Office for Nuclear Regulation

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Operating Facilities Division

Heysham 2 Reactor 8 2020 Periodic Shutdown – Structural Integrity Assessment of the Graphite Core Inspection Findings

Assessment Report ONR-OFD-AR-19-091
Revision 0
25th March 2020

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EXECUTIVE SUMMARY

The licensee, EDF Energy Nuclear Generation Limited (NGL), of Heysham 2 (HYB) power station has shutdown Reactor 8 (R8) under licence condition (LC) 30. During the periodic shutdown, the graphite reactor core has undergone inspections, in line with NGL's arrangements to satisfy expectation laid down by LC28.

NGL has completed its graphite core inspections as per their maintenance schedule and will request Consent from ONR to restart HYB R8. Therefore, my assessment of the graphite core integrity inspection results is based on the findings provided by NGL's supporting inspection documents.

I have assessed the HYB R8 2020 periodic shutdown inspection results relating to the graphite core. I have compared the findings against the claims and limits in the current graphite safety case and assessed them against the expectations laid down by the relevant Safety Assessment Principles. Overall, NGL states that the results of the graphite core inspections at HYB R8 2020 periodic shutdown are acceptable and do not challenge safe operation. However, an Independent Nuclear Safety Assessment certificate was not available at the time of my assessment. The ONR Project Inspector should therefore ensure that this certificate is available and in agreement with the views in the Engineering Change document (Recommendation 1).

According to NGL's core behaviour predictive models, the onset of keyway root cracking at HYB/Torness (TOR) could occur within the next operating period of HYB R8 (February 2022). NGL is developing a post-onset of keyway root cracking safety case to be provided for assessment by ONR by the end of 2020. I am content that the changes in the predicted onset of keyway root cracking do not affect ONR's ability to permission the restart of HYB R8. The PAR should record that NGL is in the process of producing a post-onset of keyway root cracking safety case for the graphite cores at HYB and TOR. The PAR should also record that NGL will be providing an update to the inspection strategy at HYB/TOR before the end of May 2020 (Recommendation 2).

During the inspection of the fuel channels, two full height axial cracks were found in channel D77, layer 6. The other channels inspected did not reveal any defects. In my view, the evidence from the channel inspection supports NGL's conclusions that the cracks have initiated from the bore of the brick earlier in the life of the reactor. In my opinion, the graphite core inspections results do not challenge the current claims and limits specified within the safety case and do not present any impediment to return to service of HYB R8. However, the PAR should note that a doubly cracked brick was observed in channel D77 layer 6. NGL should consider whether this channel should be re-inspected in future fuel channel inspections (Recommendation 3).

In addition, I carried out two interventions during the outage to determine the adequacy of NGL's arrangements for the inspection of the graphite core and peripheral bricks. One intervention focused on the inspection arrangements for the graphite core and another one on the inspection arrangements for the peripheral shielding wall bricks specific to the HYB/TOR design. There are no outstanding actions from these interventions which would prevent a return to service consent being granted.

To conclude, I have no objection to the subsequent PAR recommending that consent is given to return Heysham B Reactor 8 back to service.

My recommendations are as follows (to ONR's Project Inspector):

- Recommendation 1: I recommend that the project inspector confirms the Independent Nuclear Safety Assessment (INSA) statement has been made available by NGL and is in agreement with the views in the Engineering Change document.
- Recommendation 2: I recommend that the PAR records that NGL is in the process of producing a post-onset of keyway root cracking safety case for the graphite cores at Heysham B and Torness. This safety case should be produced and submitted to ONR for assessment before the first observation of keyway root cracking. The PAR should also record that NGL will be providing an update to the inspection strategy at HYB/TOR before the end of May 2020.
- Recommendation 3: the PAR should note that a doubly cracked brick was observed in channel D77 layer 6. I concur with NGL's conclusion that this is a bore crack rather than a keyway root crack. This observation therefore does not challenge the assumptions in the existing safety case. However, NGL should consider whether this channel should be re-inspected in future fuel channel inspections.

I have ascribed an ONR Assessment rating of green, requiring no formal action.

LIST OF ABBREVIATIONS

AGR	Advanced Gas-cooled Reactor
ALARP	As Low As Reasonably Practicable
BMS	Business Management System
CTO	Central Technical Office
EC	Engineering Change
ECCL	Engineering Change Commitment Log
GWd	Giga-Watt day
HOW2	(ONR) Business Management System
HSL	Health & Safety Laboratory
HYB	Heysham 2 Power Station
INSA	Independent Nuclear Safety Assessment
JCO	Justification for Continued Operation
KWRC	KeyWay Root Cracking
LC	Licence Condition
MAP	Monitoring Assessment Panel
MS	Maintenance Schedule
NCR	Non-Conformance Report
NGL	EDF energy Nuclear Generation Limited
NGTE	New Graphite Trepanning Equipment
NICIE2	New In-Core Inspection Equipment Mark 2
NNL	National Nuclear Laboratory
ONR	Office for Nuclear Regulation
PAR	Project Assessment Report
PBAP	Peripheral Brick Assessment Panel
R	Reactor
RTS	Return-To-Service
SAP	Safety Assessment Principle(s)
SCAP	Safety Case Anomaly Process
SQEP	Suitably Qualified and Experience Person
TAG	Technical Assessment Guide(s) (ONR)
TOR	Torness Power Station
TSSM	Technical Support and Safety Manager

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1 INTRODUCTION

1. The licensee, EDF Energy Nuclear Generation Limited (NGL), of Heysham 2 (HYB) power station has shutdown Reactor 8 (R8) under licence condition (LC) 30. During the 2020 periodic shutdown of HYB R8 the graphite reactor core has undergone inspections, in line with NGL's arrangements to satisfy expectation laid down by LC28.

2. NGL has completed the graphite core inspection as per the maintenance schedule (MS) and will request Consent from ONR to restart HYB R8. My assessment of the final graphite core structural integrity inspection results is based on the findings provided by NGL in supporting inspection results documents.

3. This report presents the results of my assessment of the structural integrity findings related to the graphite core inspections during the 2020 HYB R8 inspections.

1.1 Background

4. During periodic shutdowns, NGL carries out routine inspections of the fuel channels for all Advanced Gas-cooled Reactors (AGRs) to monitor the distortion and integrity of graphite core bricks and core restraint. This includes inspection of the peripheral shield wall which is a design feature unique to Torness (TOR) and HYB stations.

5. As a result of the observation of cracking of peripheral bricks at TOR R2 in 2015, NGL committed to performing a 100% visual inspection of the graphite peripheral shield wall at HYB and TOR. Engineering Changes (ECs) 356531 & 356536 provide the Justification for Continued Operation (JCO) following the discovery of cracking in the peripheral bricks (References 3 and 4). This is the first re-inspection of the peripheral shielding bricks at HYB R8.

6. For this periodic shutdown, NGL's intended scope of graphite inspections during the periodic shutdown is summarised below (Reference 5):

- Inspection of a minimum of 16 fuel channels both visually and dimensionally using a New In-Core Inspection Equipment (NICIE2);
- Trepanning of a minimum of 30 graphite specimens to a depth of 65mm using the New Graphite Trepanning Equipment (NGTE), with a target of 35 samples;
- Visual inspection of control rod channel MN66;
- Inspection of 8 fuel channels using eddy current;
- Inspection of a minimum of 12 out of 16 faces of the peripheral shield wall.

7. I conducted two site interventions during the HYB R8 2020 periodic shutdown. The first intervention, on 12th February 2020, focused on NGL's graphite core inspection arrangements whilst the second intervention, on 26th February 2020, focused on NGL's arrangements for the peripheral shielding brick inspections. The findings of these site interventions are reported in References 1 and 2. Overall, from the activities I sampled during these interventions, I concluded that NGL's arrangements in relation to the expectations laid down by LC28, with respect to the inspections of the graphite core and of the peripheral shielding walls, were appropriate and personnel at station were complying with these arrangements. Following these site interventions, I attributed an ONR rating of 'green' – no formal action, according to ONR grading guide table (Reference 6). There are no outstanding actions from these interventions, which would prevent consent being granted by Office for Nuclear Regulation (ONR) to the return to service of HYB R8.

8. This assessment has been undertaken in accordance with the requirements of the Office for Nuclear Regulation (ONR) How2 Business Management System (BMS) guide NS-PER-GD-014 (Reference 7). The ONR Safety Assessment Principles (SAP)

(Reference 8), together with supporting Technical Assessment Guides (TAG) (Reference 9), have been used as the basis for this assessment.

1.2 Scope

9. The scope of this report covers the licensee's activities performed during the shutdown associated with the examination and inspection of HYB R8 graphite core and peripheral bricks.

10. This report also considers whether the results are consistent with the HYB R8 safety case and whether return to service (RTS) is justified. In my assessment, I have taken account of the recent developments in the HYB/TOR graphite core safety cases including the claims, arguments and evidence presented in EC 356531 revision 5 (Reference 3).

1.3 Methodology

11. The methodology for the assessment follows HOW2 guidance on mechanics of assessment within the Office for Nuclear Regulation (ONR) (Reference 10). This assessment has been focussed primarily on the licensee's arrangements for the graphite core inspections and the findings from the current periodic shutdown, including inspections from the peripheral bricks.

2 ASSESSMENT STRATEGY

12. The intended assessment strategy for my assessment is set out in this section. This identifies the scope of the assessment and the standards and criteria that have been applied.

2.1 Standards and Criteria

13. The relevant standards and criteria adopted within this assessment are principally the Safety Assessment Principles (SAP) (Reference 8), internal ONR Technical Assessment Guides (TAG) (Reference 9), relevant national and international standards and relevant good practice informed from existing practices adopted on UK nuclear licensed sites. The key SAPs and any relevant TAGs are detailed within this section.

2.2 Safety Assessment Principles

14. The key SAPs applied within the assessment are included within Appendix 1 of this report.

2.2.1 Technical Assessment Guides

15. The following Technical Assessment Guides have been used as part of this assessment (Reference 9):

- ONR-TAST-GD-029 – Graphite Reactor Cores.

2.2.2 National and International Standards and Guidance

16. Due to the uniqueness of the AGR design and the lack of availability of international experience with the design of AGR graphite reactor cores, I have not explicitly referred to international standards and guidance as part of this assessment.

2.3 Use of Technical Support Contractors

17. No technical support contractors were used for this assessment report.

2.4 Integration with Other Assessment Topics

18. N/A.

2.5 Out of Scope Items

19. The following items are outside the scope of the assessment:

- structural components other than the graphite core and the core restraints are considered as a separate assessment.

3 LICENSEE'S SAFETY CASE

20. This section provides a summary of the licensee's safety case and the justification for the RTS of HYB R8.

3.1 Core burn-up at the time of the periodic shutdown

21. At the time of the periodic shutdown, the core burn-up of the reactor was 14.3304TWd (Reference 11).

3.2 Time limiting aspects of the graphite safety case

22. For HYB/TOR, the current graphite safety case is the post-stress reversal safety case NP/SC 7663 (Reference 12). The graphite safety case is limited to the onset of keyway root cracking (KWRC) and by the active core weight loss limit of 14%.

3.2.1 Onset of KWRC

23. In NGL's definition, the onset of KWRC corresponds to the presence of up to 3% cracked fuel bricks in the active core. Previously, NGL expected the onset of KWRC at HYB/TOR lead reactors (TOR R1 & HYB R7) to occur at a core burn-up of 16.0TWd (+/- 0.5TWd), or 2022 +/- 1 year (Reference 13). Based on new information, NGL have revised the estimate of the onset of KWRC such that it is earlier than previously estimated (15.8TWd or ~0.2TWd earlier for TOR R1).

24. The original estimate of uncertainty ascribed to the predictions of KWRC was a best estimate derived from Hinkley Point B/Hunterston B experience. This judgement has also been reviewed as a result of new data available for HYB/TOR. NGL stated that the uncertainty ascribed to the prediction of onset of KWRC has increased to +/- 1TWd or +/- 2 years. NGL now predicts onset of KWRC in April 2021 at HYB R8 and does not expect to reach the 10% cracking limit in the safety case until May 2021 with a 99.9% confidence (Reference 14).

25. Following the revised forecasts for the onset of KWRC, NGL has entered the Safety Case Anomaly Process (SCAP) to justify continued operation at HYB/TOR (see Reference 14). NGL's intention is to use the arguments laid out in this reference to form the basis for the RTS justification and are summarised in Reference 14 as follows:

- Recent inspections of Heysham 2 R8 have not revealed any KWRC. The observation of full height bore cracks in channel D77 is not wholly unexpected and is covered by the safety case.
- The predictions of KWRC indicate that it will arise first at shutdown and there will be a significant delay in the onset at power. There is evidence that supports this from observations of the Hinkley Point B / Hunterston B reactors. The Heysham 2 / Torness reactors have had a good operational record with no unexpected cold shutdowns in the recent past. The estimates of KWRC presented in the table above are for initial cracking at shutdown and are thus conservative.
- The conservative estimates of having a 0.1% chance of exceeding 10% cracking indicate that Heysham 2 R7 is the lead reactor in time, followed by Torness R1.

    a. The Torness R1 outage is expected to begin prior to reaching the 0.1% probability of exceeding 10% cracking.
    b. Heysham 2 R7 is estimated to reach 0.1% probability in May 2020, but noting again this is based on assuming a cold shutdown at this time.

- EC 364630 (TOR) / 364714 (HYB) included an ECCL [i.e. EC Commitment Log] to incorporate a long term inspection strategy into the safety case that is aimed at giving adequate confidence that the cores remain compliant with the DTA safety case. The case is required by the end of April 2020. The safety case has been drafted, but needs to take into account the latest KWRC predictions.
- Commitment 2 of EC364630(TOR)/364714(HYB) requires the production of a safety case to cover operation beyond KWRC onset, that is extend the DTA to beyond the essentially intact (10% cracking) assumption, by the end of 2020. Work supporting such a safety case is in progress.

26. I consider NGL's arguments with regard to the RTS of HYB R8 in Section 4.2.

3.2.2 Graphite weight loss limit

27. NGL produced a statement to support the RTS of HYB R8 whilst the graphite weight loss forecasts are being updated (Reference 15). This statement indicates that the margins against the graphite weight loss limits remain appropriate for the next period of operation. Further engagement with NGL is planned this year to review NGL's graphite weight loss management strategy for HYB/TOR.

3.3 Graphite Assessment Panel & Peripheral Brick Assessment Panel

28. The Graphite Assessment Panel (GAP) consists of graphite specialists from NGL's Central Technical Office (CTO), NGL's INSA function, from specialists at the station and external contractors. Quorate attendance is required for each meeting and is ensured at the beginning of the meeting. The information from the graphite inspections, e.g. bore measurements, crack size and morphology, etc., is collated into GAP inspection sheets. The sentencing of the defects observed is discussed at the GAP. The GAP also considers matters such as whether the inspections, dimensional measurements and trepanning have been performed adequately.

29. The minutes of the GAP meeting are circulated between the members for endorsement. If significant inspection findings are identified during outages that are not within the bounds of the existing safety case, the GAP can recommend either further inspections be conducted or a change to the safety case be made. If required, NGL will also update the MS to meet the safety case requirements.

30. The Peripheral Brick Assessment Panel (PBAP) performs a similar function to that of the GAP and is tasked with reviewing and sentencing the output from the peripheral brick inspections. The GAP and the PBAP meetings are both chaired by HYB's Technical Support and Safety Manager (TSSM), although the members of the GAP and of the PBAP can be different.

3.4 Activities related to graphite performed during the periodic shutdown

31. As part of NGL's core inspection activities during the 2020 periodic shutdown of HYB R8, the Licensee committed to the following minimum requirements as part demonstrating the continuing adequacy of the safety case (Reference 5):

- Inspection of a minimum of 16 fuel channels both visually and dimensionally using a New In-Core Inspection Equipment (NICIE2);
- Trepanning of a minimum of 30 graphite specimens to a depth of 65mm using the NGTE, with a target of 35 samples;
- Visual inspection of control rod channel MN66;
- Inspection of 8 fuel channels using eddy current;
- Inspection of a minimum of 12 out of 16 faces of the peripheral shield wall.

32. At HYB/TOR, trepanning is carried out using the NGTE which is equipped with a 65mm long cutter from which long samples can be obtained. The trepanned samples will be sent to the National Nuclear Laboratory (NNL) for testing and analysis. These results will be used to update the graphite database and the graphite weight loss forecasts. However, these will not be available before the RTS of the reactor.

3.5 Findings of the graphite core inspections

33. Since the RTS EC summarising the findings of the graphite inspections has not been completed at the time of this assessment, NGL provided a summary of the channels inspected and the findings from the graphite core inspections referred to as GAP Sheet (Reference 16). The GAP sheets have been reviewed and endorsed by the members of the GAP. The endorsed GAP minutes produced during the periodic shutdown are available in Reference 17.

34. No significant defects were observed in 15 of the 16 fuel channels inspected during the periodic shutdown. In channel D77, two full height axial cracks were found in the layer 6 brick (Type IIIC). A smaller axial crack (Type IIIA) was also observed in this brick, as shown in Figure 1.

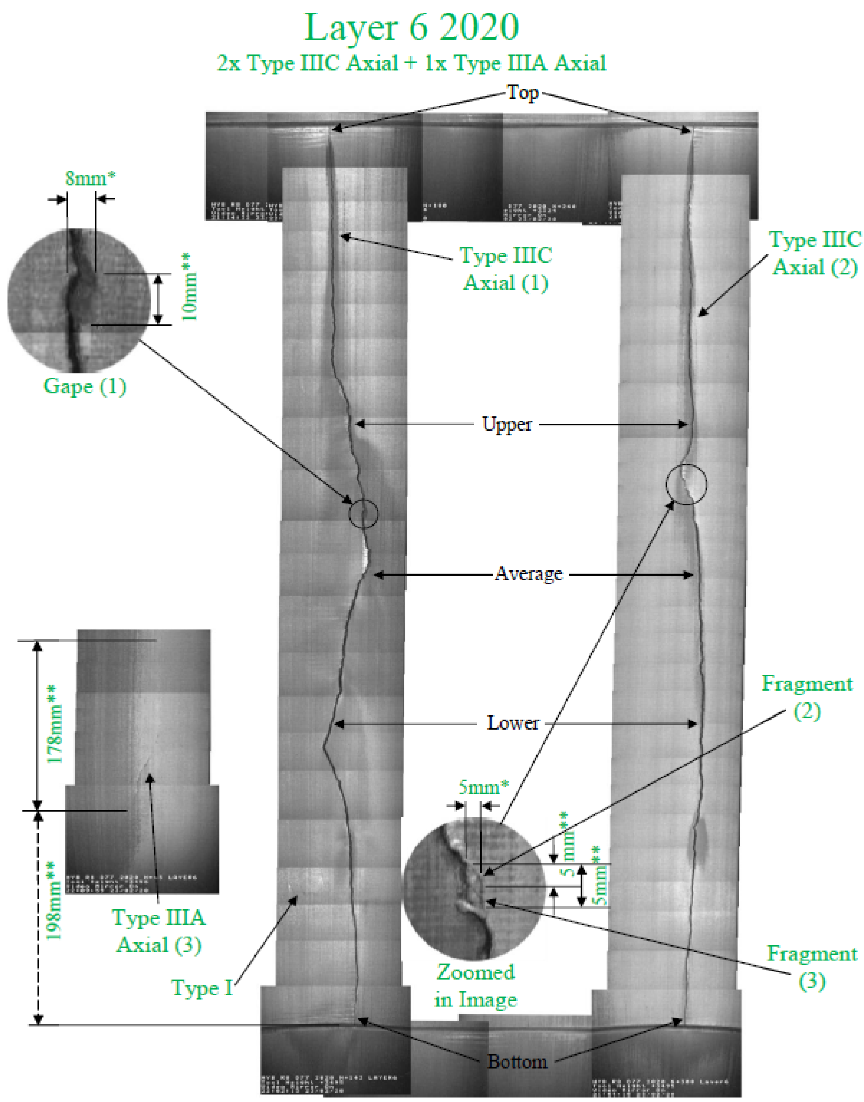

Figure 1: Doubly cracked brick with two full height axial cracks and one partial axial crack in Channel D77, Layer 6.

35. NGL has produced a verified statement reviewing the observations (Reference 18). The note concludes that:

'The observations in HYB R8 D77 of two full height axial bore cracks and a partial height axial crack is covered by the existing safety case. This is on the basis that the safety case recognised the potential for such bricks; is based on a tolerance assessment for an essentially intact core having up to 10% axial brick cracking and demonstrated the lack of a cliff edge with up to 30% brick cracking. The observation of a single brick with such cracking from all of the inspections does not undermine confidence that the Heysham 2 R8 core remains essentially intact and will remain so until the onset of keyway root cracking in the main population of core bricks.'

36. NGL concludes the ALARP review as follows:

'Overall, given that: the observations in D77 are consistent with those seen elsewhere; there is no significant channel distortion; the existing safety case has considered a greater degree of cracking in the DTA [Damage Tolerance Assessments] assessments; the safety case considers the potential for adjacent bricks being cracked; and this reactor is not considered to be a lead reactor for onset of KWRC; it is considered that the disbenefits of additional inspections during this outage outweigh the potential benefits.'

3.6 Peripheral brick inspections

37. The main purpose of this outer 'skin' of graphite is to aid in the control of graphite oxidation and to promote effective cooling of the core (References 3 and 4) by directing re-entrant gas flows such that impressed flow is maintained. For the inspection planned during the outage, the licensee defined the following scope of inspections:

- Twelve faces distributed between all four quadrants, including five faces with historical evidence of potential cracks;
- Two edge channels with NICIE2.

38. Prior to the outage, NGL listed the criteria that defined observations to bound the anticipated extent of the cracking in Reference 19. Any observations outside these bounds would require further work before HYB R8 could be returned back to service.

39. New defects or movement of the bricks observed during the peripheral wall inspections are reported in Non-Conformance Reports (NCRs).The sentencing guidelines used by the PBAP members are available in Reference 19. Table 1 summarises the findings of the inspections in the peripheral bricks during HYB R8's periodic shutdown.

Section (from EC 356536 App 3)	Description	Category	No. of NCRs	No. of Bricks *
1.1	Bricks with "Chicken Wire" cracking	A	0	0
1.3	Bricks with linear crack	A	19	18
1.5	Branched cracks	A	0	0
1.7	Morphology not seen previously	B	0	0
1.8	Linear Features	A	33	33
2.3	Adjacent bricks significantly radially misaligned >2mm	B	0	0
2.5	Significant circumferential gapping observed between adjacent bricks >5mm	B	1	N/A
2.6	Very significant circumferential gapping observed between adjacent bricks >20mm	C	0	0
3.2	Large piece of graphite missing (>100x100mm or equivalent 10000mm^2)	B	0	0
3.3	Complete brick(s) missing	C	0	0
3.4	Graphite debris identified on restraint beams	B	0	0
3.5	Blockage or partial blockage of re-entrant flow annulus between restraint tank and core	C	0	0
No Category assigned	Minor scratch or score mark not thought to be crack & misc debris	N/A	25	N/A
Total Assessed			78	51

*The number of bricks may be less than the number of NCRs as in some instances multiple NCRs have been raised on a single brick (e.g. both faces of a corner brick) and debris NCRs don't apply to a brick.

Table 1: Summary of the findings of the peripheral brick wall inspections during HYB R8's 2020 periodic shutdown.

40. The face map in Reference 20 shows that there are no clusters of defects around the core, although the PBAP indicated that more cracks tended to be found in corner bricks (see 8th PBAP minutes in Reference 23).

41. NGL claims that, based on the results of the inspection of the peripheral shield wall, it is safe to return HYB R8 back to service.

3.7 Outcome of graphite core inspection

42. Overall, NGL's inspection of the graphite core of HYB R8 has been completed for this periodic shutdown. NGL has considered the results of those inspections and are of the opinion that they do not prevent return to service of HYB R8.

3.8 Return to service engineering change

43. NGL will summarise the results from the graphite inspections in EC 365253. However, this EC was still being produced at the time of my assessment and was therefore not available for review. In the place of the EC, I have relied upon the GAP inspection sheets and minutes from the GAP meetings. These documents are reviewed and endorsed by NGL's Independent Nuclear Safety Assessment (INSA) and will be used to provide evidence in EC 365253 (see Recommendation 1). The GAP sheets and the GAP minutes are available in References 16 and 17.

4 ONR ASSESSMENT

44. This assessment has been carried out in accordance with HOW2 guide NS-PER-GD-014, “Purpose and Scope of Permissioning” (Reference 1).

4.1 Scope of assessment undertaken

45. In relation to the graphite core, I carried out the following inspections in order to determine compliance with LC 28: Examination, inspection, maintenance and testing.

- Examination of the quality and findings of the graphite core inspections;
- Examination of the quality and findings of the peripheral shielding brick inspections.

4.2 Onset of KWRC predictions

46. In NGL’s revised predictions (Reference 13), the best estimate prediction for the onset of KWRC (defined as 3% brick cracking) at HYB R8 was reduced from 16.0TWd to 15.9TWd, or by 0.1TWd. The change in the best estimate prediction of the onset of KWRC was comparable in the other HYB/TOR reactors and corresponds to approximately 3 to 4 months’ worth of operation. In my view, the change to the best estimate prediction does not appear to be significant.

47. As a result of the analysis of the data relevant to HYB / TOR, NGL has indicated that the uncertainties linked to the estimate of the onset of KWRC has increased from 0.5TWd to 1TWd, i.e. from 1 to 2 years’ worth of operation. The increase in uncertainties linked to the onset of KWRC, in my view, is the most significant change in NGL’s revised predictions and affects the confidence in the exact timing of KWRC.

48. NGL have evaluated the impact of the revised onset of KWRC predictions to estimate the burn-up / time at which they will reach the safety case limit of 10%. HYB R8 is not the lead reactor for the sister stations and as such the prediction at the 99.9% confidence is May 2021. In my opinion, the revised timing for onset of KWRC should therefore not affect the decision whether to return HYB R8 back to service following the current periodic shutdown.

49. The effect of increased uncertainty is therefore most relevant to the graphite inspections at TOR R1 and HYB R7 which are planned in July 2020 and June 2021 respectively. The current safety case, NP/SC 7663 (Reference 12), provides a demonstration of the damage tolerance of the core for up to 10% cracked bricks. The number of inspections should allow for the detection of the onset of KWRC before the 10% cracked brick limit in the current safety case is reached. This new data has provided a challenge to the existing inspection plan for HYB R7 and TOR R1. NGL will be providing an update to this strategy before the end of May 2020 (Reference 14).

50. NGL is producing a safety case to justify operation beyond the onset of KWRC, which should be available by the end of 2020. I recommend that the PAR records that NGL is in the process of producing a post-onset of KWRC safety case for the graphite cores at HYB and TOR. This safety case should be produced and submitted to ONR for assessment before the first observation of KWRC. The PAR should also record that NGL will be providing an update to the inspection strategy at HYB/TOR before the end of May 2020 (Recommendation 2).

4.3 Fuel channel inspections

GAP and findings from the fuel channel inspections

51. The RTS EC was not available at the time of my assessment. I have based my opinion on the GAP sheets and on the GAP minutes which NGL produced in References 16 and 17. Since these sheets and the minutes are reviewed and endorsed by SQEP personnel, including NGL's INSA, I view these notes as being a reliable source of information for the inspection findings. I attended a GAP meeting during my site intervention on 27th February (Reference 2). The group was quorate in accordance with their terms of reference, complied with their crack sentencing procedures and was composed of suitably qualified and experienced personnel. I am therefore satisfied that the process seems appropriate.

52. During the fuel channel inspections, no significant defects were observed in 15 of the 16 fuel channels inspected. However, a doubly cracked brick was found in channel D77, Layer 6. I consider this finding in further detail below.

Observations from Channel D77, Layer 6

53. Two full height axial cracks and a third smaller axial crack were found in the channel D77 Layer 6 brick; see Figure 1. This was the first inspection of the channel since first commissioning of the plant.

54. I observed the GAP meeting which had been specifically convened to discuss the findings from this channel (Reference 2). Following the review of the inspection data, the GAP members concluded that the morphology of the cracks and the measurements taken from the bore were evidence that the cracks have initiated from the bore (see 5th GAP minutes in Reference 17).

55. In addition to the GAP review, NGL also produced a technical note which will be added to the RTS EC (Reference 18). NGL's arguments with regards to the observation of the doubly cracked brick in channel D77 Layer 6 and the current safety case can be summarised as:

- With the exception of measurements specific to brick layer 6, shrinkage, ovality, bow and tilt measurements are within expectation;
- KWRC is not expected at HYB/TOR until 2022 (+/- one year);
- A number of doubly cracked bricks are assumed in the damage tolerance assessments (DTA) leg of the safety case;
- Given the inspection coverage during the statutory outage, NGL remains confident that the number of either singly or doubly cracked bricks in the core remains low and within the bounds of the safety case.

56. NGL therefore concluded that further inspections of the core were not As Low As Reasonably Practicable (ALARP).

Views regarding the graphite inspection findings

57. In my view, the morphology and the tortuosity of the cracks are consistent with bore-initiated cracking. 'Lipping in', characteristic of bore cracking, is also evident from the measurements, as shown in Figure 2. I therefore agree with the conclusions from the GAP that the cracks are likely to have initiated from the channel bore earlier in the life of the reactor.

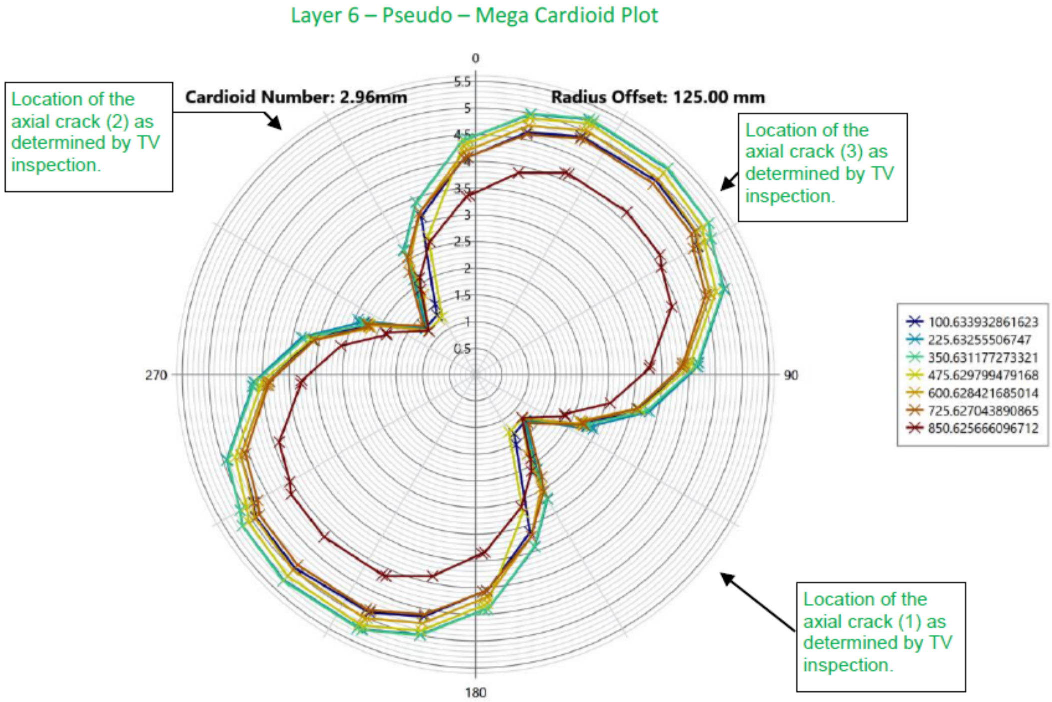

Figure 2: Bore measurements of fuel brick in channel D77, layer 6.

58. The cracks in channel D77 are the first full height axial cracks observed at HYB/TOR. More generally, HYB and TOR have a low number of early/mid-life cracked fuel bricks compared with Hunterston B, Hinkley Point B, Hartlepool and Heysham 1. In my view, NGL's conclusions are consistent with previous observations from bore cracks from Hinkley Point B, Hunterston B, Heysham 1 and Hartlepool. The ALARP statement in Reference 18 is therefore acceptable.

59. In my opinion, the smaller partial height crack visible in Figure 1 is unlikely to grow to a significant extent by the same damage mechanism as bore cracking is considered to be an early life damage mechanism.

60. The bore measurements from channel D77 were within expectation and do not show any sign of significant displacement due to the presence of the cracked brick in layer 6. Although the GAP assessors highlighted 3 fragments in Figure 1, I do not consider that these would be significant if these were to become detached.

61. Overall, the graphite inspection findings were broadly within expectation. The bore measurements show that the channel distortions remain small and do not challenge the safety case assumptions. In my view, the number of cracked bricks in the core is below the level of cracked bricks that could challenge the safety case. I am content that the presence of the doubly cracked brick in channel D77 does not undermine this conclusion. The findings of the fuel channel inspections are therefore acceptable.

62. However, the PAR should note that a doubly cracked brick was observed in channel D77 layer 6. NGL should consider whether this channel should be re-inspected in future fuel channel inspections (Recommendation 3).

4.4 Trepanning

63. Of the 35 samples planned for trepanning, one sample broke off during trepanning in the layer 6 brick in channel S89 and could not be retrieved (Reference 21). The sample was subsequently blown into the debris pot as per NGL's arrangements. I do not expect this sample to pose a threat to the core of the reactor as the debris pot is subjected to minimal gas flow.

64. In my view, the retrieval of 34 trepanned specimens is satisfactory since it is more than the minimum of 30 samples required by the MS. The weight loss and materials properties data derived from the trepanned specimens will not be available for until after the RTS. This is acceptable as the data will be used to update NGL's predictions for weight loss and the material models.

4.5 Peripheral shielding bricks

65. The peripheral brick safety case, EC 356531 now at Revision 5 (Reference **3**), was developed as a result of the discovery of cracks in the peripheral shield wall in the TOR R2 peripheral shielding bricks in 2015. This safety case is updated following each outage at HYB & TOR. It gives a comprehensive description of the inspection findings in previous periodic shutdowns. The main claim is that it is safe to operate the reactors at HYB and TOR with the observations of the peripheral brick inspections.

66. I observed a PBAP meeting on 13th March 2020. The meeting was quorate and was composed of suitably qualified and experienced personnel. The PBAP members reviewed the findings of the peripheral inspections during the periodic shutdown according to the PBAP criteria in Reference 19. The minutes of the meeting were subsequently circulated within the PBAP members and endorsed (see Reference 23). In my opinion, the PBAP process is appropriate. I consider that the PBAP sheets and minutes are a reliable source of information of the inspection findings.

Coverage of the inspections

67. The first inspections of HYB R8 peripheral bricks were carried out during the 2016 periodic shutdown. This was the first re-inspection since the first observations of cracking at HYB R8 in 2016. During the 2020 periodic shutdown at HYB R8, NGL completed the inspection of 12 of the 16 faces, 5 of which had previously been inspected in 2016. This is in-line with NGL's inspection target for this outage. Together with the 2016 inspections, this completes the safety case commitment to conduct a 100% visual inspection of the peripheral bricks.

68. During this shutdown at HYB R8, the core restraint was examined at all 12 faces adjacent to the peripheral shield wall and no significant degradation or deformation was observed. The inspection of the core restraint and the measurement of the bow and tilt of edge channels provide some indication that peripheral brick cracking is not a consequence of gross failure of the core restraint.

Inspection findings

69. NGL provided a summary of the inspections of the peripheral shield wall in Reference 22 which claims that the results of the inspections are within the bounds of the safety case in Reference 3. Overall, the PBAP members judged that the majority of the defects observed minor surface linear feature with no apparent depth (category I.8 according to NGL's classification in Reference 19). Of the defects categorised as 1.3 (linear cracks), the PBAP assessors decided to characterise some of the less discernable defects as being crack-like as a conservative measure. In my view, the PBAP assessors have taken a reasonable approach when classifying the defects.

70. The PBAP sheets in Reference 22 show that there was no significant crack opening in the large majority of the defects observed. These defects, in my view, do not pose any concern for the integrity of the peripheral bricks. The only defect of more significance was found in Face 15, Layer 4, Brick No. 2, which I consider in further detail in the sections below.

Face 15, Layer 4, Brick No. 2

71. During the inspections, Face 15, Layer 4, Brick No. 2 was found to be cracked at the top of the brick. However, the crack does not appear to extend the full height of the brick; see Figures 3 and 4. This face had not been inspected before.

Figure 3: Cracked brick in Layer 4 of Face 15, Brick No. 2 (top of the brick).

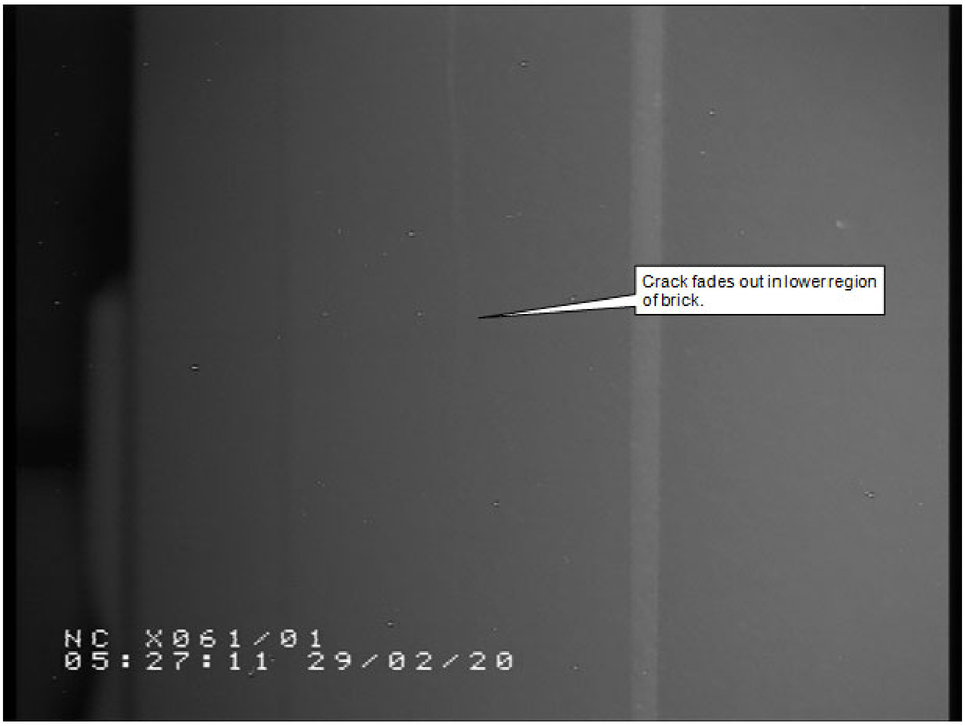

Figure 4: Cracked brick in Layer 4 of Face 15, Brick No. 2 (bottom of the brick).

72. Reviewing the result of this inspection, the PBAP noted that:

- the crack has significant separation particularly at the top of the brick;

- there is significant radial misalignment, particularly at the top of the brick and the left-hand side of the brick appears to be leaning outwards and potentially resting on the upper restraint beam;
- the adjacent bricks do not appear to be cracked or displaced.

73. The PBAP considered the significance of this defect with respect to the safety case. The following aspects were considered: the stability of the brick, the thermal consequences of a missing brick and debris. NGL noted that no missing bricks had been observed and that it was unlikely that any brick section had become dislodged. NGL concluded that the consequences with regard to re-entrant flow remain and debris would remain acceptable and are covered by the existing safety case (Reference 3).

74. In my view, the gapping would not be sufficient to cause a significant bypass of the coolant flow. Similar ‘leaning’ bricks have been found previously in the TOR reactors. The consequences of cracking are therefore considered in the existing safety case (Reference 3). In my opinion, the PBAP’s judgement with regard to this brick seems appropriate. I am therefore of the view that NGL’s conclusions are acceptable.

Overall distribution of defects

75. There are approximately 1600 bricks that make up the peripheral shield and the inspections showed that around 2% are cracked at HYB R8. The PBAP concluded that the facemap, shown in Reference 20, does not reveal the presence of any clusters of defects. The defects which were previously found in the faces inspected in 2016 do not show any sign of progression.

76. I am therefore satisfied that the overall distribution of defects seems uniform, which is consistent with the peripheral brick safety case in Reference 3.

Views on the inspection findings

77. In my view, the level of inspection completes NGL’s commitment to achieve 100% inspection of the peripheral shielding wall for this reactor over two inspection campaigns. Five faces were re-inspected and the defects observed did not reveal any evidence of progression since the last inspection in 2016. Overall, the number of defects observed remains low and uniformly distributed around the peripheral wall. I am therefore of the opinion that the defects observed do not challenge the integrity of the peripheral wall.

78. I am therefore satisfied that the findings of the peripheral brick inspections are in-line with the expectation from the safety case and do not challenge the claims in Reference 3.

4.6 Eddy current inspections

79. Due to a fault with the eddy current inspection tool, NGL has completed 6 of the 8 eddy current inspections planned during the periodic shutdown. However, eddy current inspections are not claimed within the safety case and hence are not part of the MS. NGL conduct these inspections to provide additional qualitative information on the brick-to-brick and within brick variability of the graphite weight loss.

80. In my view, there are no safety concerns resulting from the fact that two channels were not inspected using eddy current during the periodic shutdown. Eddy current inspection from six fuel channels is still a good achievement for NGL.

4.7 Completion of the outage related documentation

81. I have assessed the HYB R8 2020 periodic shutdown verified documentation and inspection results relating to the graphite core which will form part of the RTS EC (References 16, 18, 22 and 23). I have compared the findings with claims and limits within the current graphite safety case (References 3, 12 and 15) and assessed them against the expectations laid down by the relevant SAPs (Reference 8 and Table 1). Overall, NGL argues that the results of the graphite core inspections at HYB R8 2020 periodic shutdown are acceptable and do not challenge safe operation. If the results considered in this assessment report are not subject to change and are approved by INSA then I judge that this claim has been adequately demonstrated (Recommendation 1). Furthermore, I confirm that the graphite inspection requirements of the safety case have been met.

82. In my opinion, the graphite core inspections results do not challenge the claims and limits of the current safety case and do not present any impediment to return to service of HYB R8.

4.8 Overall judgement on the periodic shutdown activities

83. From the information that I have sampled, I am satisfied that the inspection programme is being adequately monitored and controlled by the GAP. Also I am content that the GAP is providing adequate oversight and challenge of the outage activities. I have based my assessment on approved inspection sheets and from a verified statement provided by the licensee in advance of the RTS EC justifying return to service. I will use the INSA clearance statement for the RTS EC 365253 in order to formally confirm that all the necessary inspections have been completed and reported prior to the RTS. I will therefore recommend to the ONR Project Inspector that the INSA clearance statement is provided as part of the licensee’s application for consent to RTS.

4.9 ONR Rating

84. With reference to the ONR assessment rating guide (Reference 6), I judge that the licensee’s work and submissions are rated Green, requiring no formal action.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

85. I have assessed the graphite core inspection results from the HYB R8 2020 periodic shutdown and found them to be within the bounds and arguments of NGL's safety case.

86. To conclude, I have no objection to the subsequent PAR recommending that consent is given to return Heysham B Reactor 8 back to service.

5.2 Recommendations

87. My recommendations are as follows (to ONR's Project Inspector):

- Recommendation 1: I recommend that the project inspector confirms the Independent Nuclear Safety Assessment (INSA) statement has been made available by NGL and is in agreement with the views in the Engineering Change document.
- Recommendation 2: I recommend that the PAR records that NGL is in the process of producing a post-onset of keyway root cracking safety case for the graphite cores at Heysham B and Torness. This safety case should be produced and submitted to ONR for assessment before the first observation of keyway root cracking. The PAR should also record that NGL will be providing an update to the inspection strategy at HYB/TOR before the end of May 2020.
- Recommendation 3: the PAR should note that a doubly cracked brick was observed in channel D77 layer 6. I concur with NGL's conclusion that this is a bore crack rather than a keyway root crack. This observation therefore does not challenge the assumptions in the existing safety case. However, NGL should consider whether this channel should be re-inspected in future fuel channel inspections.

6 REFERENCES

1. ONR-OFD-IR-19-165. LC28 Site Intervention during Heysham B Reactor 8 2020 Periodic Shutdown: Graphite Core Inspections. (CM9 2020/53320).

2. ONR-OFD-IR-19-180. LC28 Site Intervention during Heysham B Reactor 8 2020 Periodic Shutdown: Peripheral Shielding Brick Inspections. (CM9 2020/66616).

3. EC 356531 Revision 005, Justified Continued Operation (JCO) in light of the discovery of cracked peripheral bricks during the 2015 Torness R2, Heysham 2 R8 and Torness R1 2017 outage inspections. (CM9 2020/23866).

4. EC 356536 Revision 004, Proposal No. 3, Justified Continued Operation (JCO) in light of the discovery of cracked peripheral bricks during the 2015 Torness R2, 2016 Heysham 2 R8 and Torness R1 2017 outage inspections. (CM9 2018/189035).

5. HB/REPS/SD296. Proposals for the Inspection of Reactor Internals and Materials Monitoring. (CM9 2020/19294).

6. ONR Assessment Rating Guide Table – CM9 Reference (2016/118638).

7. ONR Guide NS-PER-GD-001 Revision 3 – The Purpose and Use of Permissioning. November 2019. http://www.onr.org.uk/operational/assessment/index.htm

8. Safety Assessment Principles for Nuclear Facilities. 2014 Edition Revision 1. January 2020. http://www.onr.org.uk/saps/saps2014.pdf

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11. HYB S11 R8 Statutory Outage - Graphite Intervention. Requested Document. Core Burn-up. Heysham 2 R8 2020 outage. (CM9 2020/50512).

12. Heysham 2 / Torness Graphite Core Safety Case NP/SC 7663 Version 03. 26 May 2017 - Post-Stress Reversal. (CM9 2017/457269).

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14. SCAP HYB-TOR Keyway Root Cracking Onset Predictions Condition Report. (CM9 20200/89272).

15. Graphite Weight Loss Statement for the 2020 R8 RTS EC 365253. (CM9 2020/85289).

16. Heysham 2 R8 2020 Outage. GAP Sheets. (CM9 2020/76466).

17. Heysham 2 R8 2020 Outage. GAP Minutes. (CM9 2020/76465).

18. Heysham 2 R8 2020 Graphite Inspections. Safety Case Position Following the Observation of Cracking in Channel D77. 05 March 2020. (CM9 2020/72469).

19. PBAP sentencing criteria for HYB R8 v02. (CM9 2020/64914).

20. Heysham 2 Peripheral Brick Inspections. Face map (CM9 2020/80750).

21. RE: Heysham 2 RTS EC Reference. Heysham B 2020 R8 Outage. Trepanned Samples. (CM9 2020/74394).

22. Heysham 2 R8 2020 Outage. PBAP Sheets. (CM9 2020/76464).

23. Heysham 2 R8 2020 Outage. PBAP Minutes. (CM9 2020/76461).

Appendix 1

Relevant Safety Assessment Principles considered during the assessment

SAP No	SAP Title	Description
EGR. 1	**Engineering principles:** **graphite components and structures: safety case**	The safety case should demonstrate that either: a) graphite reactor core is free of defects that could impair its safety functions; or b) the safety functions of the graphite reactor core are tolerant of those defects that might be present.
EGR. 2	**Engineering principles:** **graphite reactor cores: design: monitoring**	The design should demonstrate tolerance of graphite reactor core safety functions to: a) ageing processes; b) the schedule of design loadings (including combinations of loadings); and c) potential mechanisms of formation of, and defects caused by, design specification loadings.
EGR. 3	**Engineering principles:** **graphite reactor cores: design: monitoring**	There should be appropriate monitoring systems to confirm the graphite structures are within their safe operating envelope (operating rules) and will remain so for the duration of the life of the facility.
EGR. 10	**Engineering principles:** **graphite reactor cores: defect tolerance assessment**	An assessment of the effects of defects in graphite reactor cores should be undertaken to establish the tolerance of their safety functions during normal operation, faults and accidents. The assessment should include plant transients and tests, together with internal and external hazards.
EGR. 15	**Engineering principles:** **graphite components and structures: examination, inspection, surveillance, sampling and testing:** **Extent and frequency**	In-service examination, inspection, surveillance, and sampling should be of sufficient extent and frequency to give sufficient confidence that degradation of graphite components and structures will be detected well in advance of any defects affecting safety function.