



Corrosion Monitoring of a Natural Convection Cooled Stored

Nuclear Energy Institute
Used Fuel Management Conference 2013

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National Nuclear Laboratory



- Created July 2008
- SBM Managing Contractor Appointed April 2009
- Contract duration 3+1+1yrs (ending April 2014)
- DECC Objectives:
 - International nuclear R&D centre of excellence
 - Support new build and clean up
 - Safeguard nuclear expertise, facilities and skills
 - Deliver value for customers
 - Trusted advisor
 - Collaborations/Partnerships/Links
 - Socio-economic focus



serco

Battelle
The Business of Innovation

MANCHESTER
1824

NNL Summary Data

- Revenue ~£80m
- 6 locations in the UK
- 770 staff
 - Over 60% with science & engineering degrees / PhDs
- Key customers:
 - EDF Energy, Westinghouse
 - Nuclear Decommissioning Authority, Sellafield Ltd, Magnox Ltd (Energy Solutions)
 - UK Government, MoD, Regulators



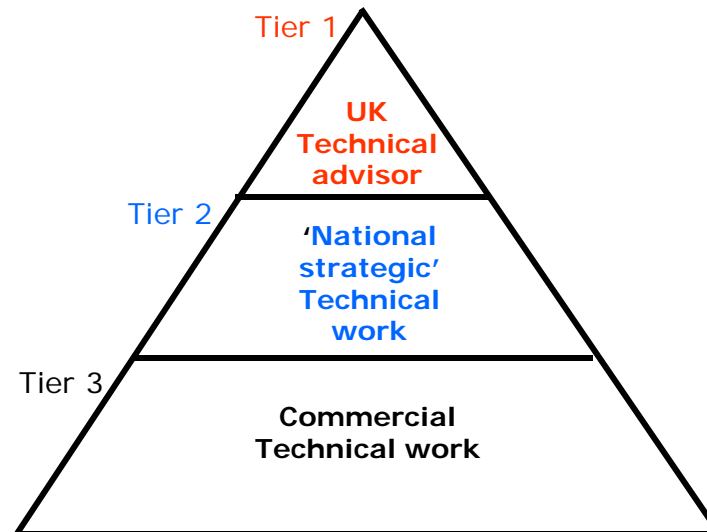
NNL's Role in UK Nuclear R&D



From 2014



- National Laboratory for both UK Government and Industry
- Support to national R&D programmes
- Host Nuclear Innovation Research Office



NNL Facilities

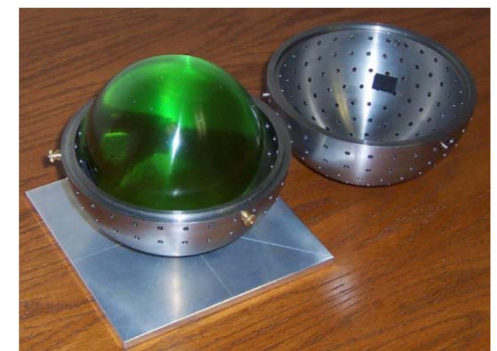
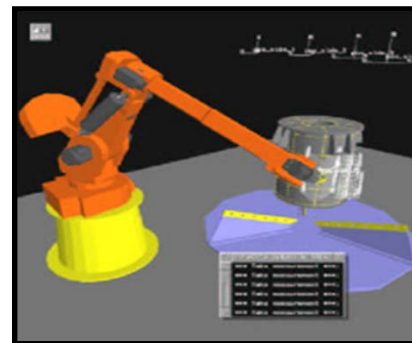
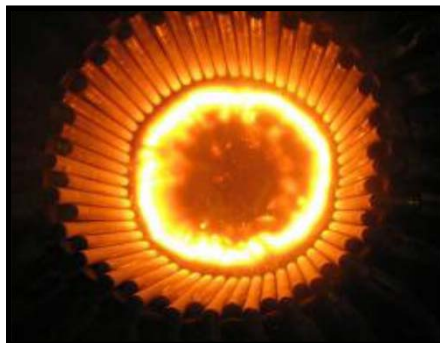


- Uranium active large scale facilities
- Active Laboratories and Rig Halls
- HA Cells
- Alpha Development Labs
- Engineering Development Facility
- Non active rig facility & labs
- High Performance Computing



NNL Products and Services

- Asset Management Technology
- Fuel and Radioisotopes
- Spent Fuel Management Technology
- Nuclear Security
- Safety Management
- Waste and Residue Processing
- Waste Management Technology
- Measurement and Analysis
- Environmental Services
- Reactor Chemistry and Materials
- Post Irradiation Examination
- Training Services



- Three main storage systems:
 - concrete casks,
 - dual purpose casks and
 - vaults
- Concrete casks and vaults have fuel stored inside air-cooled containment structures
- In general, steels used are susceptible to SCC in the presence of chloride
 - Marine environments are most aggressive
 - Chloride also in soil minerals, road salt and agricultural chemicals



Vault Store Condition Monitoring

- NNL has undertaken corrosion monitoring and assessment for a vault store
- Operational since 1991 – over 20 years experience
- Containers cooled by natural convection of air
- Store located close to the sea
- Prevailing winds are onshore



Comparison of Cooling Conditions

- Plant louvers on entry
 at height to avoid building effects
- Cask unfiltered
 ground level
- Vault louvers on entry
 at height
- Relationship of deposited salt concentrations
inside at outside building is unclear

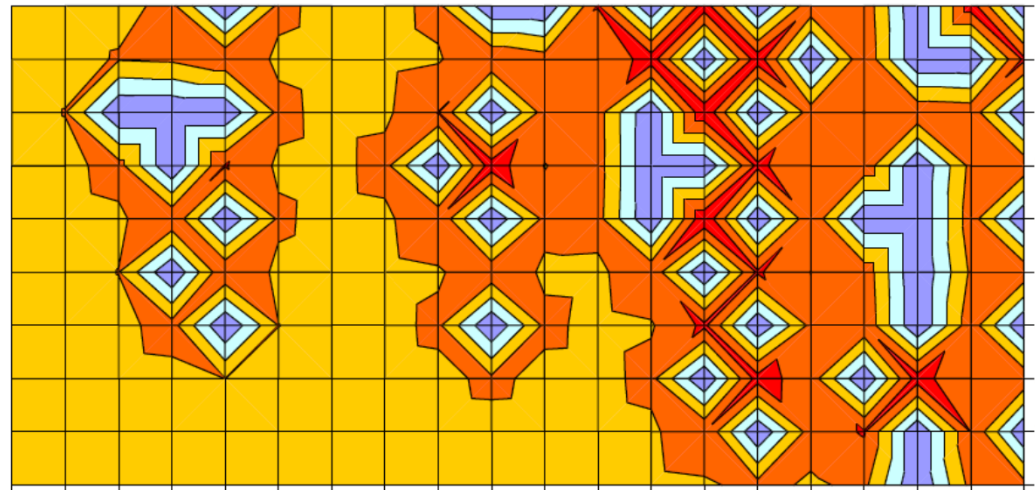
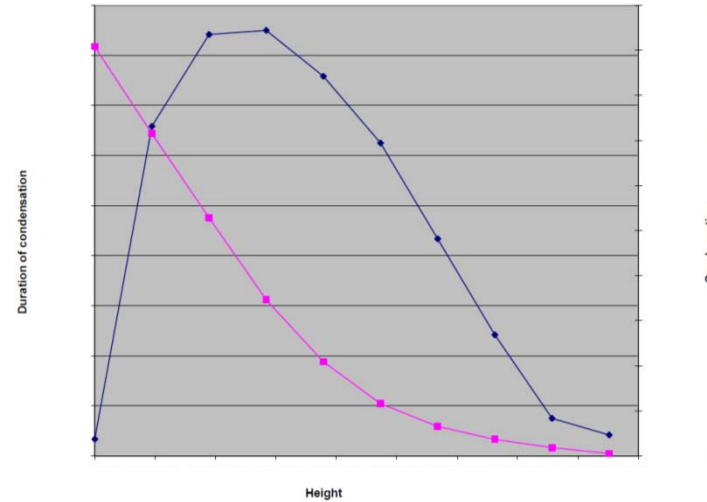


- In Facility
 - 7 monitoring locations
 - Coupons suspended in inlet plenum
 - Initially 5 coupons/ location
 - In 2005, 2 coupons replaced by 25 smaller samples at 5 locations
 - Periodic inspection
- Environmental Control
 - 2 external sites
 - Uncovered and covered arrays



Condensation on Surfaces

- Modelling
 - Buoyant air flows
 - Heat transfers
 - Condensation
- Condensation risk
 - Loading effects
 - Individual locations
 - Store profile



Modelling indicates:

- Transient condensation under certain combinations of heat loading and atmospheric conditions
- Condensation in the channel is less than that at the inlet
- Water present on channel surfaces very slightly longer than at inlet
- During condensation transients channel typically 2-3°C cooler than at coupon location

=> coupon environment is more corrosive



Non-destructive:

- Visual examination of samples
- X-ray of coupons for detection of sub-surface cracking

Destructive:

- Weight loss
- Sectioning and macroscopy/microscopy
- Analysis of pit size distributions



- Continued monitoring of in-service conditions to support continued safe operations
- Salt deposition measurements to be conducted on
 - Store coupons
 - Comparison with environmental samples

This work was funded by Sellafield Ltd, a site management contractor for the Nuclear Decommissioning Authority, as part of its Asset Management programme.



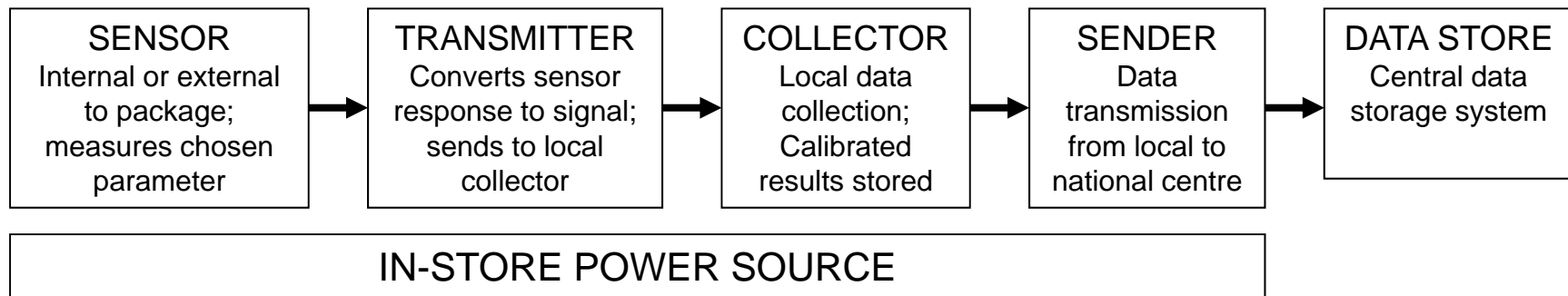
SMART Coupons

- Concept developed for generic radioactive packages
- Applicable to Dry Storage Casks



On-Line Corrosion Monitoring

- Process
 - Parameter monitoring needs assessment
 - Industry engagement to validate conclusions
 - Prioritised monitoring approaches
- System Model



- Characteristics Assessed
 - Corrosion mechanisms
 - Corrosion indicators
 - Relevant measurement parameters
 - Purpose of measuring each parameter
 - Benefits of possible solution
 - Applicability to packages
- Critical success factor - operator perspective
 - providing early warning systems focussed on risk mitigation



Needs Assessment Scoring

Attribute	High Score	Low Score
Significance for remedial action	Parameter likely to initiate near term remedial action	Parameter values only recorded
Predictive value	Parameter change likely to be driven by long term effect (>5 years)	Parameter change likely to be driven by a short term effect
Breadth of applicability	Could apply to multiple package types	Only relevant to single site/type
Ease of monitoring	Parameter requires observation of container or environment	Parameter requires observation of stored material



Characteristics

- Representative material
- Monitor for:
 - Environmental conditions: humidity, temperature, salt deposition, surface condensation
 - Onset of corrosion
- Power from:
 - Inductive coupling or
 - Power scavenging
- Recording via:
 - Wireless communication
 - Remote monitoring platform



Humidity and Temperature


<p>Capacitive & resistance humidity sensor</p>	<p>Accurate, Durable Small, Inexpensive Adapted for different environments Combined sensors Commercially available</p>	<p>Hygroscopic polymer ageing Polymer swelling Yearly changes in error Ageing of metallic layer Requires shielding Sensor replacement req'd Non-linearity</p>
<p>Thermal conductivity sensor</p> <p>✓</p>	<p>Accurate, Durable Small, Inexpensive Long service life Corrosion resistant Stable at high temp Combined sensors Commercially available</p>	<p>Requires shielding Sensor replacement may be req'd</p>
<p>Fibre Optics</p>	<p>Good radiation resistance Combined sensor Small</p>	<p>Early stage of development Requires further development</p>

Corrosion Monitoring - 1

<p>Electro-chemical noise (ECN)</p>	<p>Monitors general and local corr. High sensitivity Sensitive to rapid cracking Good reputation (test & field) No current supply to test piece Commercially available Simple set-up Simple operation</p>	<p>Manual data interpretation req'd Technique still under development Requires aqueous environment on sample surface</p>
<p>Acoustic Emission</p>	<p>High sensitivity Automated acquisition Sensitive to rapid crack propagation Good reputation (test & field)</p>	<p>Long residence time Lengthy monitoring regime Unable to detect SCC initiation/early propagation Low signal to noise ratio</p>



Corrosion Monitoring - 2

Electrical resistance / potential drop	Simple Commercially available Cost effective Well understood	Best for general corrosion Required electrical current through test piece
Field Signature Method (FSM) 	Monitors general and local corr. Analysis for pit depth/crack length Commercially available Cost effective	Current resolution about 0.05% wall thickness Matrix of sensors



- Limited number of suitable techniques
- Low level of development
- Further development required for non-aqueous environments:
 - Quartz Crystal Microbalance (QCM)
 - Surface Acoustic Wave (SAW)
 - Fibre optic



Coupon Review Conclusions

Temperature and Humidity	Thermal conductivity – combined sensor
Corrosion monitoring	Field Signature Method
Salt deposition	Not implemented, pending technology development
Power and communications	Battery + wireless RF
Networking, data acquisition and display	Existing commercial system
Coupon design	Representative material, linear/U-section specimen
Radiation	Hardness testing required



Acknowledgement

- *The work on instrumented coupons was funded by the Nuclear Decommissioning Authority (NDA) through the Direct Research Portfolio Lot 2 Framework Contract and was performed by National Nuclear Laboratory.*
- *NNL also acknowledges the contribution of Hyder Consulting and UKAEA Ltd. to the selection and prioritisation of monitoring needs as partners in the integrated project team on radioactive waste packaging*





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