Technological Development to Support a Change in the United Kingdom's Strategy for Management of Spent AGR Oxide Fuel

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International Conference on Management of Spent Fuel from Nuclear Power Reactors

19th June 2015, Vienna International Centre

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2. Outline of the planned interim storage regime
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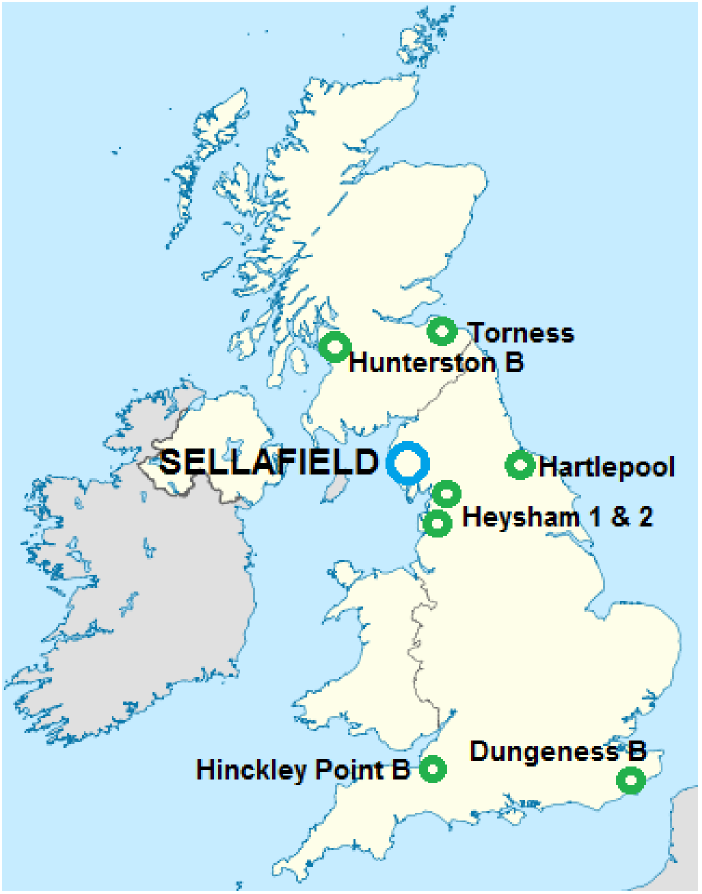
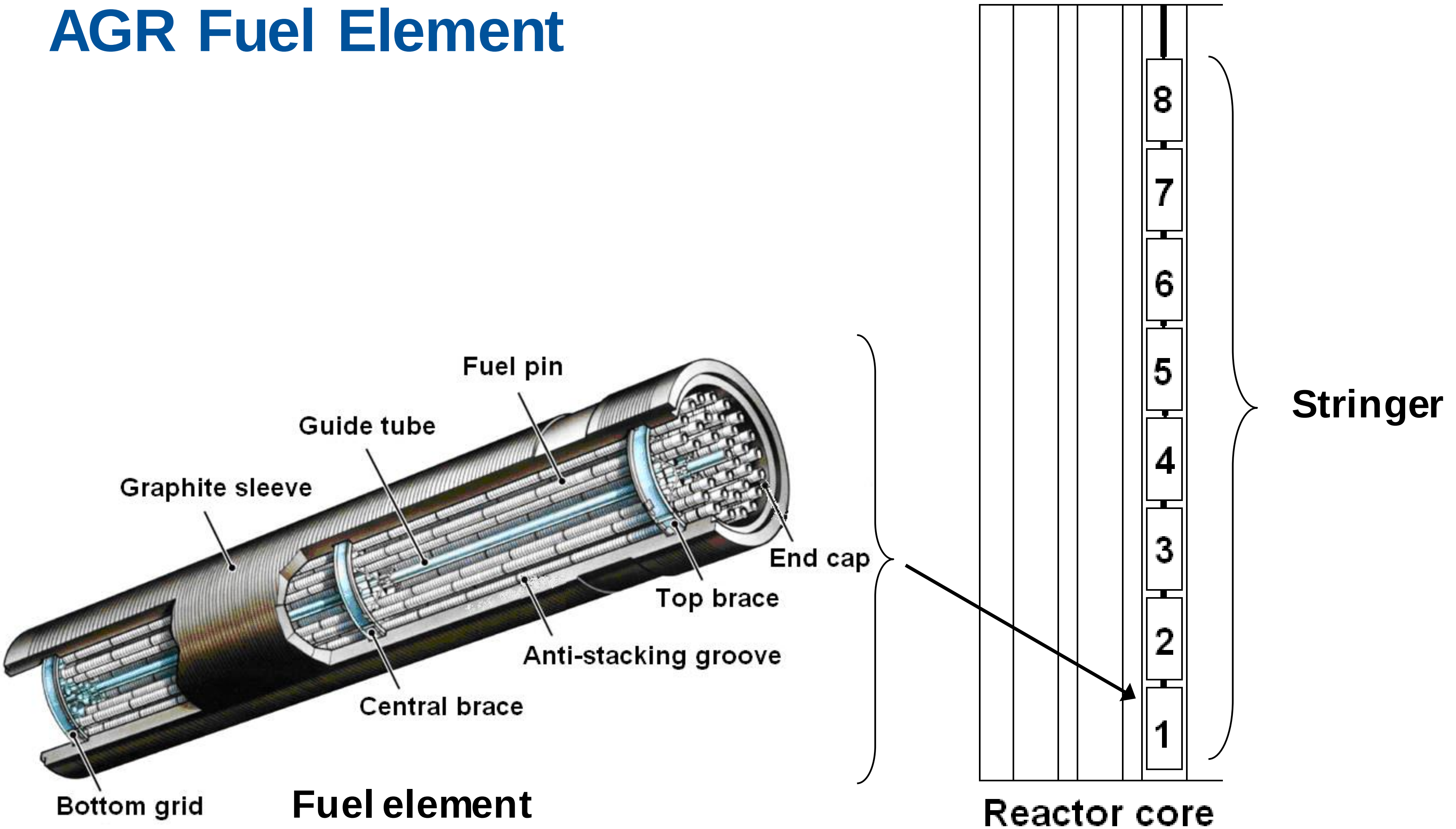
Nuclear Decommissioning Authority Oxide Fuel Strategy: Timeline



2014 - 2018	THORP reprocessing: → Complete non-UK fuel reprocessing contracts → Reprocess 'optimum quantity' of AGR fuel
2019 - 2040	Interim storage of AGR fuel (plus limited quantities of other fuels, e.g. WAGR, PIE cans, certain water reactor fuel assemblies)
2040 - 2075	Long term storage
2075 - 2086	Emplacement of fuel in geological disposal facility

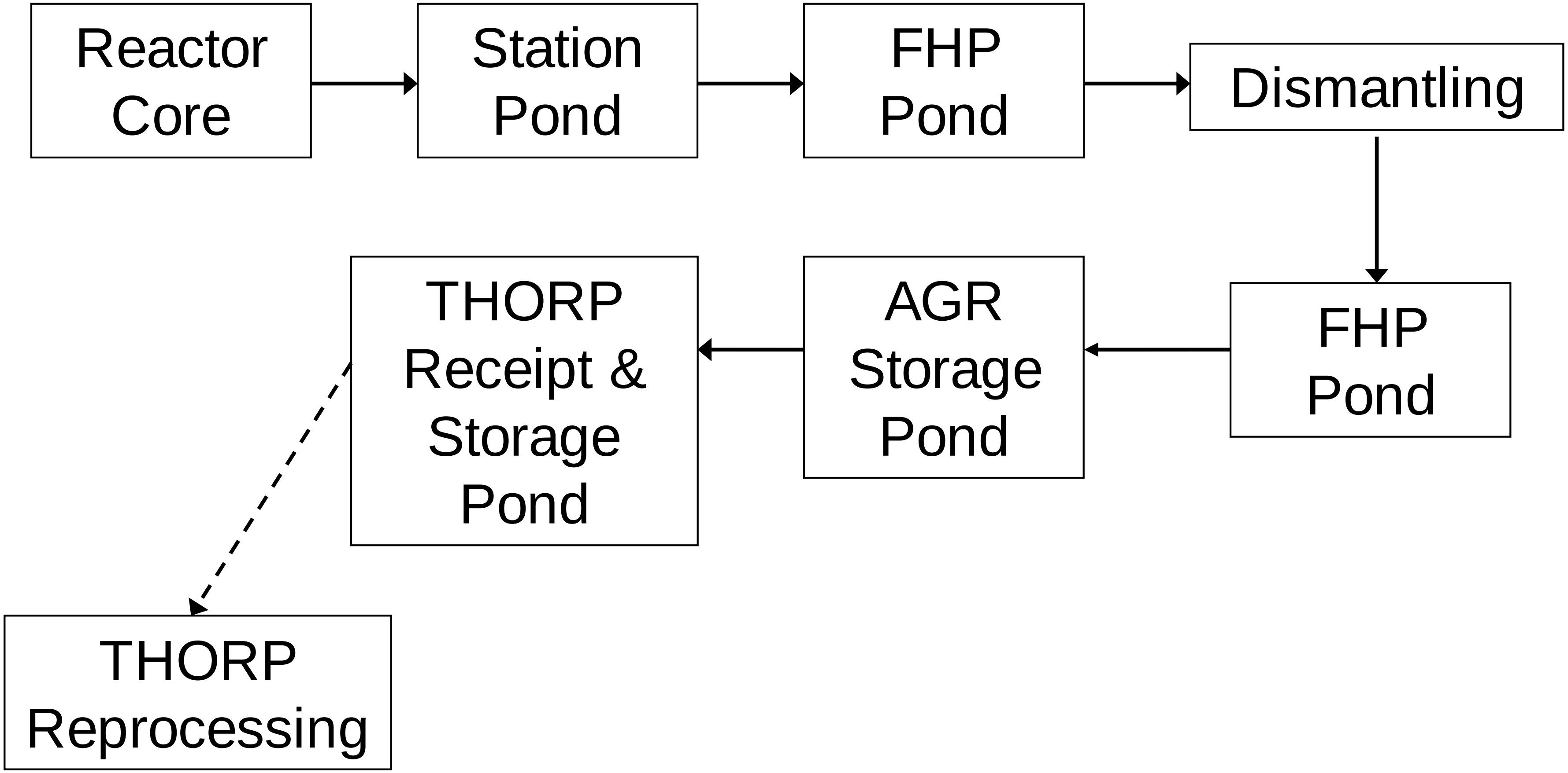
AGR Fuel Element



Changes to Fuel Condition In-reactor

- Clad ductility reduces: ^{1}n damage and He embrittlement
- Oxidation of outer cladding surface → chromia (upper elements)
- Damage to inner cladding surface: corrosive fission products & microbore cracking
- Pin pressurisation: fission gas release
- **Sensitisation to IGA:**
  - Effects material operating between 350 – 520 ºC
  - Primarily resulting from Radiation Induced Sensitisation causing Cr depletion and Ni enrichment at grain boundaries

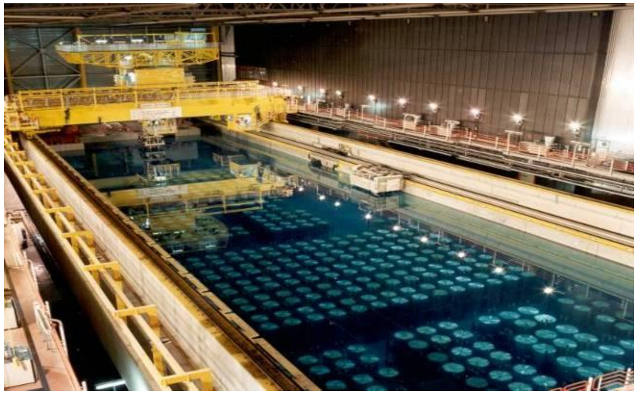
Spent Fuel Route



AGR Storage Ponds at Sellafield

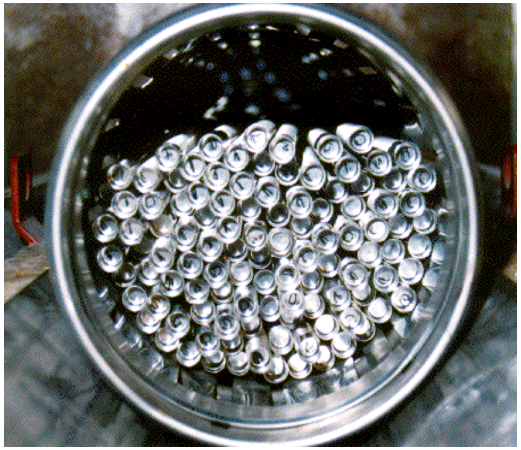
Fuel Handling Plant

AGR Storage Pond



THORP Receipt & Storage

AGR Fuel Dismantling



1 x Slotted can = Pins from 3 x Elements

Outline of AGR Interim Storage

THORP Receipt & Storage

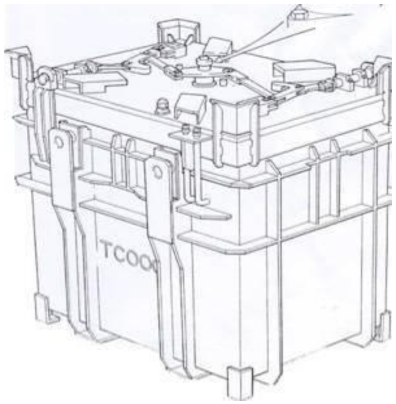
- Convert TR&S from reprocessing buffer store to interim store
- Pond water dosed with pH 11.4 sodium hydroxide (caustic) – inhibit IGA of sensitised cladding
- AGR fuel stored dismantled in 20e and new 63e containers

Outline of AGR Interim Storage: Safety Case

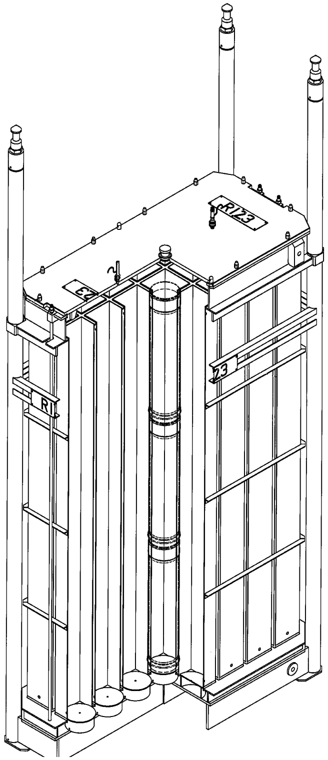
Primary containment:
Fuel cladding (*Primarily technical underpinning)*

Secondary containment:
Pond structure & other water retaining features

Substitute primary containment:
Failed fuel may be isolated within '63e rack'
'63e rack' increases facility storage capacity compared to using current '20e containers'



20e container



63e rack

Existing Technical Underpinning:
1. General corrosion & original inhibitor tests

General corrosion: <0.2 µm.yr^{-1} equivalent to 5 % of clad thickness lost over 80 year storage duration
(Determined by weight loss experiments with irradiated braces)

Original inhibitor testing:

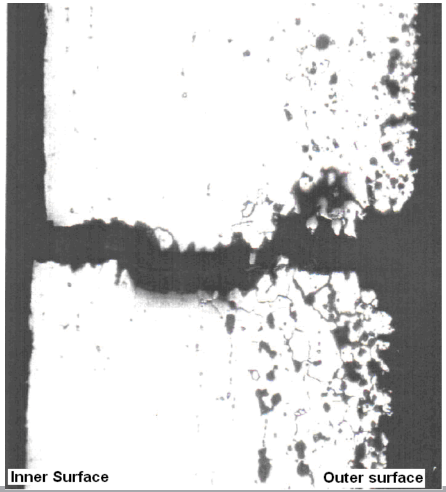
• Whole pin immersion testing:
1 – 100 ppm Cl^- - all pins failed between 80 – 350 days
10 ppm Cl^- & 200 ppm OH^- – no evidence of attack after 1 year

• Electrochemical testing of irradiated braces:
For 0.5 ppm [Cl^-], 30 ºC: predicted pH 11.7 required to inhibit IGA.   NB. Unrepresentative pre-treatment of samples.

2. Post storage examination

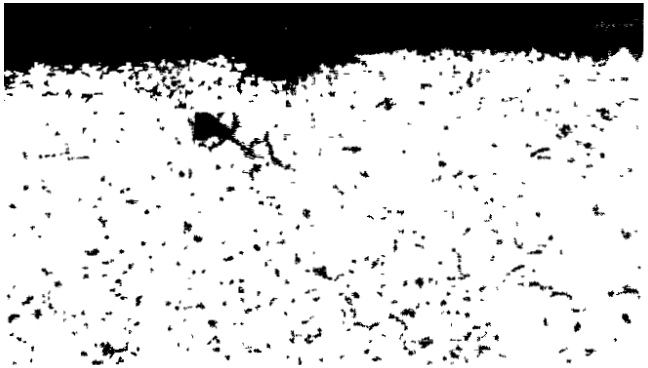
• 50 % of pins from e1 & e2 failed by IGA when stored in demin. water with $[Cl^-] > 1$ ppm for fuel irradiated >15 $GWd.t^{-1}$

• No fuel stored in caustic dosed pond water had IGA failures. But evidence of IGA to 40 µm on some samples.
5 out of 164 samples showed much deeper IGA cracking.



Failed AGR clad

[UKAEA]

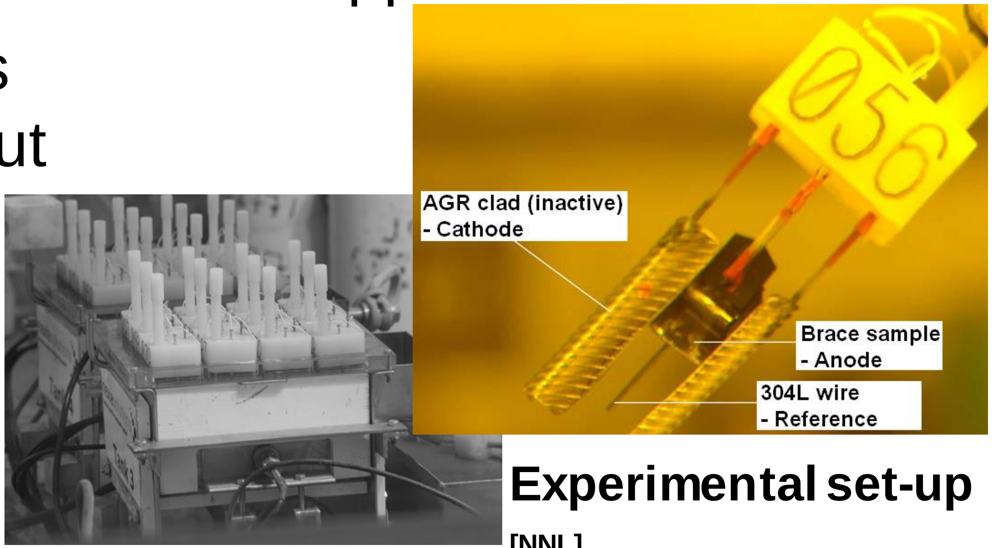


Intact cladding with superficial IGA

[AEAT]

3. Recent inhibitor testing

- Irradiated brace testing – differences from original work: taken from high burn-up fuel (<38 GWd.t^{-1}); use of ZRA so no pre-treatment required; and at T ≤ 50 ºC.
- IGA arrested by pH 11.0 in solution of 2 ppm Cl^- at 50 ºC
- Characterisation of samples demonstrated sensitisation but chromium depletion not increased compared to lower burn-up cladding examined in the 1980s



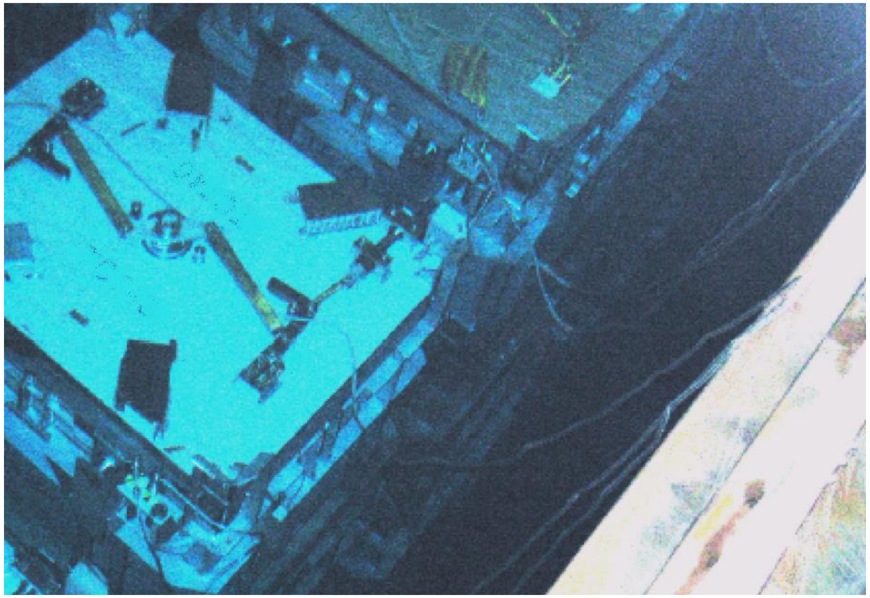
Experimental set-up

[NNL]

4. Lead-time container studies

- Fuel stored in pH 11.4 caustic dosed pond water since 1989 confirmed to be intact.

- Fuel stored in pH 9 & 0.4 ppm Cl^- remains intact for at least 1000 days (*cf*. fuel failures after 450 days at same [Cl^-] in demineralised water)



Lead-time container study

- Fuel stored in pH 9 and:

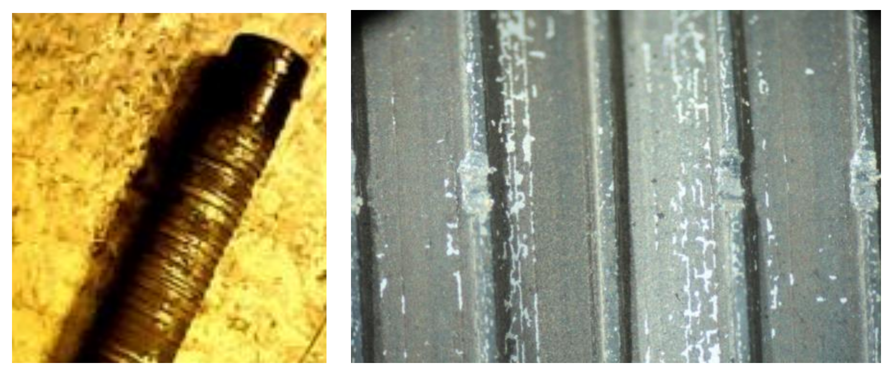
a) 1 ppm Cl^-: not failed after ~ 1250 days
b) 2.5 ppm Cl^-: not failed after 400 days
(*cf*. fuel failures after 100-200 days at same [Cl-] in demineralised water)

Scope & Status of Technical Programme:
1. Increase confidence in storage regime

Post Storage Examination of Long Stored, Intact Fuel:

- Fuel pins grouped by element number by visual examination. Confirmed by gamma scan results.
- No corrosion damage to the slotted can was noted
- Macroscopy not revealed corrosion damage. Occasional minor abrasion marks & loss of the carbonaceous deposit

e1 top end cap & cladding surface [NNL]

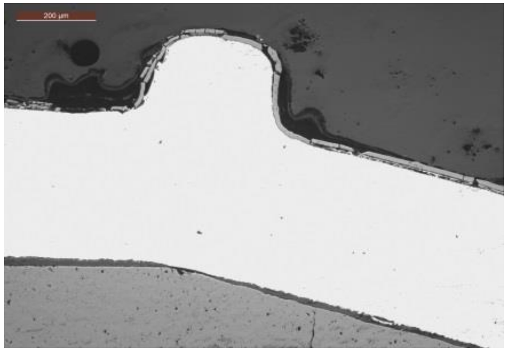


e6 top end cap & cladding surface [NNL]

Scope & Status of Technical Programme:
1. Increase confidence in storage regime

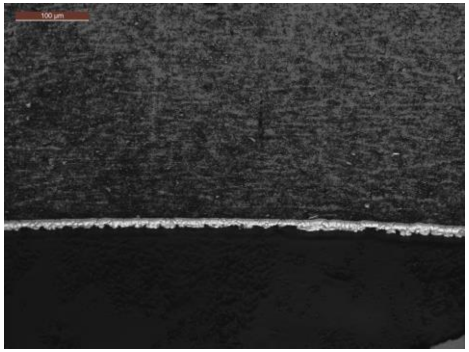
Post Storage Examination of Long Stored, Intact Fuel:

- Metallography of element 1 pin:
  - No degradation of the cladding condition beyond that typically observed during post irradiation examination (PIE)
  - Etching revealed a microstructure consistent with sensitisation
- *Further work currently ongoing*



e1 longitudinal section
(scale bar 200 µm) **[NNL]**

e1 transverse section
(scale bar 20 µm) **[NNL]**



e1 transverse (etched)
(scale bar 100 µm) **[NNL]**

2. Storage of higher burn-up fuel

- Partly assessed by recent inhibitor testing
- PIE of recently discharged fuel:
  - Assess effect of increasing cladding irradiation & reactor dwell time
  - Determine the overall microstructures, distribution and composition of precipitates, and quantify the elemental compositions at grain boundaries
  - Combination of optical microscopy, SEM & TEM
- *Results due imminently*

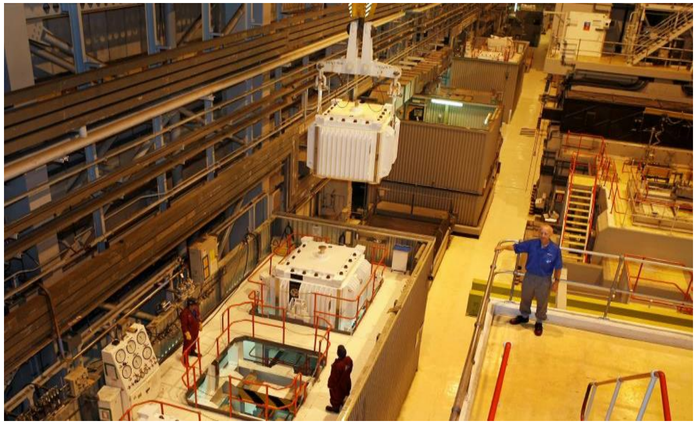
3. Characterise failed fuel

Current evidence that IGA failed fuel retains structural integrity:

- Dismantling historic failed AGR fuel elements without an increase in the incidence of pin breakages
- Successfully retrieving & transporting slotted cans of historic failed fuel pins from the AGRSP to THORP for reprocessing

PSE of 30 year stored IGA failed fuel:

- Determine whether there is evidence of:
  - Additional / larger cladding penetrations
  - Fuel pellet degradation
  - Corrosion from inner cladding surface
  - Loss of structural integrity
- *Preparations currently underway*



Fuel flask handling

4. Fuel condition monitoring

Monitor water T, flowrates etc.

Water sampling: Cs^+, Cl^-, SO_4^{2-}, pH, conductivity

Periodic hot cell examination (PSE)

Weight loss coupons

Potential drop / Field Signature Method sensor

Condition Monitoring
Online / Offline
Direct / Indirect

Local container monitoring

Remote HD visual inspection of sensitised braces

In-pond ultrasonic inspection

Eddy current inspection

Electrochemical noise corrosion sensor

Summary

Post closure of THORP reprocessing, AGR fuel will be consigned to the TR&S ponds for Interim and likely Long Term Storage (for up to 80 years) in pond water dosed with sodium hydroxide to pH 11.4

Substantial evidence that the planned storage regime is effective at maintaining AGR fuel condition based on operational experience and a range of existing research work

Some further work is ongoing to develop wet storage technology

The latest results further strengthen the technical basis

Acknowledgments

• Jim Field, Paul Standring, Laura McManniman, Bob Burns, Allan Townson – Sellafield Ltd.

• Laboratory and hot cell work reported was performed by the National Nuclear Laboratory and funded by Sellafield Ltd.

• The NDA has funded some areas of research on fuel condition monitoring.