Corrosion Monitoring of Dry Fuel Storage Containers in Nuclear Facilities.

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Clive Harrison
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Introduction

Sizewell B Power Station:

- Began Generating Electricity in 1995
- Supplies electricity to over 2 million homes
- Estimated decommissioning date 2035
- Single Pressurised Water Reactor
- 1155 MW Net Electrical Output
- The fuel consists of small uranium oxide pellets, stacked together within a zircaloy tubing to form a fuel rod.
- Fuel rods are braced together into fuel assemblies. Each fuel assembly contains 264 fuel rods arranged in a 17x17 square lattice array
- The reactor contains 193 fuel assemblies each of which extend to the height of the reactor core.
Spent Nuclear Fuel Storage at Sizewell B - Fuel Storage Pond

Spent Nuclear Fuel Storage Pond at Sizewell B
Spent Nuclear Fuel Storage at Sizewell B

- The operators recognised early in the station’s life that the licenced fuel pond capacity would not be sufficient to maintain operations through to the end of life.
- This capacity was expected to be reached in 2016.
- Original intention was to send spent fuel to the planned Geological Repository which has yet to be sited.
- As a result, interim storage options were considered to ensure operations continue through to the planned decommissioning date.
  - Wet storage in a new fuel storage pond
  - Dry storage in casks
  - Dry storage in a vault
Government approval for a new Dry Store at Sizewell B was granted in July 2011.

Dry fuel Store building construction was completed early 2016.

First 7 casks containing spent nuclear fuel were emplaced into the store in June 2017.
Dry Fuel Storage - HI-STORM 100 Cask System

- Commonly used spent nuclear fuel storage method in the US and Europe
- Spent nuclear fuel is placed into a stainless steel Multi-Purpose Canister (MPC) which is argon filled, welded shut and then placed in a steel and concrete overpack (HI-STORM 100).
- Annular gap between MPC and HI-STORM provides a passive cooling chimney effect
- Planned storage life of up to 100 years
Dry Fuel Storage – Multi Purpose Canister (MPC)

- Manufactured in 316L Stainless Steel
- Double skinned containment providing a “sacrificial barrier” to localised corrosion and SCC.
- Internal He atmosphere
- Residual stresses in the container body arise from a longitudinal seam weld, a circumferential weld at the base.
- MPC Double closure system consists of a lid welded onto the canister body followed by a closure ring welded to the lid’s top face.
Corrosion Risks – Atmospherically Induced Stress Corrosion Cracking
Corrosion Risk to MPC’s

- Atmospherically Induced Localised Corrosion and SCC

- **Factors analogous to those of ILW container storage**
  - Coastal location therefore high prevalence of aggressive salts in the air
  - Type 316L stainless steel susceptible material
  - Residual stresses present in the material
  - Long storage periods involved, potentially leading to significant aggregation of surface salts

- **Factors specific to storage of spent nuclear fuel**
  - Decay heat from the fuel leads to much higher surface temperatures, therefore increased risk of SCC
  - Air flow over the MPC surface, driven by the heat output from the fuel, will lead to different salt deposition characteristics.
Corrosion Risk to MPC’s – MPC Surface temperature Decay Curves

Figure taken from EPRI - Machiels, A., “Climatic Corrosion Considerations for Independent Spent Fuel Storage Installations in Marine Environments,” EPRI, California, 2006
Environmental Monitoring

- **External Monitoring**
  - Environmental Monitoring Station
  - Classification of the Sizewell Environment

- **Internal Monitoring**
  - Environmental Monitoring Station

- **Corrosion Simulator**
  - A full-size MPC, electrically heated and instrumented
Environmental Monitoring – Environmental Monitoring Stations

Monitoring Equipment:

- Vaiusela temperature/humidity probe connected to CR200X Datalogger (supplied by Campbell Scientific).
- Munro Air Sampler Pump with removable hose housed within double louvred Stevenson screen containment.
- Passive stainless steel salt deposition monitoring cube.

External Monitoring Station
Guidance from EPRI indicates standardised measurements of atmospheric corrosivity can be used for inter-site comparisons.

Classification of the environment in accordance with the following standards:

- BS EN ISO 9223 Corrosion of metals and alloys — Corrosivity of atmospheres — Classification, determination and estimation
- BS EN ISO 9226 Corrosion of metals and alloys — Corrosivity of atmospheres — Determination of corrosion rate of standard specimens for the evaluation of corrosivity
- BS EN ISO 9225 Corrosion of metals and alloys — Corrosivity of atmospheres — Measurement of environmental parameters affecting corrosivity of atmospheres
Environmental Monitoring – Classification of the Sizewell Environment

1 yr corrosion rate samples

Wet Candle Samples
# Environmental Monitoring – Classification of the Sizewell Environment

<table>
<thead>
<tr>
<th>Specimen ID</th>
<th>Al-1</th>
<th>Al-2</th>
<th>Al-3</th>
<th>316L-1</th>
<th>316L-2</th>
<th>316L-3</th>
<th>304L-1</th>
<th>304L-2</th>
<th>304L-3</th>
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<td>1st Yr Corrosion Rate (g/m²/year)</td>
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<table>
<thead>
<tr>
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<th>Zn-2</th>
<th>Zn-3</th>
<th>Cu-1</th>
<th>Cu-2</th>
<th>Cu-3</th>
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<th>MS-2</th>
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Corrosion Monitoring MPC

- A complete MPC body and base,
- Heated internally to provide the modelled thermal signature of a SFA filled MPC from the first loading campaign
- Capability to carry out 100% surface assessments
- Instrumentation to provide
  - temperature profiling to match thermal model
  - Local humidity measurement
  - Air-flow measurement
  - Cask base temperature
  - Cask outlet temperature
  - ToW sensors
R&D Programmes

- Work has been carried out on:
  - Residual stress measurements of SNF container welds
  - SCC testing under candidate salt composition analogues
  - Deliquescence testing of candidate salt composition analogues
Temperature profile of the surface of a SNF canister

- Fuel has been allowed to cool for 7-10 years
- Modelled decay profiles
- Dependent on ambient temperature
- Potential for periodic cycling through wet-dry conditions
R&D – Anticipated Residual Stress at SZB

- Residual stresses within a simulated SZB SNFC weld
- Stress relaxation occurred on weld removal
- Estimated original peak stress 360MPa
R&D – Early Experimental Programme

Aims of testing:

- Standardise lab testing to assess the risk of onset of SCC initiation
- Test candidate representative salt mixtures for deliquescence and SCC initiation properties
Laboratory Testing - Early Experimental Programme

Current aim is to standardise lab testing to assess the risk of onset of SCC initiation once understanding of environmental parameters has been refined.

<table>
<thead>
<tr>
<th>Species</th>
<th>SZB Swab Derived Salt (wt %)</th>
<th>Sea salt analogue</th>
</tr>
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<tbody>
<tr>
<td>Calcium</td>
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<td>Magnesium</td>
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<td>Ammonium</td>
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<td>Sodium</td>
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<tr>
<td>Sulphate</td>
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<tr>
<td>Nitrate</td>
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<tr>
<td>Chloride</td>
<td>29.6</td>
<td>54.3</td>
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316L U-bend surface 70°C 30% RH, 240 hours exposure
## Laboratory Testing - Early Experimental Programme

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<td>Nitrate</td>
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### SZB Swab Derived Salt - Deliquescence Curve - 60°C

![Deliquescence Curve Graph](image)
Laboratory Testing - Mg Cl$_2$ salt deposit

- Deliquescence and Efflorescence measurements show hysteresis
- Clear step change for deliquescence
- Modifies wet-dry assessments

Deliquescence and efflorescence profile for magnesium chloride at 60°C.
Looking Forward

- The decision to opt for dry storage for future nuclear plant fuel is based on economics and risk
- The Dry Stores act as Interim Storage Facilities
- The accepted SC for SZB is 100yrs, 20yr horizon which is updated every 10 years
- HPC has a projected 120yr life, expected to be up and running ~2035
- SZC?
Summary

- Sizewell B has become the first UK Operator to adopt the Dry Fuel Store Model
- Dry Fuel storage presents a different set of corrosion issues to that of wet fuel storage
- Main risks to the safety case arise from atmospherically induced SCC
- The heat output of spent nuclear fuel gives rise to considerations that differ to those associated with ILW storage in the UK
- Significant work is continuously being undertaken to characterise the environmental conditions in the dry store and on the MPC surface.
- R&D test programmes still in relative infancy – key driver is to standardise initiation susceptibility testing whilst the environmental envelope is further defined
Questions???