# Thermal History Mapping Technology for Turbine Engine Diagnostics

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# Objective

- Develop a diagnostic tool for non-line-of-sight, non-destructive thermal mapping of EBC-coated CMC components for temperatures up to 1650ºC (3000ºF)

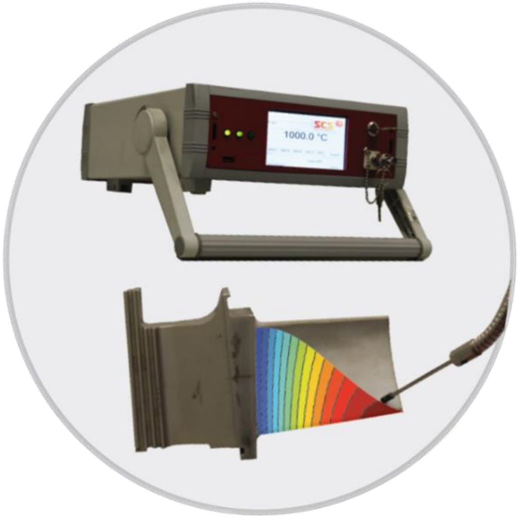
- Conventional temperature measurements have limitations
- Pyrometer: Requires line of sight
- Thermocouple: Limited to spot temperature measurements and chemical incompatibility
- Thermal paint: Limited temperature capability (up to ~1400ºC)and low resolution

# Approach

## Luminescence decay-based thermal history coating (THC) technology

# How it works

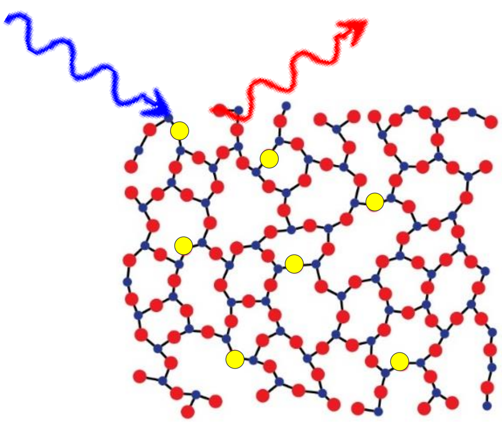
- Paint or coating applied on component
- Component is operated at high temperatures, e.g. engine test
- Once it has cooled down, instrumentation is used to deliver **past maximum exposure temperatures**
- Full surface coverage achieved by measuring points across surface



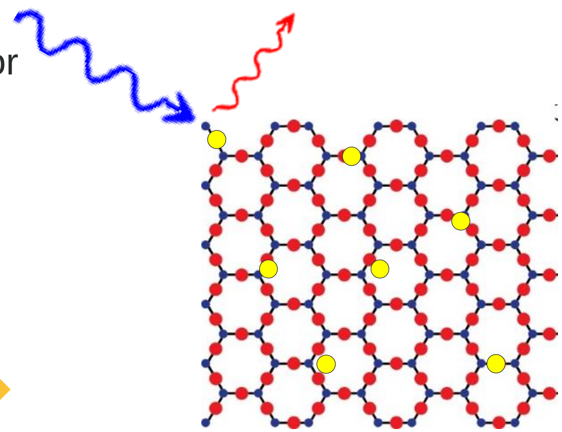
**→ SCS-developed Thermal History technology**

# Principle

- Oxide ceramics are doped to make the material luminescent
- Coating applied in the **amorphous** state
- Gradually **crystallizes** with temperature – permanently
- Luminescence changes depend on crystal structure, which in turn depends on the temperature
- Measure the decay time ($\tau$) of the luminescence (emitted light) intensity



- Rare-earth dopants in phosphor are optically active
- Degree of crystallinity affects phosphorescence

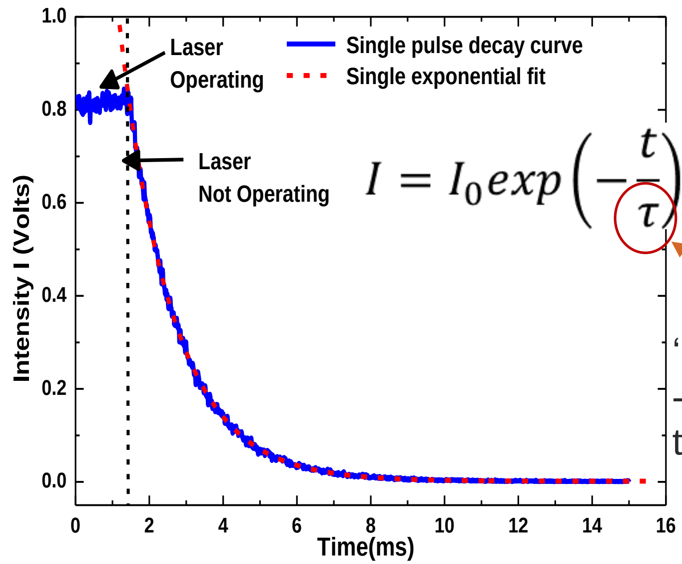



**Amorphous** **Non - reversible process** **Crystalline**

**Luminescent measurements are linked to past maximum exposure temperature**

# Principle (cont.)

- A pulsed laser excite electrons of phosphor
- Excited electrons release energy and jump to lower energy, emitting light
- Monotonic changes in lifetime decay of emitted light are exploited to determine maximum exposure temperature




'Lifetime decay' - depends on temperature

Lifetime decay measurements can be taken with SCS's portable box

# Step 1: Sensor Application

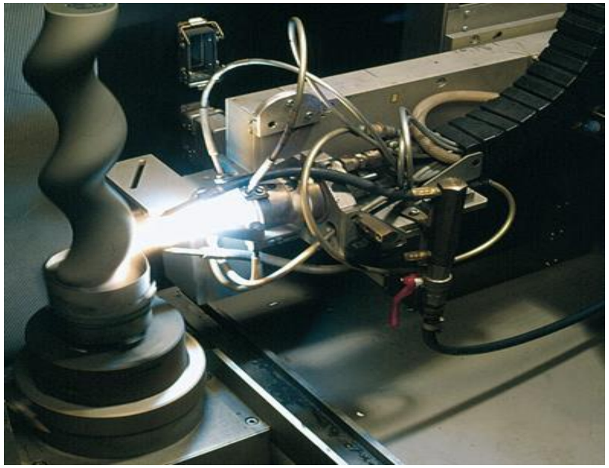
**The powder can be applied as a paint or as a coating**

## THP: PAINT– EASY TO APPLY

- Sensor powder is mixed with a binder and applied through air spraying
    - Application cost and time is lower
        - Demonstrated for temperatures < 900 °C

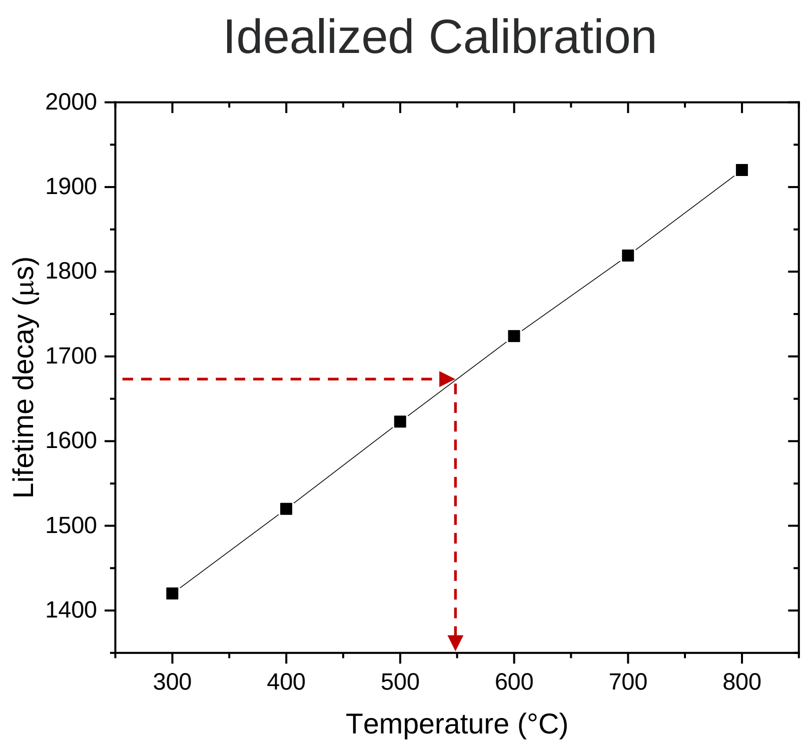
## THC: ROBUST COATING – LONG-TERM APPLICATIONS

- Sensor powder applied through industrial atmospheric plasma spray (APS) process
- Can withstand longer exposure time
- Temperature aim ranging up to 1650 °C



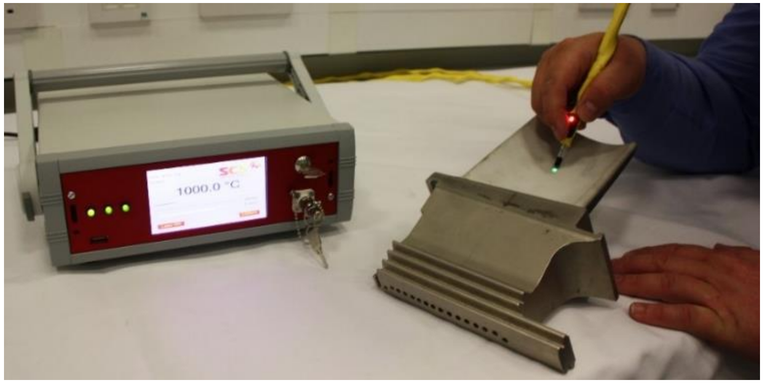
# Step 2: Calibration

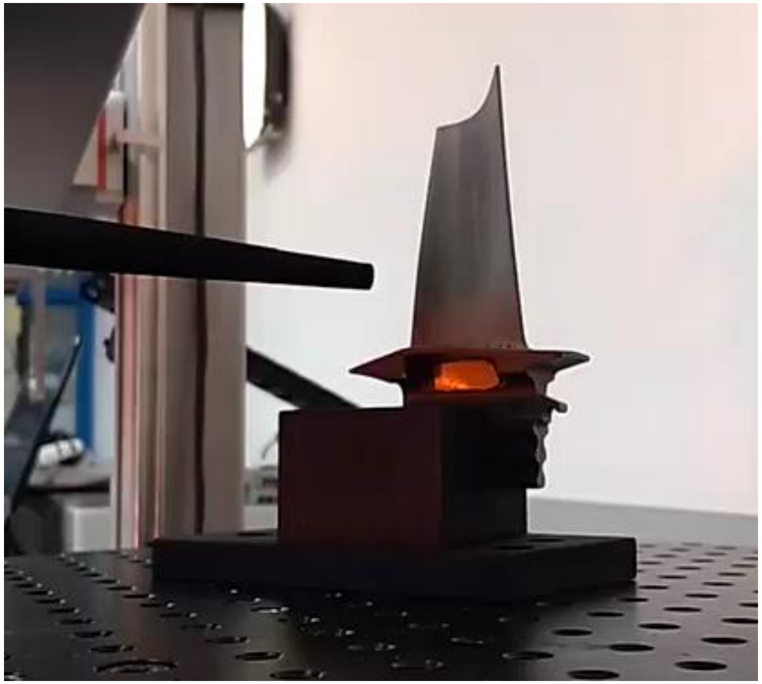
- Samples of same material as component applied with coating
- Test data analyzed to determine time at temperature
- Samples heat treated in furnace for same duration as test
- Plot ‘Lifetime decay’ vs. ‘Temperature’ calibration curve

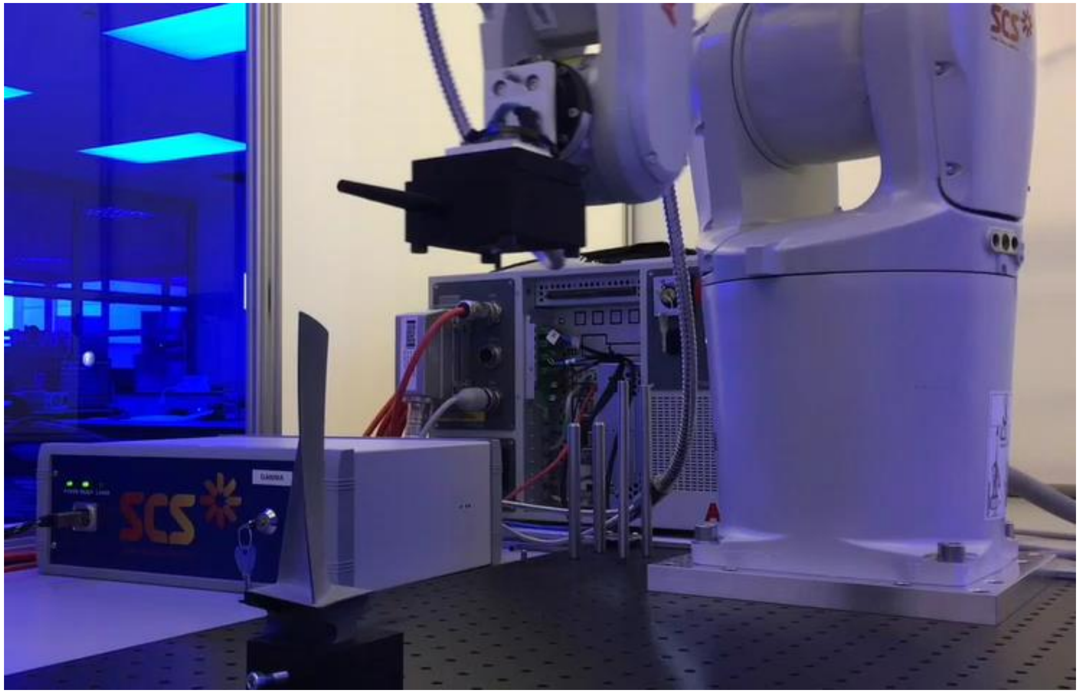


# Step 3: Measurements

- Manual or automated measurement acquisition
- In-situ measurement possible
- Spot size 0.5 mm
- One turbine blade of ~300 points in ~2.5 hr

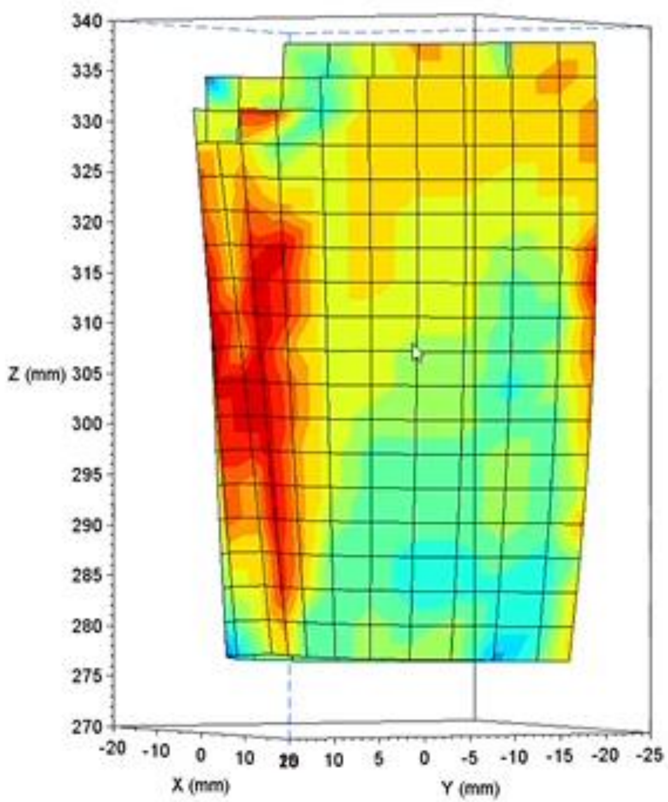


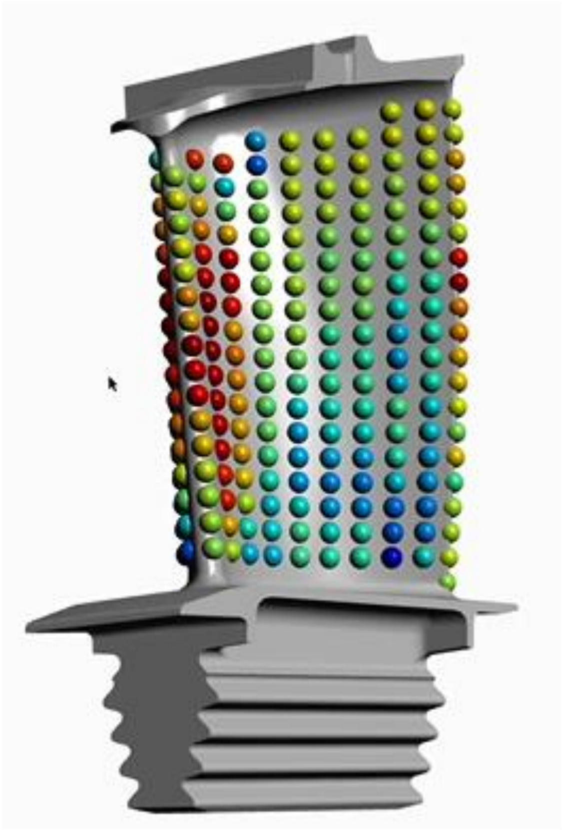





# Step 4: Data Visualization

- Temperature data can be represented on 3D coordinates
- Facilitates comparison to simulation data



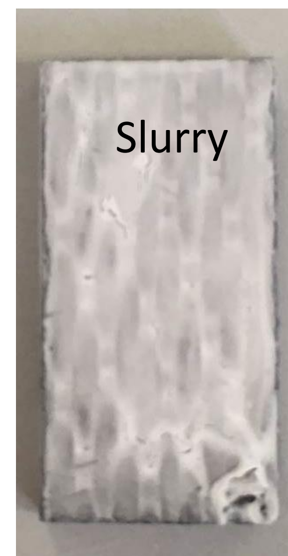
# THC Investigation for Environmental Barrier Coating (EBC)

## Materials

- Substrate: SiC/SiC CMC
  - Coupons (1” x ½”): calibration and preliminary thermal exposure study
  - Airfoil (3” x 2”): Burner rig thermal exposure
- APS EBC: $Yb_2Si_2O_7$
- Slurry EBC: $Yb_2Si_2O_7$ - based bond coat / $Yb_2Si_2O_7$ – based top coat

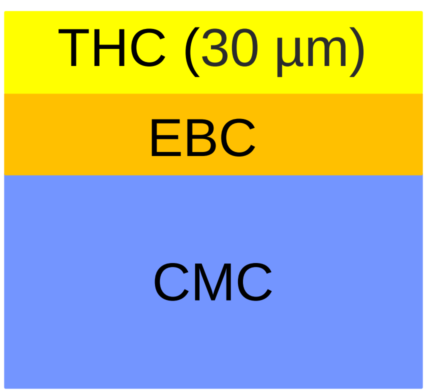
## THCs

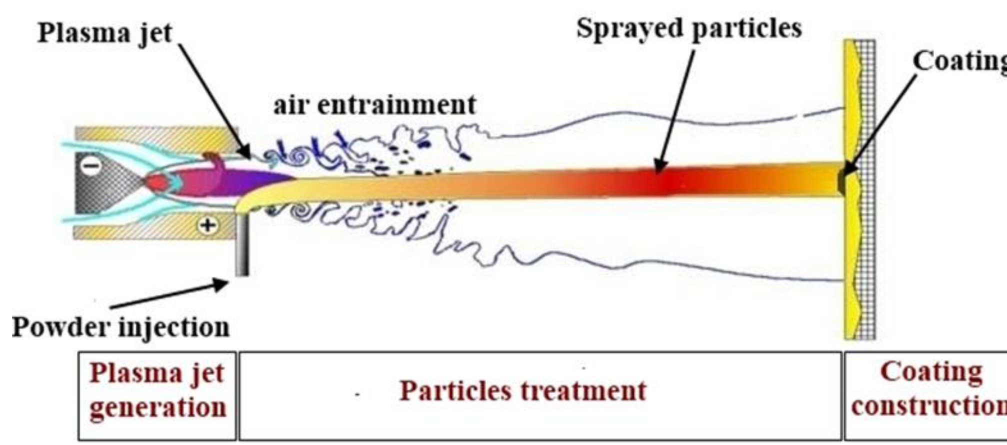
- THC A: Temperature capability goal ~1500ºC
- THC B: Temperature capability goal ~1650ºC
- Both are oxide-based materials

# THC Deposition

- Spray powder manufacture and THC deposition done through SCS
- THC deposited through Atmospheric Plasma Spraying
- THC layer only 30 µm
- Quality control:
  - THC showed good adherence to CMC coating
  - Good luminescent signal from THC
  - Homogeneous measurements along airfoil



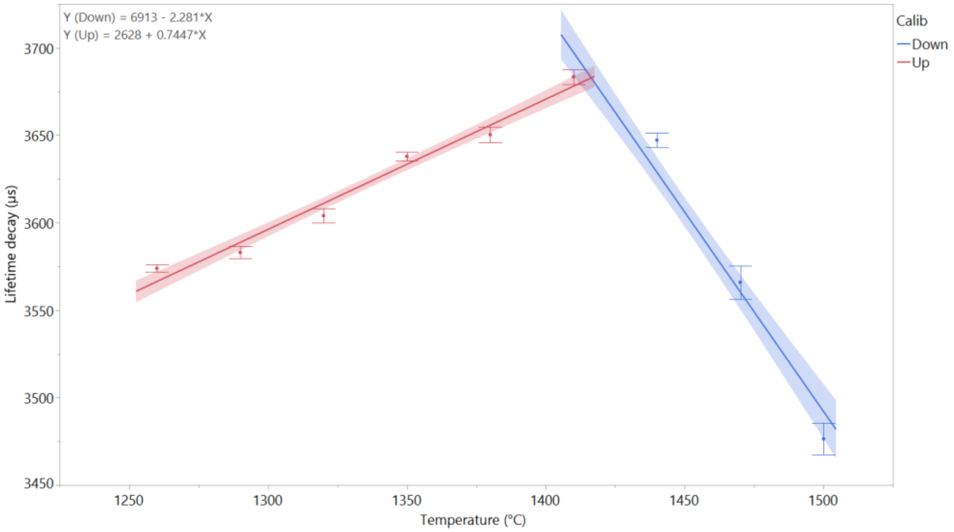



# THC A on CMC Coupons

- Two sets of EBCs were prepared on CVI SiC/SiC CMC coupons
  - APS EBC: $Yb_2Si_2O_7$
  - Slurry: $Yb_2Si_2O_7$ - based bond coat / $Yb_2Si_2O_7$ – based top coat

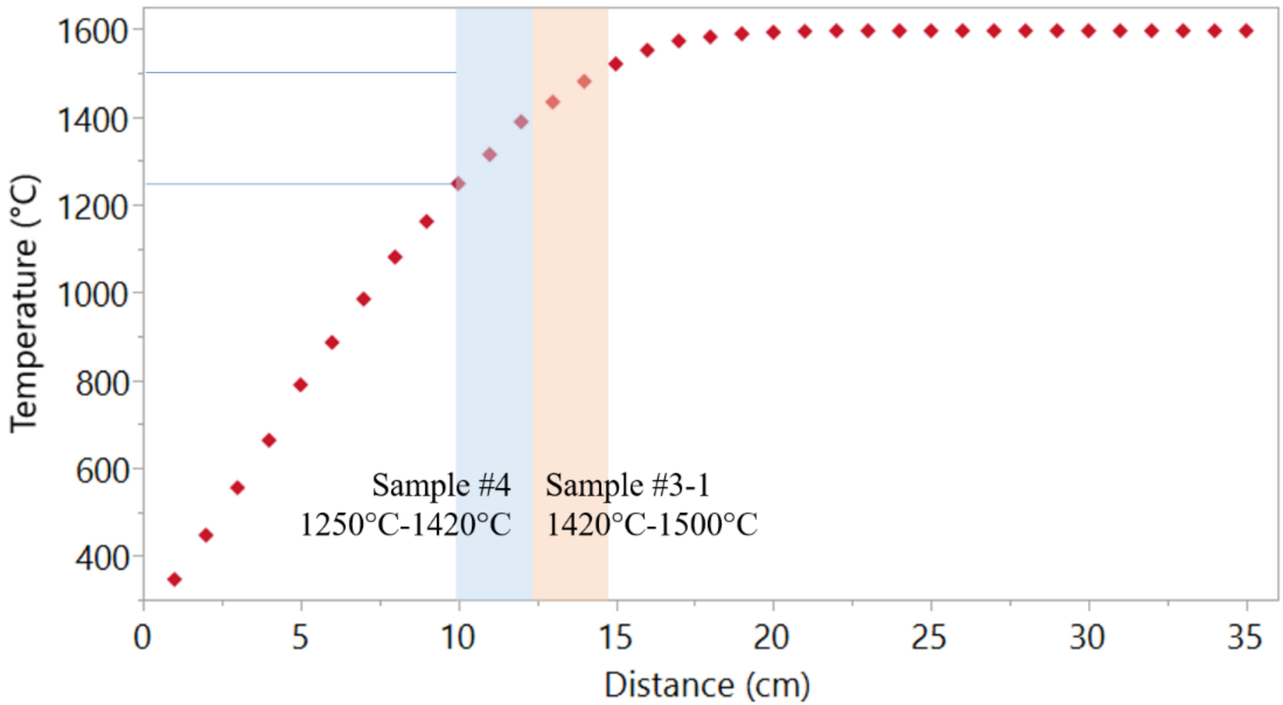
## Post-Exposure Calibration Samples and Calibration Curve

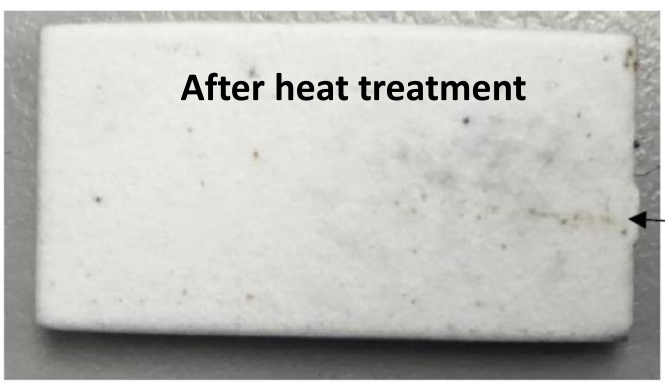
Calibration samples (1 x ½”): APS EBC




While the calibration data is not monotonic, through the analysis of the signal and samples it is possible to determine which side of the calibration peak the data corresponds to.

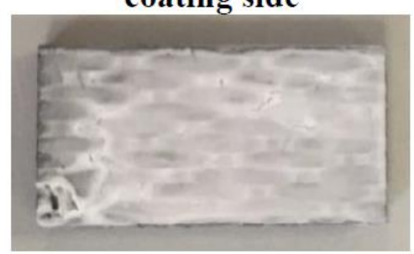
# Furnace temperature distribution, showing the target location of samples #4 and #3-1 during gradient testing (THC A)




Sample #4 (APS EBC)

**Before heat treatment – coating side**

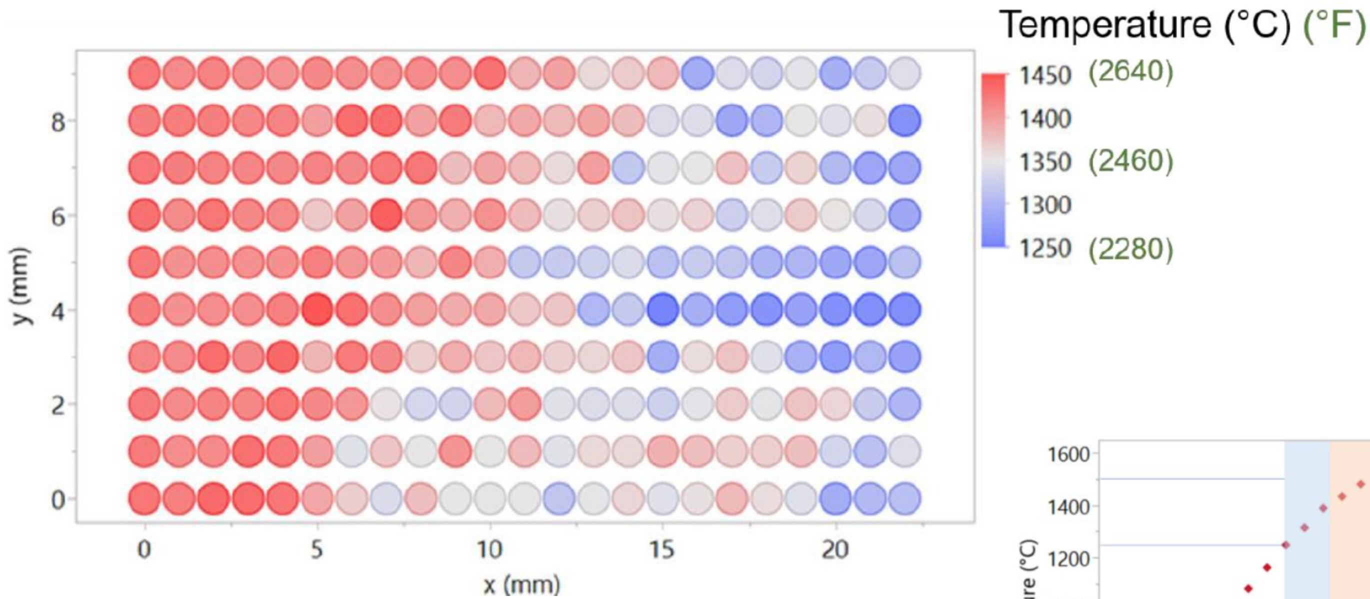


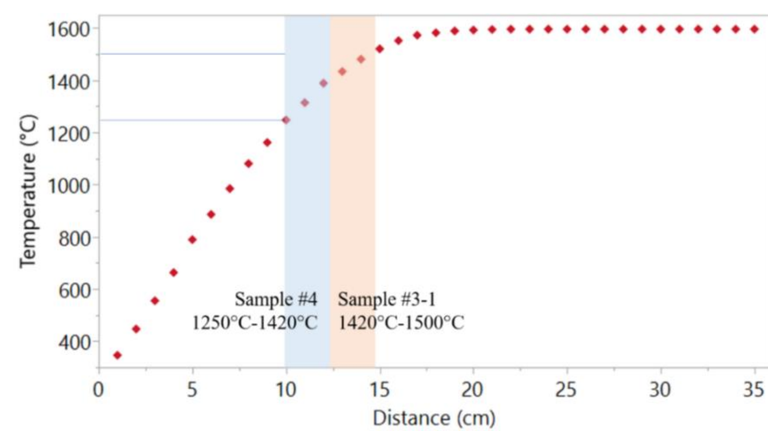
**After heat treatment – coating side**

Sample #3-1 (Slurry EBC)

Chemical reaction between THC A and EBC

# Thermal Map of Sample #4 (THC A)

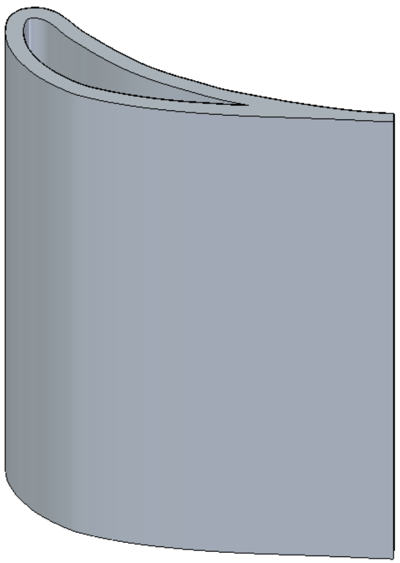



Fairly good agreement with the calibration

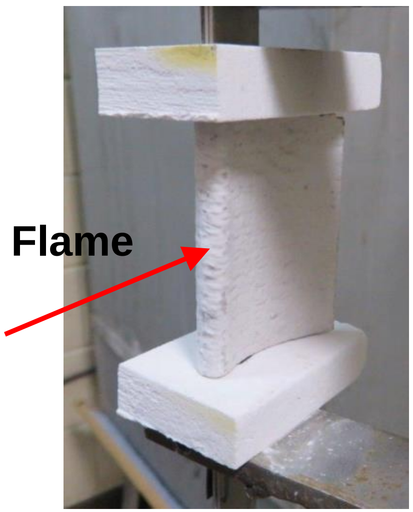
# THC B on CMC Airfoil

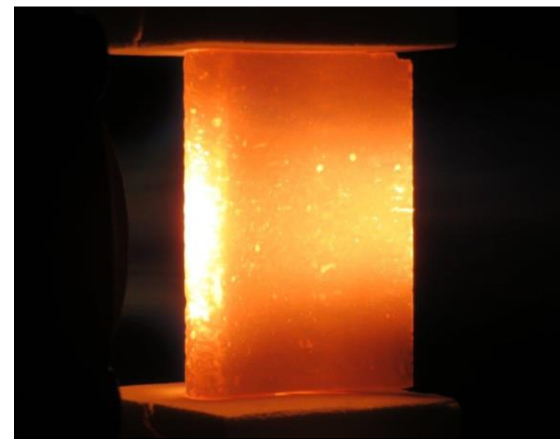
- Airfoil is coated by Slurry EBC
- Cannot use THC A due to slurry interactions
- THC B investigated



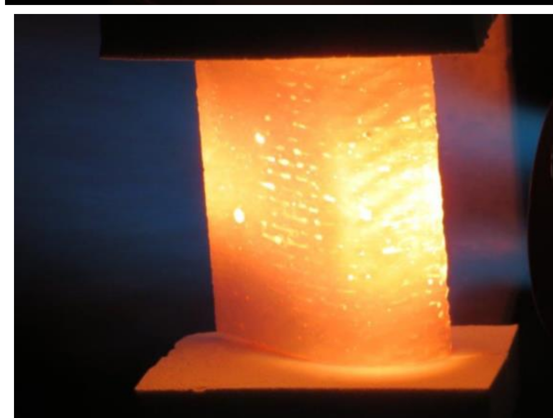
# EBC Deposition and Burner Rig Test

- EBC prepared on MI SiC/SiC CMC coupons and airfoil
  - MI for coupons are of different pedigree from MI for airfoil - may lead to disparity in luminescence decay time
  - Si melted during exposure
  - Slurry: $Yb_2Si_2O_7$ - based bond coat / $Yb_2Si_2O_7$ – based top coat



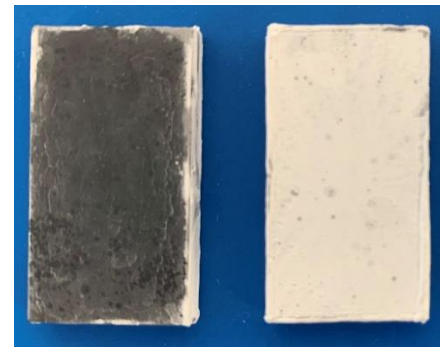
CMC Airfoil
Burner Rig
Exposure

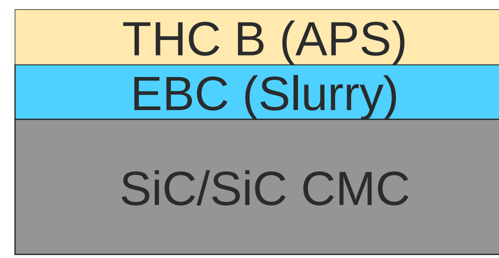


# THC Deposition

- **THC B** Spray powder manufactured and deposited through SCS

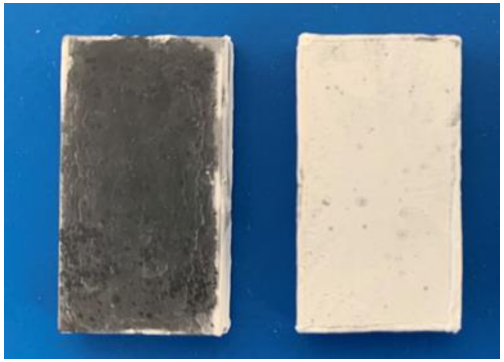
- THC B deposited through Atmospheric Plasma Spraying on
  - EBC (Slurry) coupons
  - EBC (Slurry) airfoil
- THC B layer 30 µm
- THC B showed good adherence to EBC
- Good luminescent signal from THC B
- Homogeneous measurements along airfoil before testing



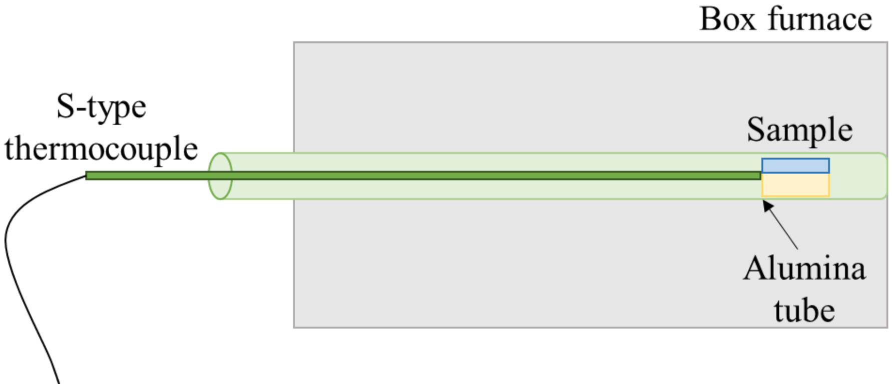


# Calibration

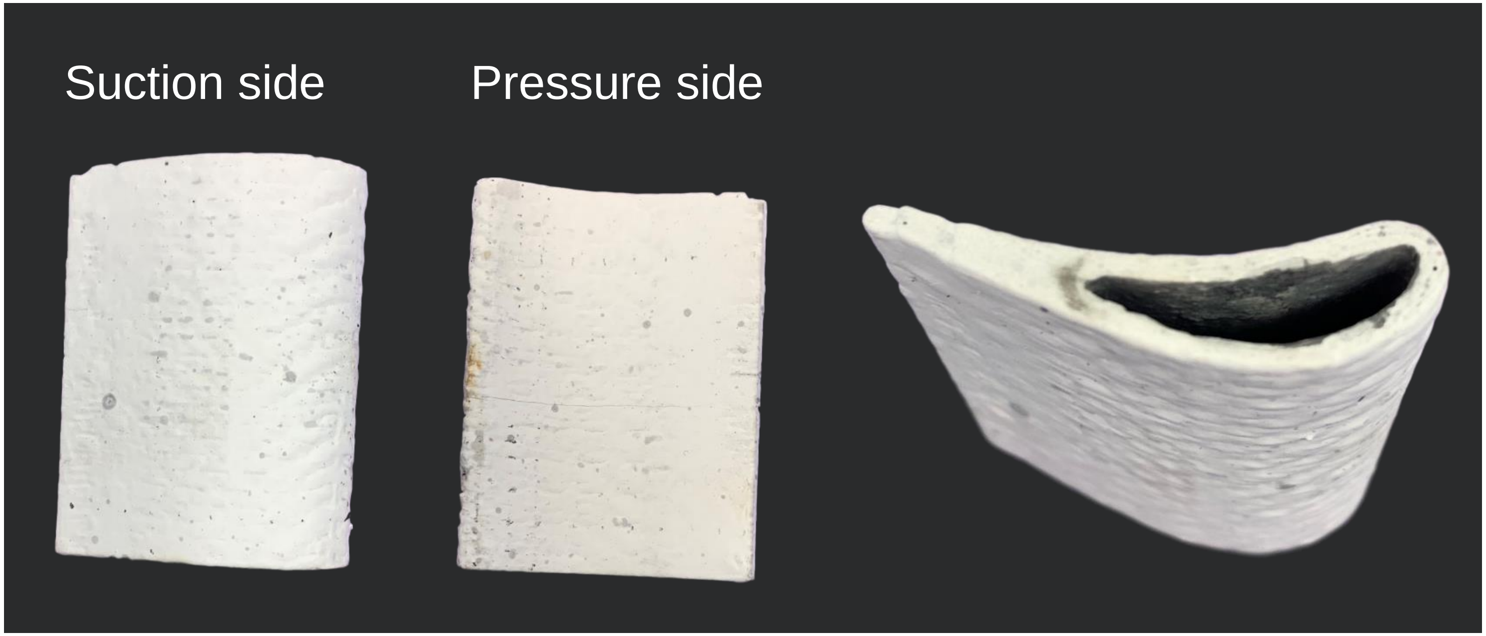
- Calibration is performed on slurry EBC-coated CMC coupons
- THC applied with same parameters at the same time as the airfoil



- Heat treatment carried out in box furnace, in air
- Coupons heat treated for 30 minutes at temperatures between **1100°C** (2010°F) and **1500°C** (2730°F)
- Exposure time matched to the airfoil test duration



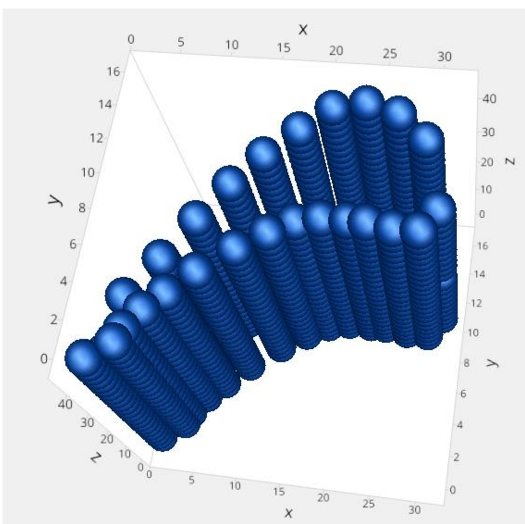
# Air Foil After Testing



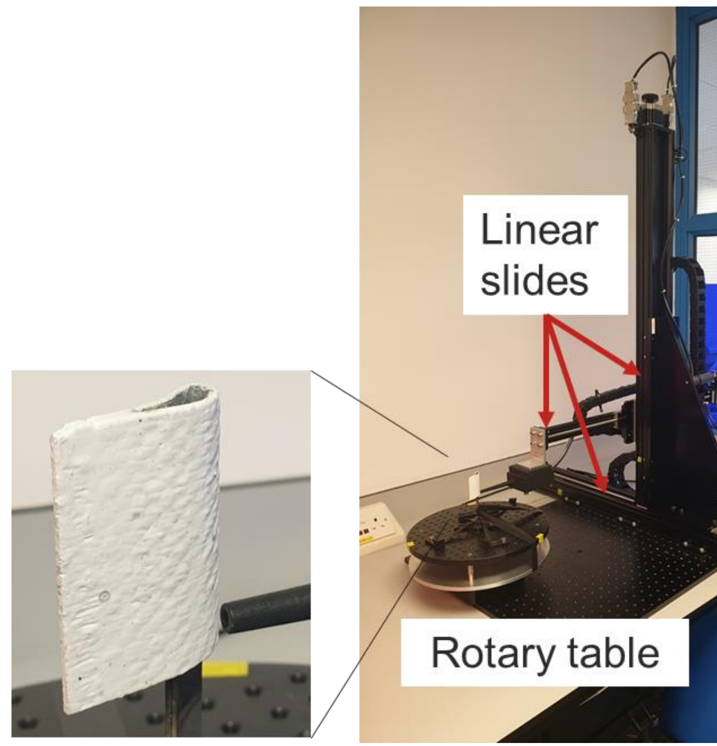

- After testing, the THC B showed no visual imperfections
- THC B showed full adherence on the EBC
- **No interaction between EBC (Slurry) and THC B**

# Measurements

- Measurement performed at SCS using custom-built instrumentation and automation system
- Total of 600 measurement points measured along airfoil formed of 26 columns

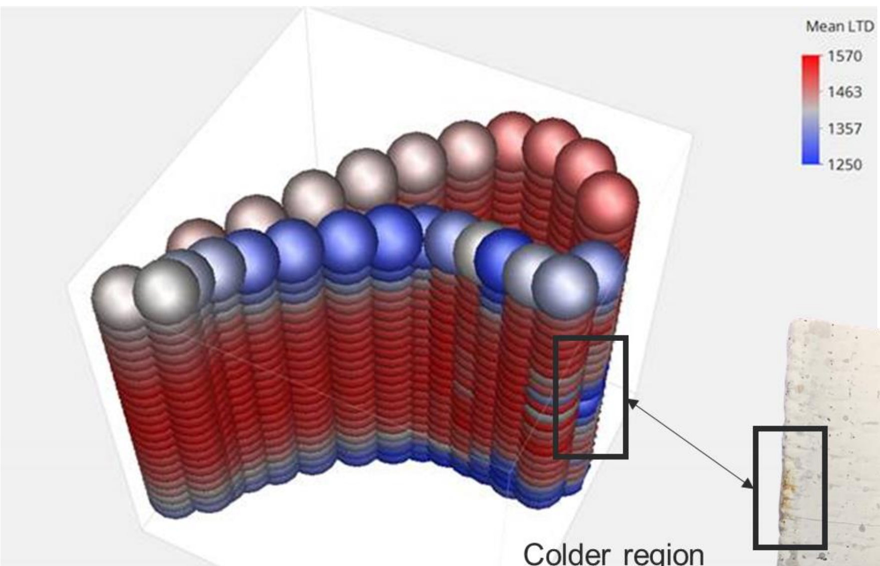


SCS automated measurement Gantry system

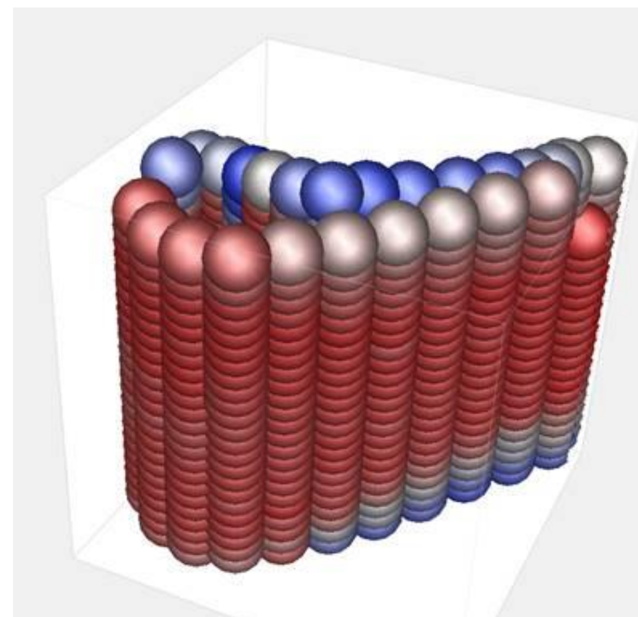


# Luminescence Map

- Lifetime decay measurement showed changed across the component surface
- Higher lifetime decays towards the middle
- Overall, higher values on pressure side

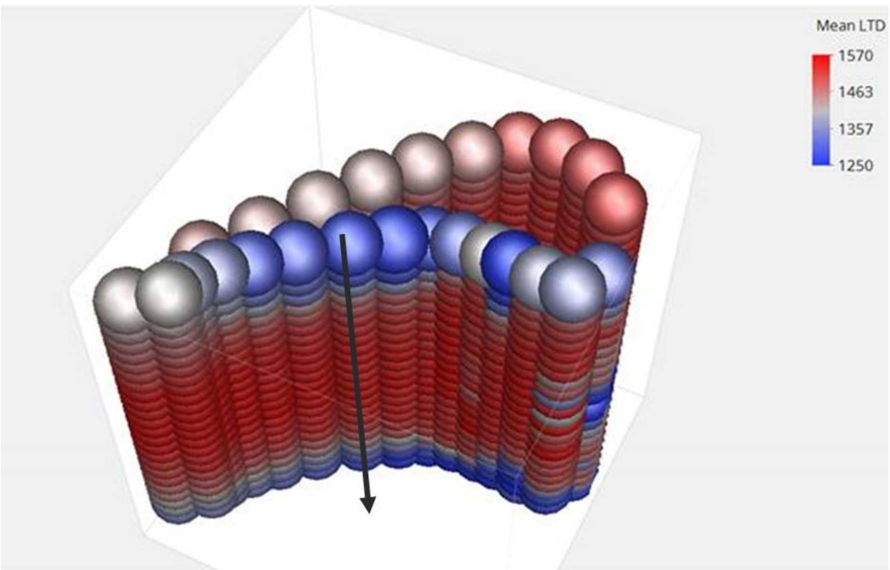


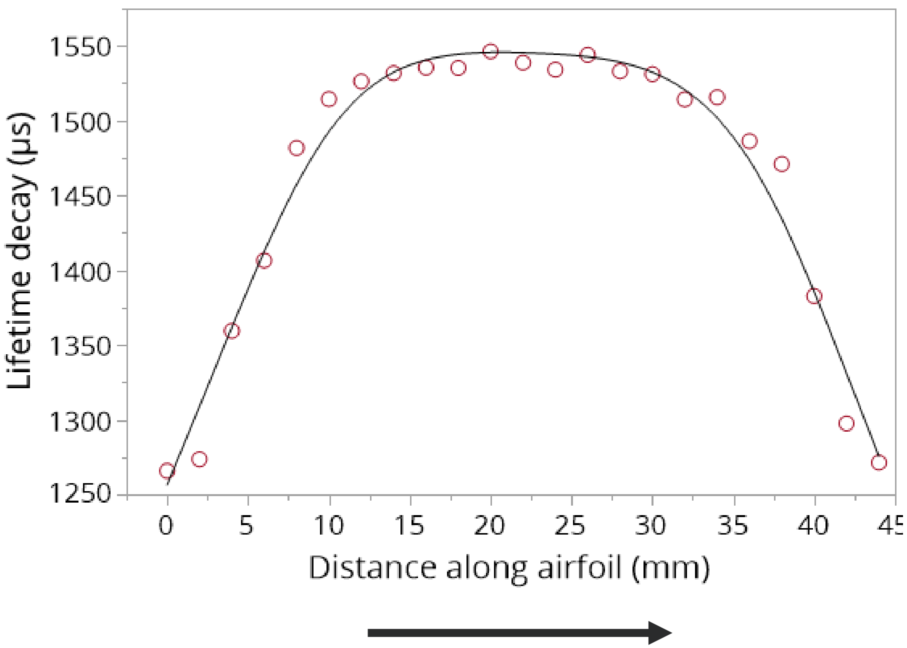

Colder region corresponds to irregular appearance



# Luminescence Results

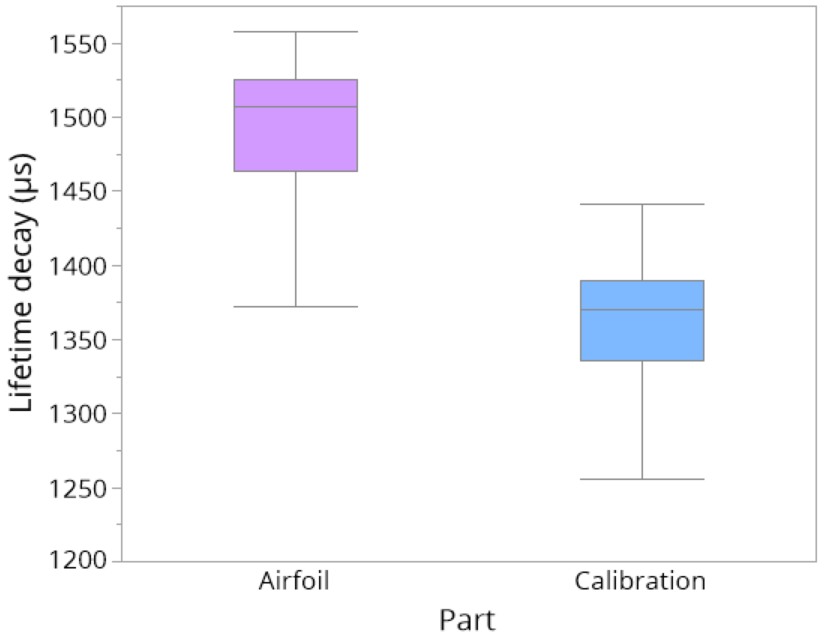
- Lifetime decay down column on pressure side highly symmetrical



# Calibration of the Airfoil Data

- Measurements on airfoil showed dynamic changes in lifetime decay
- **However, lifetime decay values on airfoil and calibration did not match**
  - Suggests differences between THC-B on airfoil and on calibration coupons
- Possible reasons may include:
  - Difference in exposure environment for airfoil (burner rig) vs. calibration (lab air) may affect THC-B
  - Differences in substrate (different pedigree of MI CMC)




- Next - Develop thermal map using correlation factor and pyrometer temperature measurement data

# Conclusion

- Two thermal history coatings evaluated on EBC-coated CMC
- THC A evaluated on coupons
  - Successfully validated the feasibility
  - Chemically incompatible with slurry EBC
- THC B evaluated on airfoil
  - Chemically compatible with slurry EBC
  - Disparity in lifetime decay between calibration coupons and airfoils
  - Investigation underway to understand the root cause
  - Correlation factor in conjunction with pyrometer data will be used to map the airfoil temperature

# Acknowledgements

- Sue Puleo (NASA): Slurry preparation
- John Setlock (U. of Toledo): EBC application on coupons and airfoil
- Dennis Fox (NASA) and Mike Cuy (Vantage): Airfoil burner rig testing