Corrosion Monitoring of Dry Fuel Storage Containers in Nuclear Facilities.

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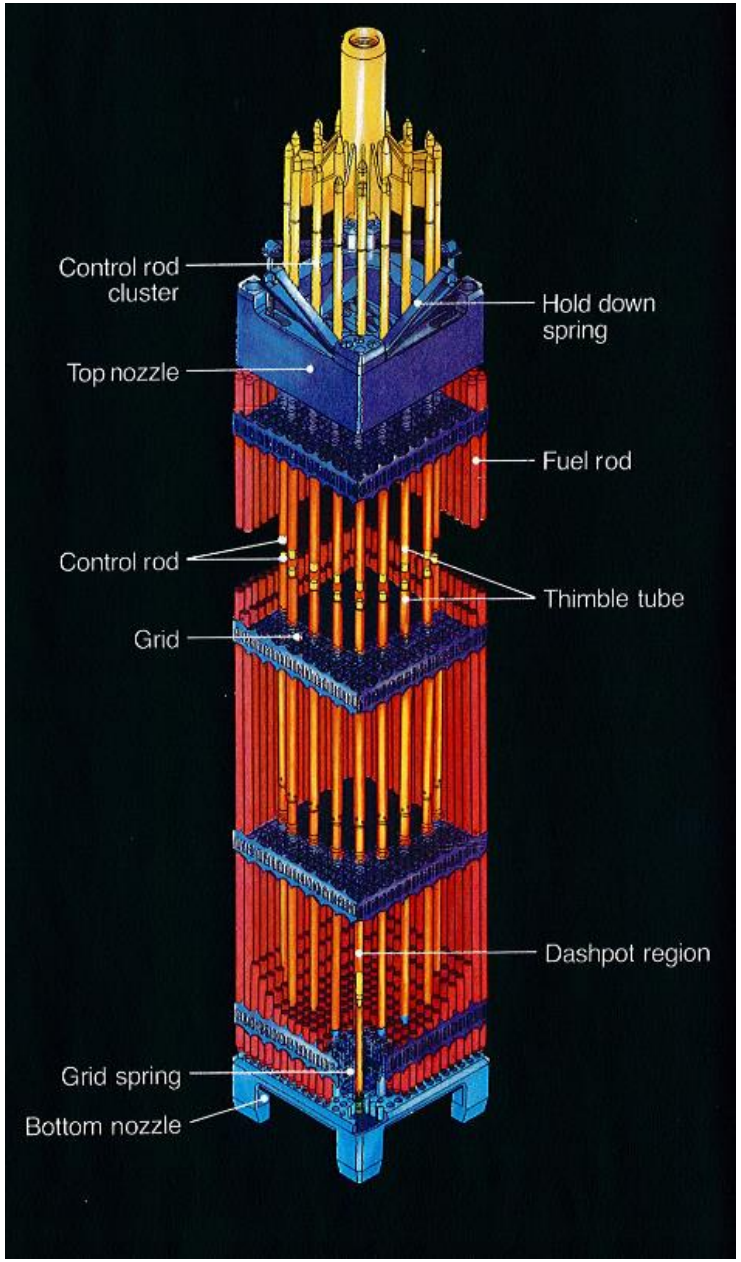
Contents

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

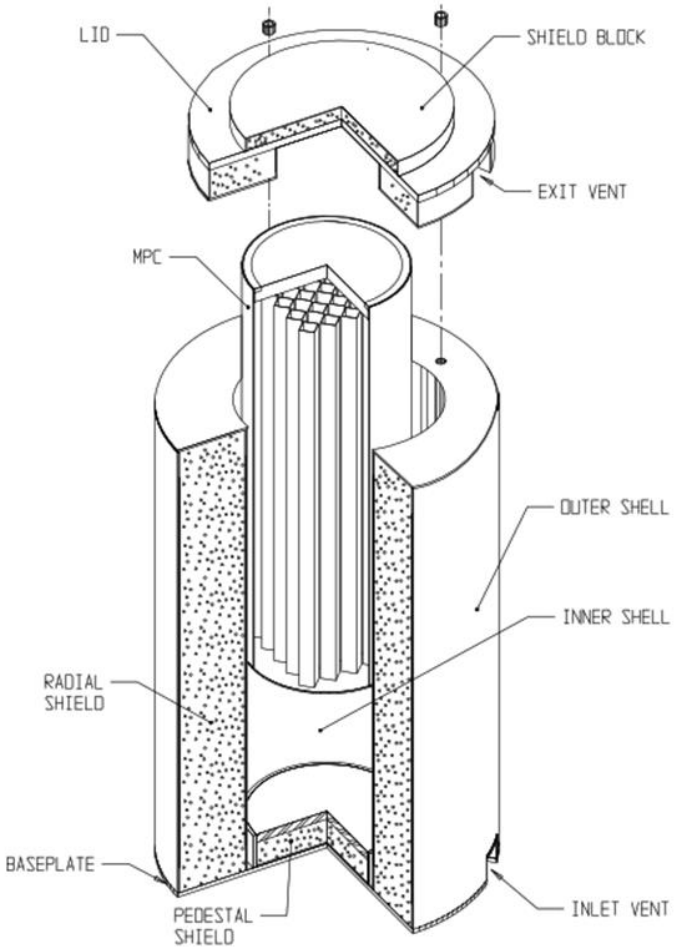
- The operators recognised early in the station's life that the licenced fuel pond capacity would not be sufficient to maintain operations through to the end of life.
- This capacity was expected to be reached in 2016.
- Original intention was to send spent fuel to the planned Geological Repository which 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

Dry Fuel Storage Building

- 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.

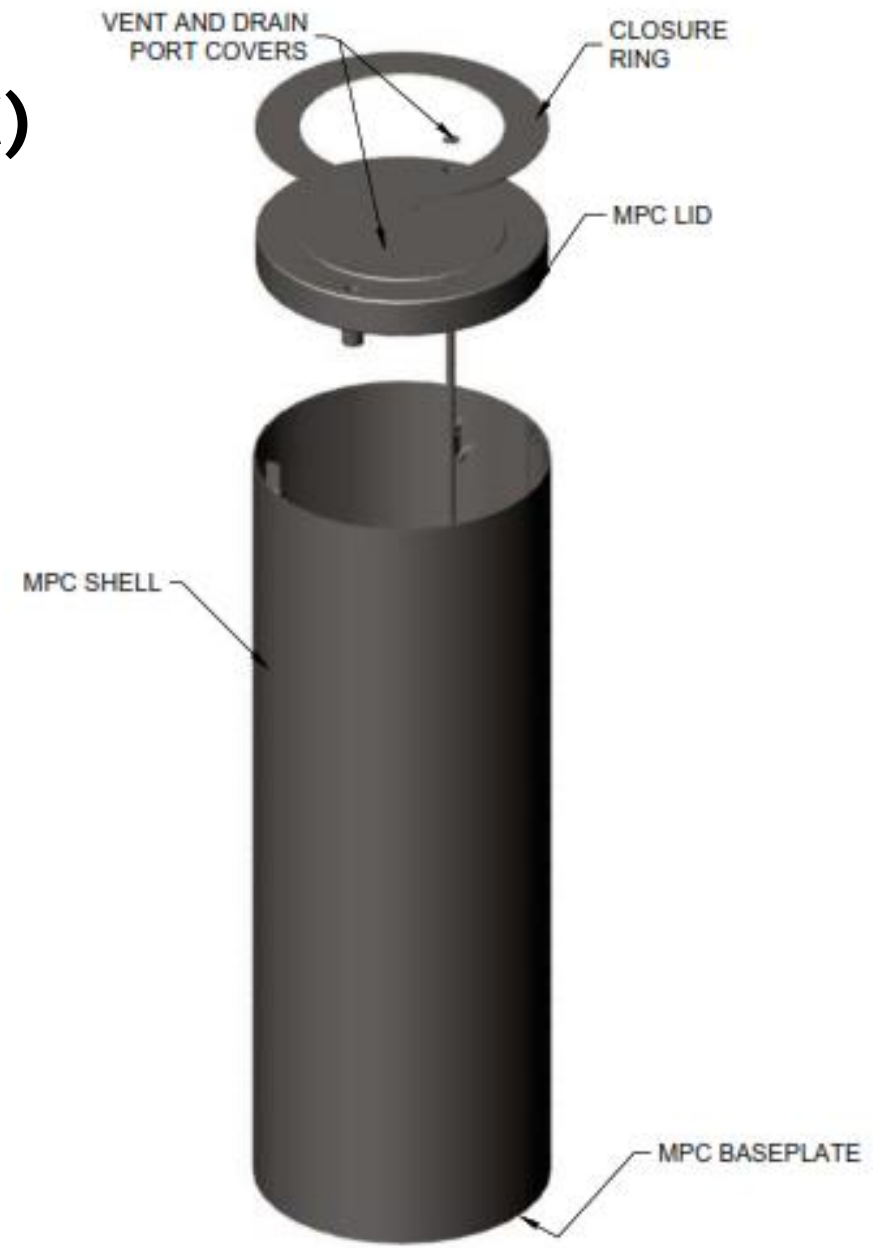
Dry Fuel Storage - HI-STORM 100 Cask System

- 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 to100 years

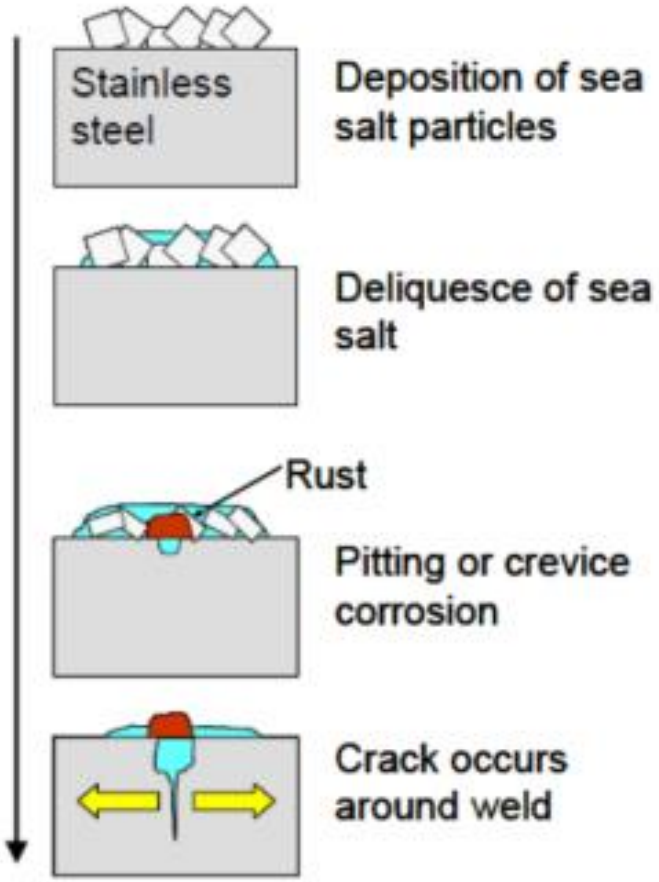


Dry Fuel Storage – Multi Purpose Canister (MPC)

- 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

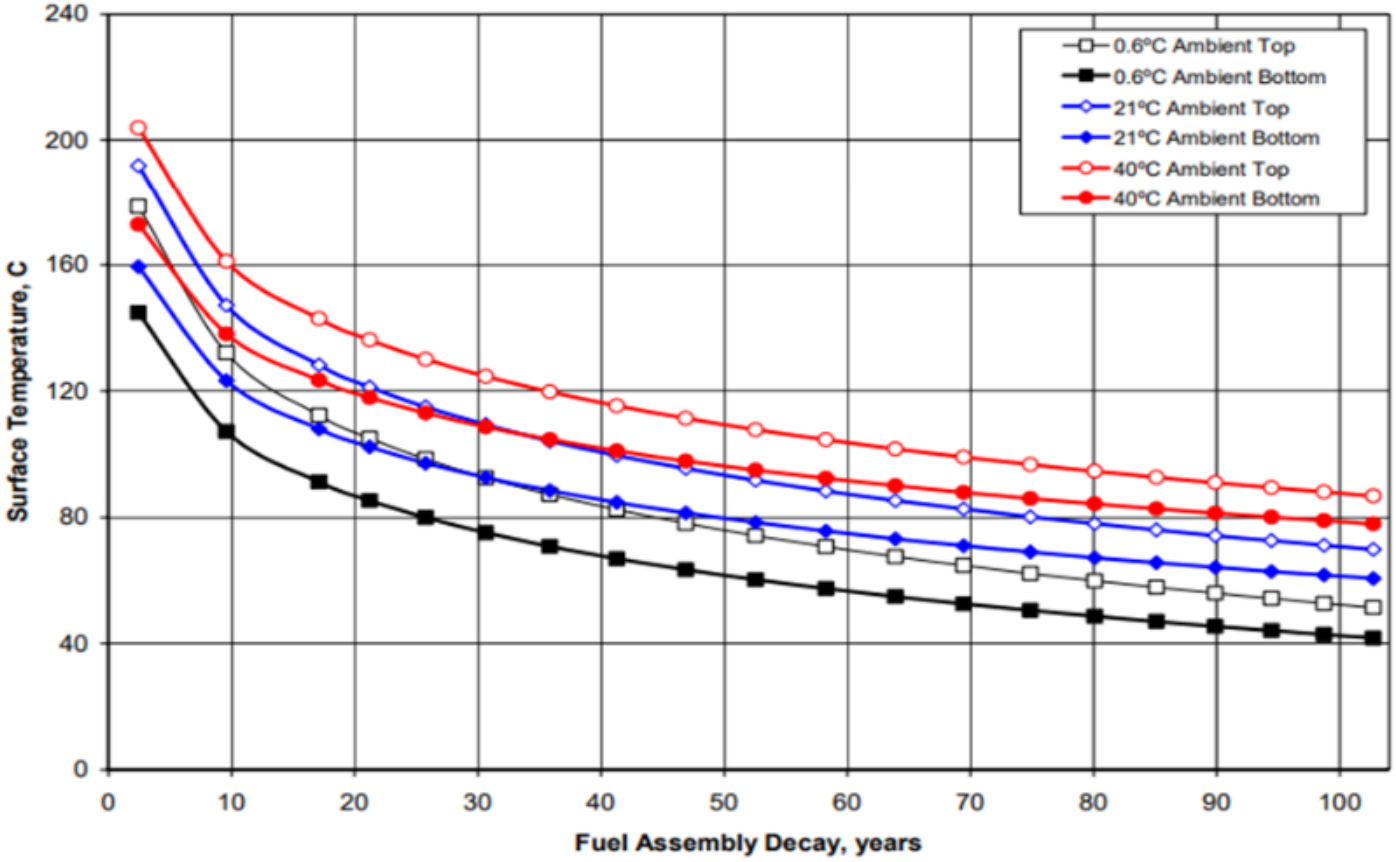


Figure taken from EPRI - Machiels, A., "Climatic Corrosion Considerations for Independent Spent Fuel Storage Installations in Marine Environments," EPRI, California, 2006

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

External Monitoring Station

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.

Environmental Monitoring – Classification of the Sizewell Environment

- 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

	Specimen ID								
	Al-1	Al-2	Al-3	316L-1	316L-2	316L-3	304L-1	304L-2	304L-3
1st Yr Corrosion Rate (g/m^2year)	3.38394	2.75171	2.38358	0.24379	0.34081	0.19440	0.60071	0.31664	0.27006
Corrosivity Category (BS EN ISO 9223)	C4	C4	C4	N/A	N/A	N/A	N/A	N/A	N/A
	Specimen ID								
	Zn-1	Zn-2	Zn-3	Cu-1	Cu-2	Cu-3	MS-1	MS-2	MS-3
1st Yr Corrosion Rate (g/m^2year)	12.02577	7.35354	7.05160	24.56043	21.32539	17.32778	201.9792	180.3602	186.2751
Corrosivity Category (BS EN ISO 9223)	C3	C3	C3	C4	C4	C4	C3	C2	C2

Corrosion Monitoring MPC

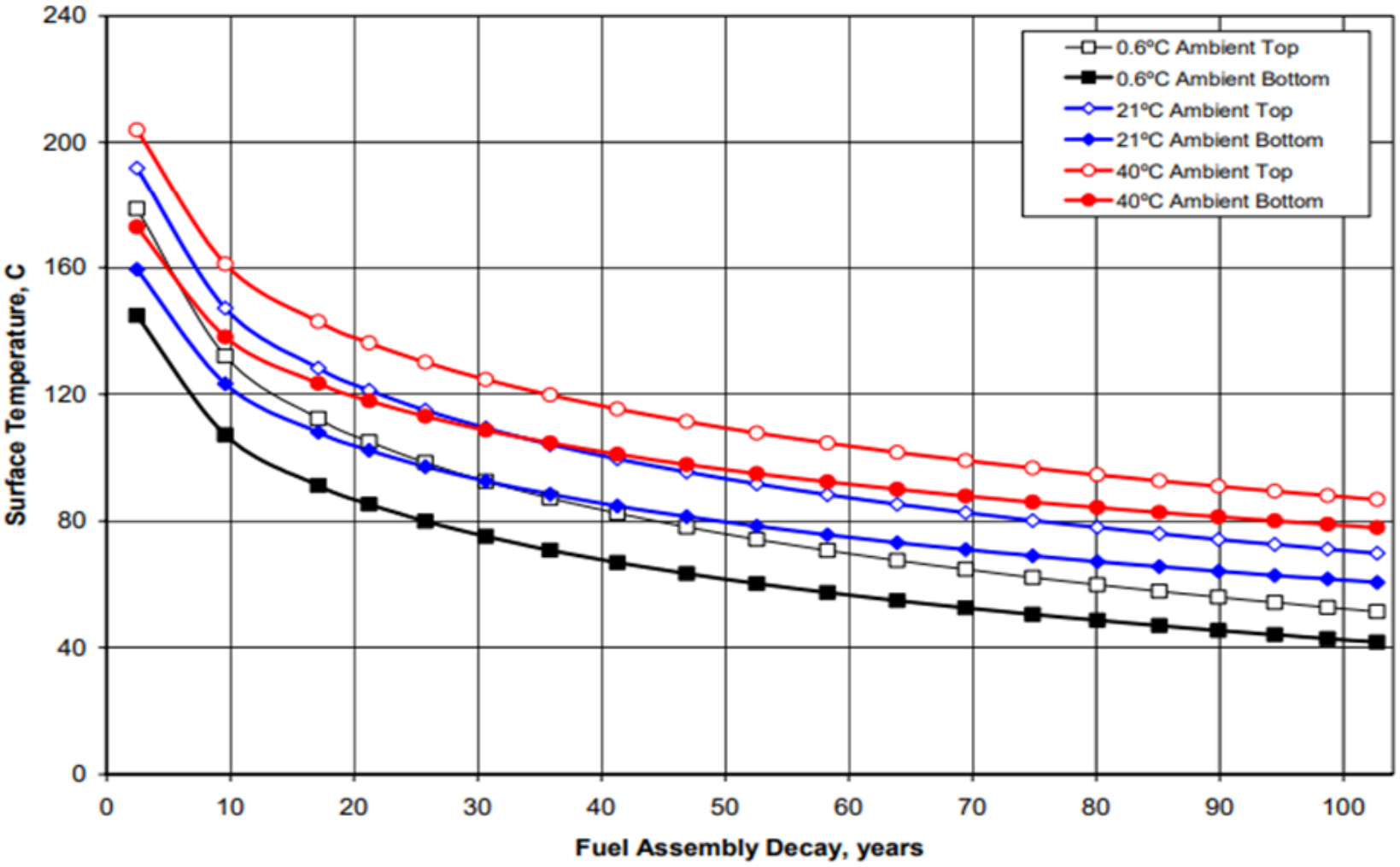
- A complete MPC body and base,
- Heated internally to provide the modelled thermal signature of a SFA filled MPC from the first loading campaign
- Capability to carry out 100% surface assessments
- Instrumentation to provide
  - temperature profiling to match thermal model
  - Local humidity measurement
  - 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

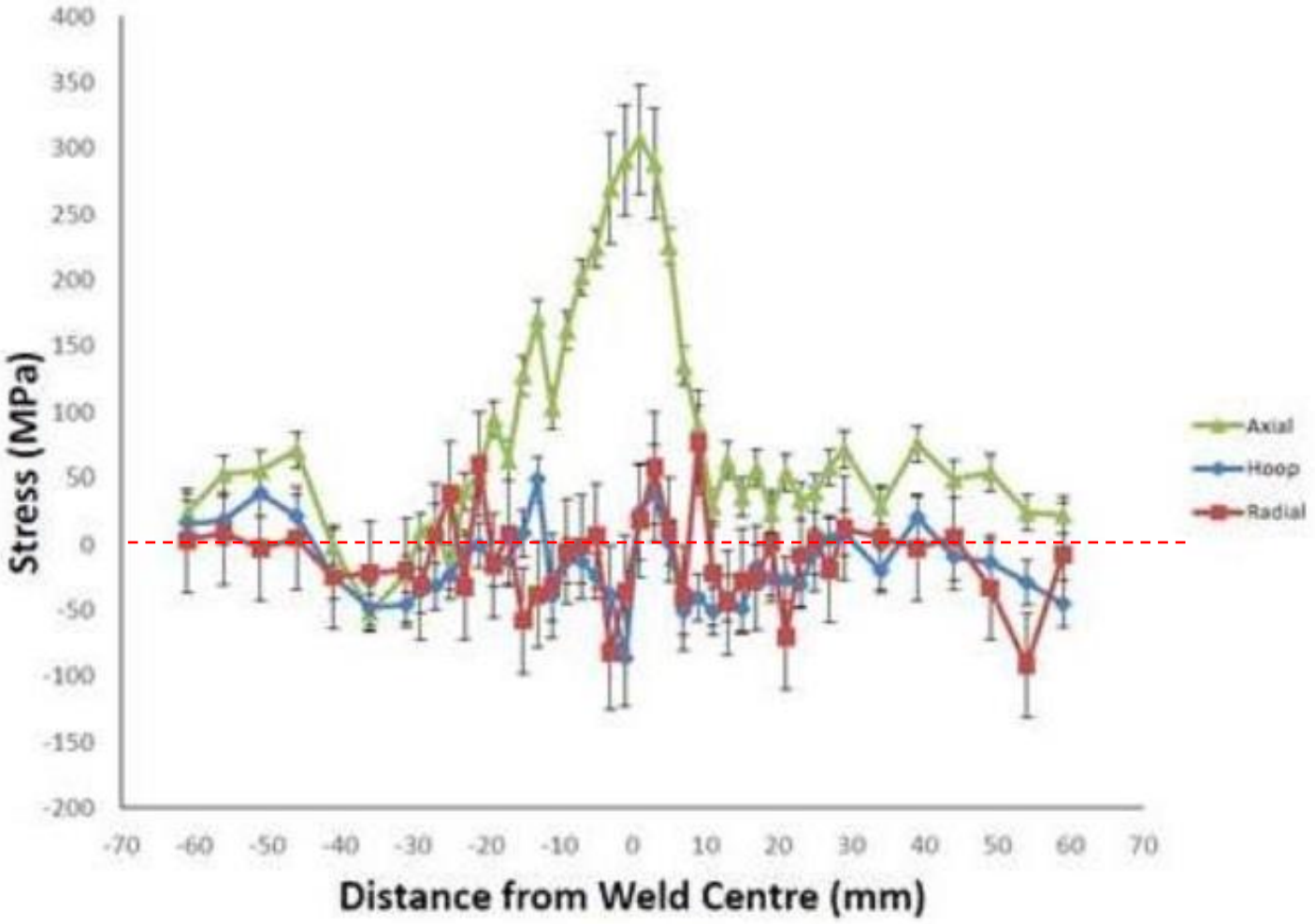
Temperature profile of the surface of a SNF canister

- 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

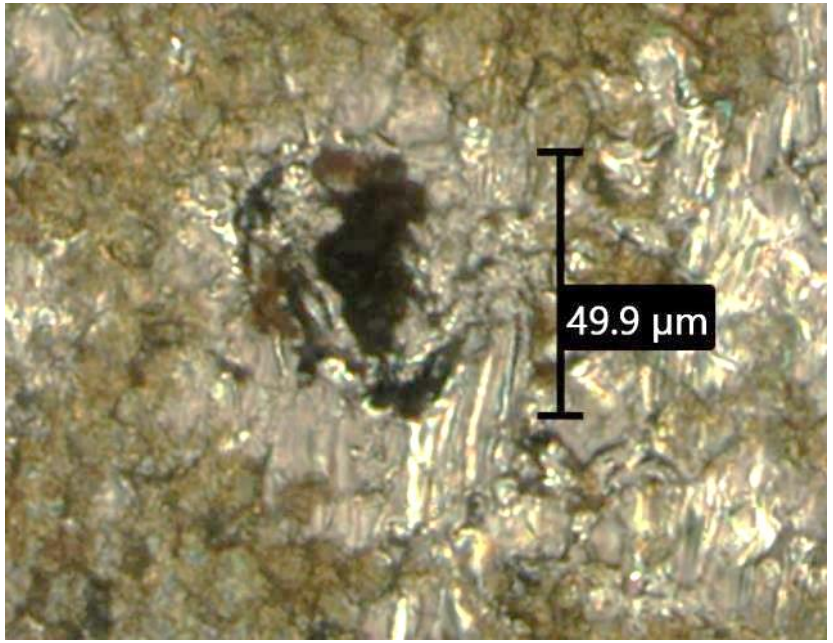
Aims of testing:

- 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

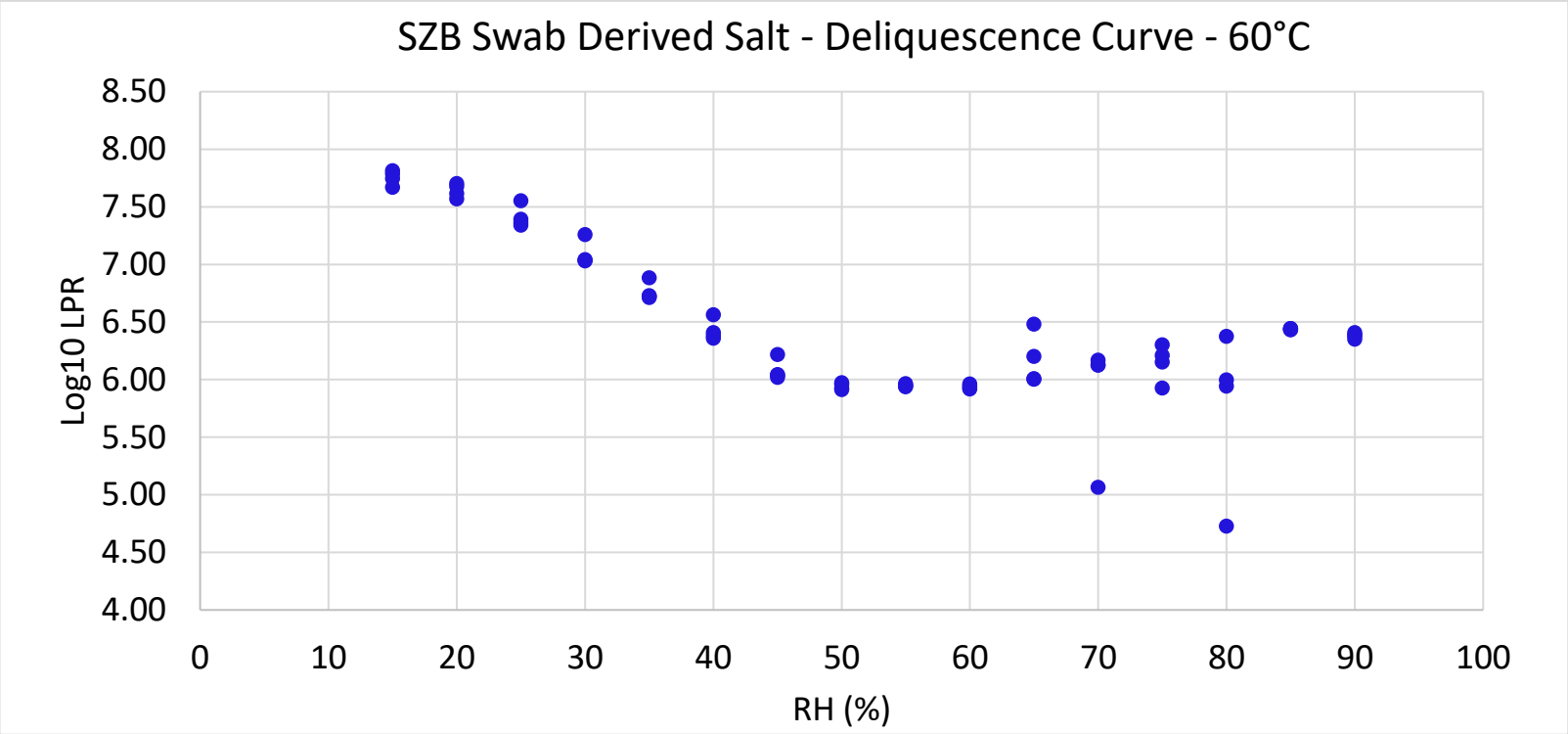
Species	SZB Swab Derived Salt (wt %)	Sea salt analogue
Calcium	8.3	0.2
Magnesium	3.3	2.9
Potassium	6.6	
Ammonium	13.5	
Sodium	16.8	35.7
Sulphate	12.2	6.7
Nitrate	9.7	
Chloride	29.6	54.3



316L U-bend surface 70°C 30% RH, 240 hours exposure

Laboratory Testing - Early Experimental Programme

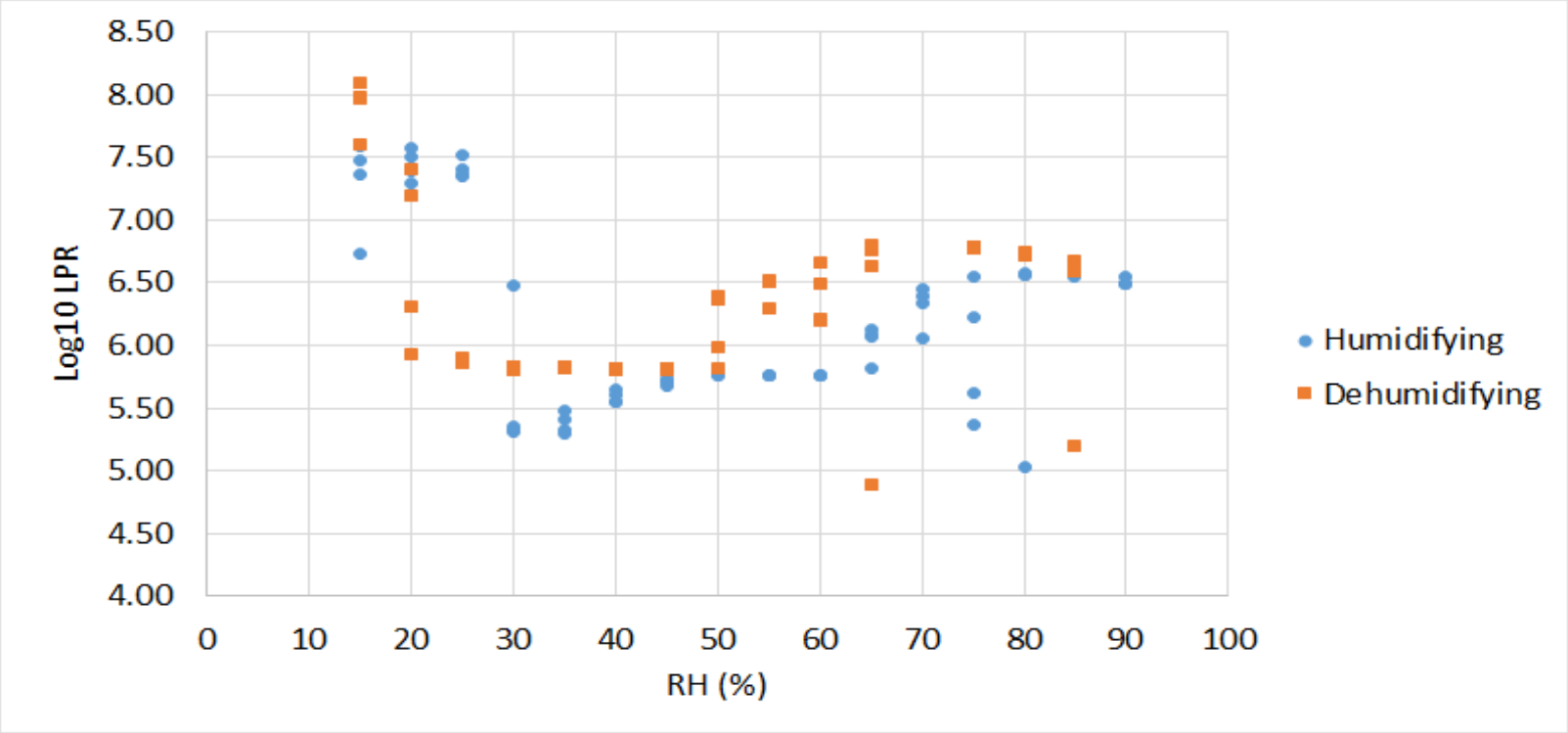
Species	SZB Swab Derived Salt (wt %)
Calcium	8.3
Magnesium	3.3
Potassium	6.6
Ammonium	13.5
Sodium	16.8
Oxalate	-
Sulphate	12.2
Nitrate	9.7
Chloride	29.6



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 10years
- 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???