Introduction

This paper summarises the expected findings of graphite Inspections in the Hinkley Point B Reactor 4 outage in 2018 and compares this to the actual results. It is a technical document that refers to the number and type of cracks in the graphite bricks in the core and how they are developing.

Each reactor in the fleet has a different operational age due to differences in the way they have been operated since they started generating and in the batches of graphite used. Graphite inspection results expected during each outage are unique to the reactor they refer to and safety cases will also depend upon the particular core state and assumptions on graphite progression for that particularly reactor.

The internal stresses in the graphite bricks change over time and as a result we expect cracking to occur in some of the bricks as they age. This is a well-known phenomenon which was fully considered as part of the stations' design and included in our operational safety case. We have been working over many years to fully understand and prepare for these late life changes to the reactor core, and regular inspections at all our plants have provided a clear understanding of how the reactor cores age.

The cracks we have found in the past, and those we expect to confirm during future inspections, have no impact on the normal operation of the reactor and would only present a challenge in the event of a major earthquake. Even though the chances of this happening are extremely remote, it is right that we base our safety case on the most extreme possibility and it is therefore modelled for a one in 10,000 yearevent.

EDF Energy is committed to being open and transparent around all our activities, including the operation of our fleet of nuclear power stations. Our website has more information including a downloadable fact sheet and a video interview with Dr Jim Reed, an international expert on graphite reactors.

Further information, including some technical documents, can be requested via media@edfenergy.com

Hinkley Point B Reactor 4 2018 Statutory Outage Graphite Core Inspections

Inspection Scope

The three yearly Hinkley Point R4 statutory outage inspections were carried out in support of our current safety case. The maintenance schedule requirement is 31 fuel channels, 1 control rod channel and a minimum of 30 trepanned samples from 5 fuel channels.

To meet the maintenance schedule the agreed scope for the inspections was:

- 26 central fuel channels from rings 1 to 9.
- 5 edge fuel channels from ring 10.
- 10 fuel channels inspected in air.
- 21 fuel channels inspected in CO_2.
- One control rod channel of TV inspection
- Trepanning of a target of 36 samples from 6 channels, with a minimum of 30 samples from 5 channels.

Proposed Fuel Channel Inspections

Half of the fuel channels selected for inspection were representative channels to give an indication of the core as a whole, the other half were targeted to find cracks and any indication of fuel channel distortion. Representative channels were picked using the core geometry, brick geometry and fuel channel burn up. 16 channels were new inspections and 15 were inspected in the past and give an indication of how brick cracking is developing across the core. This is important to ensure that the core behaviour aligns with scientific understanding of how degradation occurs.

Seven of the channels for inspection were recently refuelled.

During refuelling, information is gathered from the loads on the fuel stringers, this can give indication of where cracks occur. Inspection of these channels confirms the information gathered from the fuel load traces. One channel was selected due to indications that cracks may be present.

13 of the fuel channels selected were inspected to assess the condition of the core restraint by assessing the distortion of any channel around the edge of the core. 5 of these edge channels are in ring 10 and 8 are in ring 9. Ring 9 counts as both edge and central.

This combination of channel locations meant that there were 26 central fuel channels inspected.

3 channels were selected for repeat trepanning to help track the material properties.

Summary of existing safety case

The operation of our stations is governed by a series of safety cases. These are essentially the rulebooks for how we operate all aspects of our power stations and are reviewed by our independent regulator the Office for Nuclear Regulation (ONR). The existing safety case defines the period of normal operations for the reactor until its next inspection outage. The assessments demonstrate that there is no challenge to control rod insertions for a core with at least 350 cracked bricks.

350 cracked bricks do not define the limit of safe operations; it is a prudent safety case assumption at this stage in the lifetime of a reactor. EDF Energy expects to demonstrate safe operation with significant safety margin with higher levels of key way route cracking.

Expected findings Prior to Outage

There are two main mechanisms for brick cracking.

One, known as Bore Cracking, occurs early in life as the graphite changes due to irradiation and temperature effects. The number of Bore Cracks in the reactor is small and any increase is very limited as the reactors are now mature. Bore cracks can either run vertically up and down a brick (axially) or can run in a circle around the brick (circumferential)

The second type of cracks, Keyway root cracks (KWRC), are generated later in the life of the graphite bricks and are the main mechanism that the inspections are intended to find so that we can fully understand the state of the core now and going forward. KWRC always run axially up and down a brick. Although Bore Cracks look very similar to Keyway Root Cracks, the analysis carried out following the inspections can easily discriminate between the two. The measuring equipment measures the graphite channels to an accuracy of 0.1mm down the whole channel which is 10m high.

The expected findings in an outage are separated into Bore Cracks and Keyway Root Cracks. The details for the Hinkley Point B (HPB) Reactor 4 (R4) inspections are provided below.

<u>Bore Cracking Expectations</u>
For full height axial bore-initiated cracks (top to bottom vertically in one brick), model predictions suggested that the most likely outcome is one or two new singly-cracked bricks, and no new doubly-cracked bricks.

A range of 1-9 additional singly-cracked bricks or 1-4 doubly cracked bricks would be within expectations

The most likely location for any newly seen full height bore-initiated (early life) axial cracks was in Layers 6 to 9 of edge channels that have not been previously inspected. The probability of finding new cracks in previously-inspected central channels, or in Layer 11 of any channel, was thought to be low.

Edge channels and bricks higher and lower in the channels are expected to crack differently due to the different temperatures and irradiation they experience during normal operation.

For circumferential cracking (cracks which go round the brick rather than top to bottom), 6 new circumferential cracks were thought the most likely outcome, with a range of 1 and 13 being within expectations

<u>Keyway Root Cracking</u>

Prior to the outage a number of scenarios were set out to determine whether a revision to the safety case would be required:

Route A is within the current agreed safety case

- 0-2 Keyway root cracked bricks in representative channels,
- 0-2 in targeted channels,
- 0-1 outside the peak rated layers in representative channels,
- 0-1 bricks with multiple keyway root cracking

Route B is within expectation and justification covered by a safety case presented within 60 days of the outage

- 3-6 Keyway root cracked bricks in representative channels,
- 3-4 in targeted channels,
- 2 outside the peak rated layers in representative channels,
- 2-3 bricks with multiple keyway root cracking

Route C is sufficiently outside expectation that a new safety case would be required.

- 7 or more Keyway root cracked bricks in representative channels,
- 5 or more in targeted channels,
- 3 or more outside the peak rated layers in representative channels,
- 4 or more bricks with multiple keyway root cracking

Inspection Results

The results of the inspections were assessed against acceptance criteria:

- One new keyway root cracked brick was observed: a targeted, main population brick. This had a narrow crack opening (minimum measured crack opening at the bore over the bearing key height of 0.25mm).
- No keyway root cracked bricks were observed in the representative channels.
- No significant channel distortion was measured (largest measured channel bow of 6.5 mm), and no significant change in channel distortion in repeat inspected channels. Crack opening and damage progression in existing cracked bricks are acceptable and at the lower end of expectation.
- All measurements were within expectations Pre-outage statistical forecasts of the times to reach the Operational Allowance of 350 singly axially cracked bricks are, with zero KWRC observed in the representative channels inspected, beyond the end of 2019 at 99.9% confidence. Return to service is therefore supported and the operating period will be confirmed in the 60-day safety case for HPB R4.
- One new full height axial bore crack was observed. There were 6 new full circumferential cracks observed and these present no challenge to core distortion.
- Overall the results were within acceptable expectations – Observations lie within expectation and within the safety case. No further inspections are required to support return to service.

Summary

The HPB R4 core inspection results were within expectation and the existing graphite core safety case. The results will be summarised in the HPB R4 60-day safety case which will demonstrate a justified period of safe operation for R4 up to a core burn-up to c. mid-2020, noting that the next core inspections on R4 are planned for February 2020.

EDF Energy is determined to be open and transparent around all of our operations. However for security and commercial reasons it is not always possible to publish all of our reports or findings. If you feel the information you require is not covered in this document please contact us at [media@edfenergy.com] and we will endeavour to respond to your query.

Glossary

Axial	A vertically aligned defect
Bore crack	A crack which starts at or near the centre of the brick and moves outwards
Brick bow	A measure of how much the brick shape deviates from straight
Channel bow	A measure of how much an entire channel deviates from straight
Channel tilt	A measure of how much a channel leans from straight
CO_2	Carbon Dioxide
Circ	A circumferentially aligned defect
Doubly cracked	A brick that contains 2 Type IIIC/Full axial cracks
HPB	Hinkley Point B
JPSO	Justified Period of Operation: the defined period of operation of a reactor until its next inspection outage
Inspections	detailed measurements and video taken while the reactor is shutdown
KWRC	A Keyway Root Crack, a crack emanating from a radial keyway feature on the outside of the brick. The crack extends inwards to the brick bore
Lambda	A measure of brick bore shape, e.g. largest diameter divided by smallest diameter. This indicates how much the brick shape is changing over time
Low Lambda	This is a value that could indicated the brick is at risk of cracking
Monitoring	routine indications of the reactor performance measured during power operation
NICIE	New In-Core Inspection Equipment, a tool used to measure and video the fuel channels
Ovality	A measure of how oval the brick bore is
Peak rated	These are layers 4-7 and are the layers that receive the most irradiation. The fuel channels contain 12 layers of bricks.
Ring	Refers to the distance from the centre of core. The core contains 10 rings of fuel channels
R4	Reactor 4
Shrinkage	A measure of how much the brick bore diameter has reduced since the reactor started operating
Singly cracked	A brick that contains 1 Type IIIC/Full axial crack
Trepanning	Cylindrical samples of diameter 19mm are cut from fuel moderator bricks of measurement of density and material properties in an off-site shielded facility
Type IIIA	This is a short crack
Type IIIC	This is crack >80% of the circumference of a brick or >80% of the brick height
TV	Television (Video) inspection