SOFC Quality Control and the Role of Manufacturing Defects in Stack Longevity

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Acumentrics SOFC, Inc

- SOFC division established in 2000, “Powder to Power” in a single facility in Westwood, MA

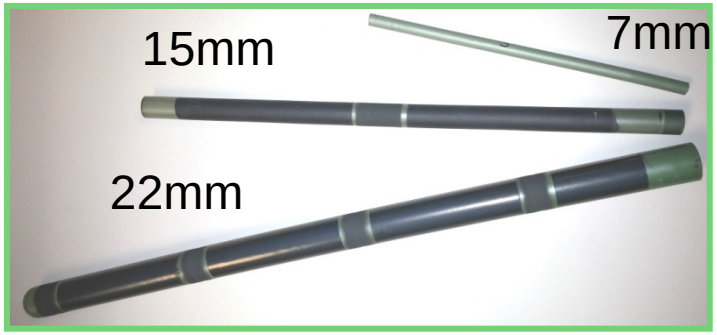
- “Rugged” small tubular SOFC s
  - 30 min startup and shutdown
  - Unattended operation in remote locations throughout the US
  - 250-1500 W commercial power products (natural gas and LPG
  - 250+ shipped units with over 2 million operating hours
  - Our longest running commercially deployed stacks have been operating for 28,000+hrs

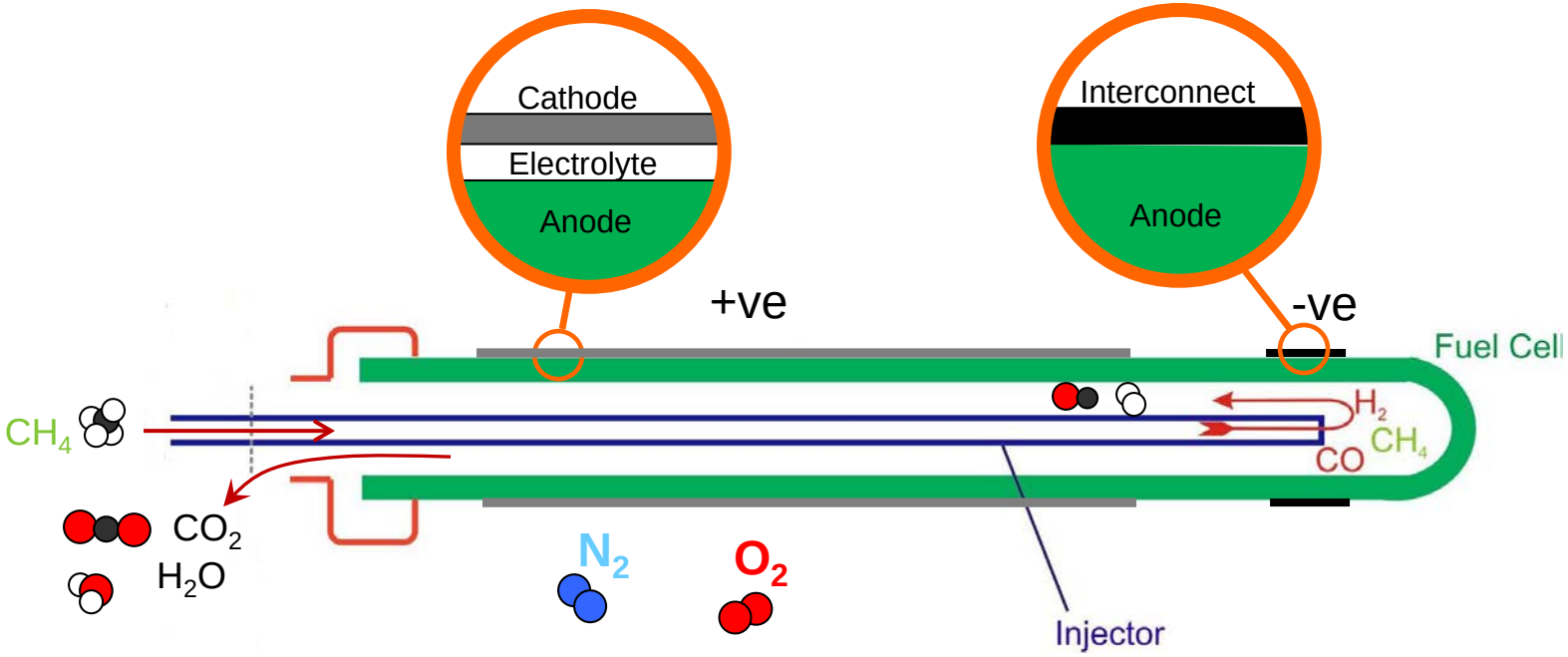
Remote LPG and NG Applications

Acumentrics
Trusted Power Innovations

Acumentrics SOFC background

- Small tubular
- Common anode
- LSCF/SDC/YSZ/Ni-YSZ
- Lanthanum chromite IC





Commercialization of SOFC

- Acceptance in widespread markets
- Low lifecycle cost
  - Low production costs
    - Mass automated production
    - Low cost materials
    - High cell yields
  - **Low warranty cost**
    - **Reliability**
      - Design and assembly methods
      - BOP system
      - **Stack**

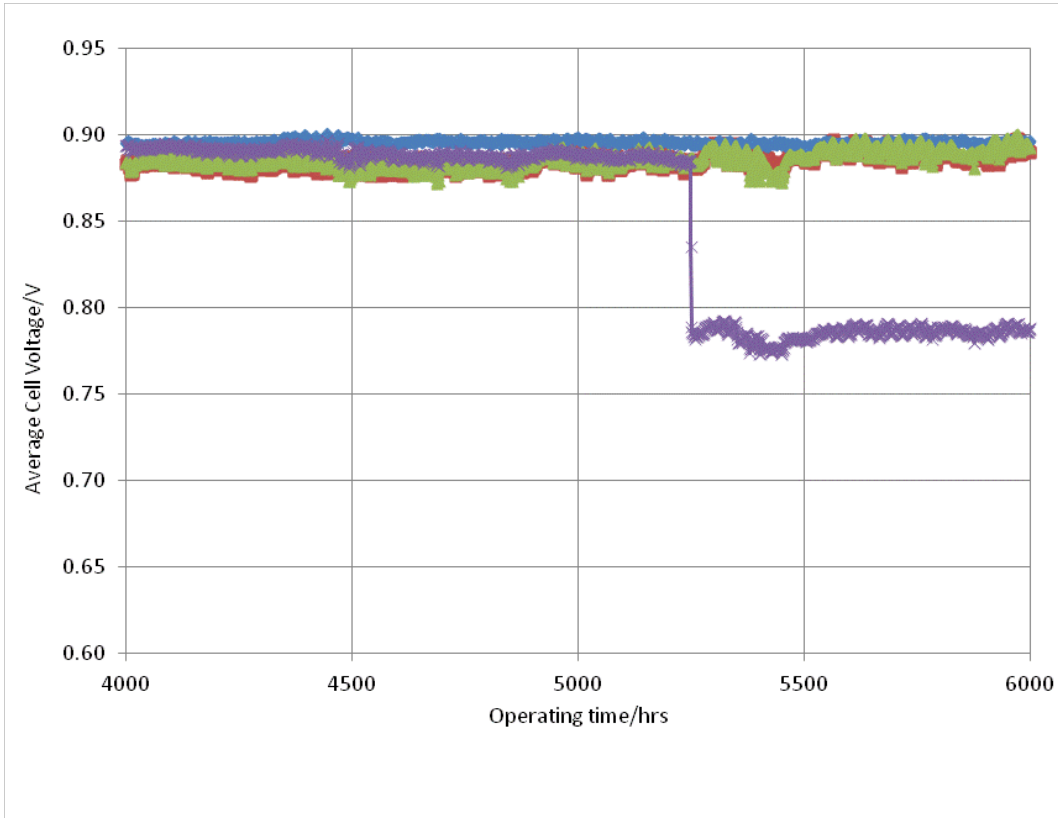
SOFC Stack Reliability

Stack reliability is dependent on both the inherent degradation rate of the fuel cell stack, and the MTBF of a cell.

Premature failure of one of the individual cells more likely to impact the sustainability of commercial ventures.

Target:

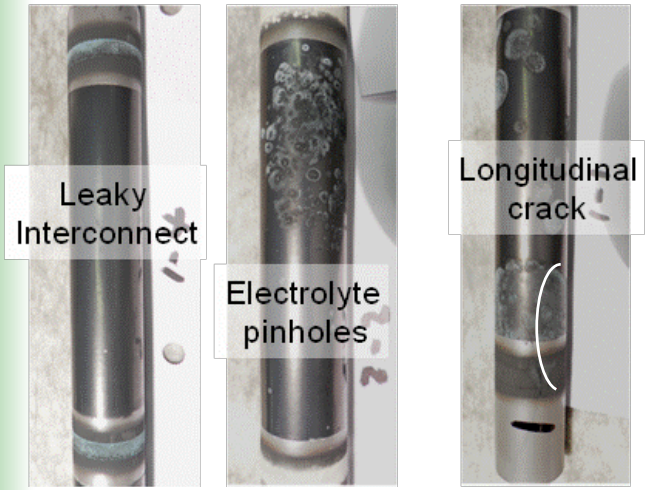
- Stack design
- Stack assembly
- Cell Reliability



SOFC Quality Assurance Problem

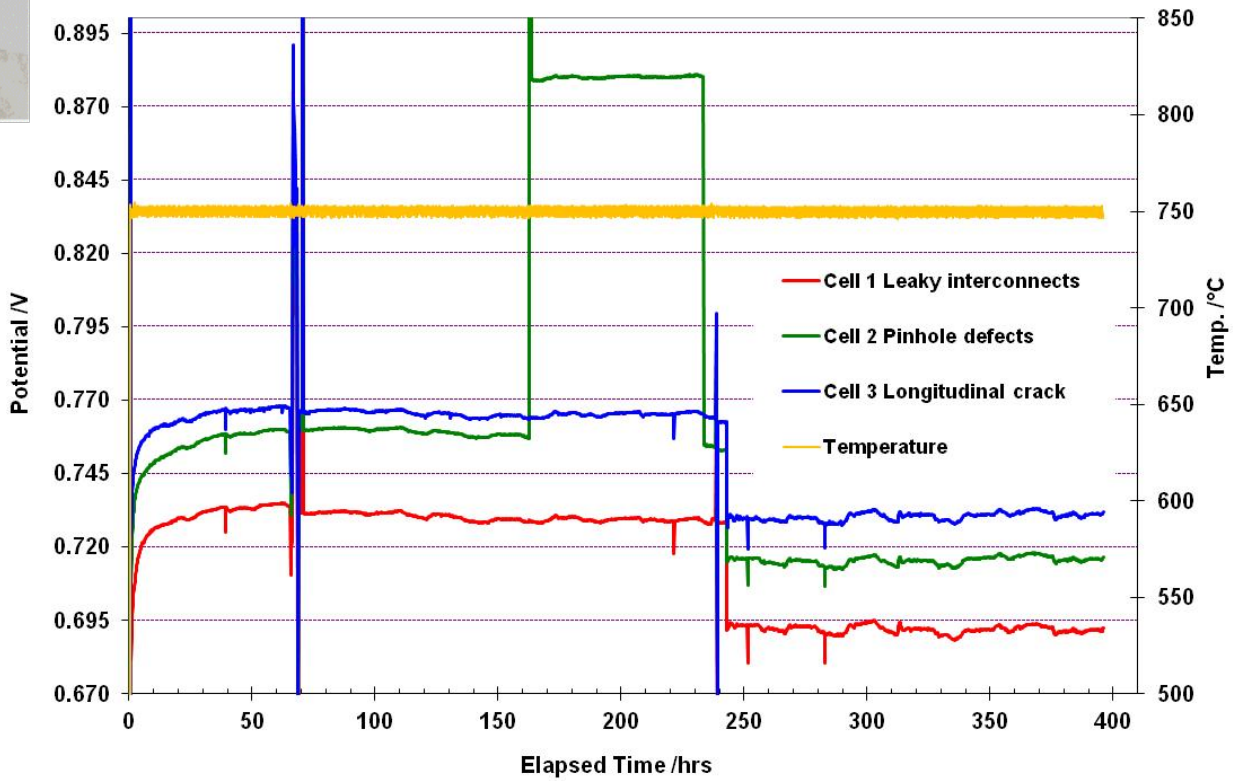
- Ideal cells may be able to hit the 40khr target. What about production cells which may have imperfections, what level can be tolerated?
- Practically can only test commercial stacks for a few days and immediate performance is no guarantee of long term reliability
- What QC measures at room temperature (*ex situ*) are relevant at high temperature operation (*in situ*) ?

Real Defect Examples and Test Results



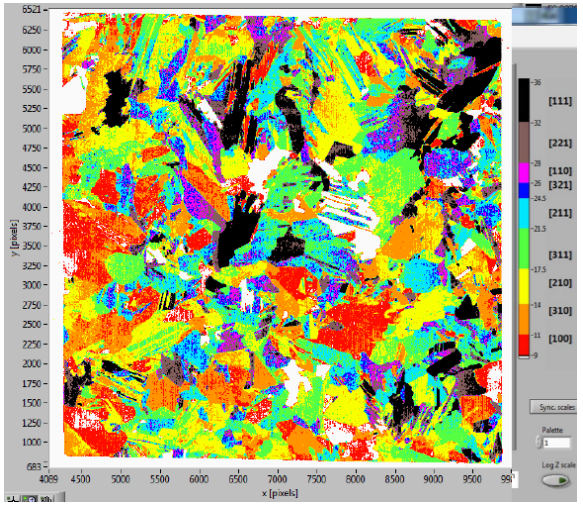
Examples of flaws visually identified on cells

No obvious degradation to distinguish case!

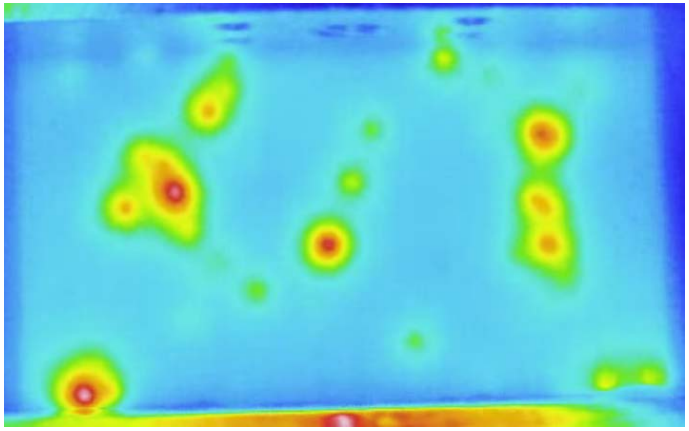


Fuel Cell Manufacturing Project at NREL

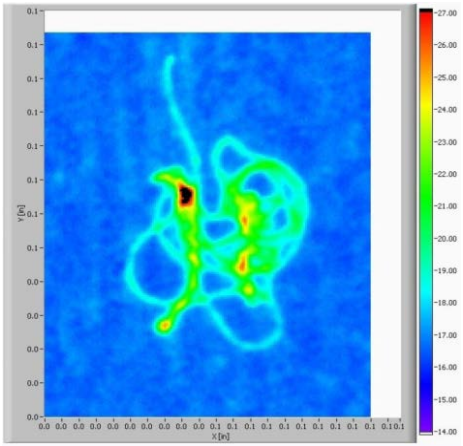
- Aims to understand quality control needs from industry
- Develops diagnostics
  - Modeling to guide development
  - In situ testing to understand the effects of defects
- Validates diagnostics in-line
- Transfers technology



Grain orientation on PC cell by optical reflectance



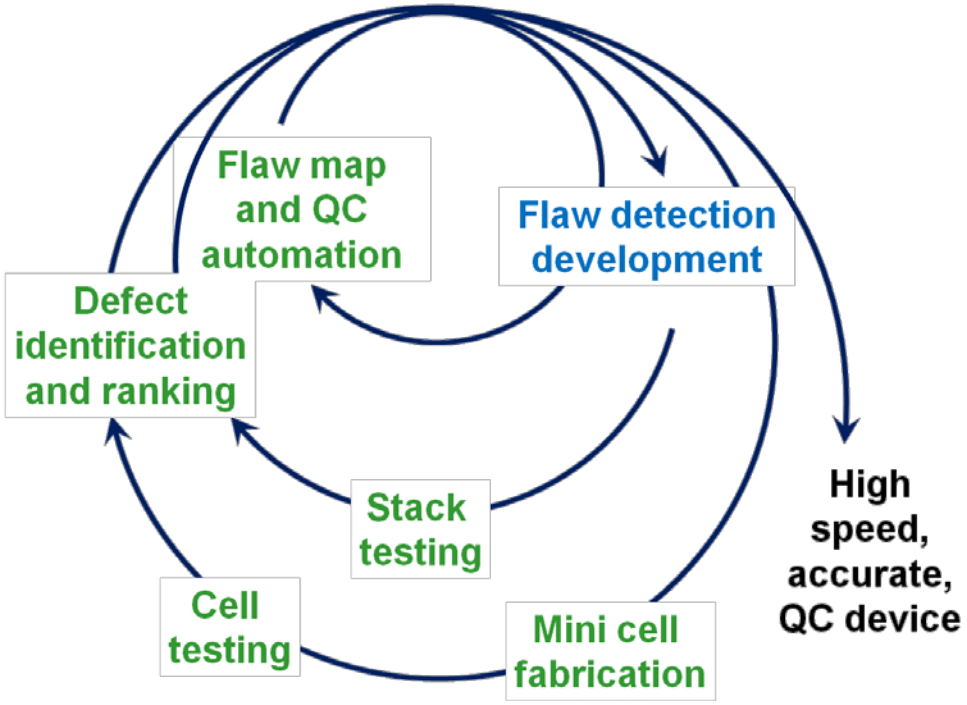
PEM MEA shorts by Thermography



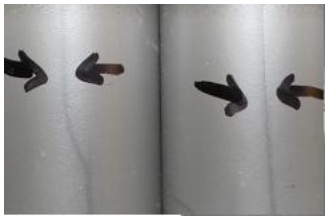
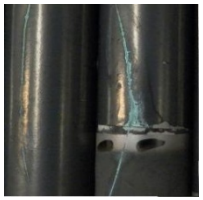
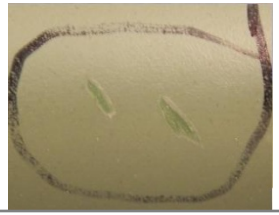
Planar SOFC electrolyte scratch by optical reflectance

Quality assurance with NDT

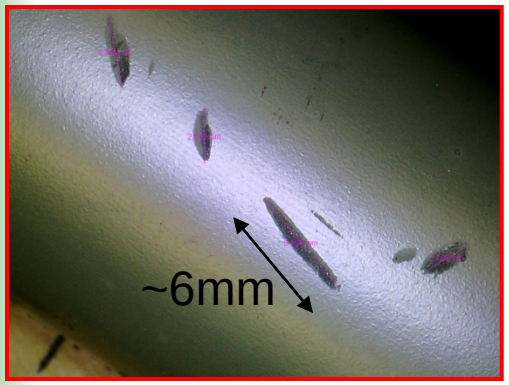
- A common problem in for non destructive testing through imaging: Detector technology has improved that we can see imperfections at the 10 μm level *e.g* Defects in structural elements, pipes , tumors in tissue
- Effective quality control requires knowledge of what are truly cell defects (as opposed to minor cosmetic imperfections)



Examples of Conspicuous Defects

Description	Example	Description	Example
Contamination caused pit (<1mm)		Crack formed in processing	
Anode material agglomerate pop-out (~1mm)		Crack visualized by dye	
Crack (1~10mm) formed in green state processing		Pinhole (~μm) visualized by chemical etching	
Surface electrolyte scratch (1~10mm) (handling)		Pinhole (~μm) visualized by dye	
Coating agglomerate (slurry quality) (1~5mm)			

Example – Pre-firing Electrolyte Scratch



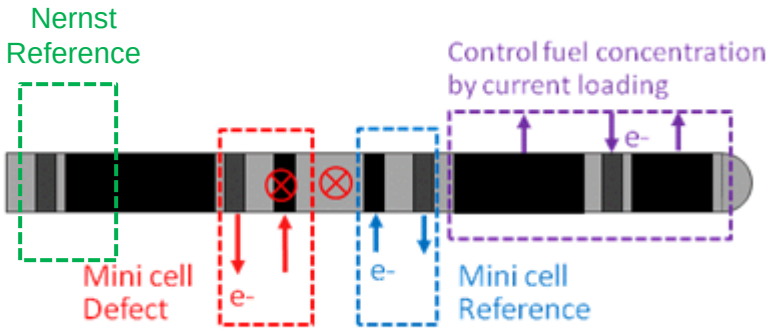
As discovered

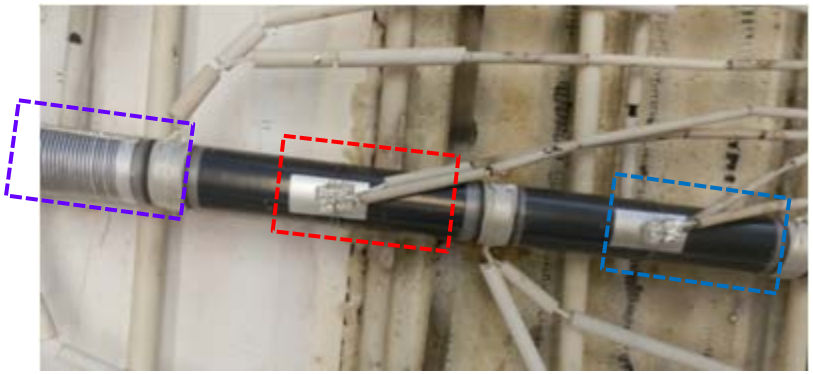
After SDC firing

After cathode
coating and reduction

After Ag CC applied

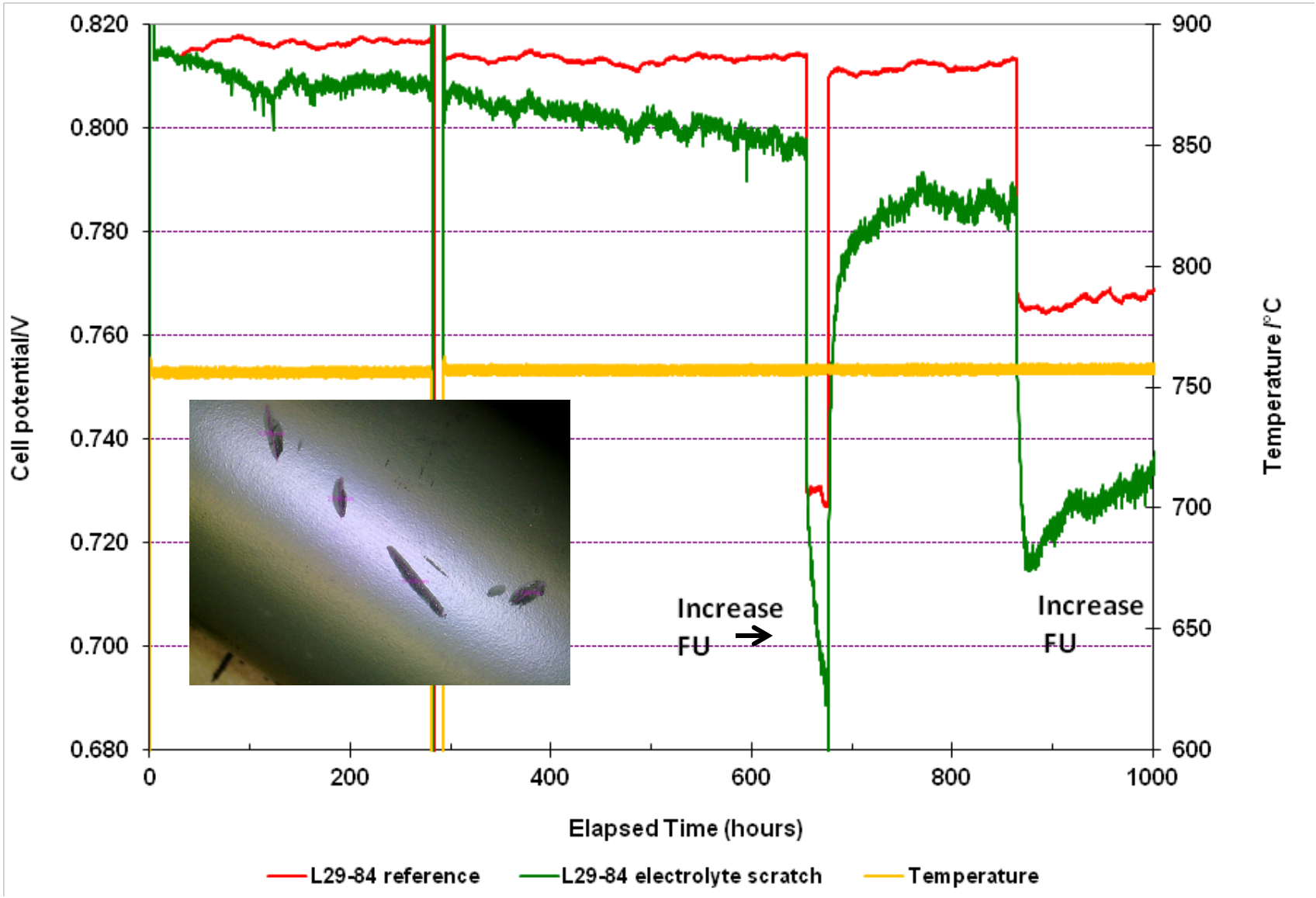
Mini Cell Testing



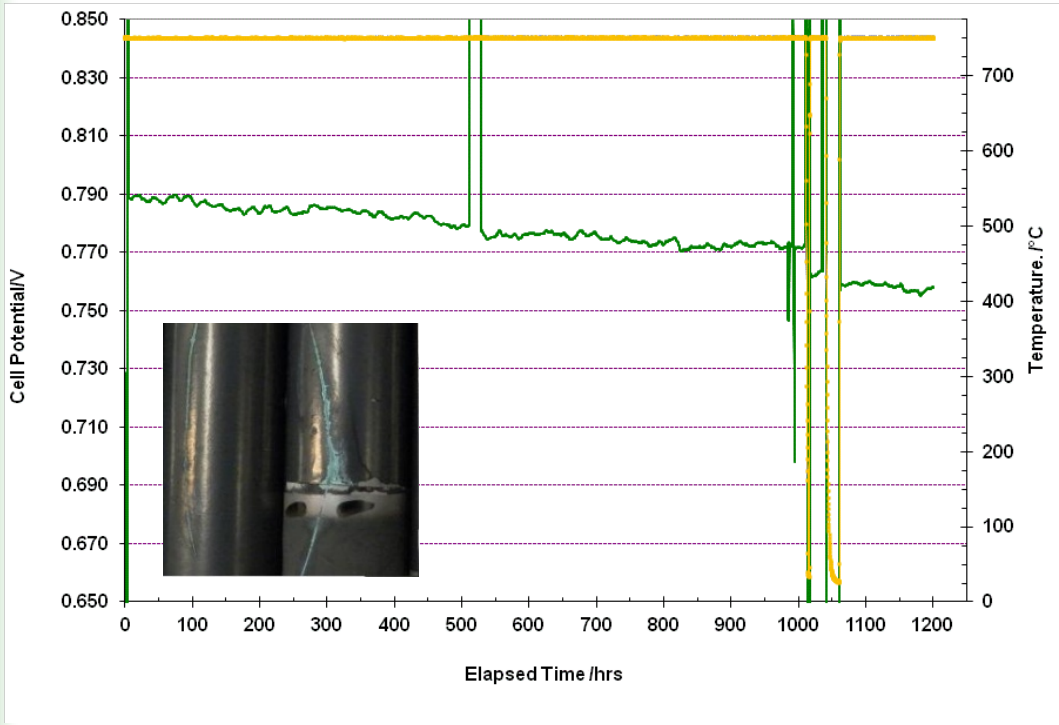


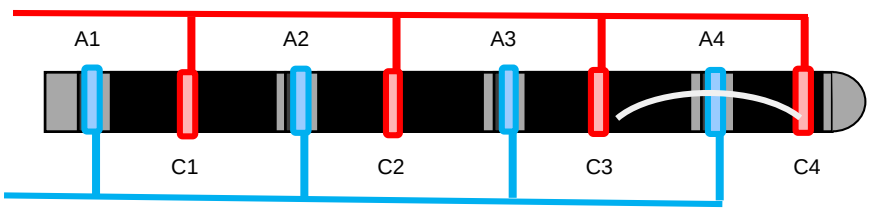
- Possible environment of a cell defect in a stack
  - Temperatures 680-830°C
  - Cathode atmospheres 21%-13% O2
  - Anode atmospheres commensurate with 0-80% FU
  - Different local current densities 150-600mA/cm^2
- Possible transients
  - Thermal and load cycling

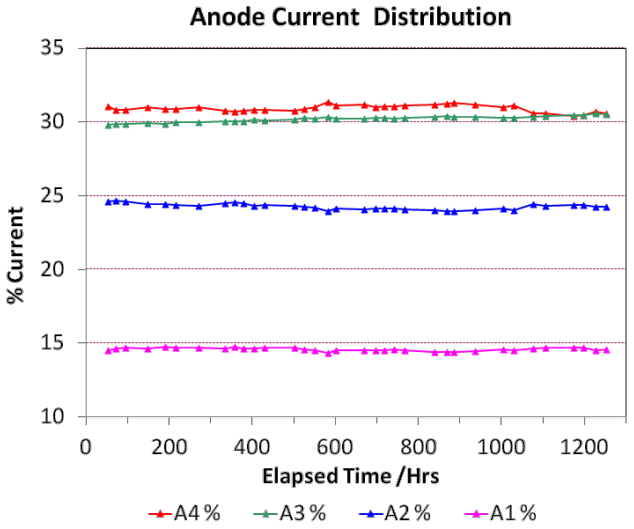
Pre-firing Electrolyte Scratch

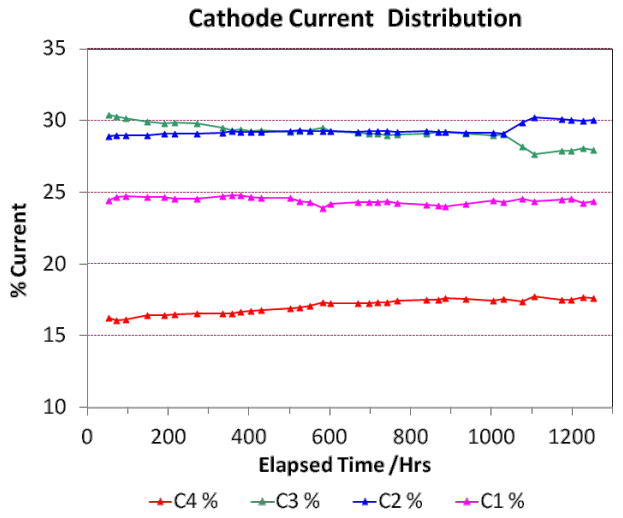


Example- Cell Testing Cracked Cell



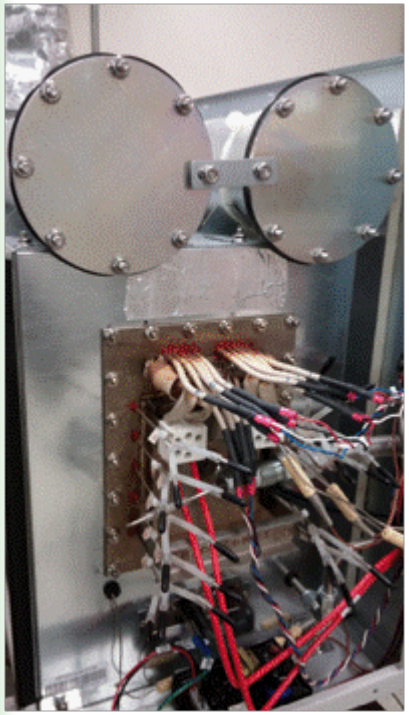




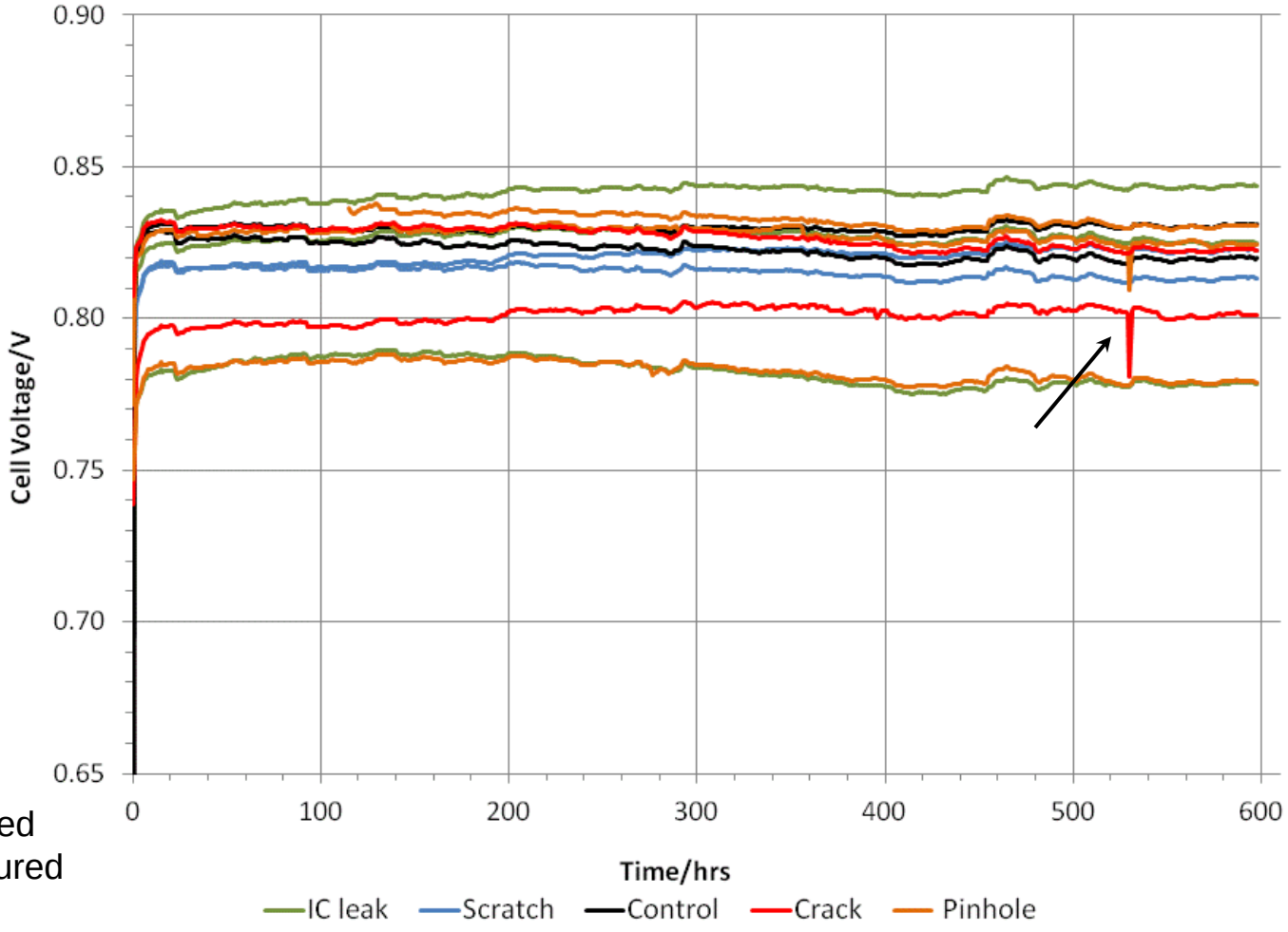


Example Stack Testing , Multiple Defects

20 Cell Stack test

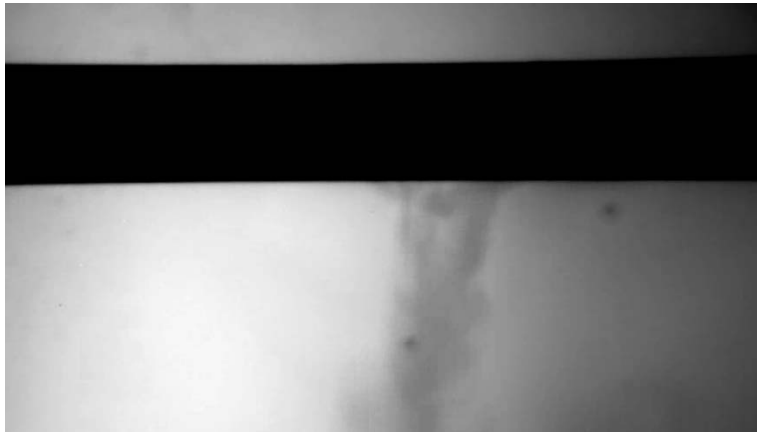


- Cells individually monitored
- Fuel concentration measured at cell outlet



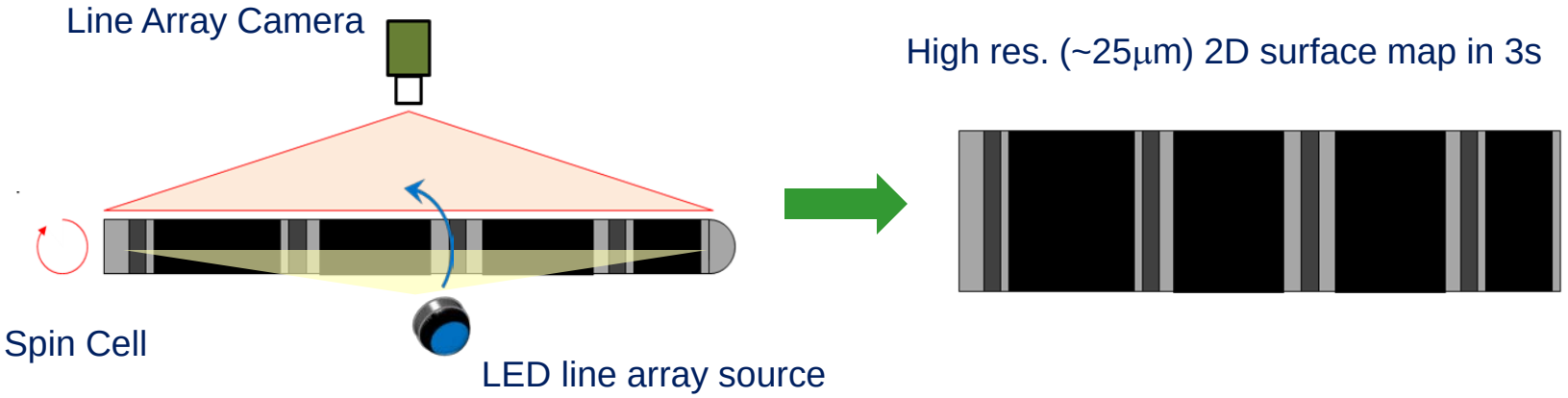
Some NDT Techniques

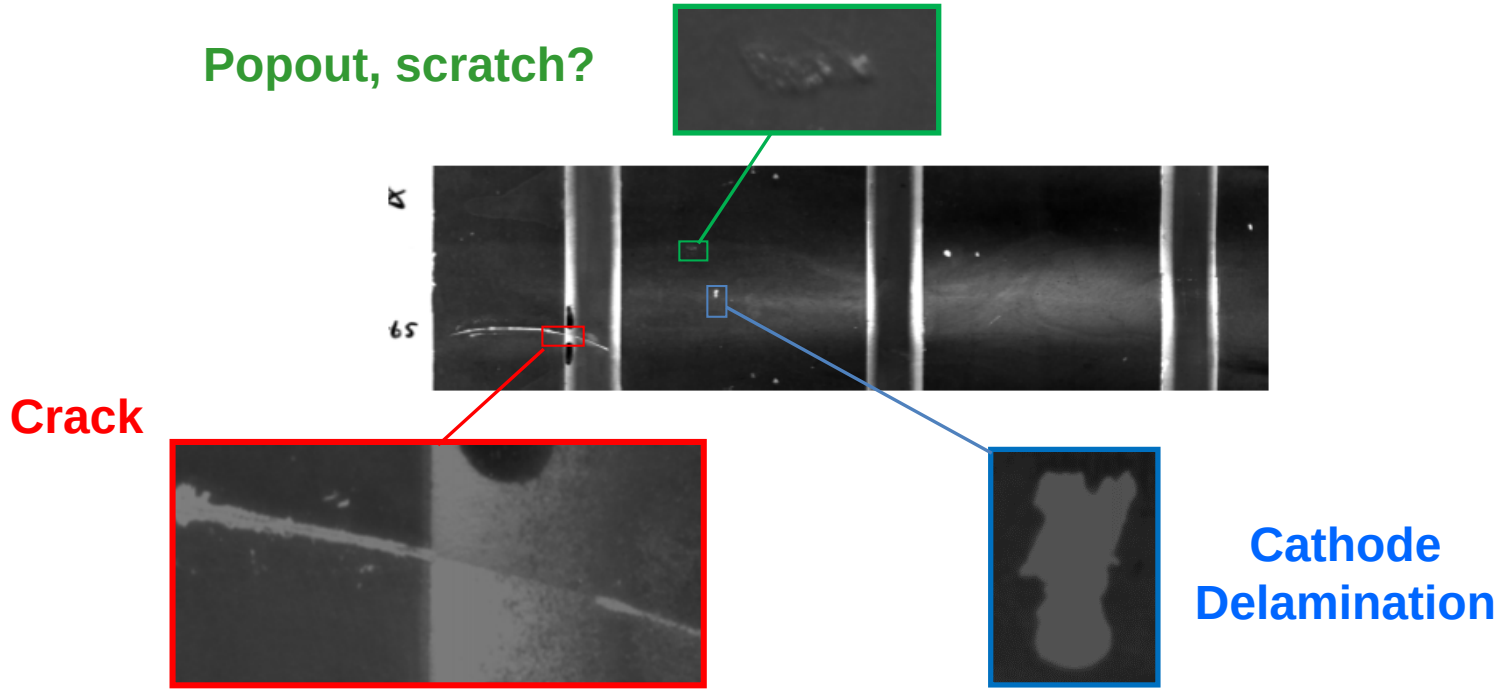
- Optical Reflectance Imaging – surface anomalies
- IR Imaging with thermal activation - for surface/subsurface non-homogeneities (Thermal Scanning)
- IR imaging with voltage excitation – for electrical shorts
- IR imaging with CO_2 pressurization– for cracks
- IR imaging with ultrasound excitation for cracks, separations
- Acoustic transmission signature – for internal cell defects



Crack visualization by
IR absorption of CO_2

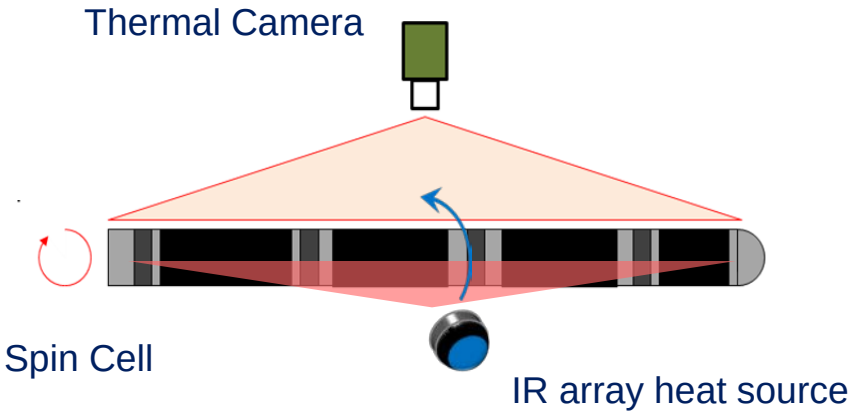
Optical Reflectance Scanning

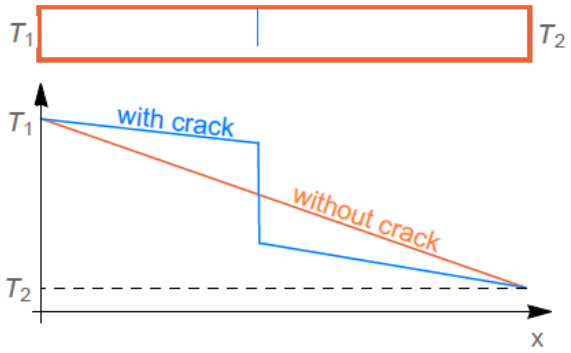


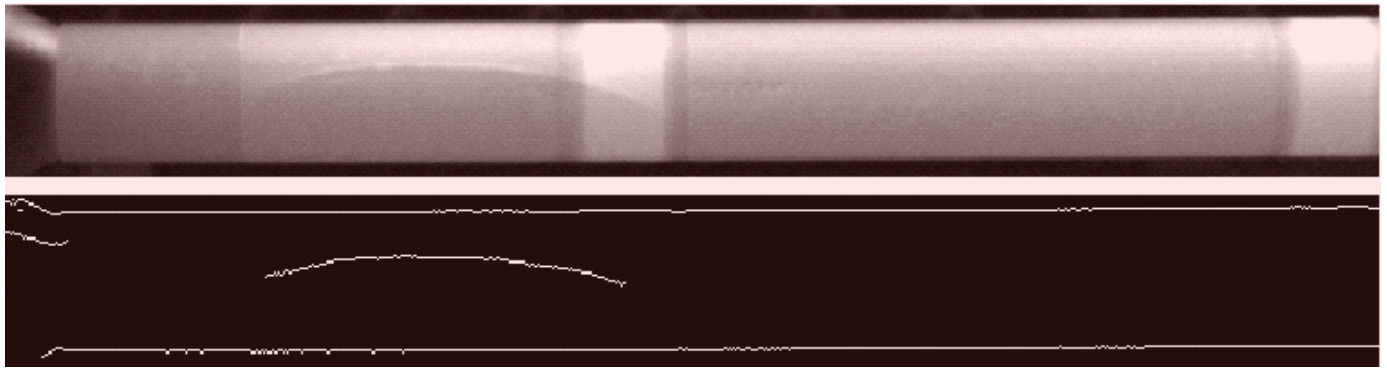


Thermal Scanning – External Heat

- Anomalous development of the temperature field in due to near surface non-homogeneity

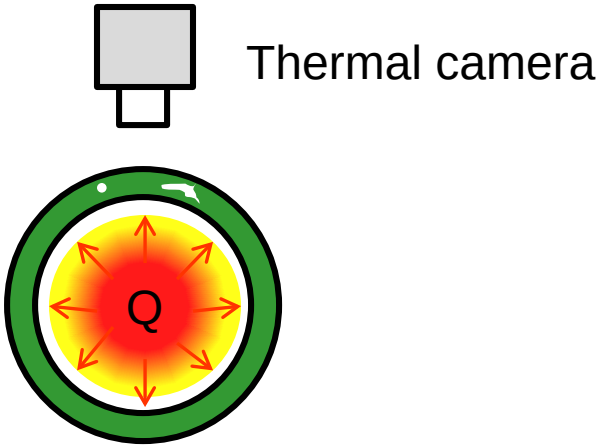


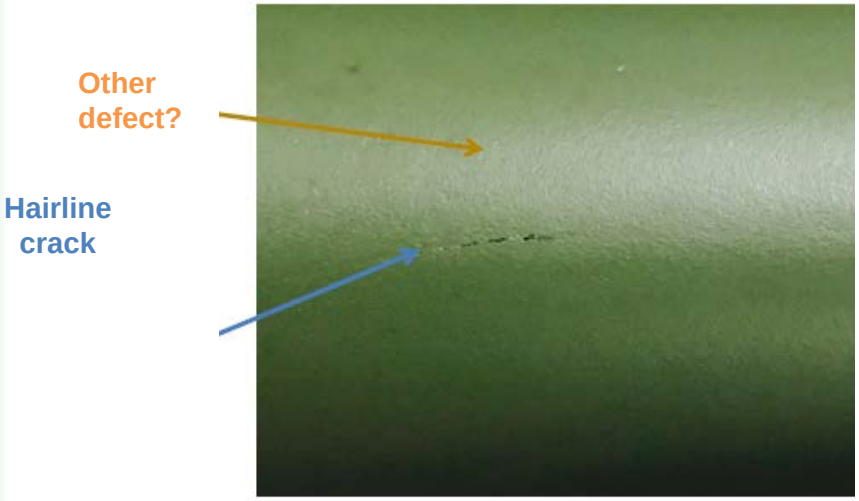


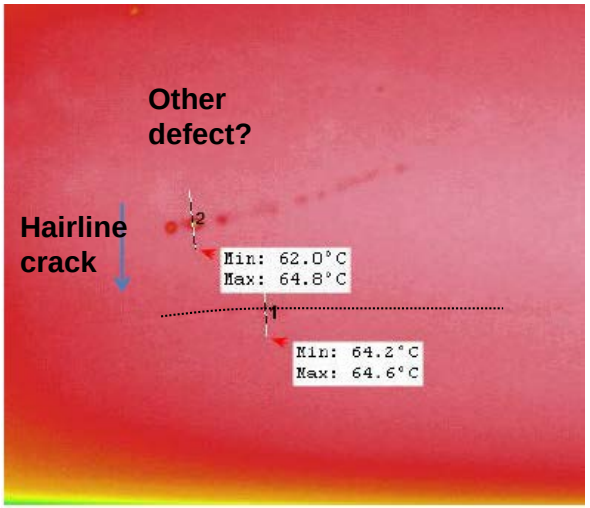


Thermal Scanning – Internal Heat

- Anomalous development of the surface temperature field due to internal defects
- Potential for detecting “invisible” imperfections

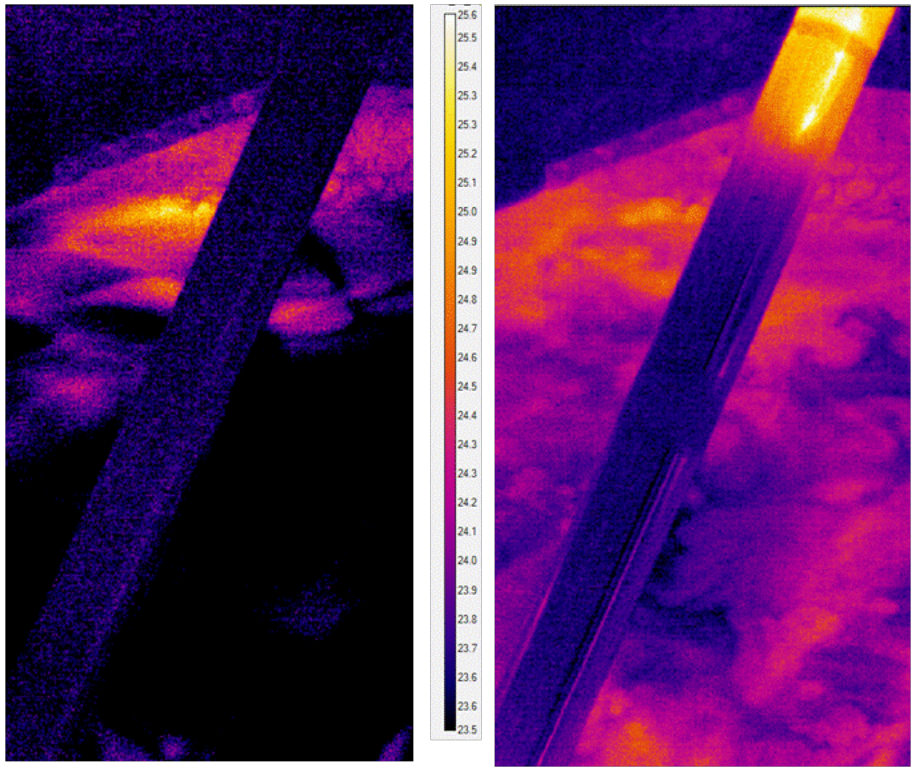


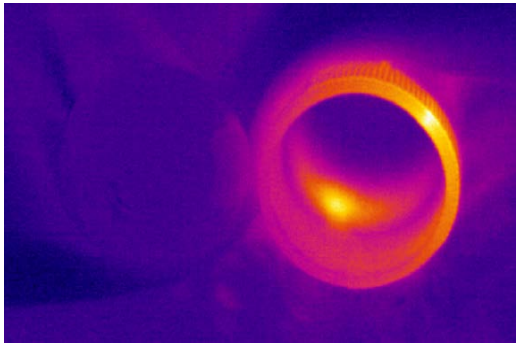




Ultrasound Excited Thermography

- A low frequency ultrasound is coupled to the test article causing the faying surfaces of defects to heat up by friction or clapping





Summary

- In order to practically reach 5 year operating lifetimes for a stack we need to protect against early cell failure
- Even as materials degradation is lessened, each cell manufacturer needs to address the difficult cell quality assurance problem; *what ex situ QC is relevant for high temperature operations.*
- Modern NDT techniques exist for high speed automatic mapping of cell defects
- We need to understand what imperfections are truly debilitating defects in order to set appropriate thresholds
- This understanding should be experimentally and theoretically driven

Acknowledgements

- DOE & NETL . Project Manager Joe Stoffa
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- Acumentrics Engineering Team