Electrochemical Techniques and Corrosion Research with Industry Partners at Western Chemistry

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May 1, 2019

Western Science

SURFACE SCIENCE WESTERN

SKB

nwmo

NUCLEAR WASTE MANAGEMENT ORGANIZATION

SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

PREMIER LEAGUE

ELECTROCHEMISTRY & CORROSION SCIENCE

Corrosion Research Team

Well-Equipped Lab in Dept. of Chemistry

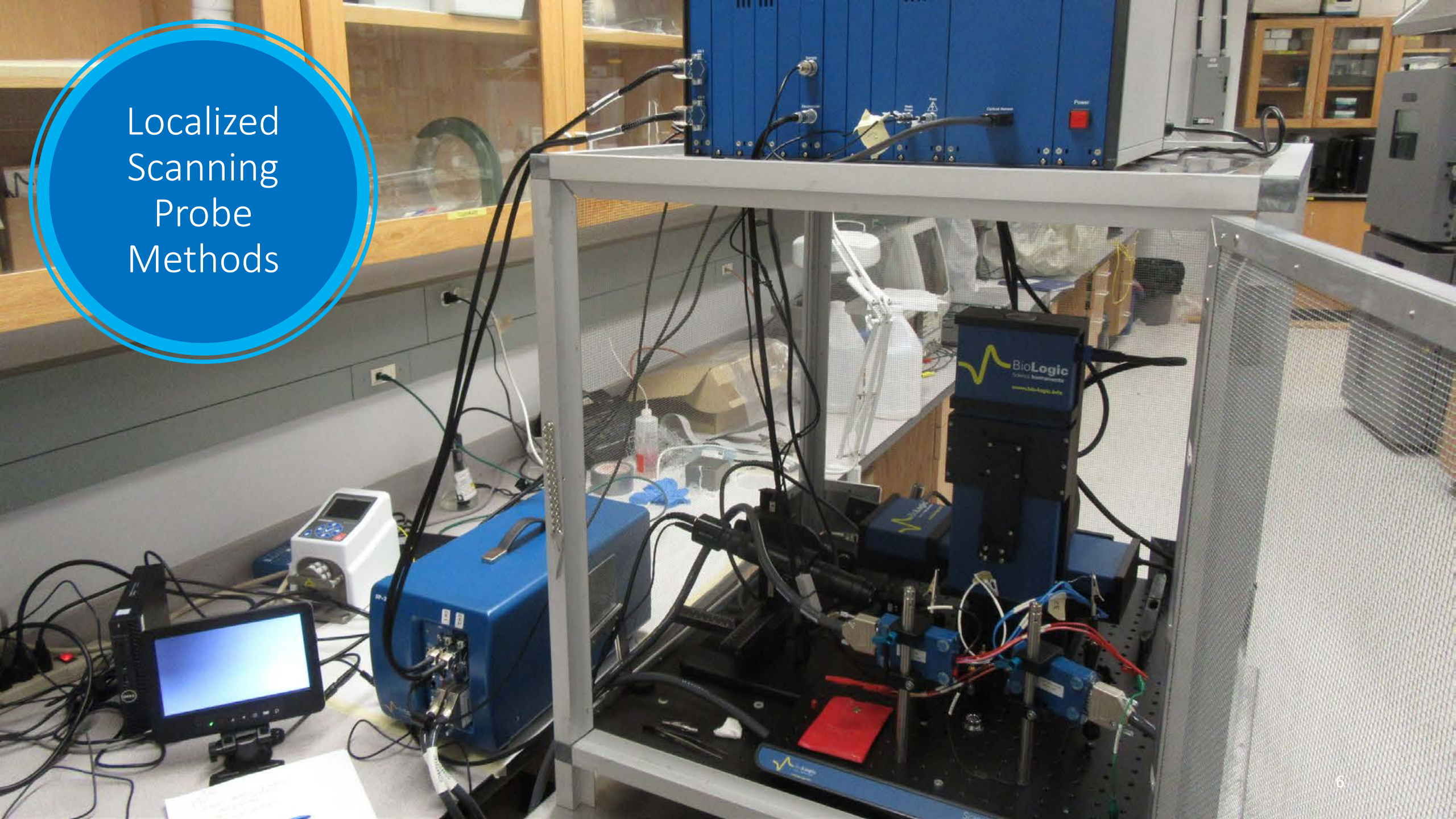
PREMIER LEAGUE
ELECTROCHEMISTRY & CORROSION SCIENCE

https://ecswestern.org/

Sample Preparation Facilities

High Temperature Electrochemistry

Localized Scanning Probe Methods



Innovative
Novel
In-House
Designs

Other Equipment/Techniques

- Potentiostats (dozens) and FRAs
  - Voltammetry
  - Potentiometry
  - Polarization curves
  - EIS (Impedance Spectroscopy)
- Rotating disk and ring-disk
- Photoelectrochemistry
- IGF hydrogen analyzer
- Anaerobic chambers
- Scintillation counter
- Electrochemical quartz crystal microbalance
- Zero resistance ammeters
- Low current DC source
- Custom electrochemical cells
- Microelectrochemical cell
- ADC/DAC systems
- Rigorous QA regime

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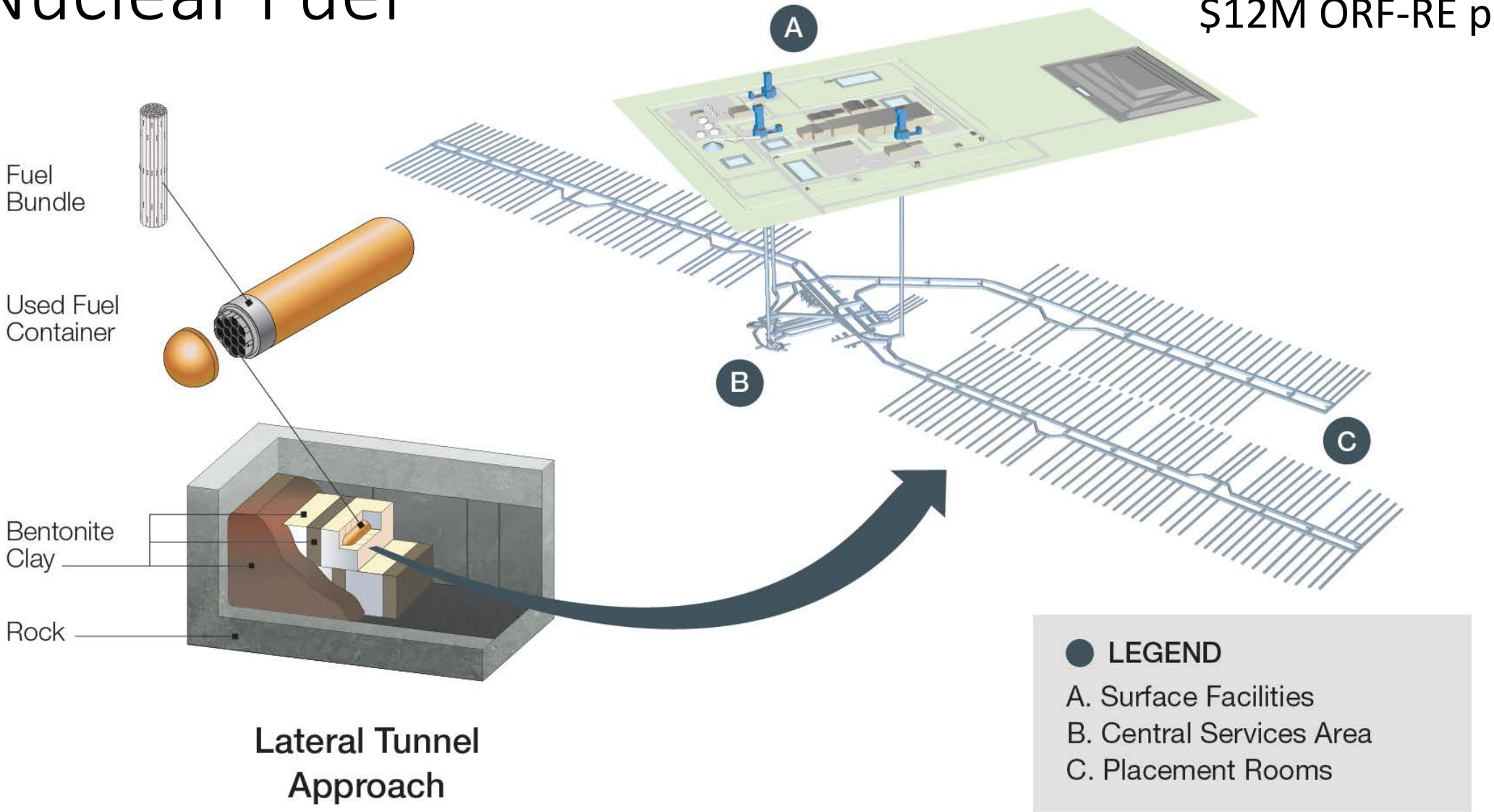
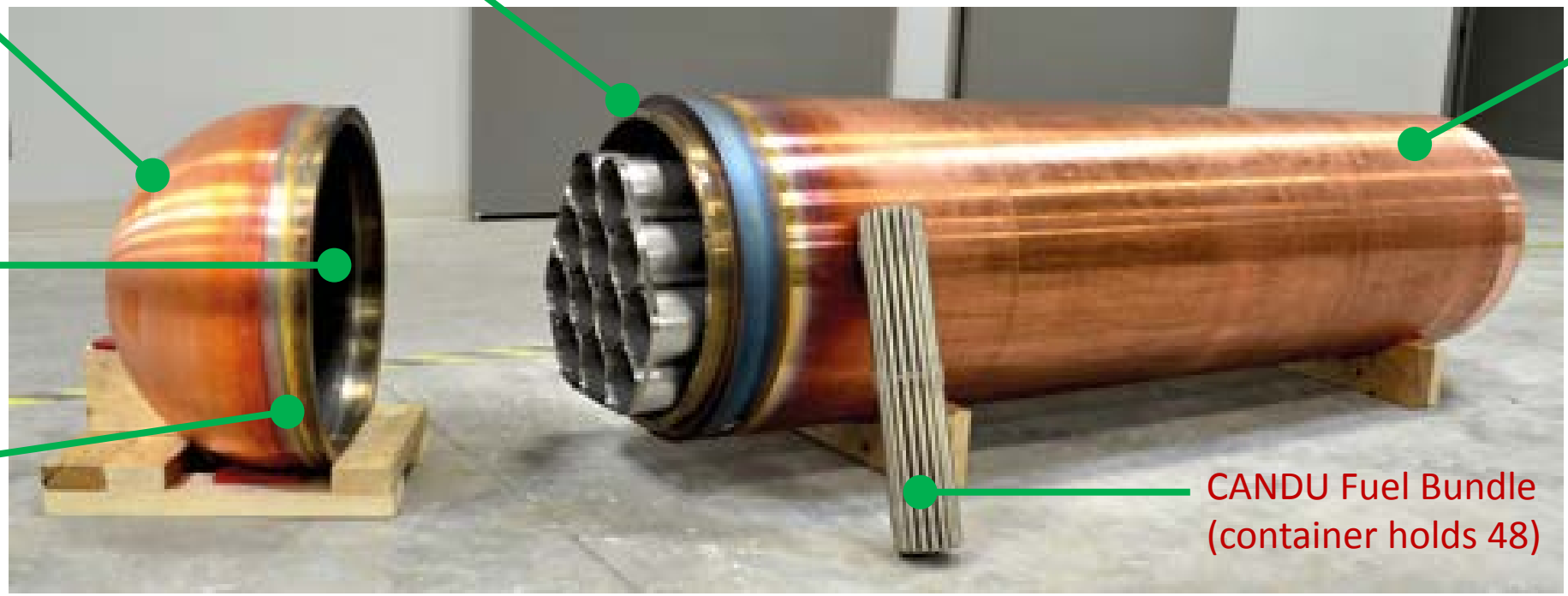
Deep Geological Disposal Concept for Spent Nuclear Fuel

$12M ORF-RE project

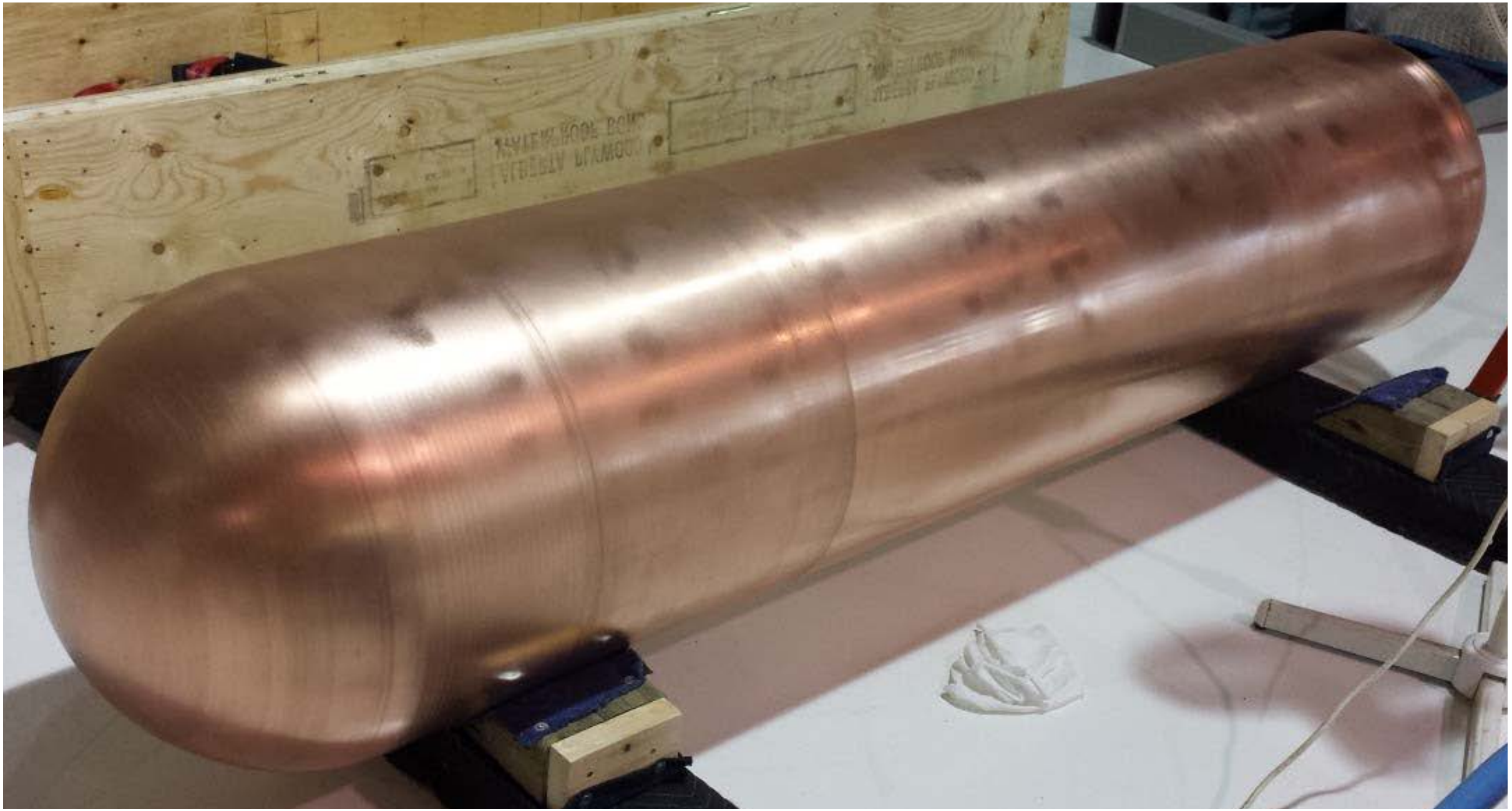


M. Garamszeghy, Report TR-2012-13, *Nuclear Waste Management Organization (NWMO)*, Toronto, 2012.

Mark II Container Design Features



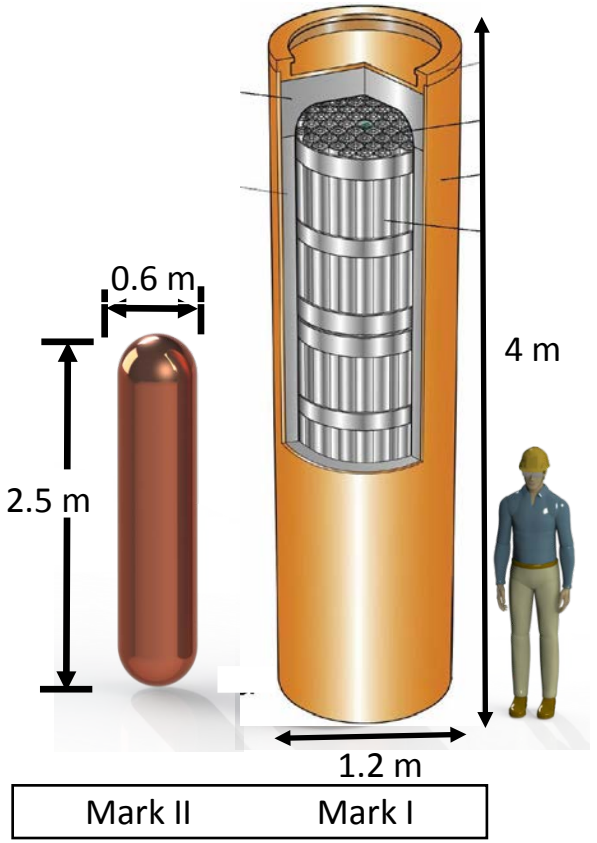
- Evaluation of the properties and corrosion performance of the coatings
- Corrosion performance compared to that of P-deoxidized wrought copper (as used in Sweden), for which a large database of corrosion information already exists

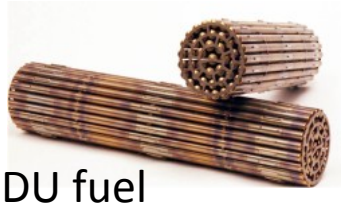


Full-sized container after closure, welding, and spray coating.

Evaluating the New “Mark II” Container

- Smaller, lighter (enabled by size of CANDU fuel)
- Manageable weight
- Standard ASME/ASTM steel vessel
- Deposited copper layer for corrosion protection (electrodeposited or cold spray coated)
- Copper only 3 mm thick
- More reliable
- $2 B cheaper
- Can be manufactured in Canada





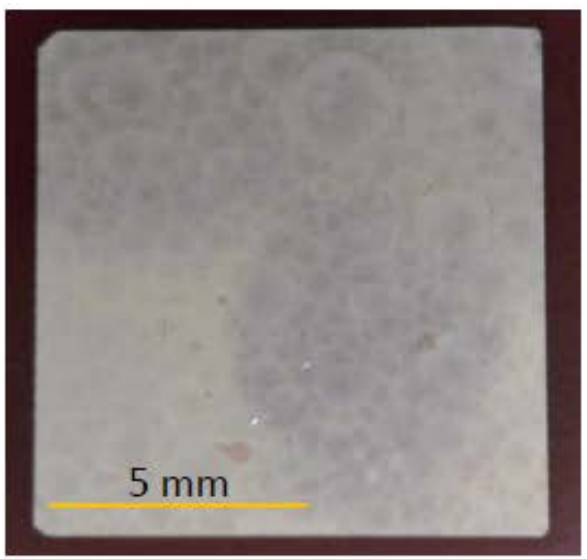
CANDU fuel bundles

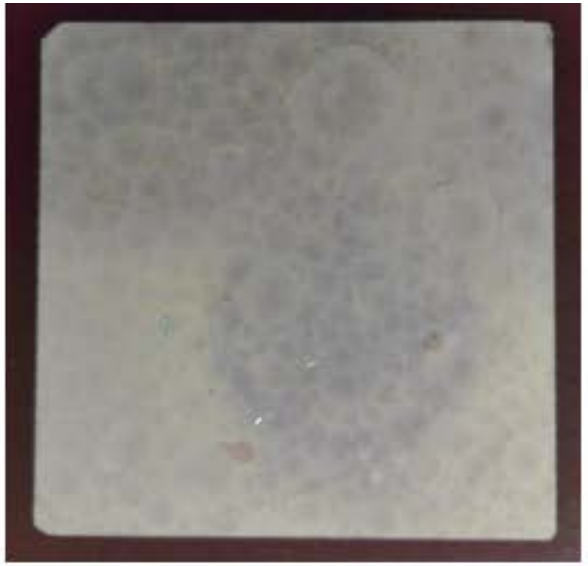
- Large container similar to those considered in Sweden and Finland
- More difficult to manipulate
- Inner steel vessel inserted into outer wrought copper shell
- Copper 25 mm thick
- Manufacture and assembly more challenging (1 mm gap)
- Canada lacks capability to produce this container

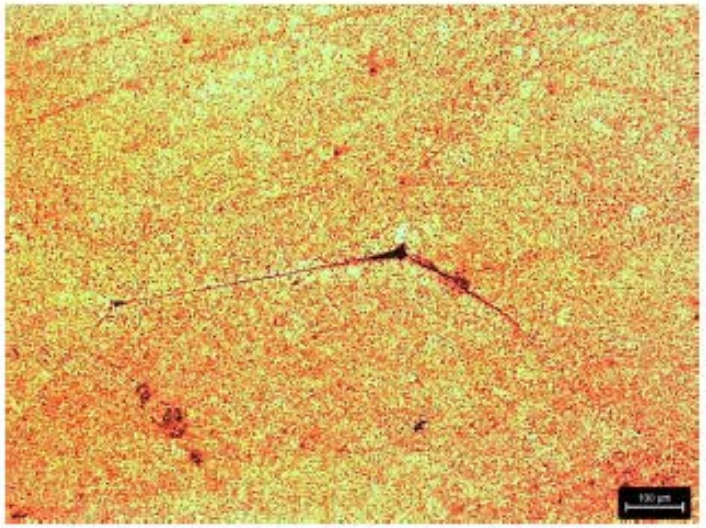
Electrodeposited Copper Coating

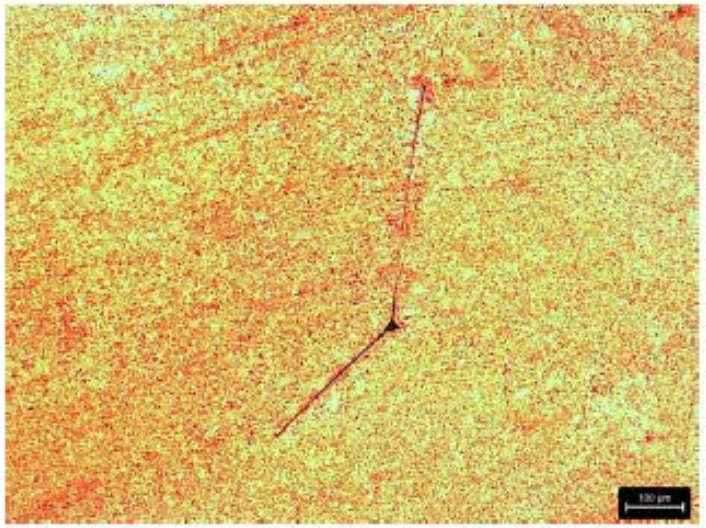
R. Crowe et al., NWMO Report, NWMO-TR-2016-01 (2016).

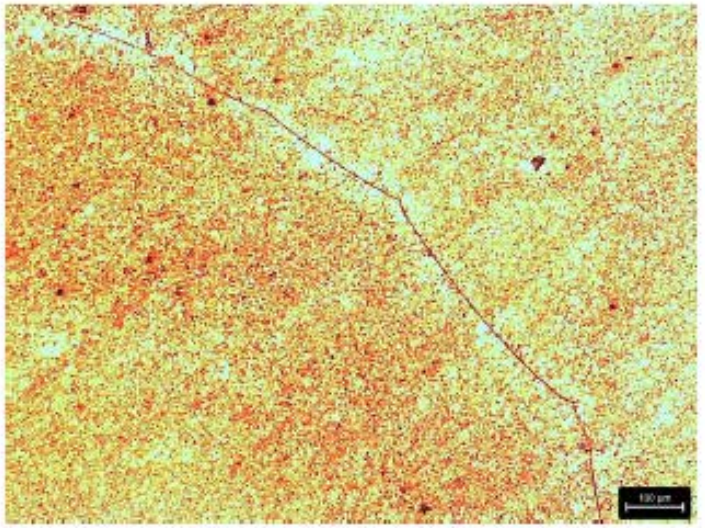
Refining the Electrodeposition Process



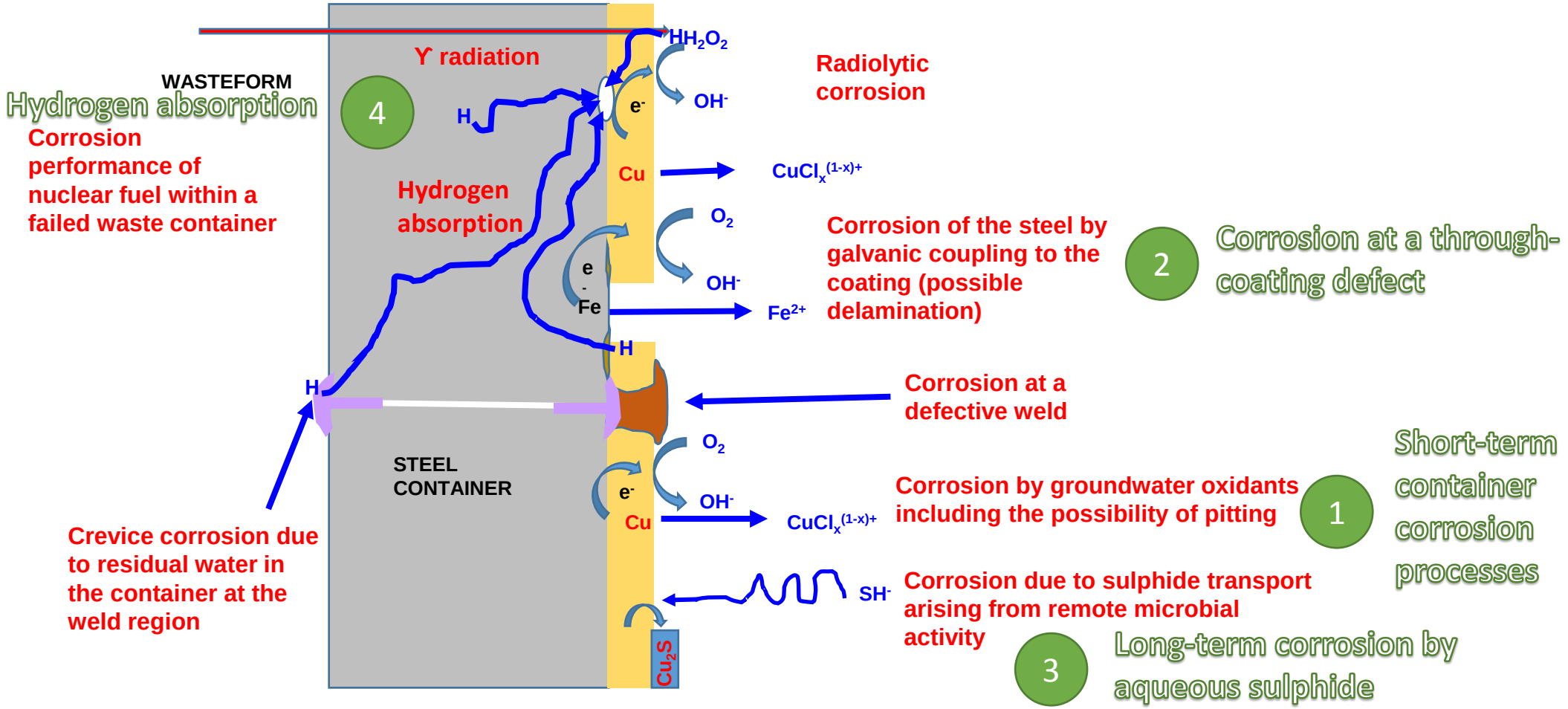






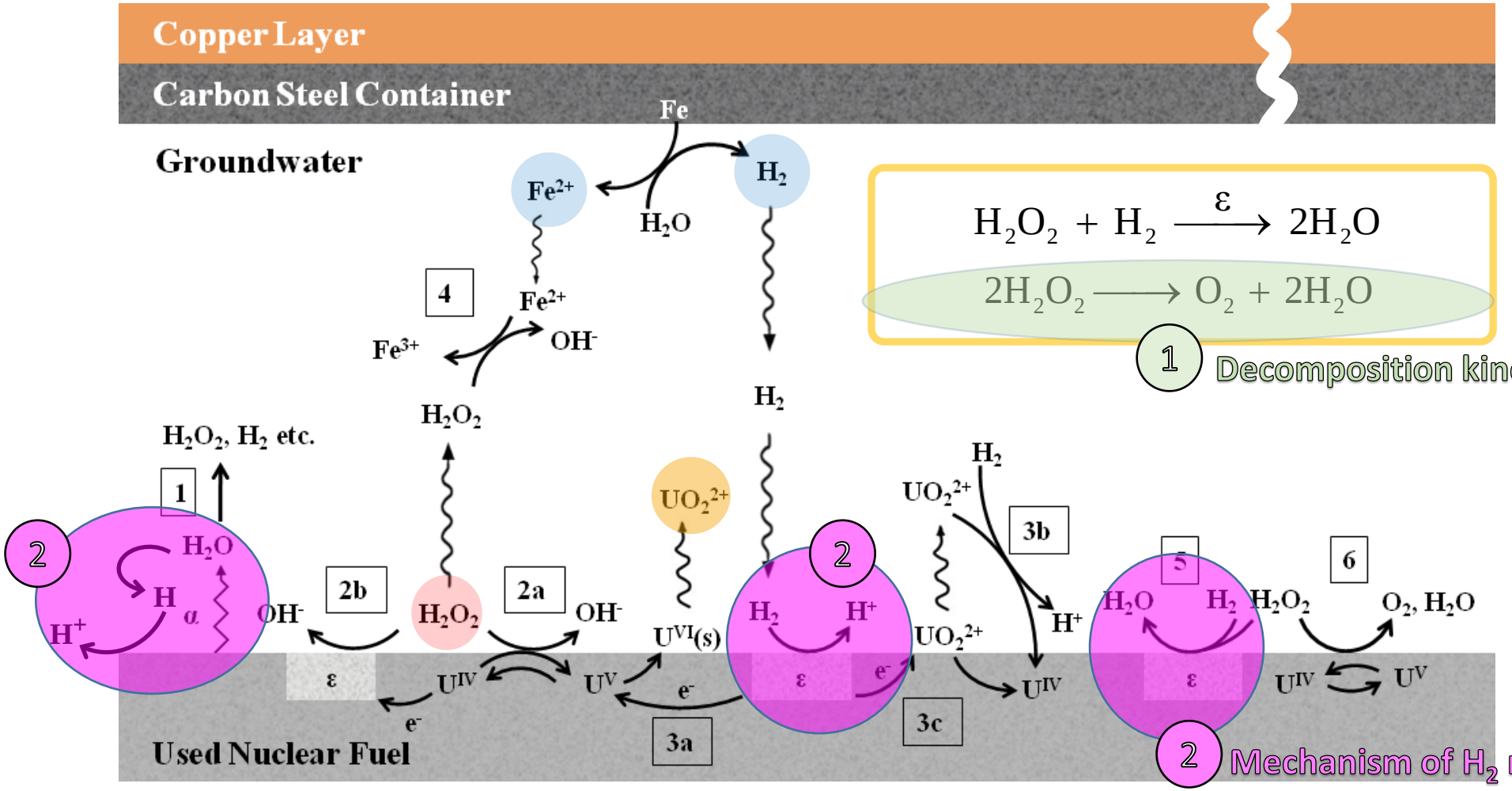


Possible Container Corrosion Processes in Anticipated Repository Groundwaters



Z. Qin, et al.; "The Establishment of Active/Passive Corrosion Conditions on Copper-coated Waste Containers in a Canadian Nuclear Waste Repository", *Accepted for Publication*, CEST, (2017).
T.E. Standish, et al.; "Galvanic corrosion of copper-coated carbon steel for used nuclear fuel containers", *Accepted for Publication*, CEST, (2017).
J. Chen, et al.; "The influence of sulfide transport on the growth and properties of copper sulfide films on copper", *Corr. Sci.*, **87** (2014) 223-238.

Reactions Inside a Failed Container



$$H_2O_2 + H_2 \xrightarrow{\varepsilon} 2H_2O$$

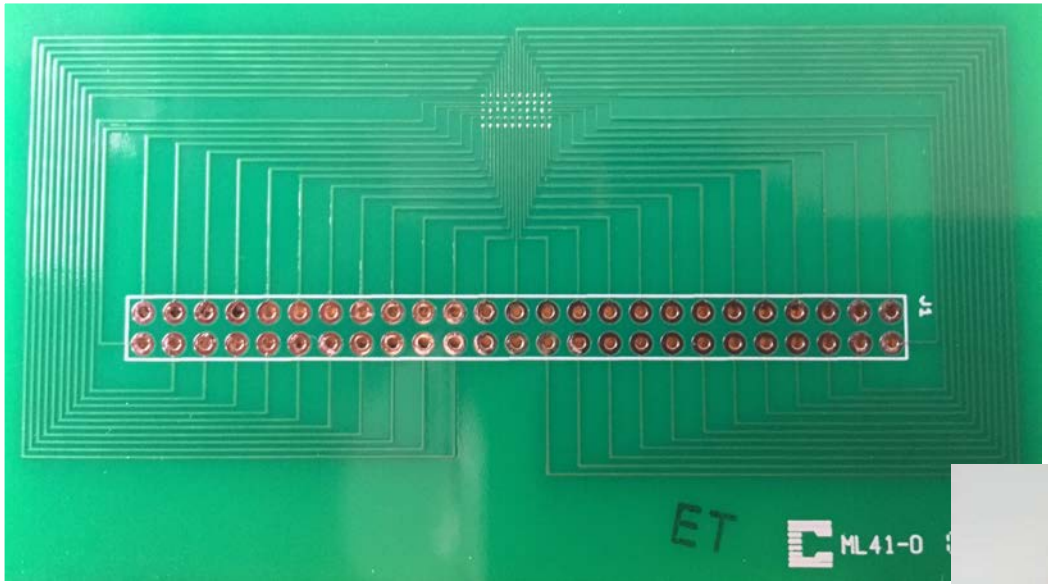
$$2H_2O_2 \longrightarrow O_2 + 2H_2O$$

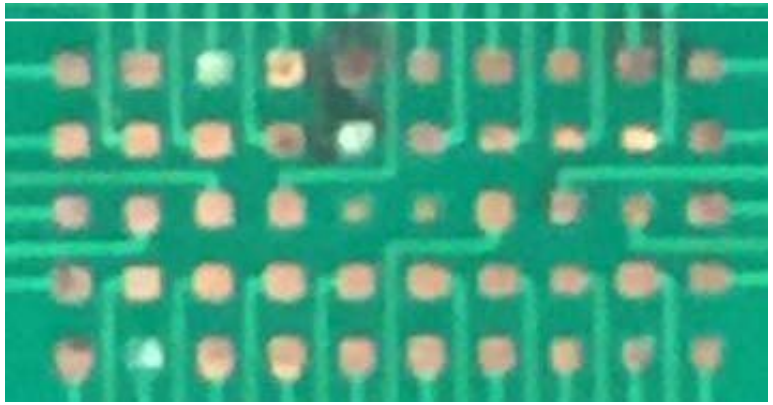
1 Decomposition kinetics of H_2O_2

2 Mechanism of H_2 reactions

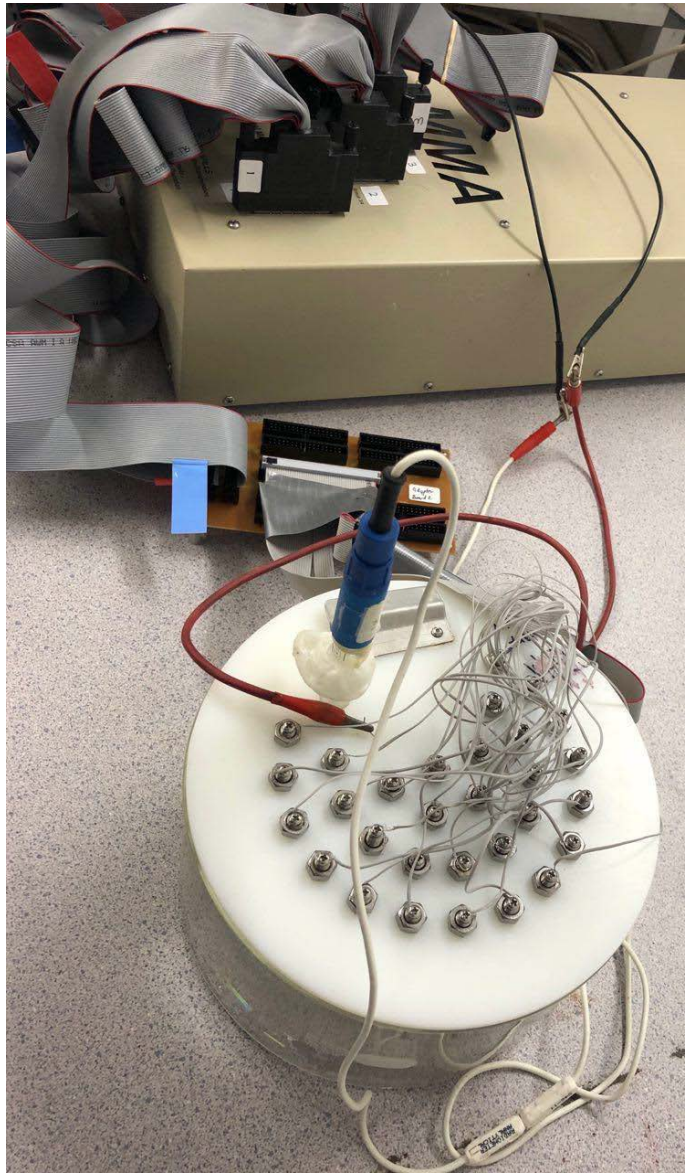
N. Liu, et al.; "The Electrochemical Study of Dy_2O_3 Doped UO2 in Slightly Alkaline Sodium Carbonate/Bicarbonate and Phosphate Solutions", Electrochim. Acta, **235** (2017) 654–663.
N. Liu, et al.; "Modelling the Radiolytic Corrosion of α-doped UO_2 and Spent Nuclear Fuel", *J. Nucl. Mater.*, Submitted (2017).
N. Liu, et al.; "Influence of Gd doping on the structure and electrochemical behavior of UO_2", *Electrochim. Acta*, Submitted (2017).
M.E. Broczkowski, et al.; "The role of dissolved hydrogen on rare earth-doped uranium dioxide corrosion in the presence of hydrogen peroxide", *J. Electrochem. Soc.*, **158** (2011) C439-C444.

Short-Term Container Corrosion Processes





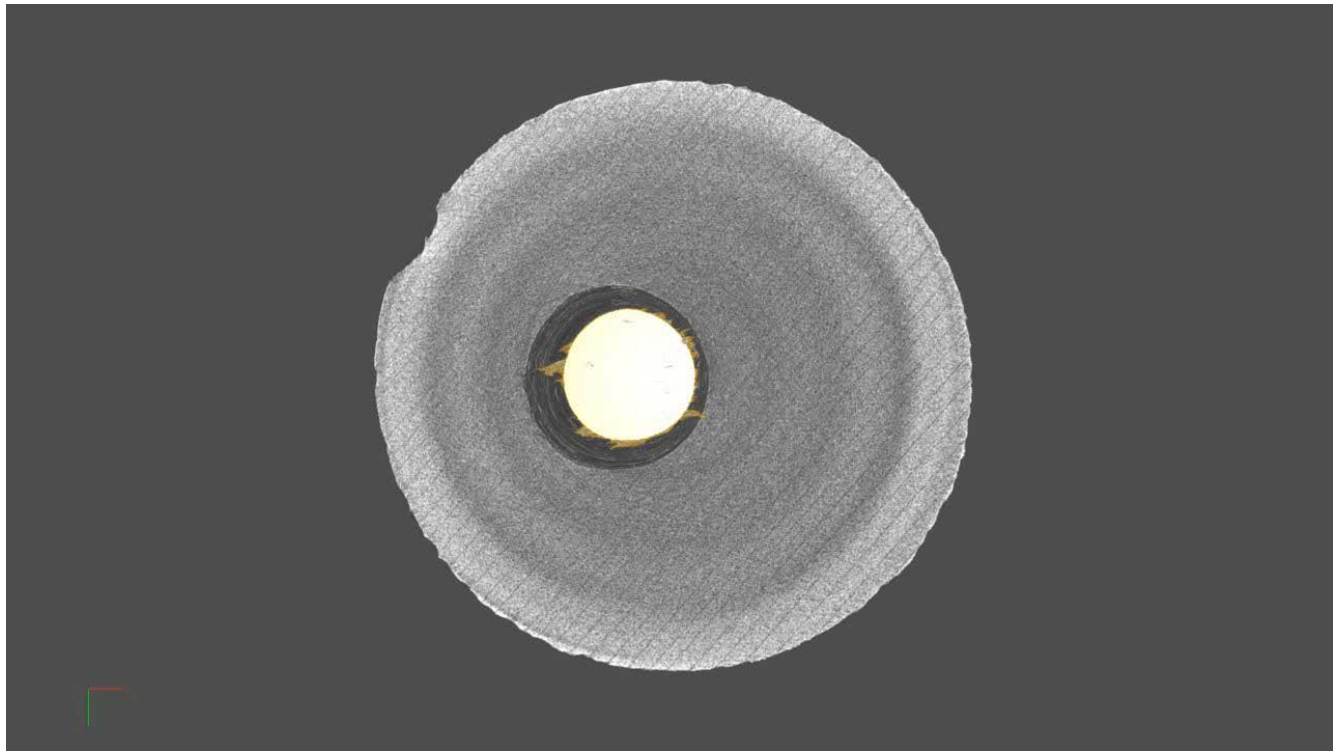
Multichannel microelectrode array: up to 100 electrodes

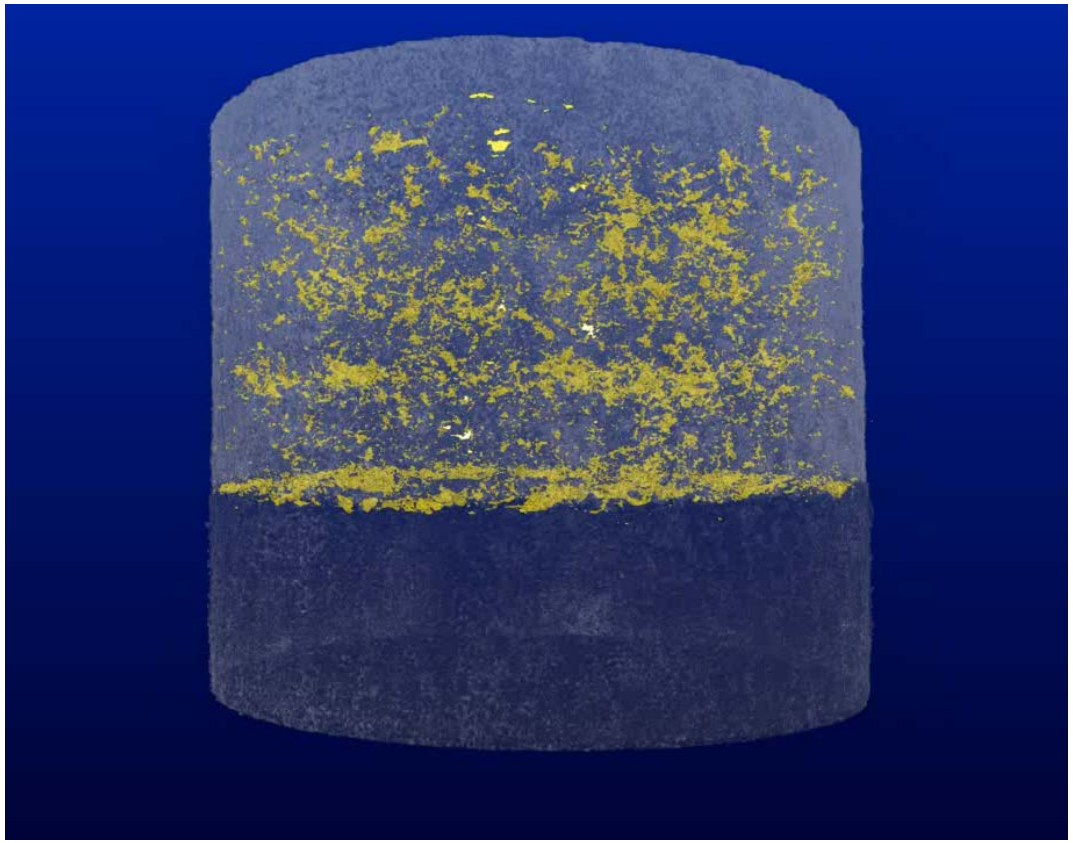


Z. Qin, et al.; "The Establishment of Active/Passive Corrosion Conditions on Copper-coated Waste Containers in a Canadian Nuclear Waste Repository", *Accepted for Publication*, CEST, (2017).

Corrosion at a Through-Coating Defect

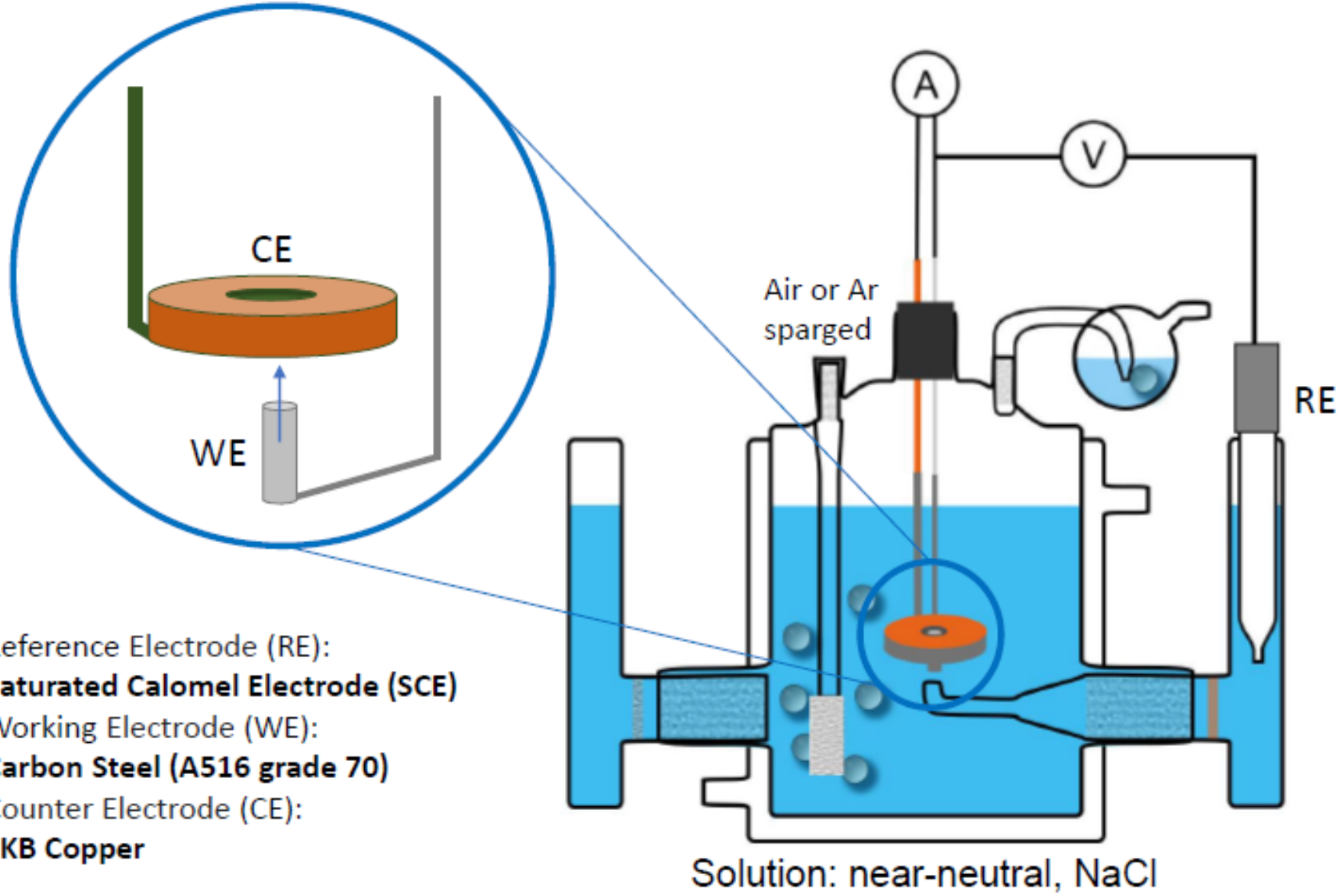
X-ray µ-Tomography Study of Galvanic Corrosion in Copper-Coated Steel Samples





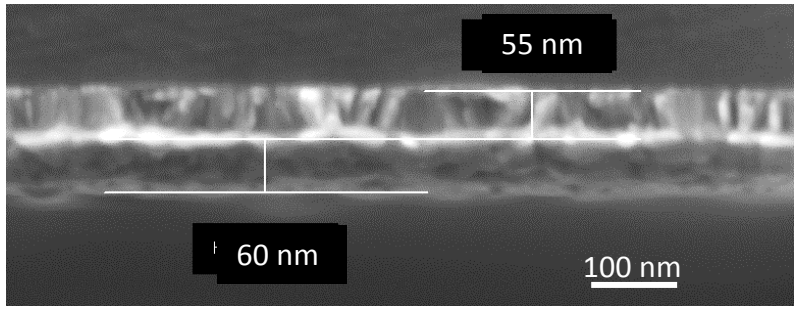
T.E. Standish, et al.; "Galvanic corrosion of copper-coated carbon steel for used nuclear fuel containers", *Accepted for Publication*, CEST, (2017).

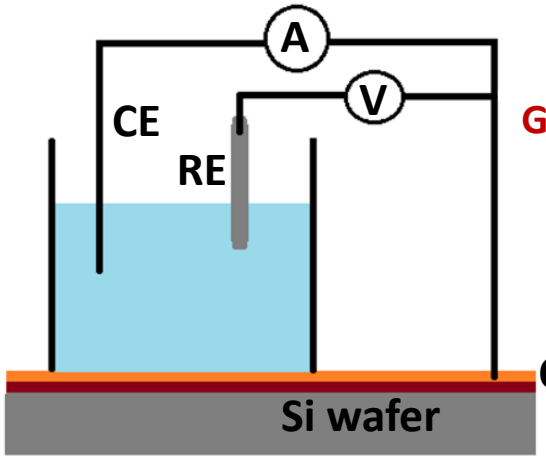
Galvanic Coupling



Reference Electrode (RE):
Saturated Calomel Electrode (SCE)
Working Electrode (WE):
Carbon Steel (A516 grade 70)
Counter Electrode (CE):
SKB Copper

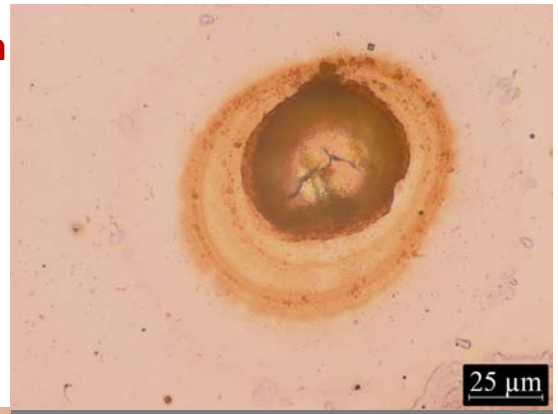
Hydrogen Absorption

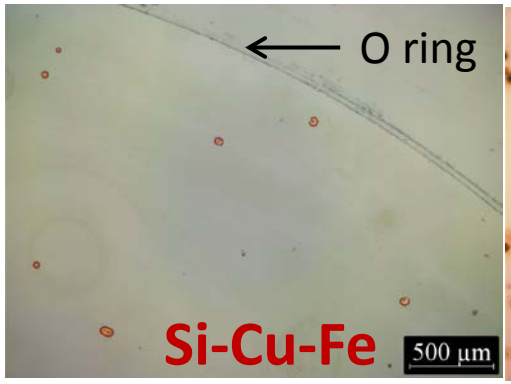


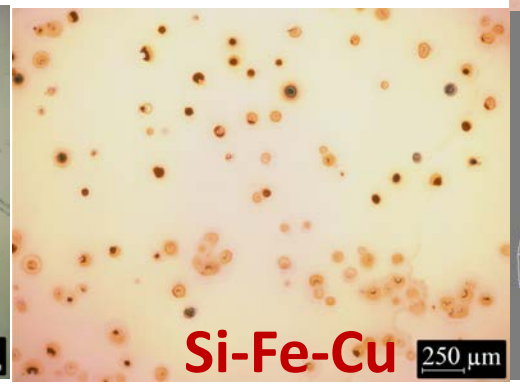


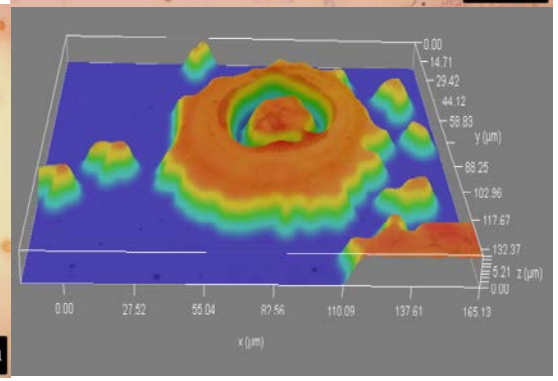
Galvanostatic polarization
-1 mA, 30 min

Coatings



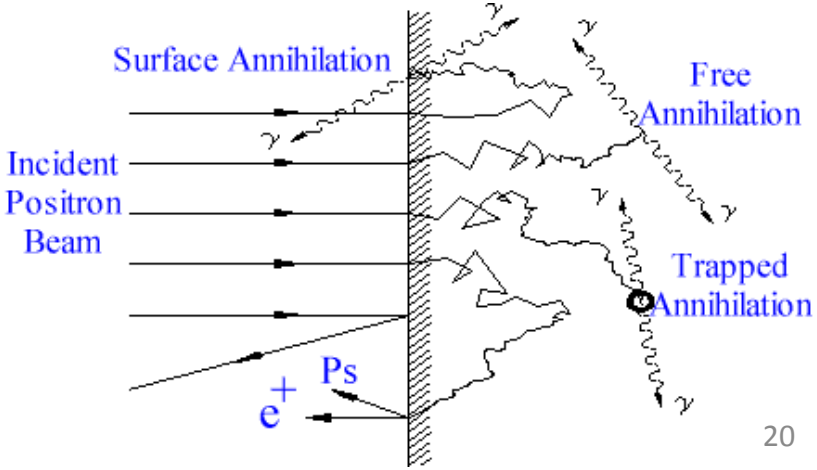




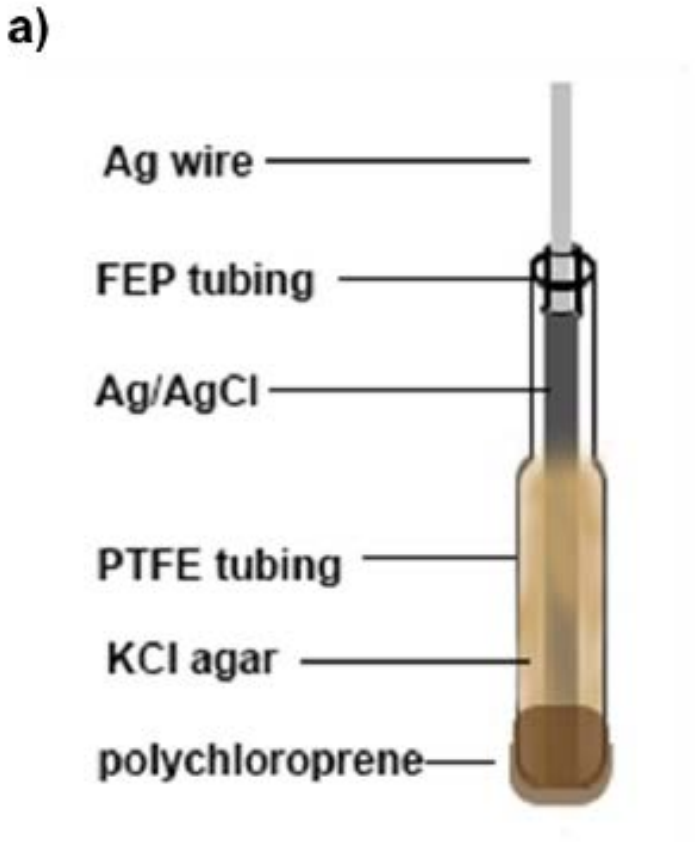


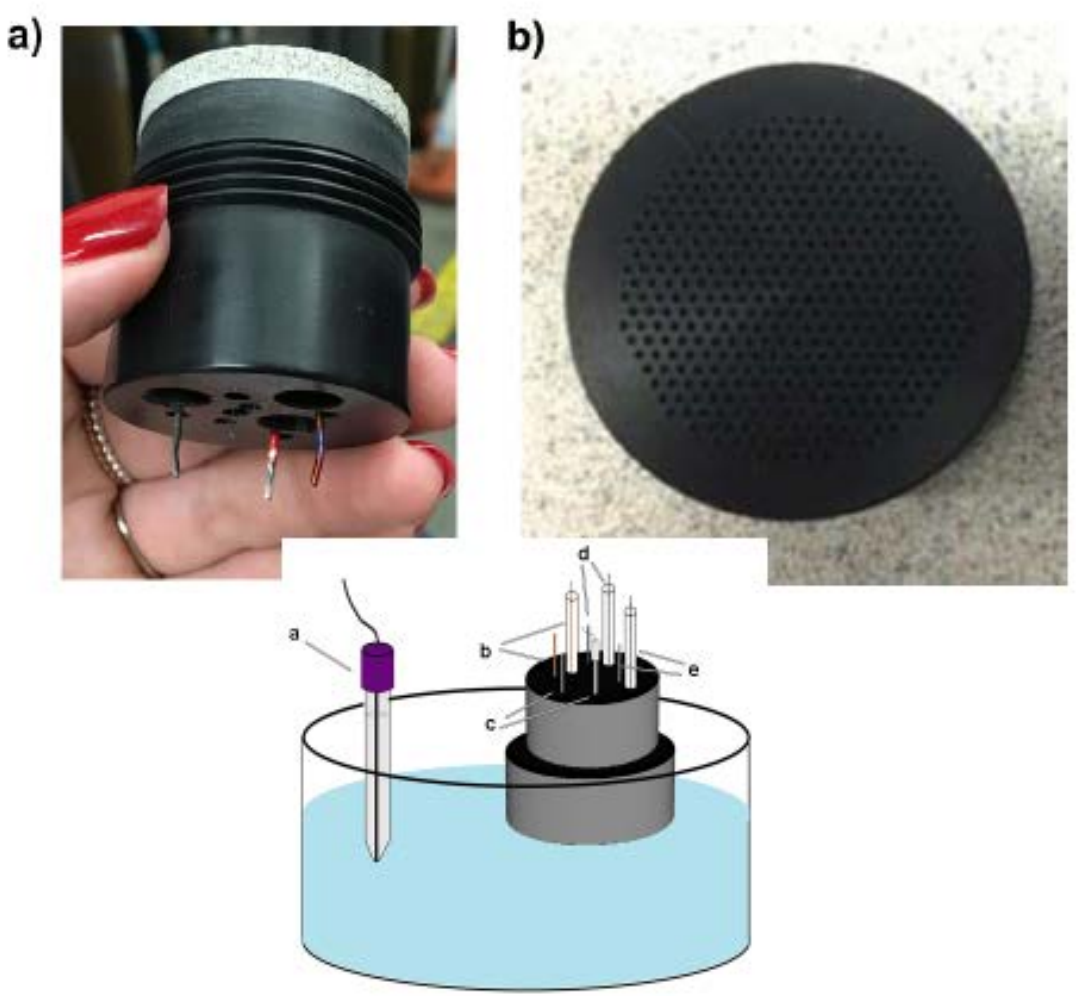
M. Vezvaie, et al.; "Hydrogen absorption into titanium under cathodic polarization: An in-situ neutron reflectometry and EIS study", *J. Electrochem. Soc.*, **160**(9) (2013) C414-C422.

Positron Annihilation Doppler Spectroscopy

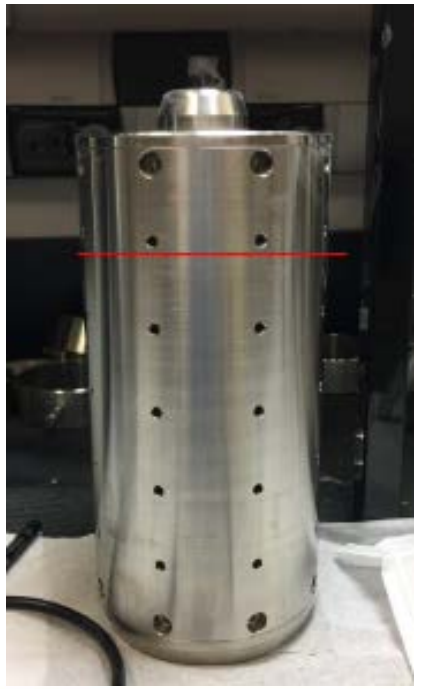


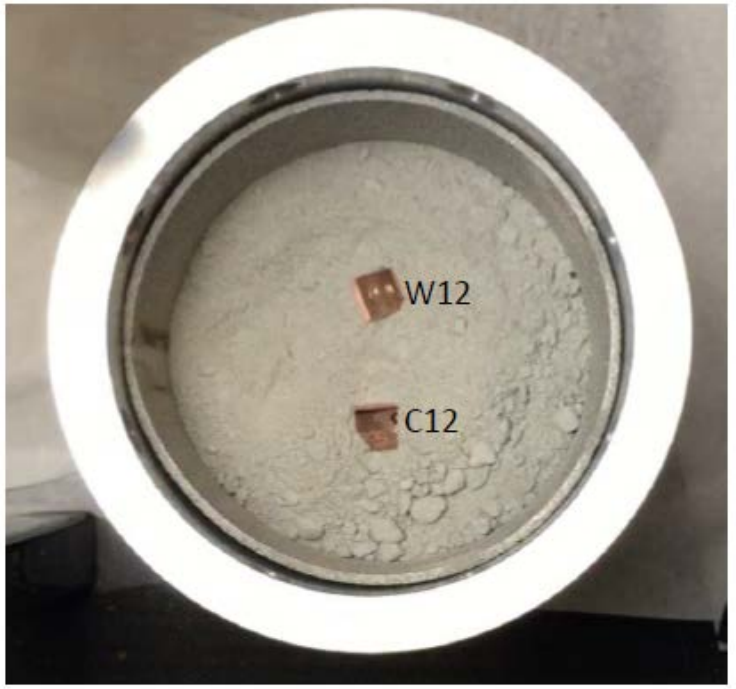
Embedded Chemical Sensors in Clay





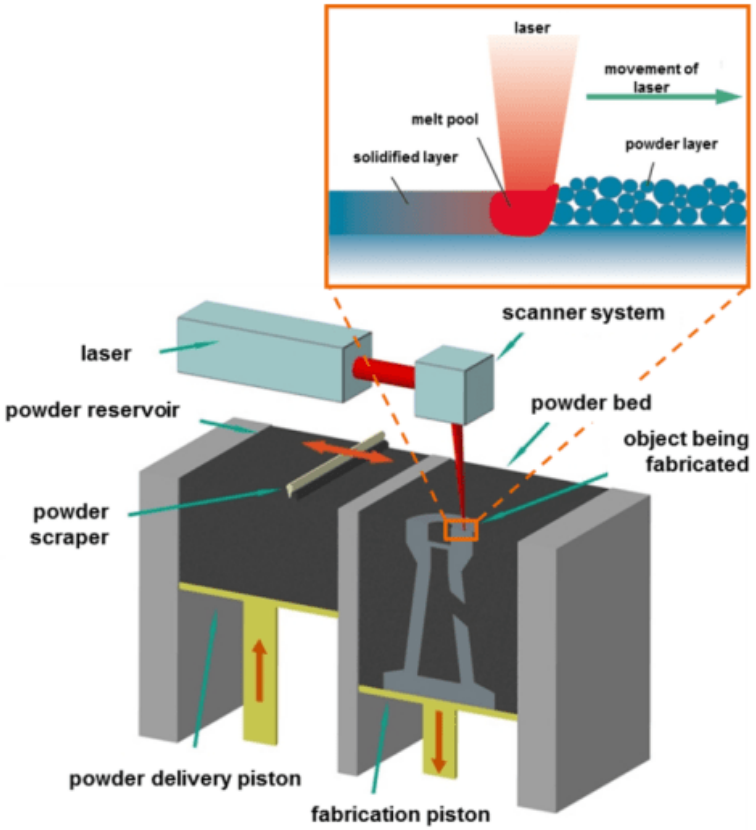
Pressure Cells and Ocean Modules

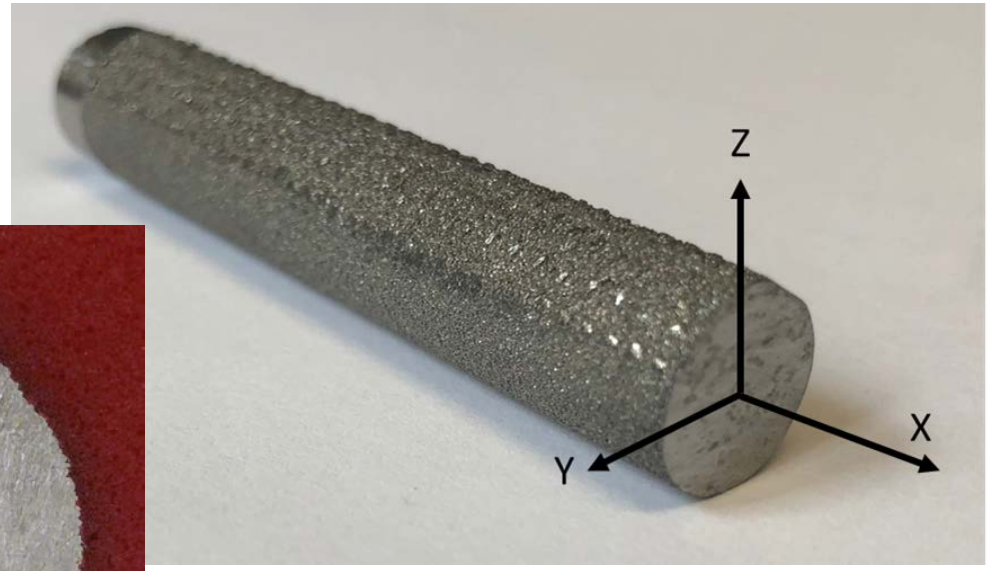


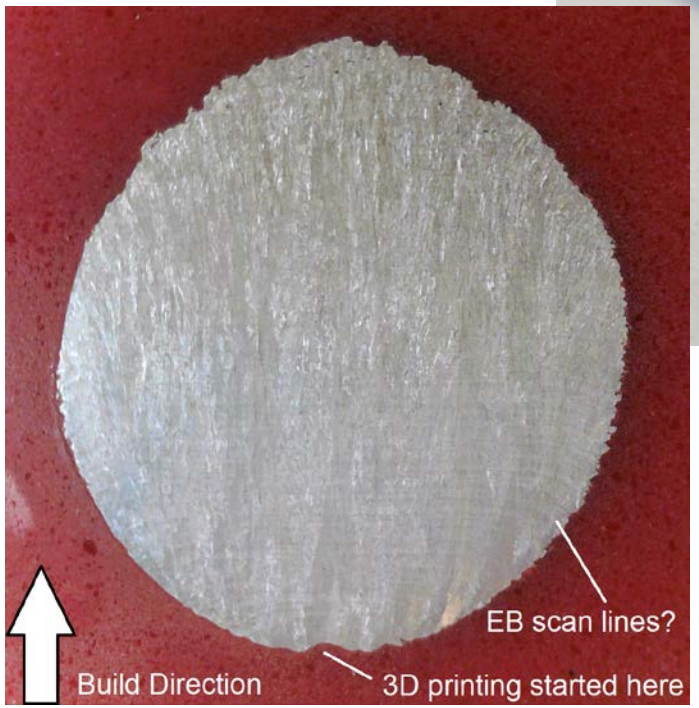


Corrosion Properties of Ti-6Al-4V Samples Fabricated by Additive Manufacturing (3D Printing)

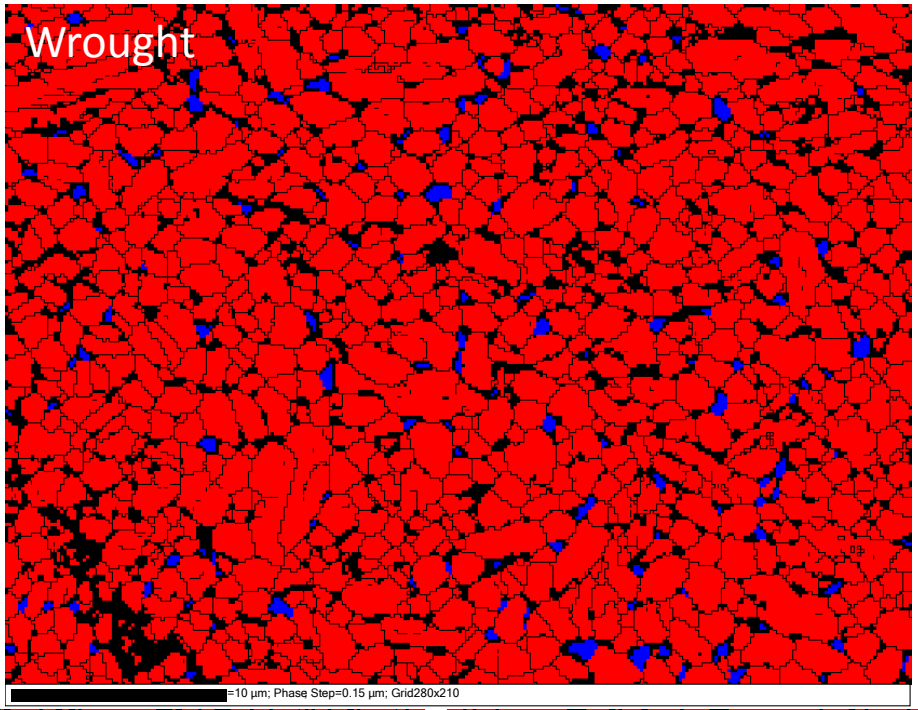
Powder bed fusion additive manufacturing (3D printing)







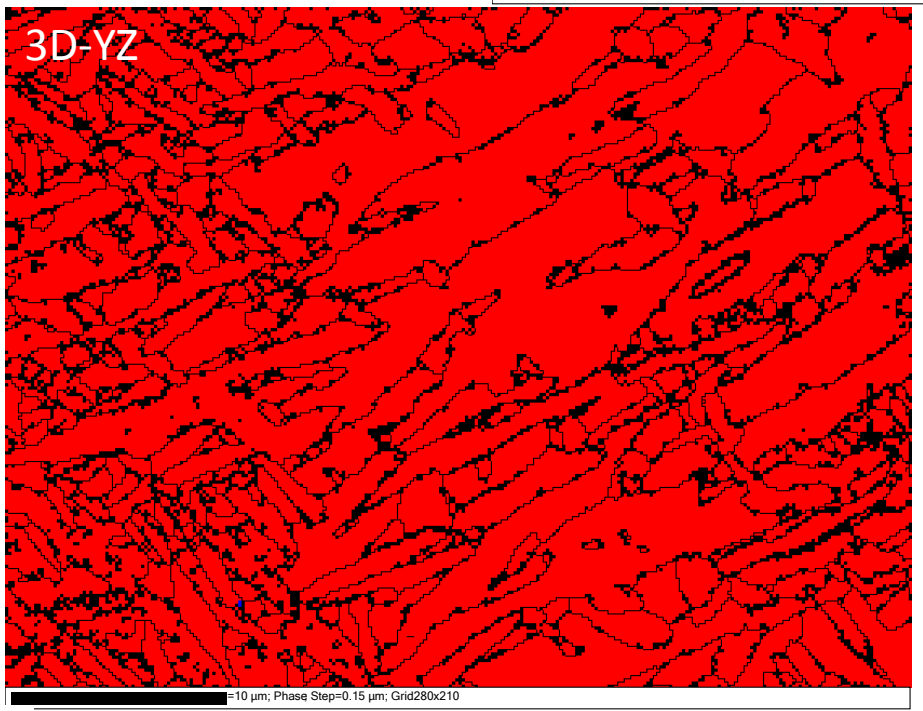
EBSD results showing phase distribution

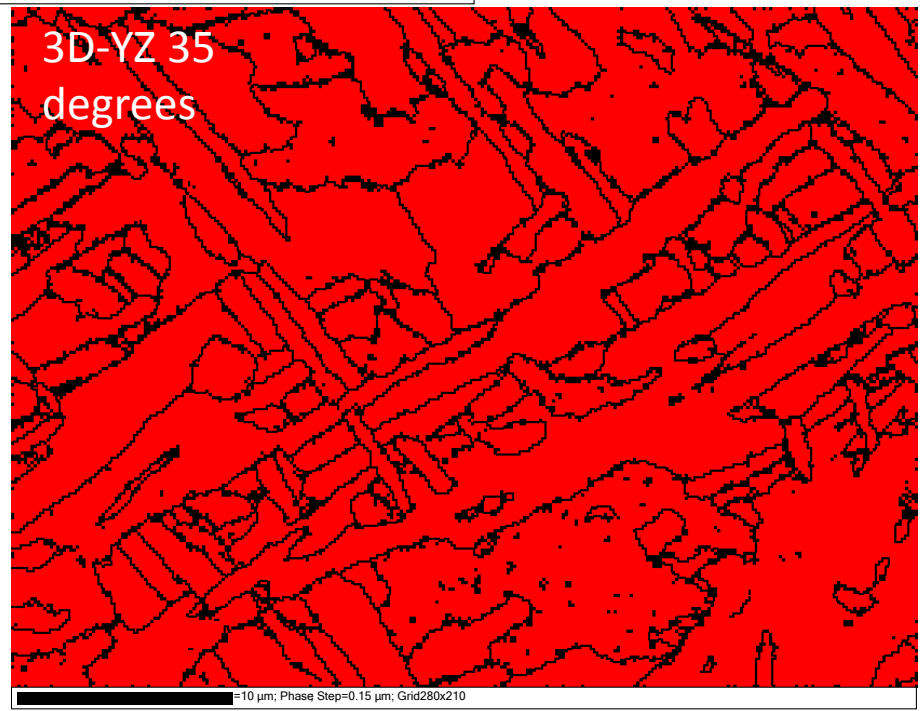


Phase-RED Ti-Hex [84.2%]

Phase-BLUE Titanium cubic [1.7%]

10 µm





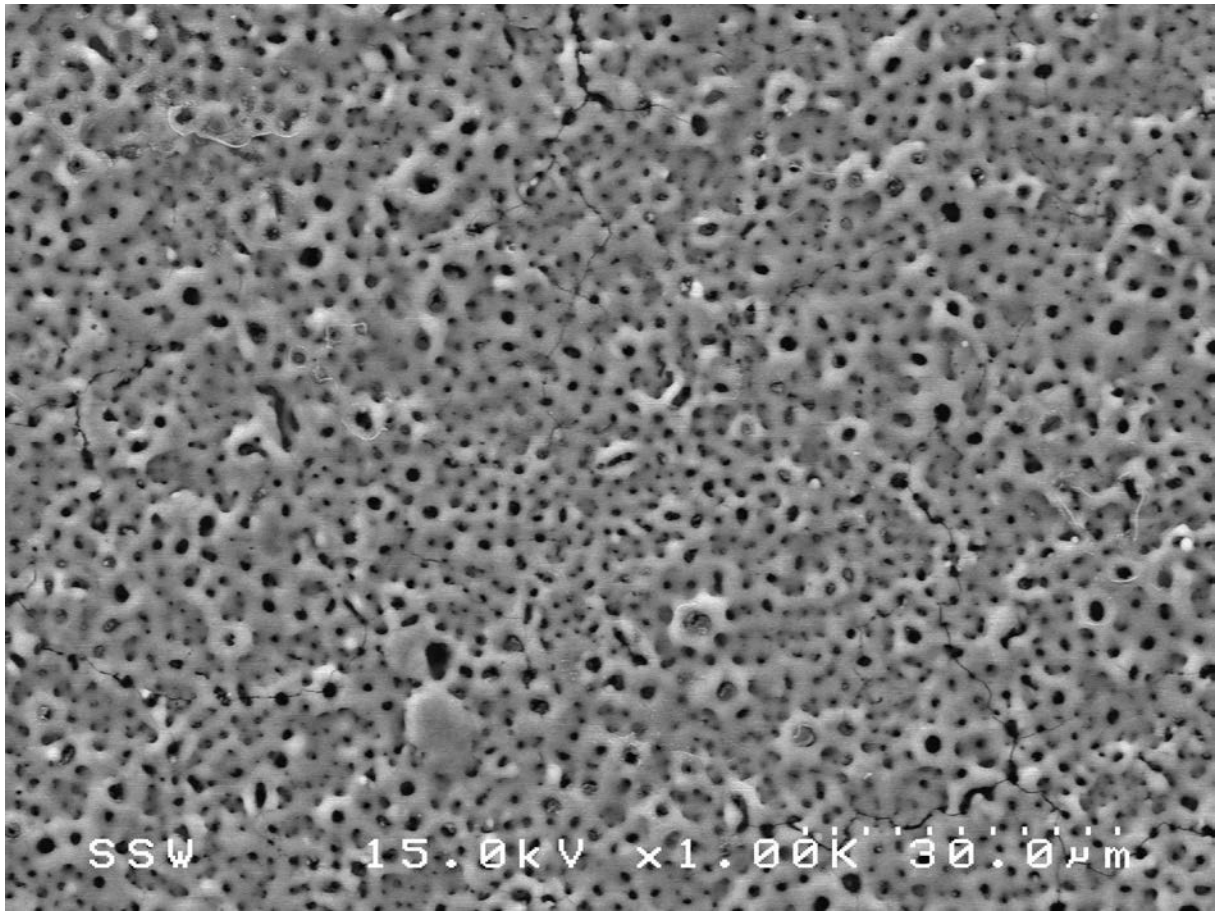
Plasma Electrolytic Oxidation of Magnesium Alloys

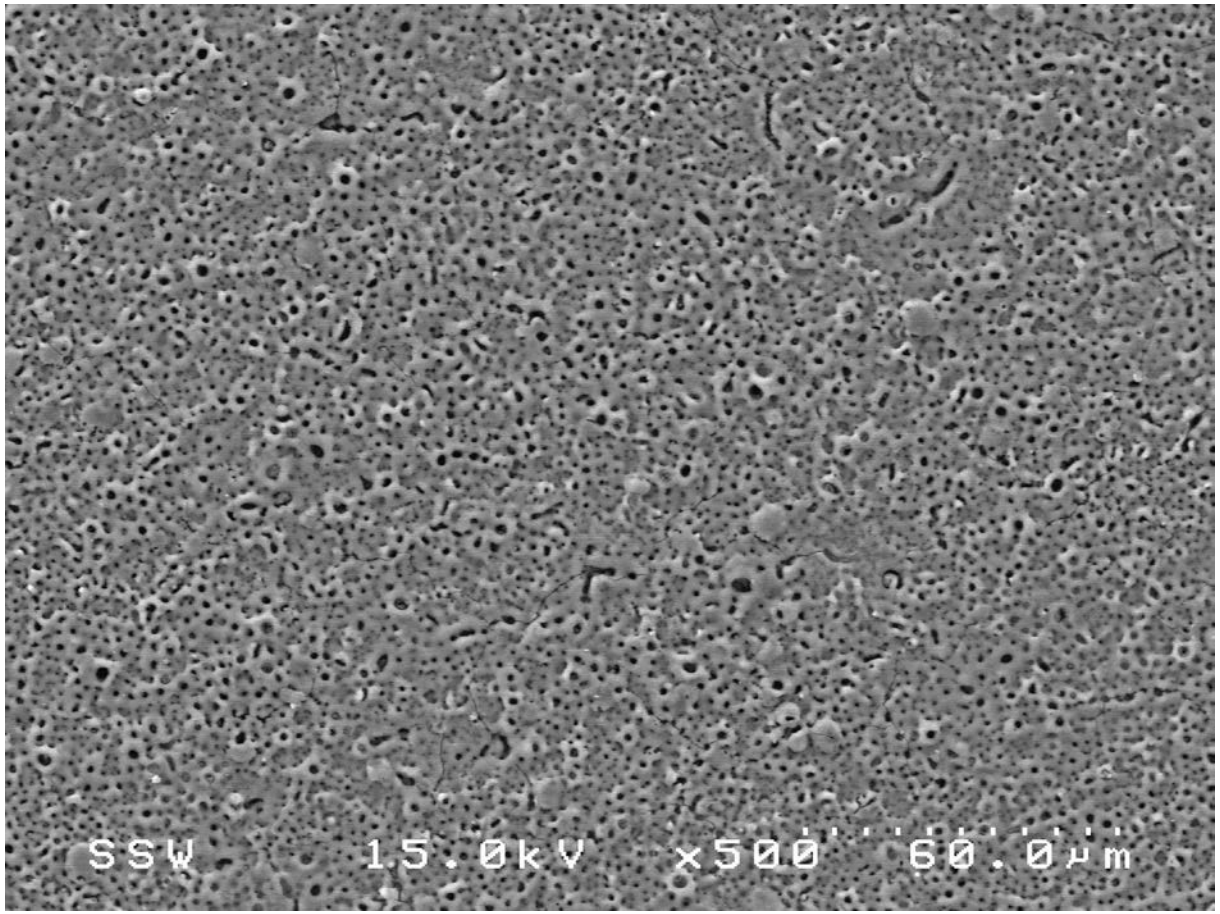
NEW electrochemical surface treatment to produce thick protective oxide coatings on metals

Parameters which can influence the coating properties

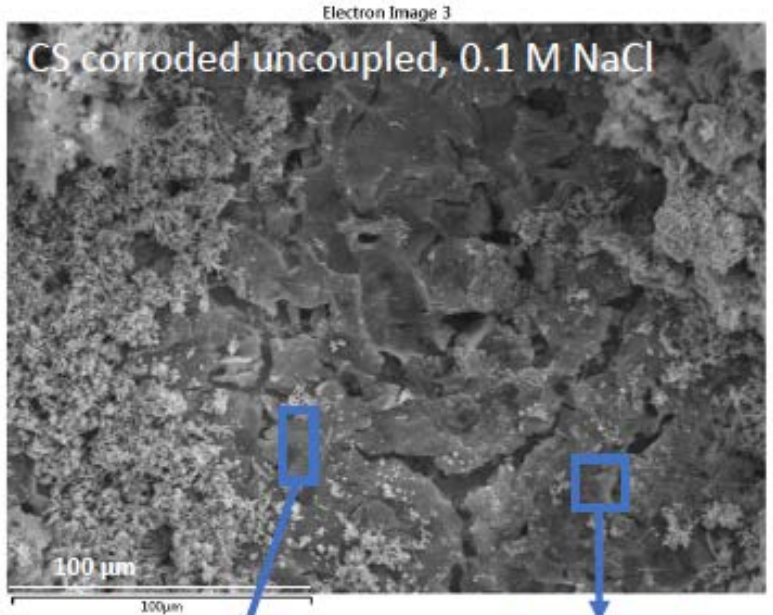
- ✶ Electrolyte Composition
- ✶ Coating Process Duration
- ✶ Applied Current Density
- ✶ Electrolyte Temperature

Surface morphology of PEO coatings on Mg



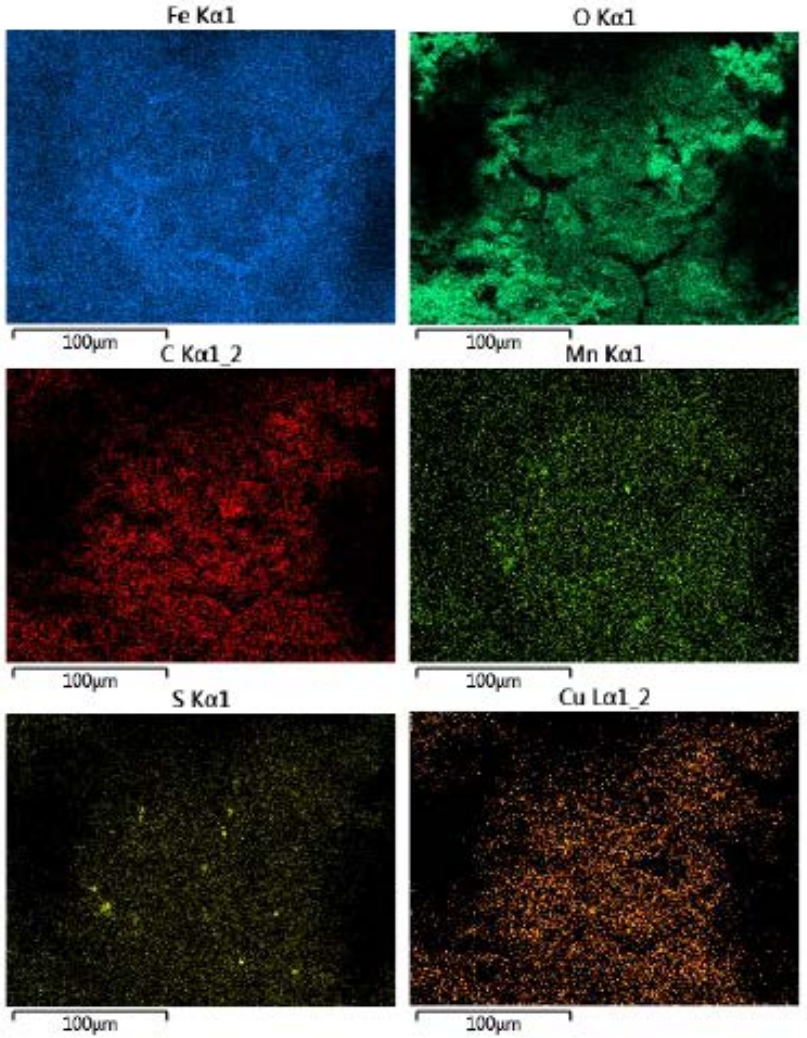


Complementing Electrochemistry with Surface Analysis



Spectrum 11	
Element	Wt. %
Fe	76.3
O	11.3
C	7.9
Mn	1.8
Cu	1.0

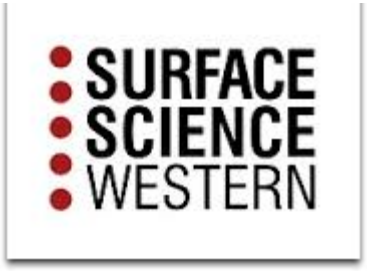
Spectrum 11	
Element	Wt. %
Fe	69.6
O	16.1
C	6.7
Cu	1.4
Al	1.3
Cl	1.3
Mn	1.3
Cr	1.2



Degradation issues in various industries

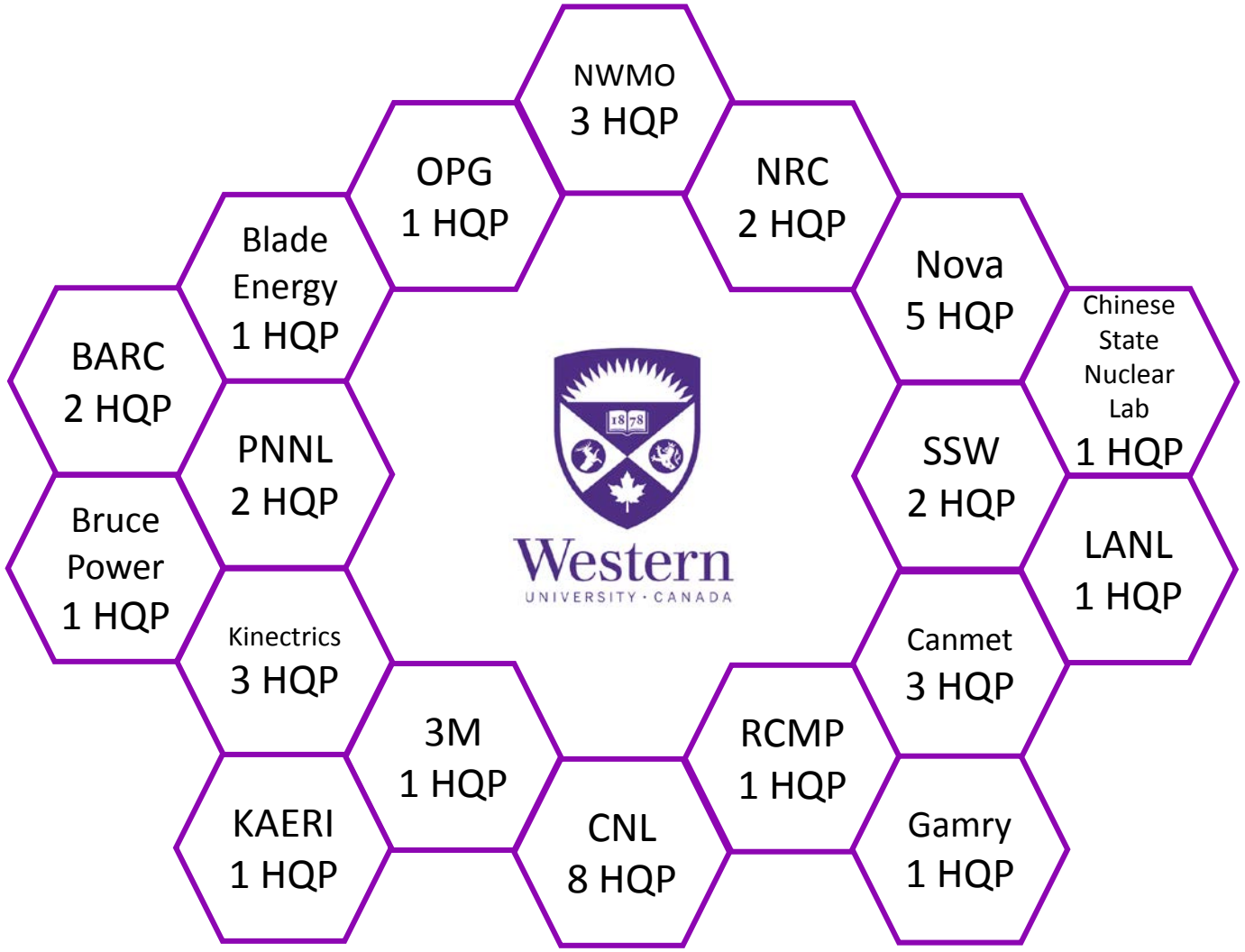
- Corrosion of Ni-based superalloys in fluoride-containing environments
- Galvanic corrosion of metals coupled to carbon composites
- Degradation of heat exchangers/radiators
- Corrosion and degradation of powder coated metal components
- Cathodic protection and coating disbondment in oil and gas pipelines

- Development of custom equipment and instrumentation



Other Benefits to Partners

Development of HQP: employable expertise for industry.



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