SPENT FUEL CHARACTERIZATION FOR MANAGEMENT OF SPENT FUEL IN THE UK

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NATIONAL NUCLEAR LABORATORY

UK spent fuel and management strategy

Current issues in spent fuel management

R&D themes supporting failed fuel storage

Magnox Reactors

26 reactors built between 1956 and 1971

Design life ~20 years

Most operated > 40 years, max 47 years

Last station closed 2015.

Total nominal output 4.4 GWe

Magnesium clad, natural Uranium fuel

~50,000 tU fuel reprocessed

< 1,000 tU fuel to be reprocessed

~300 tU of legacy Magnox fuel and residues

AGR and PWR Reactors

AGR

7 stations, 880 – 1,230 MWe

total output 8.2 Gwe

started operation 1976-1989

scheduled closure 2023-2030

Stainless steel clad, hollow UO_2 fuel

Fuel discharges 150-200 tU/y

PWR

1 station, 1,198 MWe

started operation 1995

scheduled closure 2035

expect 20 years extension

Zircalloy clad, UO_2 fuel

Fuel discharges ~25 tU/y

Legacy Fuels

Legacy fuels from

- research reactors
- prototype reactors

<500 tHM

Fuel being consolidated

Long term storage pending disposal

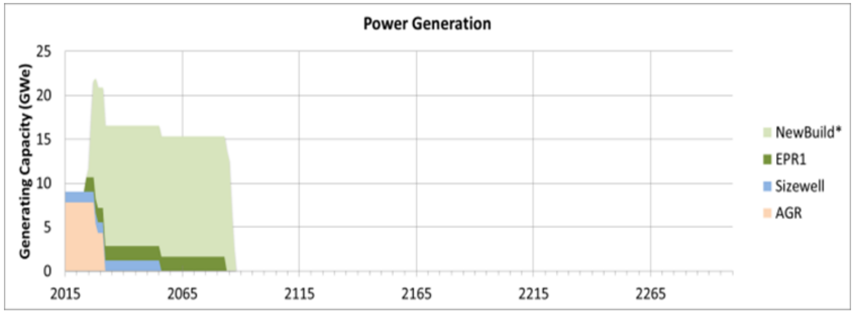
Fuel Storage Requirements

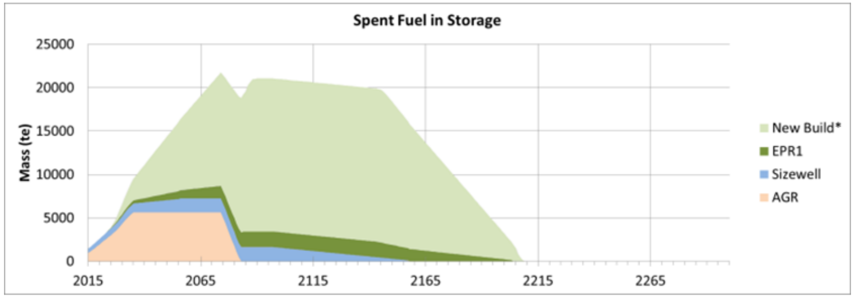
UK has started a new build programme, initially based on Gen 3+ LWR stations

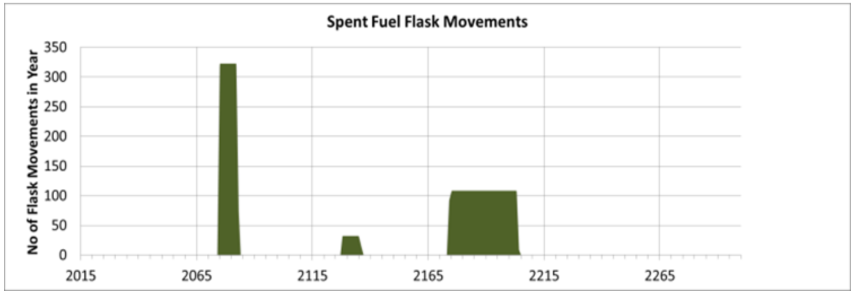
Possible profile of spent fuel for 16 GWe of new LWR stations operating for 60 years, showing

- power generation,
- spent fuel in storage and
- transfers to a GDF

Interim Storage of Thermal Reactor Fuels Implications for the Back End of the Fuel Cycle in the UK. EPJ Nuclear Sci. Technol. 2, 21 (2016).







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UK New Build

Hinkley Point C:

- 3.2 GWe capacity (2 EPR)
- Under construction
- Earliest operation 2026

Sizewell C:

- 3.2 GWe capacity (2 EPR)
- Stage 2 consultation complete
- Investment decision pending

Bradwell B:

- Pre-planning stage
- GDA started
- Hualong One

National Strategy

- Strategy has been to reprocess Magnox and AGR fuel:
  - Low corrosion resistance of Magnox fuel
  - Initial issues with corrosion of AGR fuel
  - Energy security
  - Preparation for transition to fast reactor fuel cycle
  - International business

- Disposition (approximate quantities):
  - Magnox ~50,000 te reprocessed
  - AGR ~6,000 te reprocessed <6,000 te to be stored
  - PWR <2,000 te to be stored

- Strategic change due to:
  - Reduced international business
  - No immediate prospect of fast reactor deployment
  - Mismatch between capacity and need
  - Good storage performance over >20 years
  - Refurbishment costs

UK Spent Fuel Management Policy

"Spent fuel management is a matter for the commercial judgement of its owners, subject to meeting the necessary regulatory requirements"

Fuel Storage Strategies

AGR

Reactor pond storage capacity < 1 year

Routine transport of fuel

Centralised pond storage

Repackage

Transport

Disposal ~2075-2090

LWR

Pond storage capacity 10-20 years

Storage in reactor pond

AR dry storage

Repackage

Transport

Disposal > 2090

Dry storage being evaluated as contingency

UK spent fuel and management strategy

Current topics in spent fuel management

R&D themes supporting failed fuel storage

Current topics in SNF Management

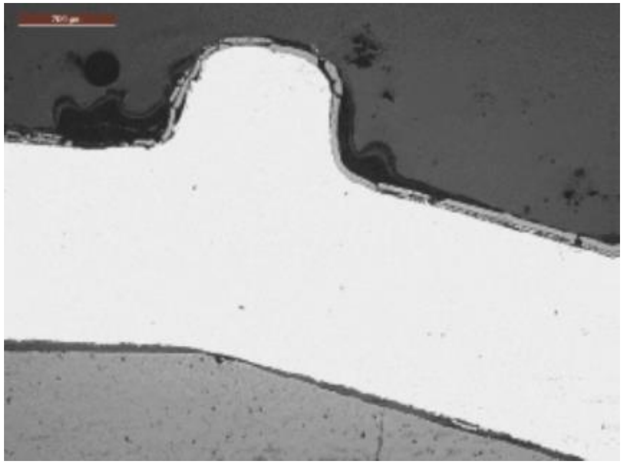
- AGR fuel – underpinning longer term wet storage (up to 100 years)
- LWR fuel – underpinning long term performance of canisters
- Re-use of separated Pu as MOX or fast reactor fuel (or disposal)
- Consequential challenges

Context for Spent Fuel R&D

AGR fuel

Experience > 25 years pond storage

Hambley, DI. Technical Basis for Extending Storage of the UK's Advanced Gas-Cooled Reactor Fuel. Paper 7722. Global 2013, Salt Lake City, USA.



LWR fuel

international experience with DSCs

new storage capacity in mid-late 2030s

Sound technical basis for current storage

Ongoing R&D commitment

Strategic Challenges

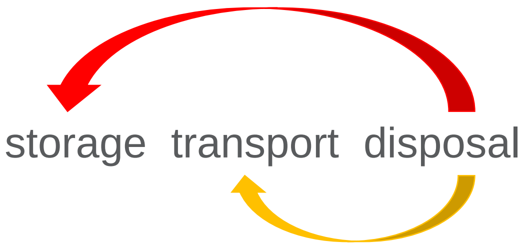
AGR fuel - change from reprocessing to long term storage

LWR fuel - long term storage of high burn-up fuel

Exotic fuels – managing a variety of fuels many in degraded condition

Re-use of separated Pu as MOX fuel or disposal

Optimising back end:



Incentivising centralised storage

Managing knowledge, skills and capability across long periods of minimal activity

are disposal requirements going to challenge current storage assumptions ?

Technical Challenges

Understanding fuel and system behaviour

Designing out likely failure modes

Keeping defence in depth approach

Utilising passive safety as far as possible

Demonstrating system performance

Reducing total cost: discharge to disposition

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Current R&D Themes

Fuel evolution over decades/centuries

Monitoring of fuel condition and local environment

Contingencies and severe accident

Ageing management of SF pools

Drying behaviour of defective spent fuel

Degradation mechanisms and ageing management plans for cask storage

Post storage transportation

Comparison of AGR & LWR fuel behaviour in GDF

PIE Facilities (in support of storage/disposal)

13 hot cells - HA

- 2.5m x 4m x 11m
- 5 workstations
- Internal cranes
- Operational, Processing and PIE services

PIE techniques

- Eddy current
- Gamma scan
- Pin puncture & gas analysis
- Hydrogen measurement
- Visual inspection
- Ceramography
- Thermal & mechanical properties

Understanding Fuel Characteristics

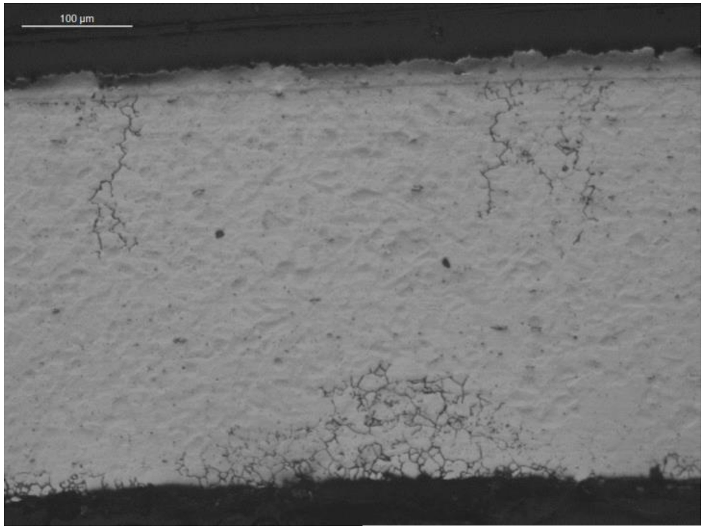
PIE to evaluate irradiated fuel characteristics:

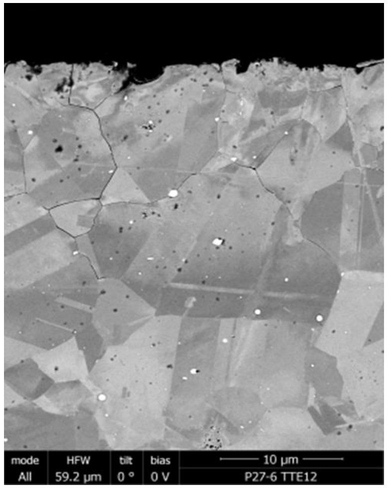
- evolution at increasing burn-up
- data to validate models
- characteristics of limited relevance for in-reactor performance

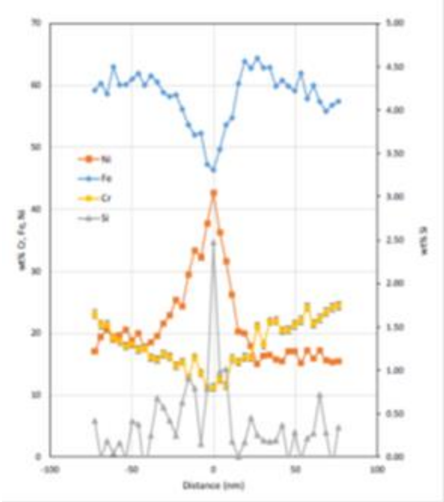
Techniques:

- optical Microscopy
- scanning Electron Microscopy
- transmission Electron Microscopy
- focussed Ion Beam
- micro-hardness
- residual stress measurement

Modelling







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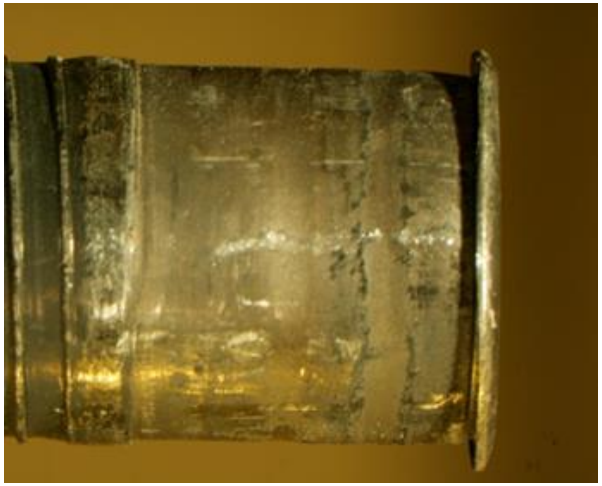
Post Storage Examination

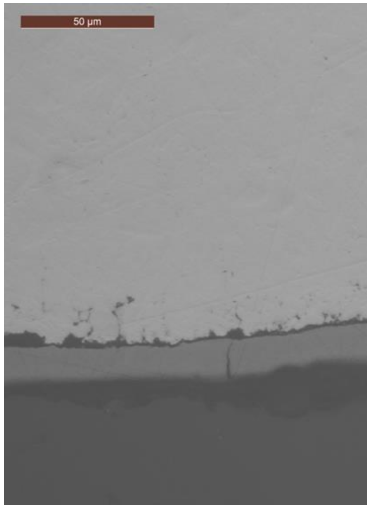
Examination of long-stored fuel to assess degradation :

- Cladding condition
- General and local corrosion
- Consequence of drop test

Techniques:

- gamma spectrometry
- optical Microscopy
- Scanning Electron Microscopy
- Transmission Electron Microscopy
- low impact drop test





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Resilience

Testing to evaluate impact of abnormal conditions on fuel integrity:

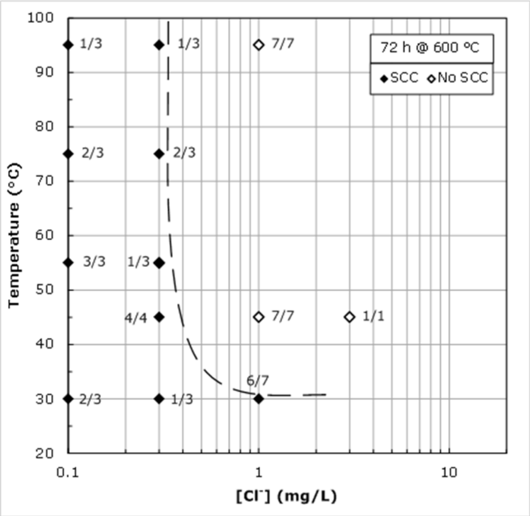
- Corrosion studies on simulants
- Corrosion testing on irradiated cladding

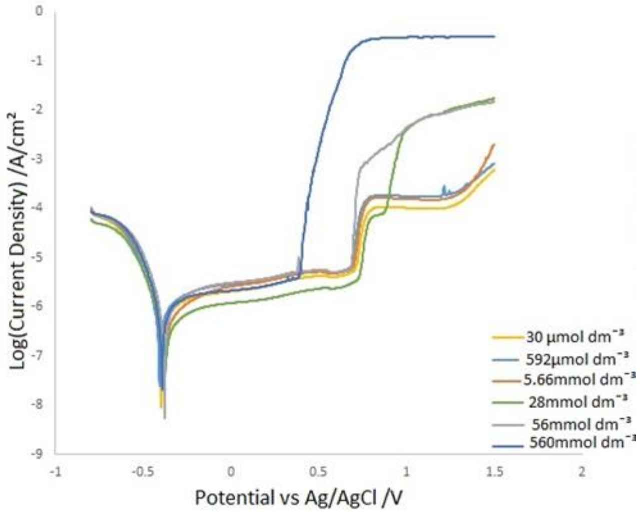
Techniques:

- Electrochemistry (University of Lancaster)
- C ring testing
- Microscopy
- Field signature method

Modelling

Howett, EH, Boxall, C, Hambley, D, Higgins, J. AGR Cladding Corrosion: Part 1: Investigation of the Effect of Interim Storage Conditions on Unsensitised 20/25/Nb Stainless Steel. Corrosion Science(2018) submitted.





Fuel Drying

Characterisation of fuel

Drying trials on small samples

Monitoring of dried fuel

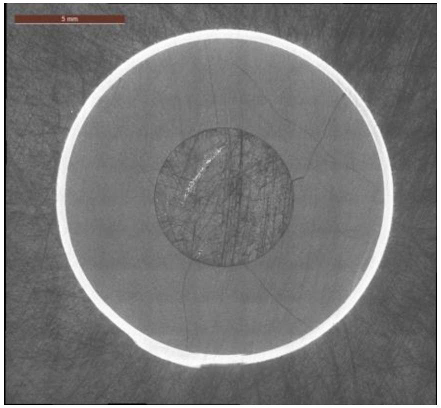
Techniques

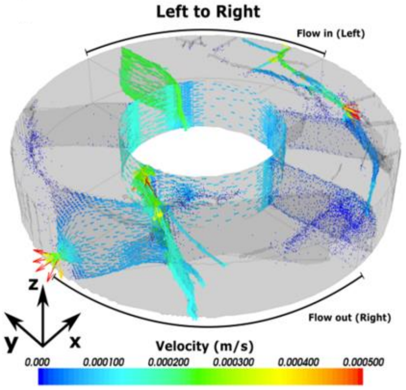
- Optical microscopy
- TGA
- Bespoke drying equipment
- Humidity monitoring of hot cell storage

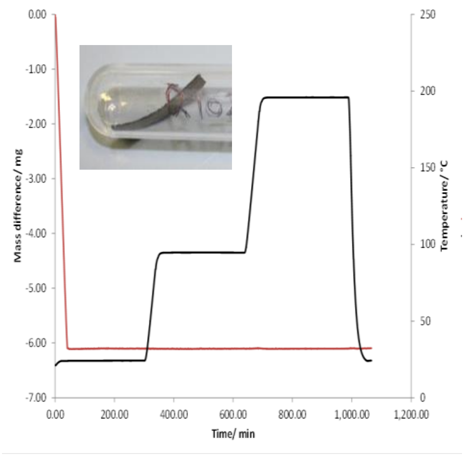
Modelling

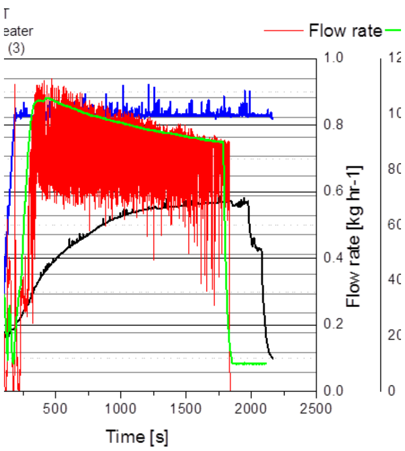
Thomas, RN, Paluszny, A, Hambley, D, Hawthorne, FM, Zimmerman, RW. Permeability of observed three dimensional fracture networks in spent fuel pins. Journal of Nuclear Materials 510 (2018) 613-622.

Goode. J, Harbottle, D, Hanson, BC. Vacuum drying of advanced gas reactor fuel. Progress in Nuclear Energy 109 (2018) 145-158.









Managing Degraded Oxide Fuel

Assessment of radiolysis effects

Testing of storage can behaviour

Recovery of legacy oxide fuels

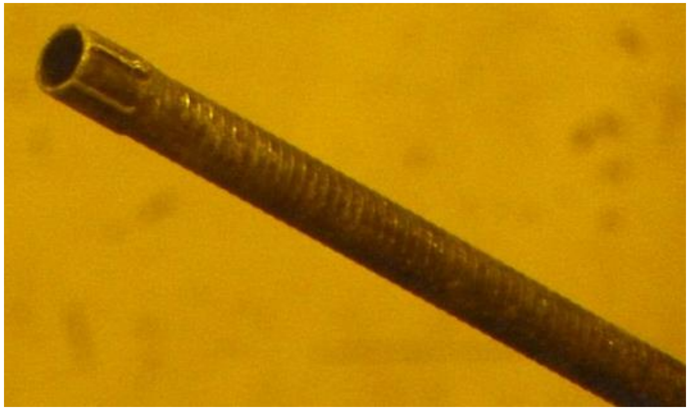
Analysis of corrosion products

Techniques used

- Hydraulic testing
- SEM
- XRD
- TGA
- Leaching trials

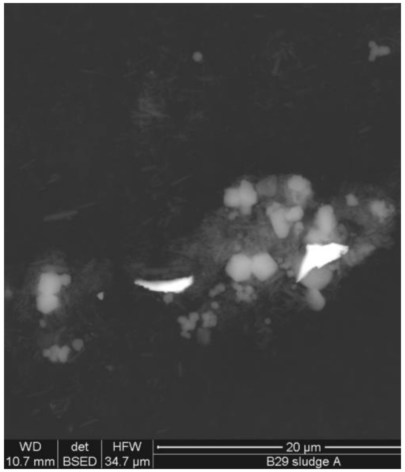
Proposed work on

- Radiolysis yield from wetted fuel
- Measurement of water on irradiated fuel
- Low temperature oxidation of irradiated fuel



Condition of test reactor fuel after 40 years exposure to water

Dried corrosion product



Backscatter image of corrosion product

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Managing Degraded Uranium Fuel

Recovery of containerised U metal fuels

Rates of UH_3 formation and hydrolysis

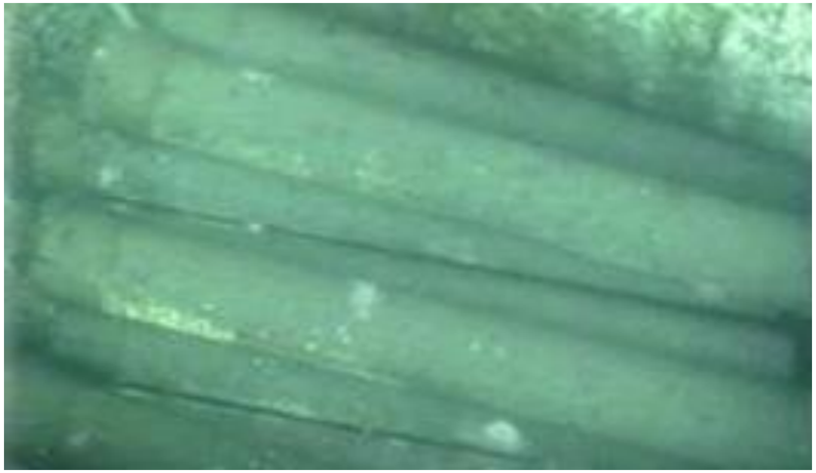
Release Fractions from UH_3 oxidation

Thermal modelling of stored U fuel

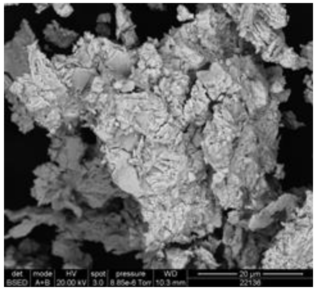
Technical basis for vented storage of U fuel

Orr, R, Godfrey, H, Broan, C, Goddard, D, Woodhouse, G, Durham, P, Diggle, A, Bradshaw, J. Formation and physical properties of uranium hydride under conditions relevant to metallic fuel and nuclear waste storage. Journal of Nuclear Materials 477 (2016) 236-245.

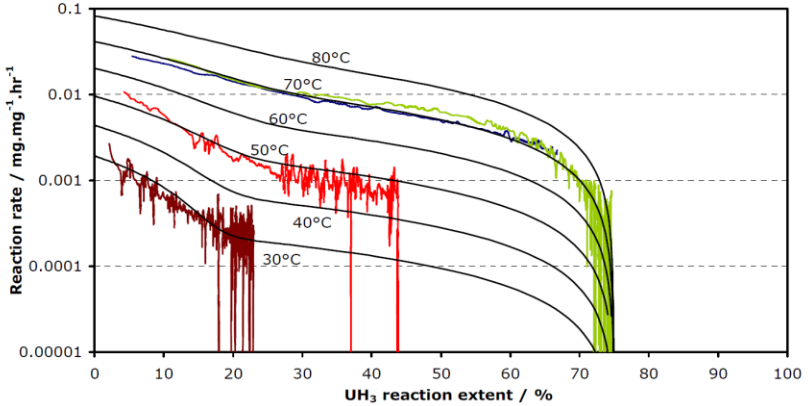
Orr, R, Godfrey, H, Broan, C, Goddard, D, Woodhouse, G, Durham, P, Diggle, A, Bradshaw, J. Kinetics of the reaction between water and uranium hydride prepared under conditions relevant to uranium storage. Journal of Alloys and Compounds 695 (2017) 3727-3735.



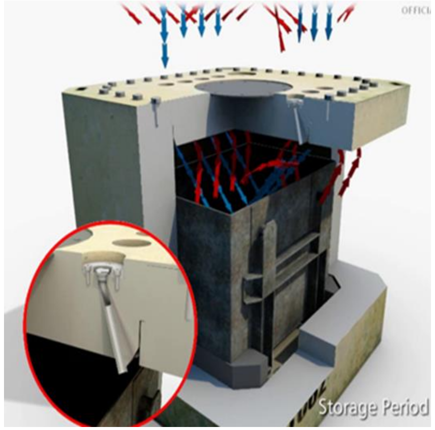
Pond–stored legacy U metal fuel containers



Morphology of UH_3



Rates of hydrolysis for UH_3 formed at different temperatures

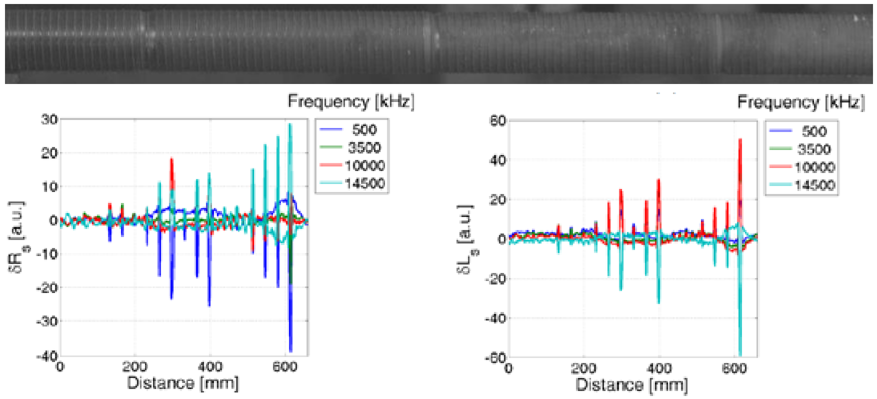


Vented storage concept

Monitoring & Mitigation Technologies

Detection of fuel pin corrosion during storage

- Electrochemical noise
- Ultrasound
- Eddy current
- Instrumented corrosion coupons

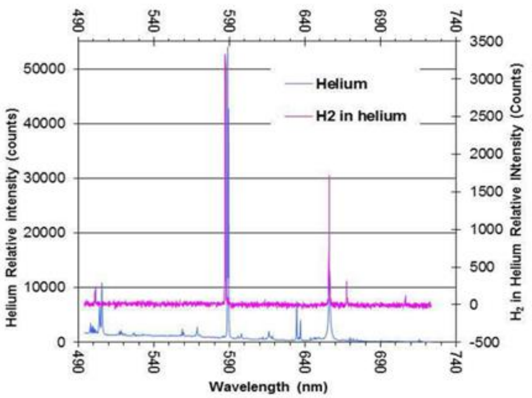


Section of AGR fuel pin and eddy current results for robotic scan of EDM defected fuel pin

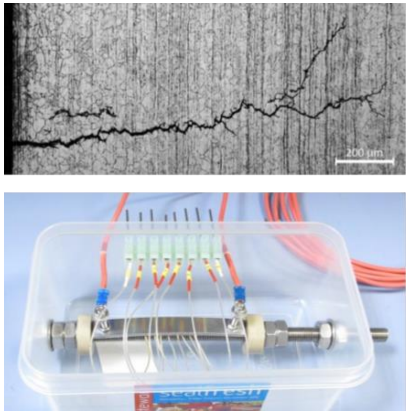
Monitoring of dry storage atmosphere using LIBS

Smith, N, et. Al. "Within-canister monitoring of xenon in spent nuclear fuel gases during storage and disposal using stand-off laser-induced breakdown spectroscopy" in preparation.

Stable hydrogen getter



LIBS detection of H_2 in He



SCC crack and test concept

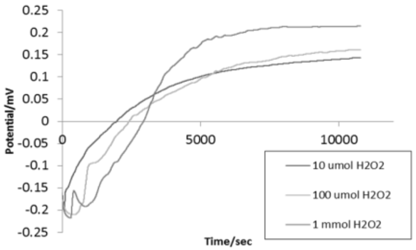
Characterisation of Fuel for Disposal

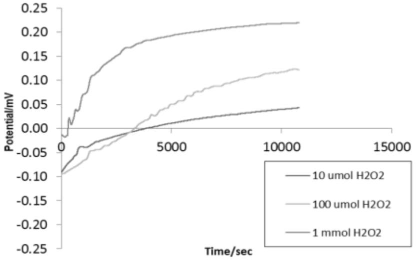
Characterisation of irradiated fuel and simulants

- Electrochemical studies
- Microscopy
- Gamma scanning
- Simulant manufacturing

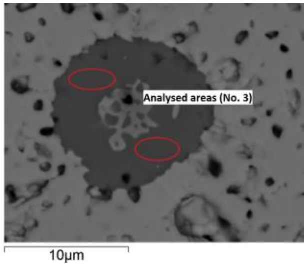
Leach Testing of irradiated fuel

Modelling





Effect of H_2O_2 concentration on open circuit potentials of (i) UO_2 and (ii) 43 GWd /tU SIMFUEL



Grey-phase precipitate in AGR SIMFUEL

Hiezl, Z, Hambley, D , Padovani, C and Lee, WE. Processing and microstructural characterisation of a UO2-based ceramic for disposal studies on spent AGR fuel. Journal of Nuclear Materials 456 (2015) 74–84.

Rauff-Nisthar,N, Boxall, C, Hambley, D, Hiezl, Z, Lee, WE, Padovani, C and Wilbraham, R. Corrosion Behaviour of AGR SIMFUELS. ECS Trans. 2015, volume 66, issue 17, 85-94

Anwyl, C, Boxall, C, Willbraham, R, Hambley, D and Padovani, C. Corrosion of AGR fuel pin steel under conditions relevant to permanent disposal. Procedia Chemistry 21(2016) 247-254.

UK Spent Fuel Management - Summary

UK is building a new generation of LWRs

Strategy has moved to open ‘cycle’, with option for future return to closed cycle if needed

Disposal facility siting process initiated December 2018

Existing storage technology and infrastructure will meet spent fuel management need for ***current*** reactors

10 year decision making period for new stations

Focus on knowledge, skills and capability maintenance

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Thank you for your attention

Any questions ?

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