ATREX ENERGY

POWERFUL POSSIBILITIES

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

July 19th, 2016

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Atrex Energy

Contents

Acumentrics
Advanced Power Solutions

ATREX ENERGY
POWERFUL POSSIBILITIES

Acumentrics
Trusted Power Innovations

300+ SOFC units shipped

60,000 RUPS™ units shipped

1.5kW SOFC
LPG and NG

2U Lead Acid
or Li-ion 2kW RUPS

3kW JP8 fueled SOFC

1U Li-ion 1.5kW RUPS

Atrex Energy – Capabilities and Resources

- SOFC - “Powder to Power” all in one 30,000 sq ft facility in Walpole, MA
- 52 Employees, electrical, mechanical, chemical and material, automation, firmware - engineers and manufacturing staff
- Research, development and testing laboratory
  - Ceramics forming & processing
  - Commercial manufacturing
  - Power electronics
  - Prototype machining
  - Chemical reactor design
  - Thermo-mechanical design and integration
  - Ground up board and firmware development

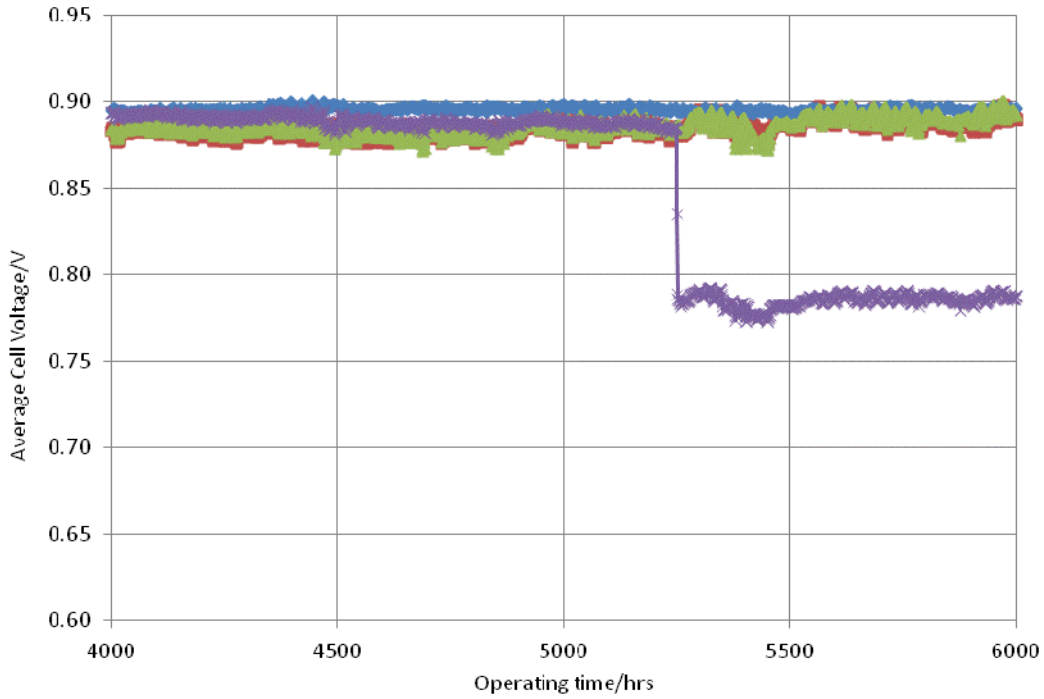
Project Motivation

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 in the early stages.

Target:

- **Stack design**
- **Stack assembly**
- **Cell reliability**



Previous Ending Remarks (2015)

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

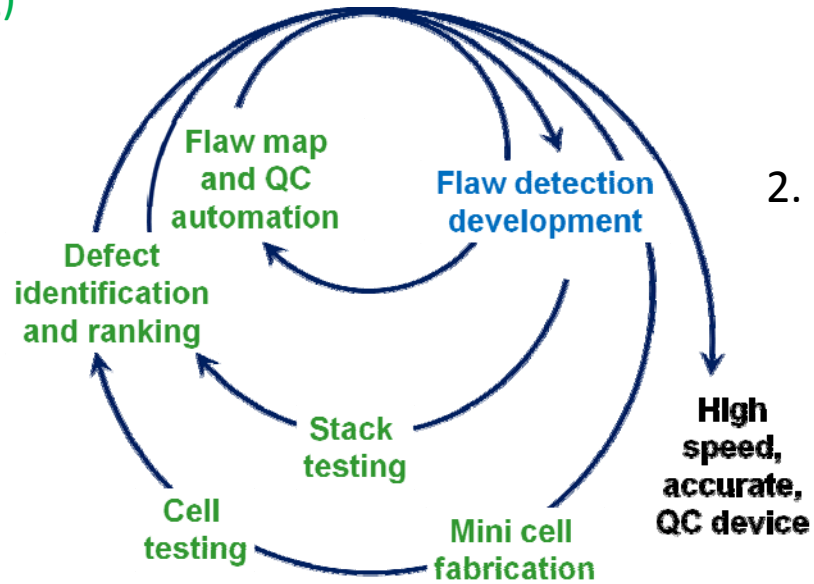
We need to understand what imperfections are truly debilitating defects in order to set appropriate thresholds

This understanding should be experimentally and theoretically driven

Project Goals

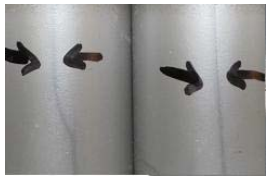
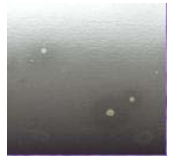
1. **Experimental investigation of cell "imperfections"; do we see a signature for degradation at high temperature?**
2. **Development of automatable imaging techniques for identification of imperfections *with intelligent screening for defects***

1. Mini-cell testing (similar to button cell testing)
2. Stack testing (20 cell stacks)
3. Microscopic characterization of imperfections

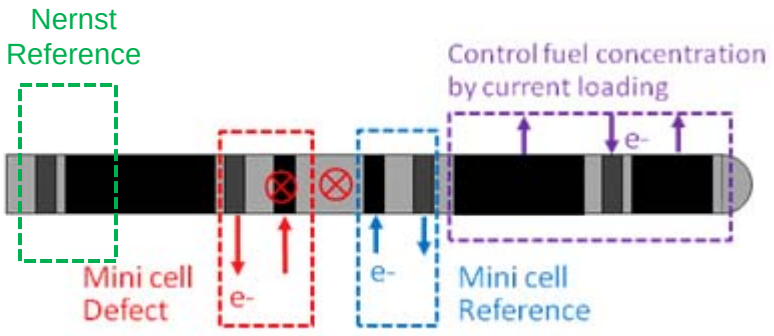


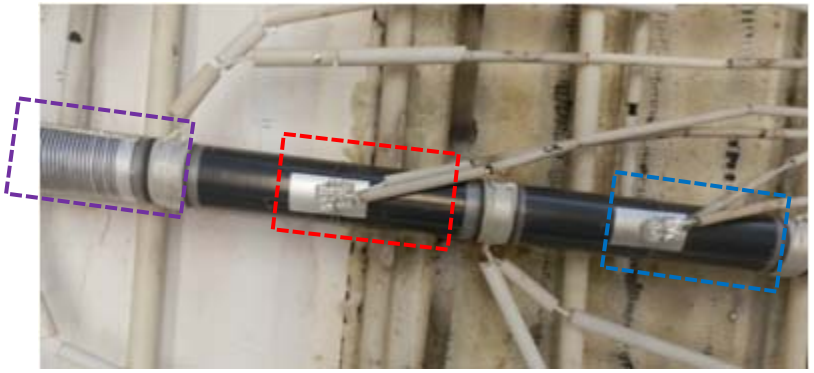
1. Screening of imaging techniques (NREL Fuel Cell Manufacturing project)
2. Build of QC device (Atrex Energy)

Visually 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)			

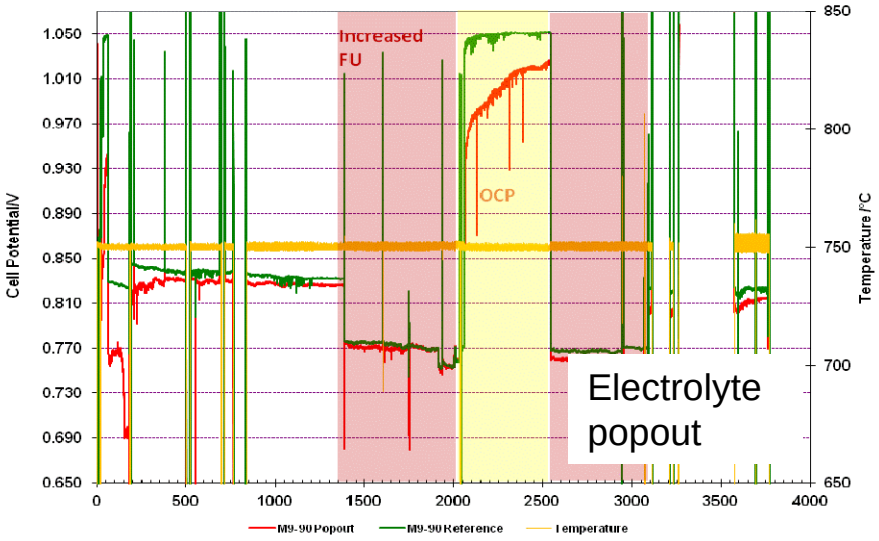
Mini Cell Testing

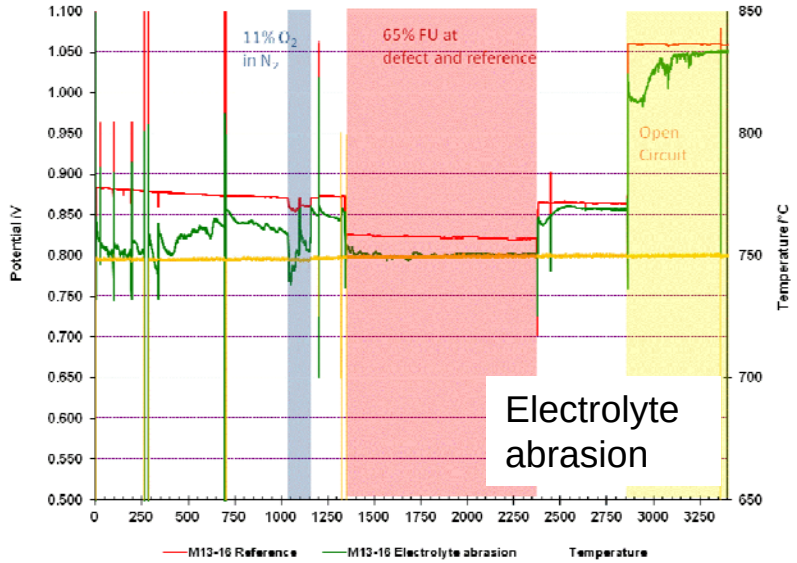


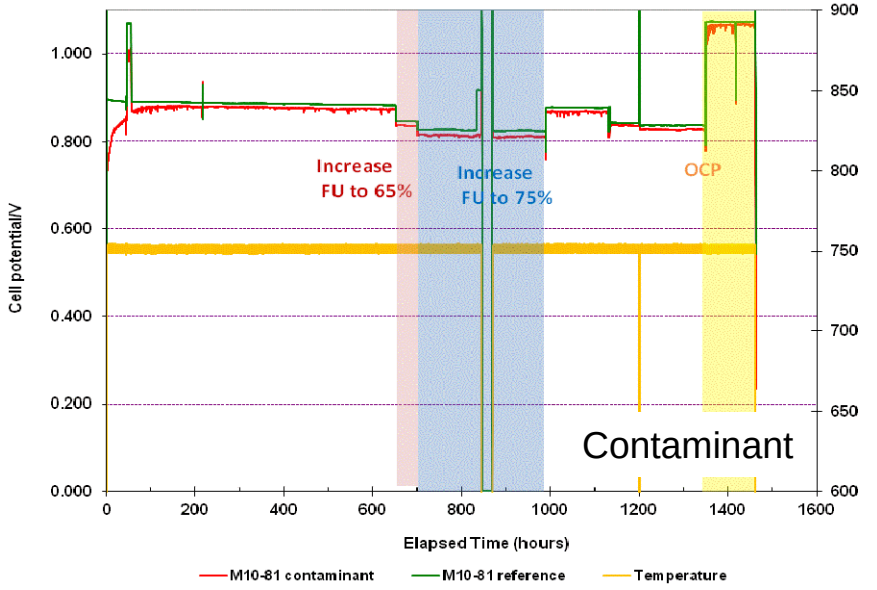


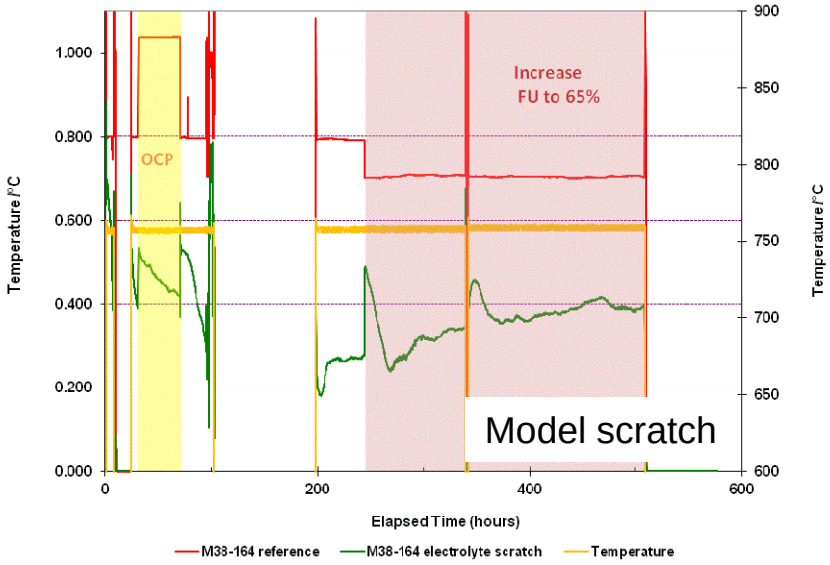
- Possible environment of a cell defect in a stack
  - Temperatures 680-830°C (however all testing at 750C to date)
  - Cathode atmospheres 21%-13% O2
  - Anode atmospheres commensurate with 0-75% FU
  - Local current densities 150-700mA/cm^2
- Possible transients
  - Thermal and load cycling

Cell Testing Summary









“Natural” Scratch Further Processed

As discovered

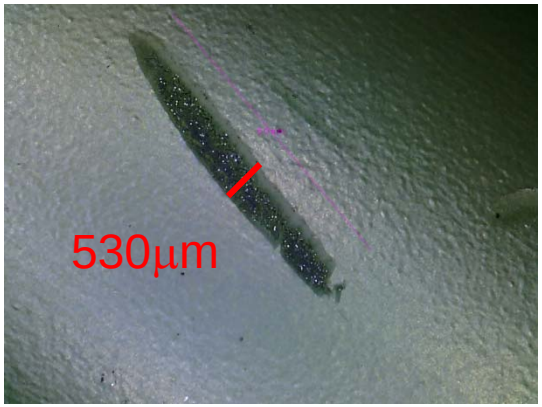
After SDC firing

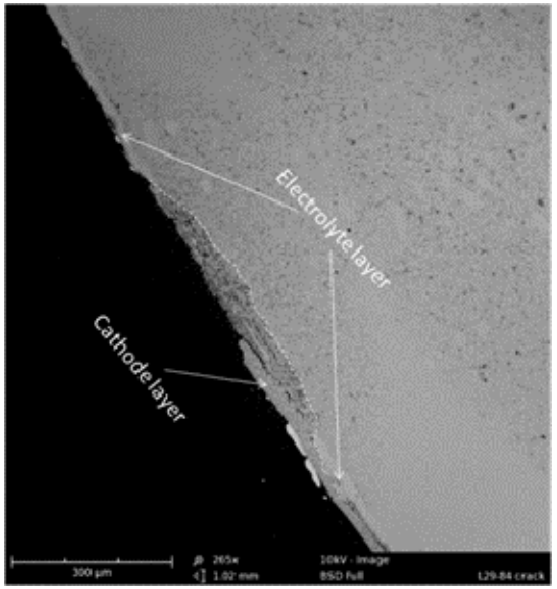
After Ag CC applied

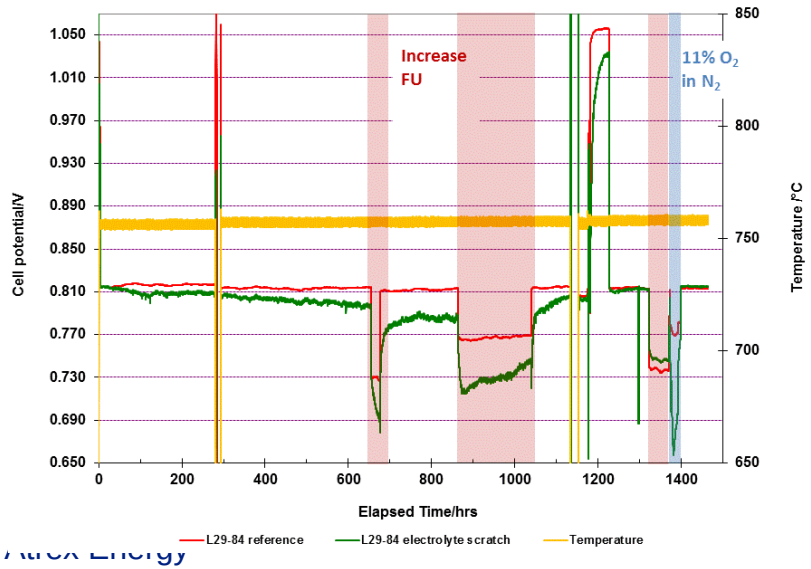
After Cathode
coating and reduction

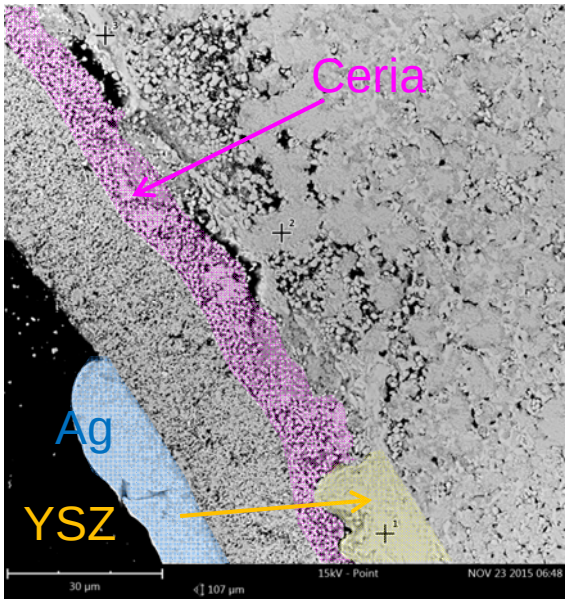
“Natural” Scratch 530µm wide

Healed from 900hrs when at 65% FU

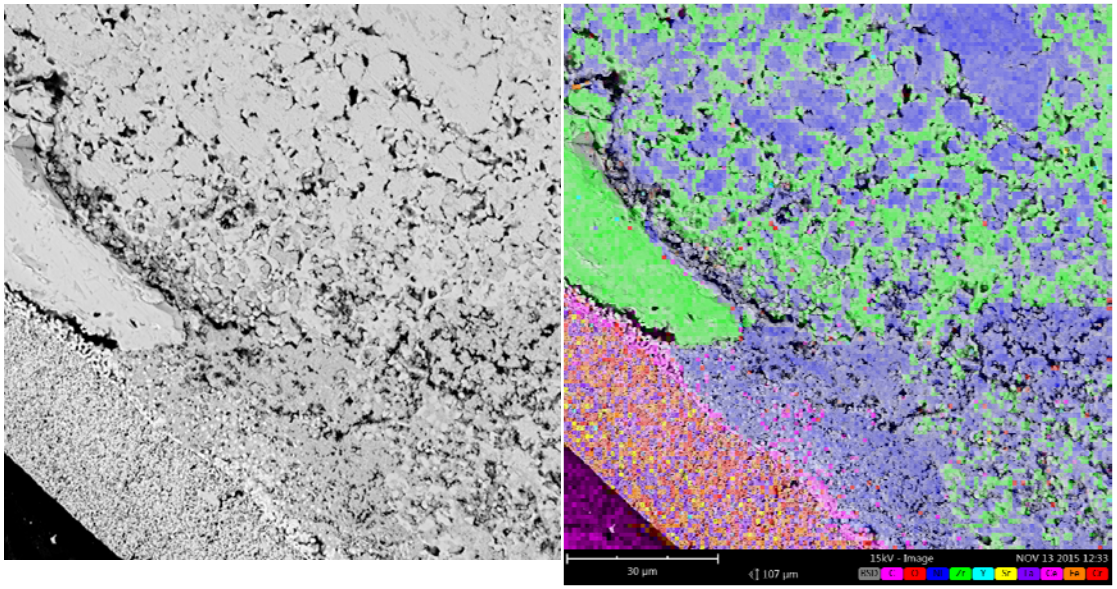


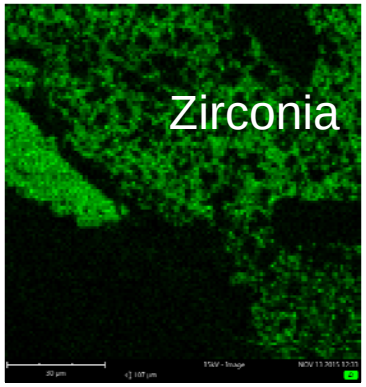


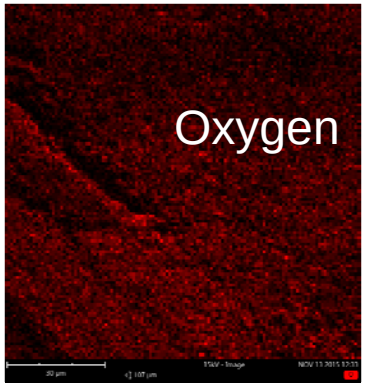


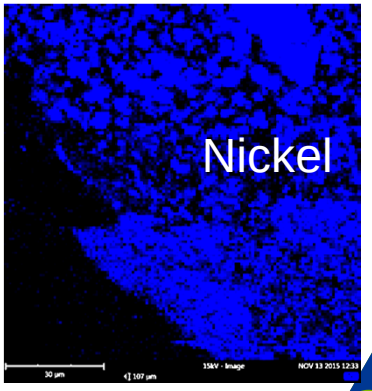


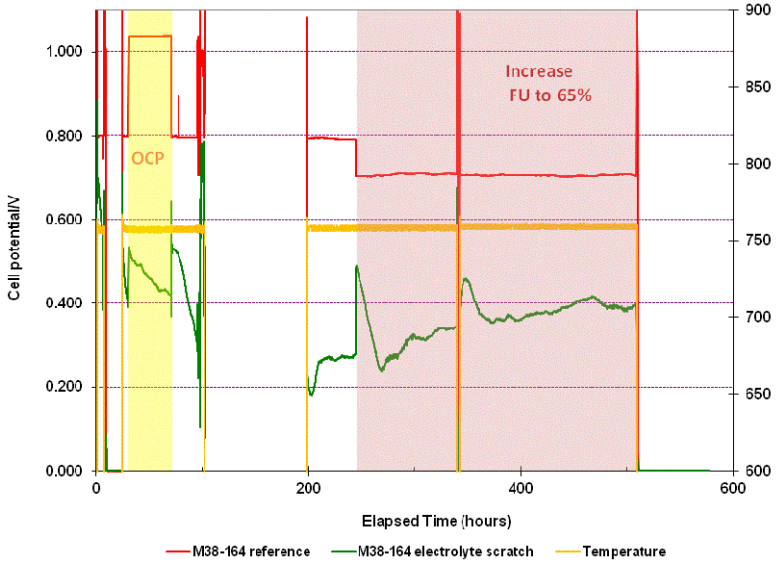
Artificial Scratch 280µm wide



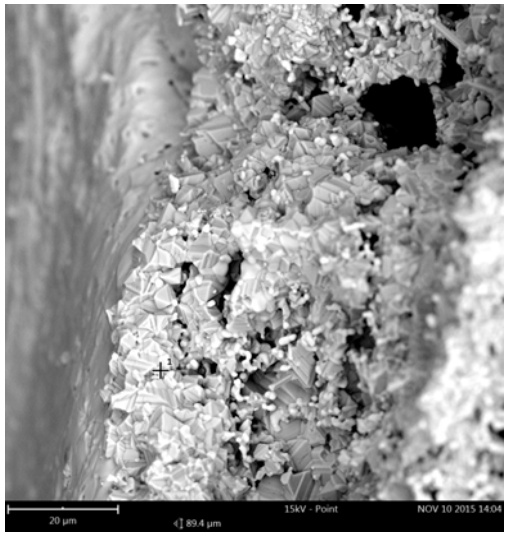


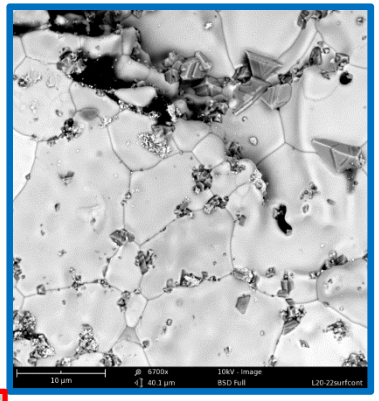


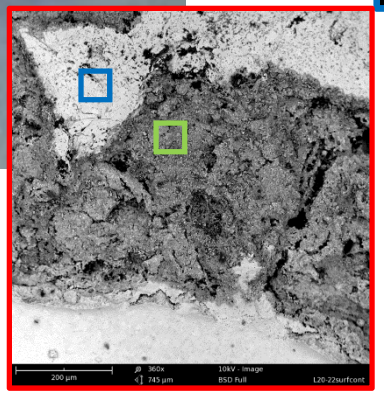


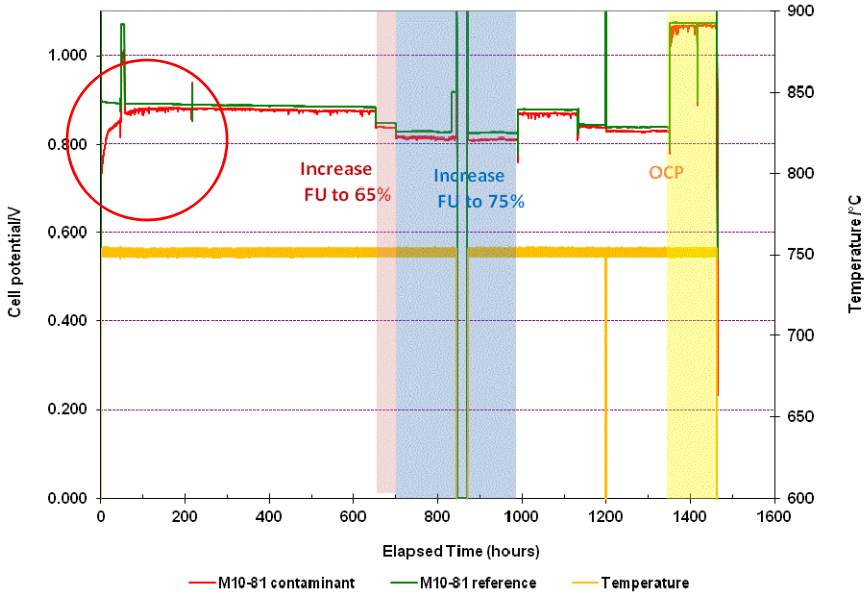


Electrolyte Contaminant, NiO agglomerate

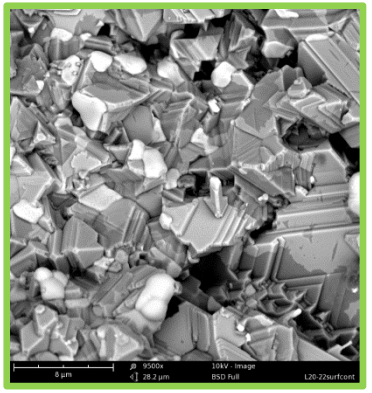




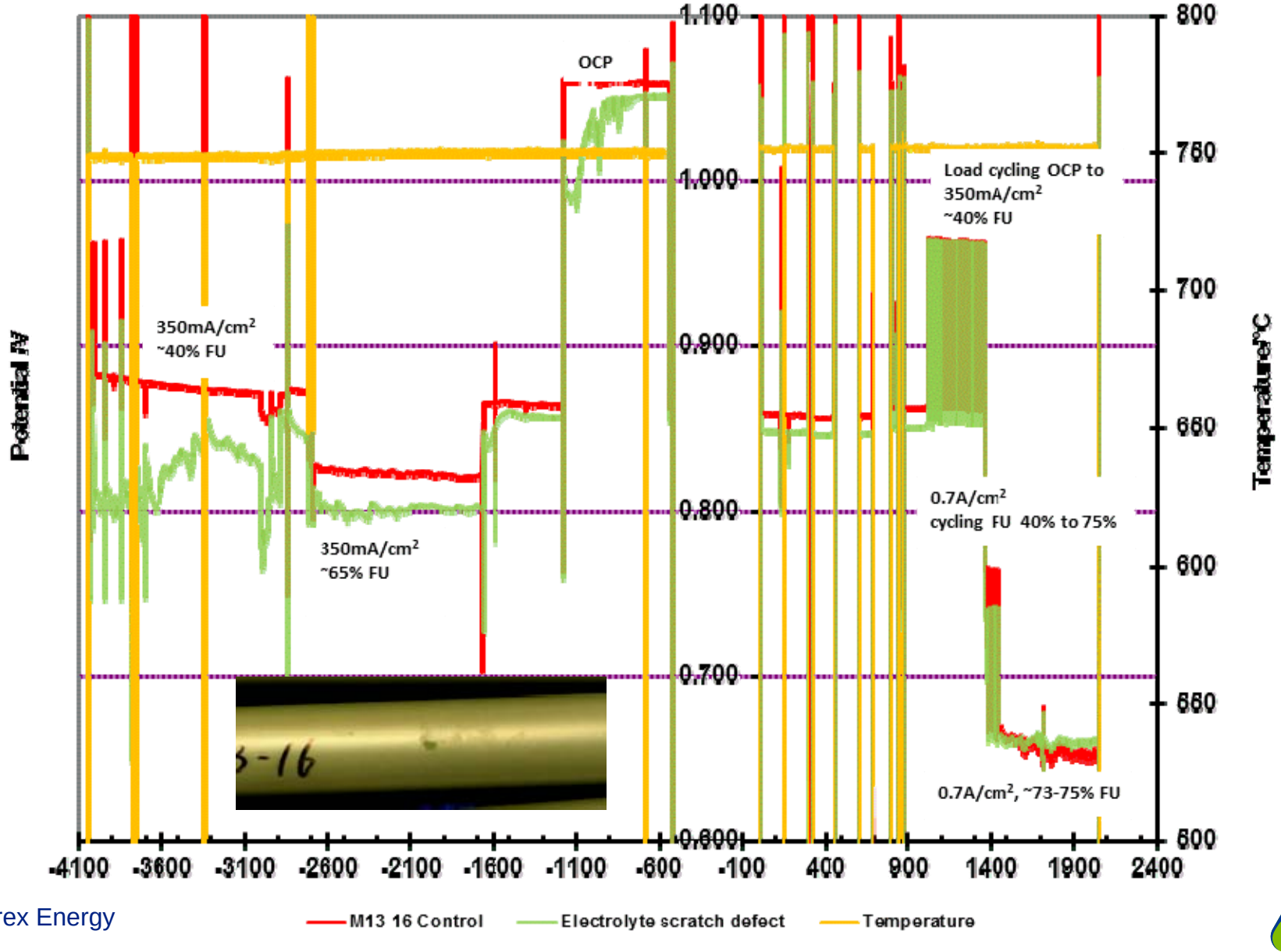




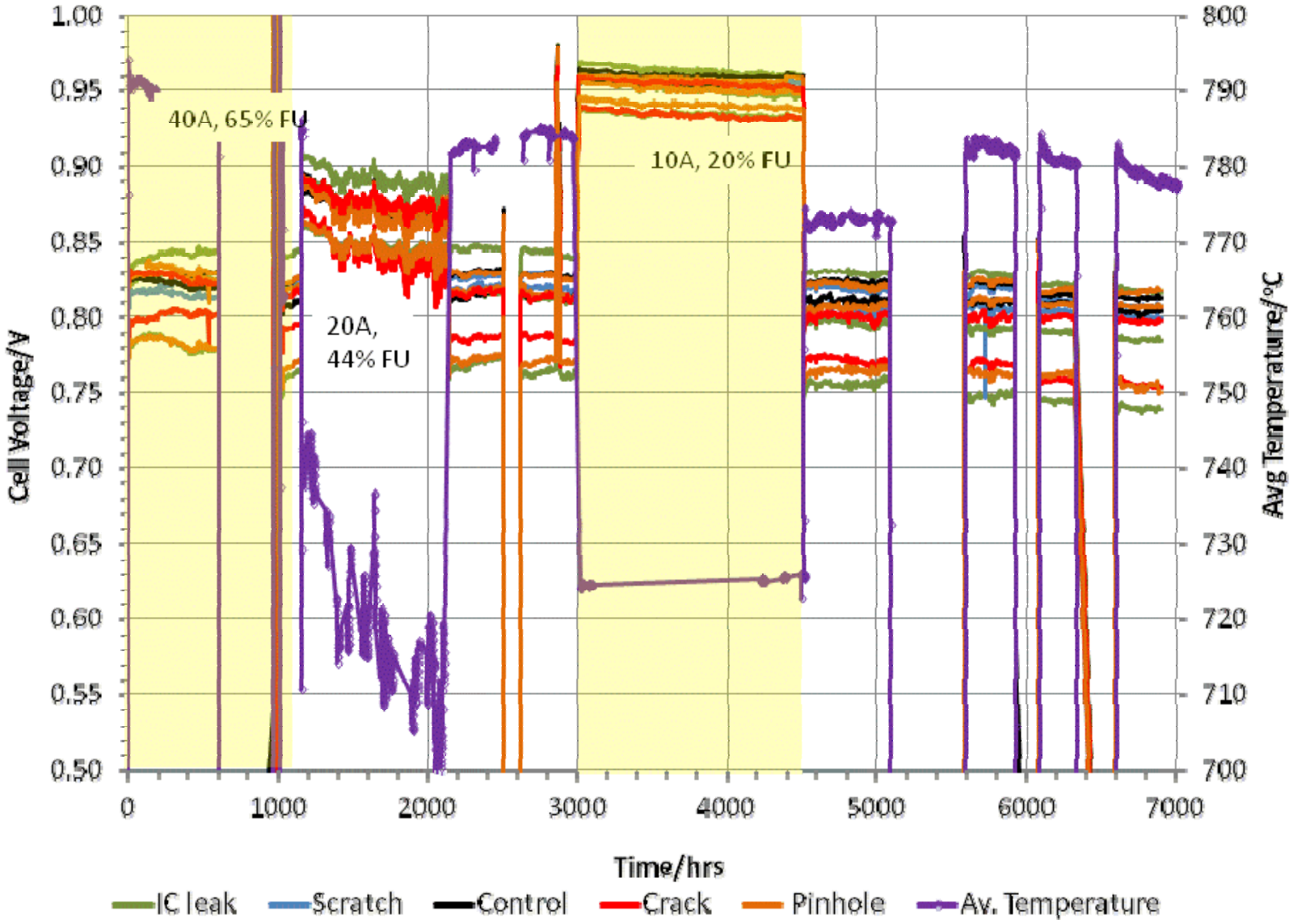
Element	At%
Ni	49.6
O	45.2
Cr	1.9
Zr	1.4
Y	0.5
Al	0.9
Fe	0.5



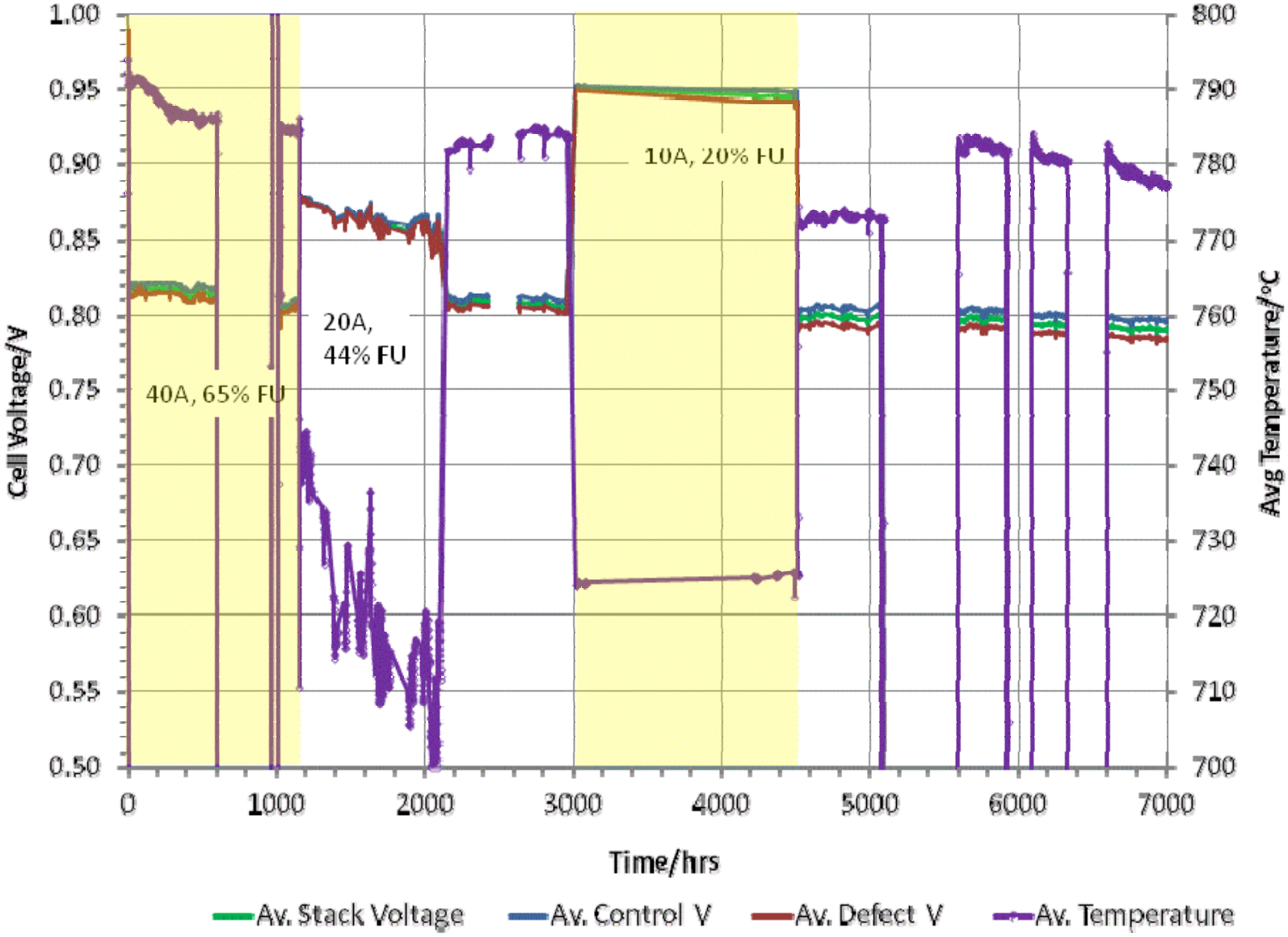
Electrolyte Abrasion Defect



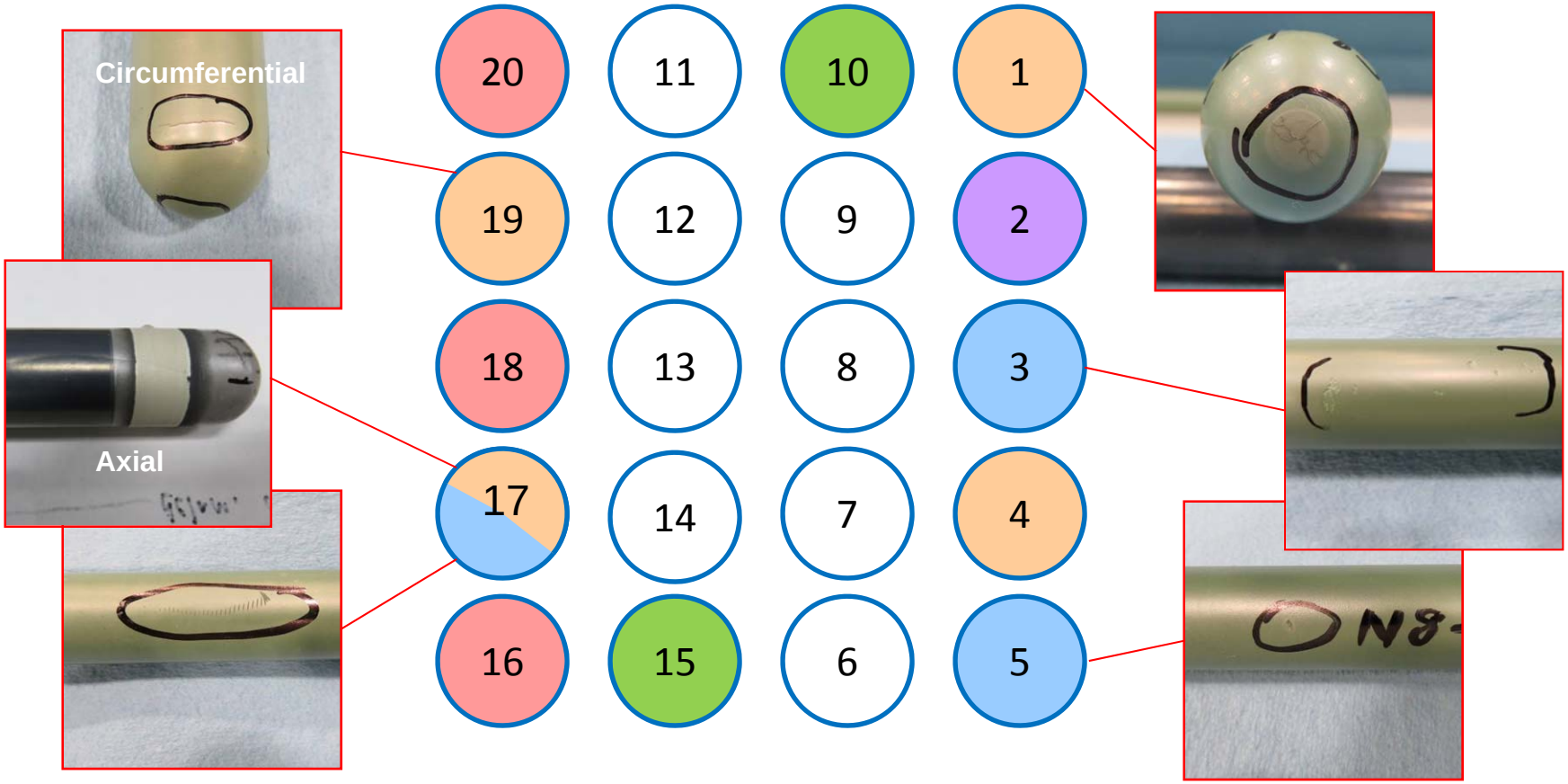
Stack Testing CT-1



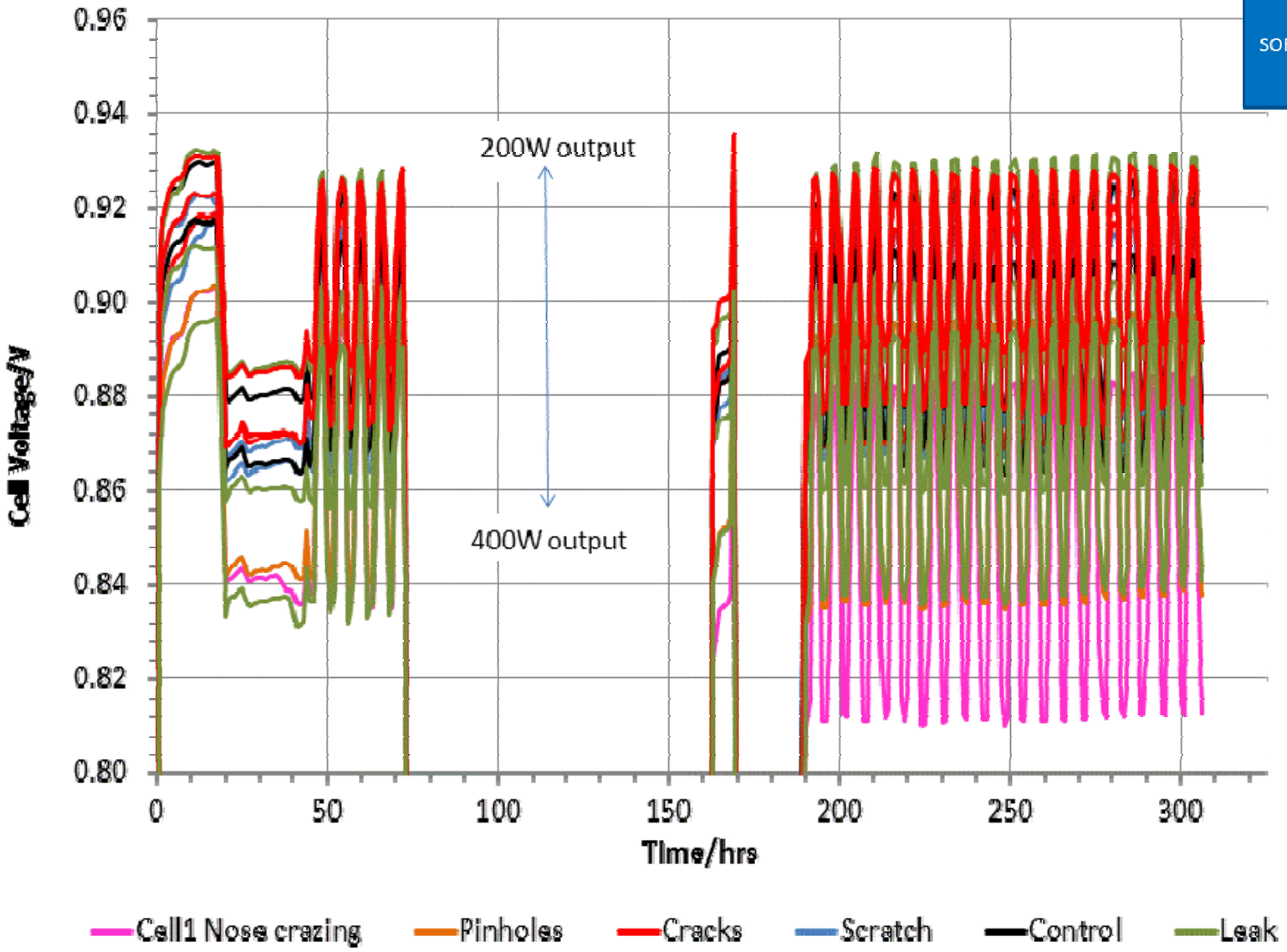
Average Stack Voltages CT-1

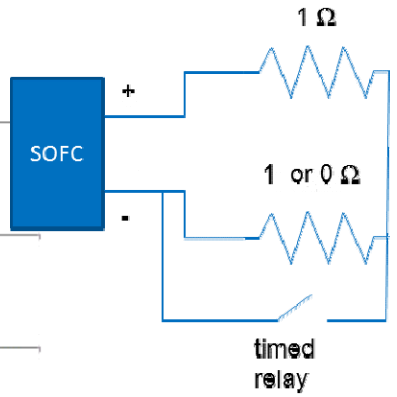


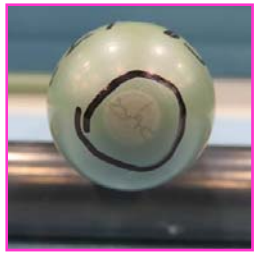
CT-2 Stack Test, Defect Placement Key



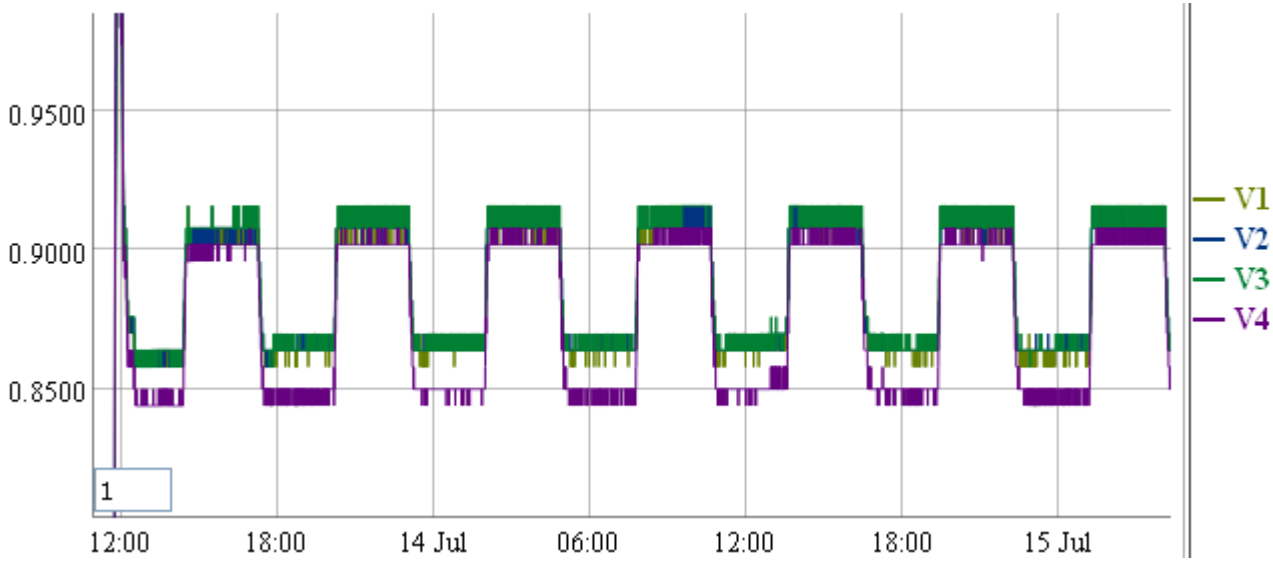
Load cycling of “imperfect” stack (CT-2)

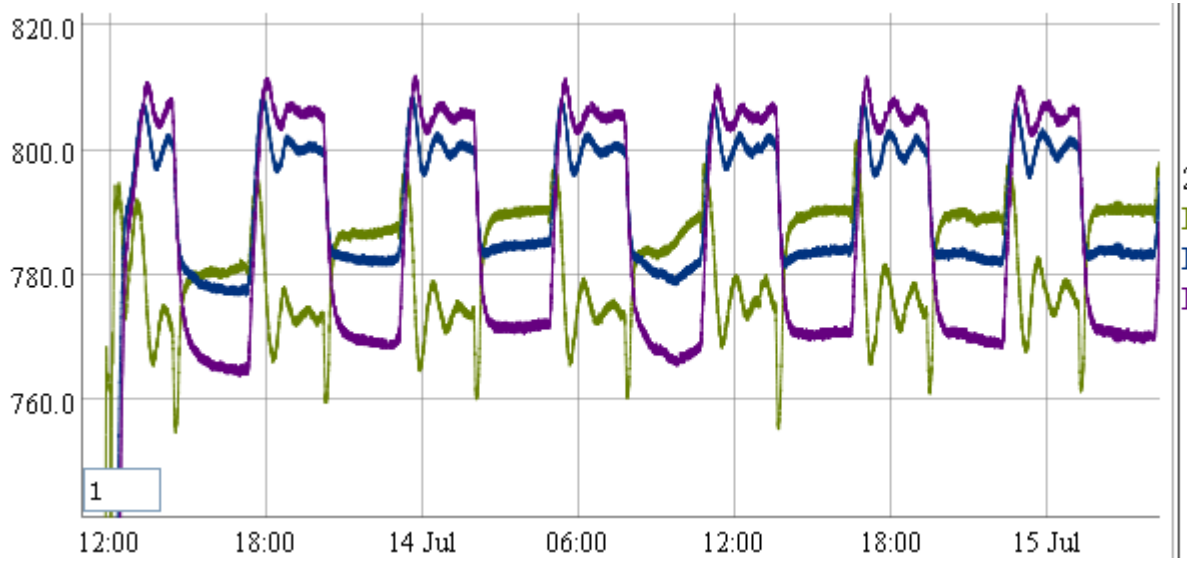






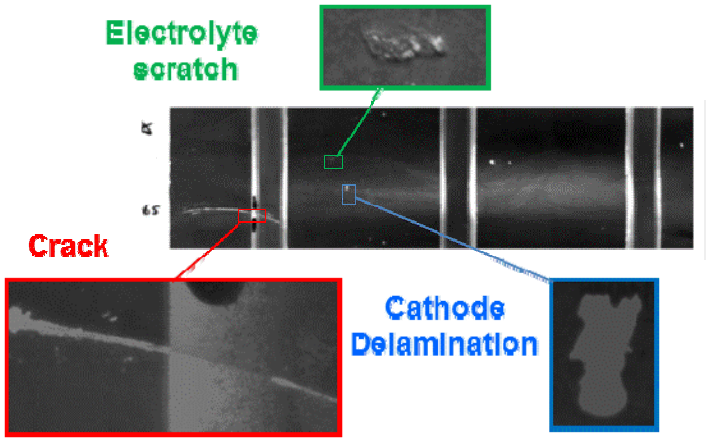
Load cycling → Temperature cycling



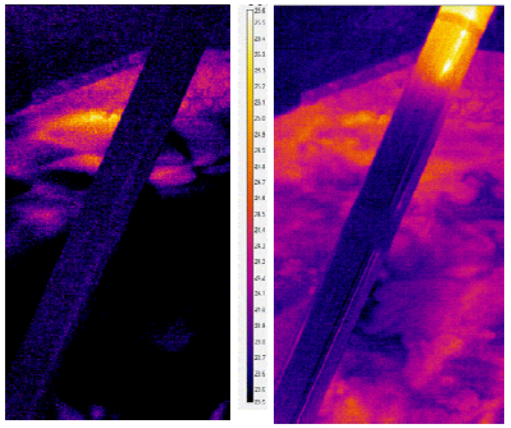


Imaging of Imperfections

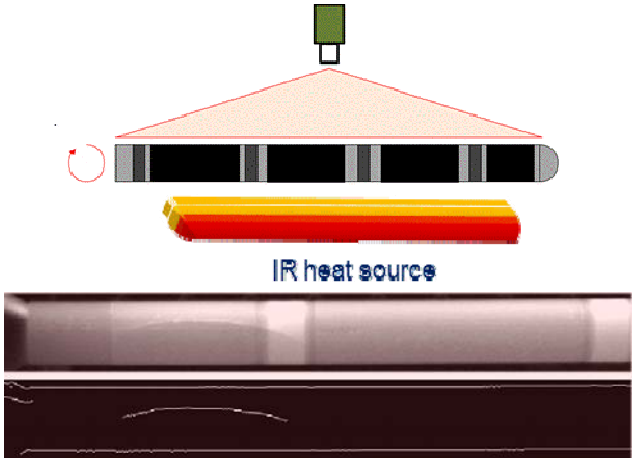
Optical Reflectance



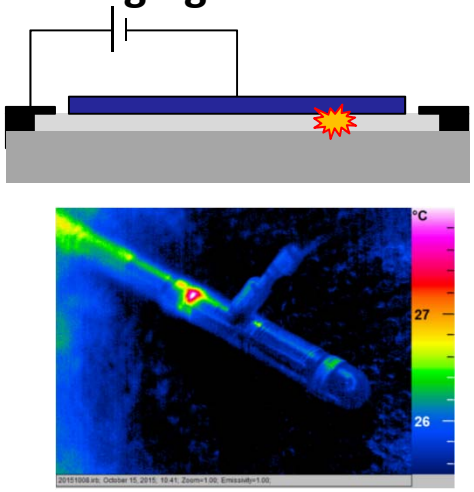
Thermal IR Imaging – Ultrasound Excitation



Thermal IR Imaging – Thermal Excitation

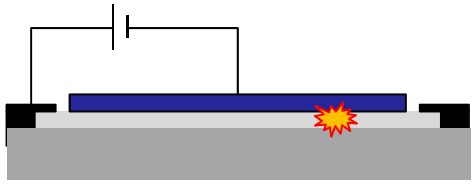


Thermal IR Imaging – Electric Excitation



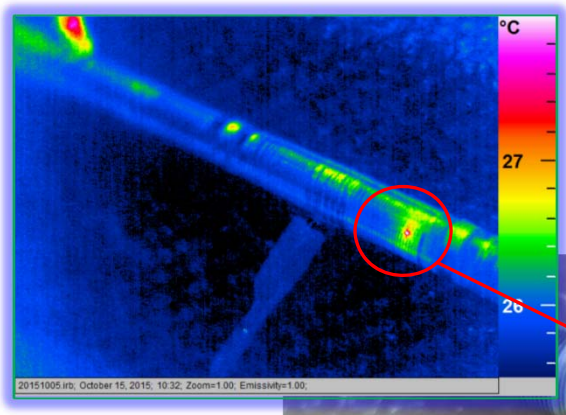
Imaging of Electric Shorts

Heat signature of joule heating from an electric short can be easily picked up by a thermal camera (~0.1W)

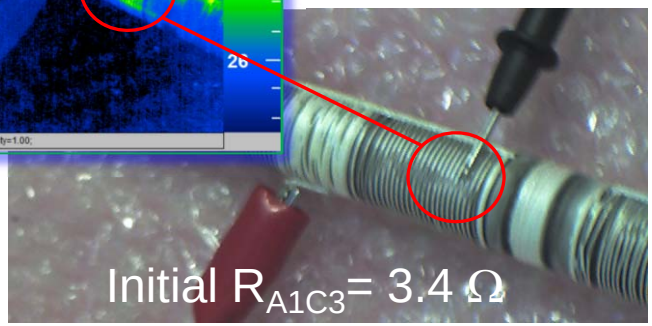


Have not found any examples of electrical shorts in production; have found a few examples in old stacks. Useful technique for investigating degradation phenomena

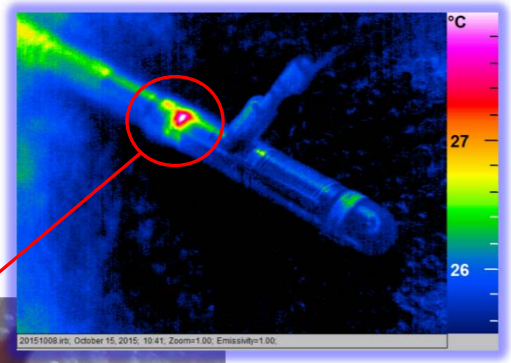
e.g. cell tested in field for 9000 hrs



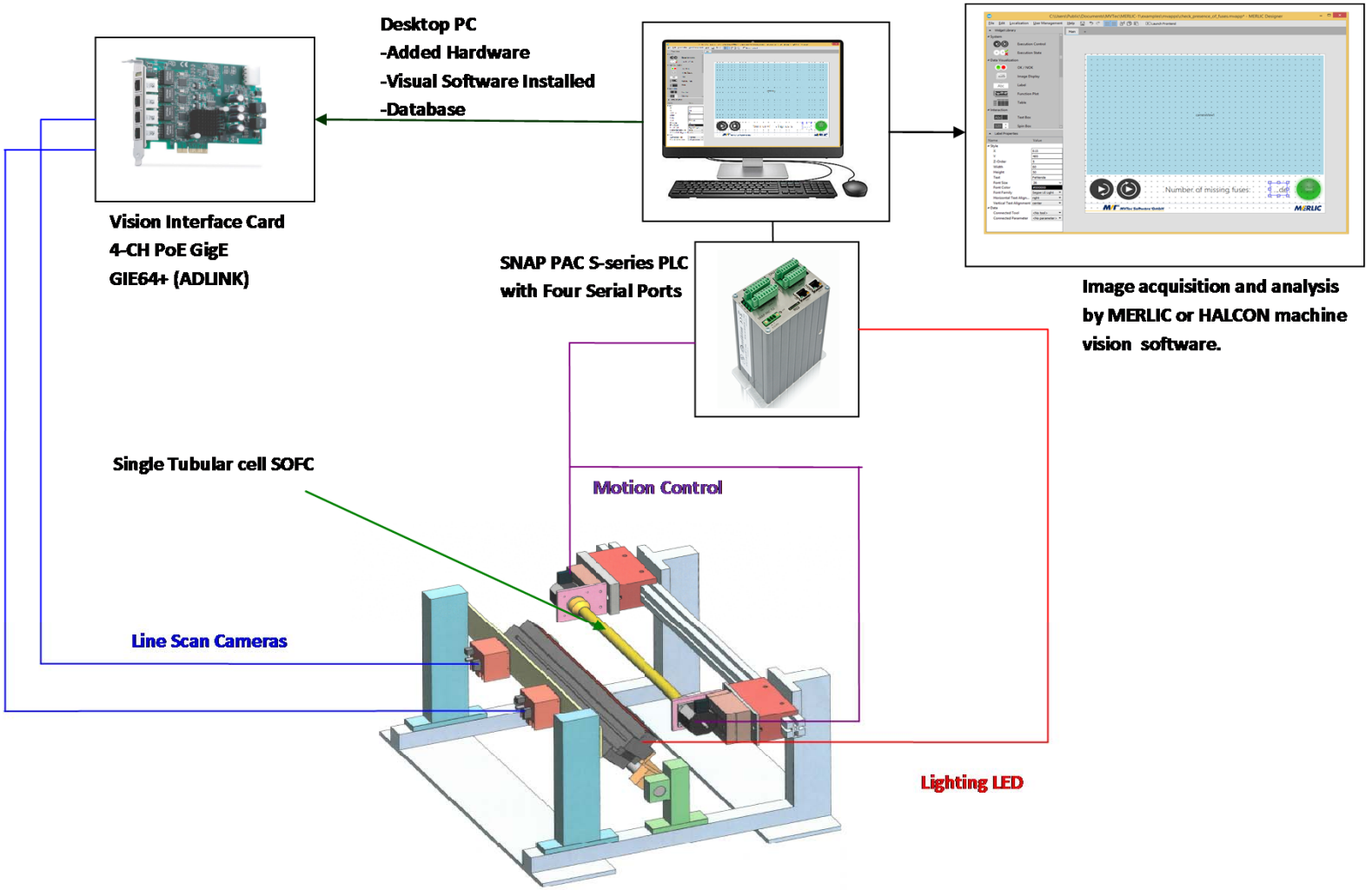
Short in middle of cathode



Short along edge of cathode



Conceptual Vision Inspection Station



Summary

Even after 1000s of hours of testing at the extremes of operation the imperfections have not lead to catastrophic failure of stacks

Member of an imperfection class (e.g. scratch) may yet develop morphologies under processing and then operation

Cracks and electrolyte abrasions/scratches are still recommended for screening out – threat of gas leakage, electric shorting

A variety of imaging techniques have been screened and shown utility . No one technique is likely to be able to capture all imperfections of a single kind . e.g. Some cracks got past optical reflectance and ultrasound activation but were picked up by thermal scanning

What about the invisible defect?

Acknowledgements

DOE Contract :DE-FE0023478

NETL Project Manager Joe Stoffa

DOE NETL Managers

NREL Fuel Cell Manufacturing Project,

Michael Ulsh, Peter Rupnowski, Bhusan Sopori

Atrex Energy Engineering Team

Wensheng Wang, Jesus Solis, Steve Murphy