Safety and Operational Challenge of Graphite Moderator Component Cracking

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Hunterston B

• Inspection at Reactor 3 in early 2018 showed there were more cracked bricks than anticipated

• Inspection at Reactor 4 in late 2019 showed the damage progression was more complicated than first though

• Both reactors have been off-line while further inspection took place, further analysis completed, more experiments carried out to demonstrate strong and clear safety margin despite graphite degradation
Hunterston B

- Inspection at Reactor 3 in early 2018 showed there were more cracked bricks than anticipated.

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- **Both reactors have been off-line** while further inspection took place, further analysis completed, more experiments carried out to demonstrate strong and clear safety margin despite graphite degradation.
£300k
Lost income per day

£12 billion
Potential lost revenue

£100 Million
Spent in last 10 years – anticipated spend in next 24 months

1000 years
EDF Energy

Nuclear regulator permits restarting of reactor 4 at Hunterston B

EDF Energy is expected to restart reactor a year after it was shut down over safety concerns

Jillian Ambrose
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156
Original design

• Sufficient Graphite to act as a moderator (but by design slightly under moderated)
• Structure sufficiently straight to allow free movement of control rods and the fuel
• Structure to direct the gas flow to keep the fuel (and graphite) at the design temperatures
Seismic model and core distortion

Pre-stressed, Concrete Pressure Vessel, PCPV

Graphite Core

Bedrock

PCPV Foundation

Seismic ground motion
Seismic Assessment

age 34 fpy

Intact Core 22mm

Typical channel shape

Sensor Rod limit

Normal Rod limit

Safety factor 6

Safety factor 3

0 mm 30 mm 60 mm 120 mm
Core Ageing = more shrinkage (bigger gaps),
More oxidation (weaker components)
More cracking (slacker core)
More complex cracking (even slacker conditions)
Hunterston B R3

• 1st Inspection
• 23 representative central channels with 25 new full height axial cracks (KWRC/Induced)
• 2nd Inspection
• 58 of 58 channels completed with 69 new full height axial cracks
• Look at BBC or EDF energy page
28:84 - BL5 KWRC (Re-inspection)
34:72 - BL4 KWRC (Re-inspection)
2018 Numbers of Cracked Bricks

Relative Likelihood

Number of Cracked Bricks in Core

Phase 1 (23 Channels)
Phase 2 (38 Channels)
Combined
• Major programme to show we understand how the evolution of stress and loading in the core
• Major analytical programme to demonstrate tolerance to many more cracked bricks
• This was supported by experimental programme
• Increased inspection across the fleet of AGR reactors
• Making sure diverse methods to shut reactor down (Nitrogen and boron balls) as upgraded to ensure will work after a seismic event
• ..... To give significant defence in depth
• About 300 people working on the project
• NRG Petten working on Material Test reactor experiment to get data ahead of need
• NNL measuring graphite properties trepanned from reactors
• Fraser Nash working on graphite properties and stress analysis
• Wood and Atkins working on whole core modelling
• Wood working on Experimental rigs
• Universities of Bristol, Oxford, Strathclyde, Glasgow, Loughborough, Manchester, Leeds, Imperial College, .........
• Internal (INA) and External Regulators (ONR)
Lessons to be learned

- As a responsible operator when the core state get way ahead of demonstrated tolerance – there are inevitable challenges to be faced

- There was always a good explanation of what had been AFTER it had been observed - do we know how to better predict the behaviour BEFORE it happens?

- End end is fast approaching for the AGRs. We wish to operate HNB to 2023 but we also wish to be in control so there is a **planned closure** (to defuel efficiently and the mange arrangements for station staff)
End of Generation Criteria

• **Inspection** evidence beyond bounds of ability to demonstrate tolerance

• **Monitoring** of core state during operation beyond acceptable behaviour (eg failure of free control rod entry)

• Graphite core **modelling analysis** demonstrates tolerable Core state will be reached within next period

• There is a **loss in confidence** in the ability to model core behaviour
First thought of possible examples

• Following inspection challenges equate to End of Generation
  • Not suitable to recharge fuel into a channel following inspection (eg debris, multiple-segment bricks, etc)
  • There is degradation of interstitial bricks in control rod channels
  • The measured core distortion is greater than that predicted by models
  • Cracking of fuel bricks introduces even further new mechanism (that was not anticipated)
  • Loss of fuel channel wall integrity due to friability over a defined area (eg significant proportion of a brick)
First thought of possible examples

• Monitoring examples in operating reactor
  • Unsuccessful movement of fuel
  • Control rods do not freely move due to core degradation
  • Evidence fuel temperatures are increasing due to core degradation