pre-spall??
- ◆ Very early results suggest polarized back-satter laser data correlate with vertical crack density in APS TBCs

## ■ New NDE effort to address oxide CMC's has started