Locating Failed Fuel Pins in Advanced Gas-cooled Reactor Fuel
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AGR Fuel

Locating Failed Fuel Pins in Advanced Gas-cooled Reactor Fuel
Why Locate Failures?

Interim storage of fuel in open ponds:
Non-destructive techniques to separate sound and failed pins are important
Why Locate Failures?

To support reactor operations
AGR - Failure Modes

- Many of the failure modes listed are historic, and are no longer expected due to design changes
- Many similar failure modes to LWR: Fretting, PCI and Fission Gas Overpressure
- A key difference: Failed AGR fuel is not intended to have contact with water at any stage in process of discharge to PIE facility.
- Failure modes that have been experienced:
  - Clad Collapse
  - Pin Brace Interaction
  - Fission Gas Overpressure
  - Pellet-Clad Interaction
  - Clad Recrystallisation
Example Appearance of Failure Sites

Fission Gas Overpressure

Pin-Brace Interaction

Pellet-Clad Interaction
Characteristics Relevant to Detection

Pellet-Clad Interaction

Pin Brace Interaction
Other Features Relevant to Detection

Oxidation of clad and carbon deposition (from coolant) can fill failure site

Carbonaceous deposit on surface – can mask failure sites
Other Features Relevant to Detection

Ribbed stainless steel clad – not suited to Eddy current methods

No End-Plenum
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Locating Failures – Process Flow

- Debottle Elements and Bottle Gas Sniffing
- Element Inspection
- Dismantle of Element and Examination of Pins
- Deposit Sampling
- NOLT
- High Magnification Examination
- High Magnification Examination
- Gamma Scanning
- Pin Puncture
- Metallography and SEM to confirm Air abrasion
- SEM to measure density + morphology
- Extra detailed SEM looking at particulates on clad-facing and gas-facing sides
Step 1: Locate Failed Element

- Debottle Elements and Bottle Gas Sniffing
- Element Inspection
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- Deposit Sampling
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Step 1: Locate Failed Element
Bottle Sniffing Results – Detection of Kr-85

Background

Low Europium ROI

Krypton ROI

Peak from background Caesium 137

High Europium ROI

Element 7

BACKGROUND ONLY - INTACT ELEMENT

Element 6

Kr-85 peak - FAILURE SIGNAL

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Step 2: Inspect Element

- Debottle Elements and Bottle Gas Sniffing
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- Metallography and SEM to confirm Air abrasion
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Step 2: Inspect Element - Grids
Step 2: Inspect Element - Pins
Step 3: Leak Test Pins

- Debottle Elements and Bottle Gas Sniffing
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Step 3: Leak Test Pins

Pressure tube in coupling rig

Sniffer head and movement rig

Coupling Rig Base Assembly

Pressure Tube Socket Half

Pressure Tube Plug Half

Motor Module

Counting Module

Main Frame

Roller Modules

Sniffer head
Step 3: Leak Test Pins

Leak Test Results – IRGA detection of Nitrous Oxide leaking from pin
Step 4: Confirm Failure Location

- Debottle Elements and Bottle Gas Sniffing
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- NOLT
- High Magnification Examination
- High Magnification Examination
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- Pin Puncture

- Metallography and SEM to confirm Air abrasion
- SEM to measure density + morphology
- Extra detailed SEM looking at particulates on clad-facing and gas-facing sides
Step 4: High Magnification Inspection

Failure mechanism: Pellet-clad interaction

Multiple small crack-like features noted on outer facing side of upper part of fuel pin

Metallography later confirmed through-wall penetration
Step 4: High Magnification Inspection
Step 5: Gamma Scan Fuel Stack

- Debottle Elements and Bottle Gas Sniffing
- Element Inspection
- Dismantle of Element and Examination of Pins
- Deposit Sampling
- NOLT
- High Magnification Examination
  - Gamma Scanning
  - Pin Puncture
- Metallography
Step 5: Gamma Scan Fuel Stack
Step 5: Gamma Scan Fuel Stack

Analysis of Cs relocation can indicate failed fuel pins – even where no visually obvious distinction is present.
Step 5: Gamma Scan Fuel Stack

Cs reaction with insulator
Step 6: Pin Puncture

Debottle Elements and Bottle Gas Sniffing

Element Inspection
Dismantle of Element and Examination of Pins
Deposit Sampling

NOLT

High Magnification Examination

High Magnification Examination

Gamma Scanning

Pin Puncture

Metallography
Step 7: Investigate Failure

- Debottle Elements and Bottle Gas Sniffing
- Element Inspection
- Dismantle of Element and Examination of Pins
- Deposit Sampling
- NOLT
- High Magnification Examination
- High Magnification Inspection
- Gamma Scanning
- Pin Puncture

- In-Situ Carbonaceous Deposit Assessment
- SEM of carbonaceous deposit
- Operational information
Supporting Data in Failure Investigation

High Magnification Examination

Macroscope/Abrasion

SEM of Deposit Flakes
Conclusions

• Variety of failure modes experiences historically.

• Pins are required to be tested non-destructively in order to preserve integrity of sound pins (for disposal purposes).

• A number of factors provide a unique challenge:
  • Fuel design (ribbed fuel pins, no plenum)
  • Failure characteristics (eg carbon infill, secondary failures).
  • Operating features (eg carbonaceous deposit)

• Short length rods (1m) provide significant handling advantages

• A range of different techniques are applied to locate failure sites, with techniques used in combination.