Office for Nuclear Regulation

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Operating Facilities Division

Heysham 1 Reactor 2 2018 Periodic Shutdown – Assessment of the results of the Graphite Core Inspections

Assessment Report ONR-OFD-AR-18-027
Revision 0
AUGUST 2018

EXECUTIVE SUMMARY

During the 2018 Heysham 1 Reactor 2 periodic shutdown, the graphite reactor core has undergone surveys, as required by the graphite core safety case. The Licensee, EDF-Energy Nuclear Generation Limited, has produced an Engineering Change document that summarises the findings of the graphite inspection and claims that these support the overall graphite safety case.

As part of Licence Condition 30, I have assessed the Engineering Change document and compared the findings with the current graphite safety case and the relevant Safety Assessment Principles. Overall, the Engineering Change document makes the single claim that the results of the graphite core inspections at Heysham 1 Reactor 2 2018 periodic shutdown are acceptable and do not challenge safe operation. I judge that this is a claim that has been adequately demonstrated. 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.

The Licensee has carried out a scope of inspection and trepanning that satisfies its safety case commitments and demonstrates that the extent of bore cracking is consistent with expectations. Thirty-six specimens have been trepanned from the core during this shutdown, which exceeds the minimum safety requirement by six specimens. The trepanned specimens will be analysed in due course and will provide further data informing the current weight loss predictions. Sixteen fuel channels were visually inspected and the bore measurements from fifteen fuel channels were taken during the outage. A control rod channel was also visually inspected and did not reveal any defects at the bore. The inspections of the fuel channel and control rod channel bores are well within the safety case requirements and support the claim that the core condition does not challenge safe operation. In my assessment, I also consider that the 12% active core weight loss limit is unlikely to be reached until 2020 at the earliest. The licensee recently submitted a safety case to ONR to seek agreement to increase this limit to 17%. At the time of my assessment, this safety case was being considered by an ONR fault studies specialist.

In my opinion, the graphite core inspections results are within the bounds of NGL's safety case and do not present any impediment to return to service of HYA R2. I have no objection to the subsequent PAR recommending that consent is given to return Heysham 1 Reactor 2 back to service.

I have therefore attributed an overall ONR rating of 'green' – no formal action.

Recommendations

<u>To ONR Project Inspector:</u>

- Recommendation 1: Based on my assessment of the Heysham 1 Reactor 2 2018 Graphite Core Inspection Results and Justification for Return to Service, I have not found any reason to prevent me recommending that consent is given to Heysham 1 Reactor 2 return back to service.
- Recommendation 2: At the time of my assessment, an Independent Nuclear Safety Assessment certificate was not available. The Project Inspector should therefore ensure that this certificate is available and in agreement with the views in the Engineering Change document.
- Recommendation 3: that the PAR reflects that the current limit of 12% associated with steam-ingress reactivity faults could be reached in 2020 and that NGL has submitted a revised safety case, which will require ONR's

approval, to raise this limit from 12% to 17%. NGL has also introduced a new graphite weight loss methodology which needs to be discussed in a level 4 meeting being planned with NGL.

LIST OF ABBREVIATIONS

AGR	Advanced Gas-cooled Reactor
BMS	Business Management System
EC	Engineering Change
GCPT	NGL Graphite Core Project Team
GWd	Giga-Watt day
HRA	Hartlepool Power Station
HOW2	(ONR) Business Management System
HYA	Heysham 1 Power Station
INSA	Independent Nuclear Safety Assessment
LC	Licence Condition
MS	Maintenance Schedule
NGL	EDF energy Nuclear Generation Limited
NICIE2	New In-Core Inspection Equipment Mark 2
ONR	Office for Nuclear Regulation
PAR	Project Assessment Report
R	Reactor
RTS	Return-To-Service
SAP	Safety Assessment Principle(s)
SQEP	Suitably Qualified and Experience Person
TAG	Technical Assessment Guide(s) (ONR)

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1 INTRODUCTION

1. During the 2018 Heysham 1 (HYA) Reactor 2 (R2) periodic shutdown, the graphite reactor core has undergone surveys, as required by the graphite core safety case (References 1, 2 and 3). The Licensee, EDF-Energy Nuclear Generation Limited (NGL), has produced an Engineering Change document (EC) (Reference 4), which summarises the findings of the graphite inspection and claims that these support the overall graphite safety case. Therefore, assessment of the final graphite core structural integrity inspection results as part of Licence Condition (LC) 30 (3) will be based on the findings presented in the EC and other supporting documents.

2. The scope of reactor core inspections for HYA R2 is set out below:

- TV inspections of sixty fuel channels per station over three years.
- Channel bore measurement inspections of ten fuel channels at every periodic shutdown (three-yearly) on each core.
- Trepanning of a minimum of thirty samples, with a target of thirty-six samples from at least six fuel channels, subject to reasonable practicability, at every periodic shutdown (three-yearly).
- TV inspection of one control rod channel at every periodic shutdown.

3. The findings of the laboratory examinations of the trepanned specimens are not expected before the return to service of HYA R1 and are not considered in this assessment report. They will be used to further develop an understanding of the condition of the graphite reactor core by NGL's Graphite Core Project Team (GCPT).

4. The following report presents the results of my assessment of the structural integrity findings related to the graphite core inspections during the 2018 HYA R2 inspections.

1.1 Background

5. This report assesses the findings of the graphite core inspections of HYA R2 during the 2018 periodic shutdown, which are presented in the EC (Reference 4) and supporting documentation provided by NGL. Assessment was undertaken in accordance with the requirements of the Office for Nuclear Regulation (ONR) How2 Business Management System (BMS) guide NS-PER-GD-014 (Reference 5). The ONR Safety Assessment Principles (SAP) (Reference 6), together with supporting Technical Assessment Guides (TAG) (Reference 7), have been used as the basis for this assessment.

1.2 Scope

6. The scope of this report covers the licensee's activities performed during the shutdown associated with the examination and inspection of HYA R2 graphite core and whether return to service (RTS) is justified. I have taken account of recent developments in the HYA and Hartlepool (HRA) graphite core safety cases including the claims

1.3 Methodology

7. The methodology for the assessment follows HOW2 guidance on mechanics of assessment within the Office for Nuclear Regulation (ONR) (Reference 8). This assessment has been focussed primarily on the results of the graphite core inspections during the HYA R2 2018 periodic shutdown as detailed in the EC supporting the RTS of the reactor (Reference 4).

2 ASSESSMENT STRATEGY

8. 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

9. The relevant standards and criteria adopted within this assessment are principally the Safety Assessment Principles (SAP) (Reference 6), internal ONR Technical Assessment Guides (TAG) (Reference 7), 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

10. The key SAPs applied within the assessment are included within Table 1 of this report.

2.2.1 Technical Assessment Guides

11. The following Technical Assessment Guides have been used as part of this assessment (Reference 7):

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

2.2.2 National and International Standards and Guidance

12. 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

13. N/A.

2.4 Integration with Other Assessment Topics

14. N/A.

2.5 Out of Scope Items

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

- Inspection results from all non-graphite related components;
- The findings of the laboratory examinations of the trepanned specimens are not expected before the return to service of HYA R2 and are not considered in this assessment report. They will be used to further develop an understanding of the condition of the graphite reactor core by the GCPT.

3 LICENSEE'S SAFETY CASE

16. This section provides a summary of the licensee's safety case and the justification for the RTS of HYA R2. I provide my assessment of the graphite inspection findings in relation to the RTS of HYA R2 in Section 4 of this report.

3.1 Core burn-up

17. At the time of the 2018 periodic shutdown, the core burn-up for HYA R2 was 11861.7GWd (Reference 9).

3.2 Objectives of the graphite inspections

18. During the HYA R2 periodic shutdown inspections were performed within selected channels of the graphite core to determine:

- The number, size and morphology of any cracks observed in the selected channels;
- The change in dimensions of the bricks as a result of irradiation induced shrinkage of the graphite;
- Any change in the distortion of the core in terms of fuel channel bow, brick bow and channel tilt;
- The estimated weight loss of the core based upon trepanned specimens removed from fuel channel walls.

19. This assessment compares the first three of these results above against relevant sections of the HYA graphite core safety case (References 1, 2 and 3) to determine whether they pose any challenge to the return to service of HYA R1 for a further three years of operation.

3.3 Current safety case limits

3.3.1 Brick cracking

20. In terms of cracking, the current safety case is valid up to the predicted onset of keyway root cracking predicted at a core burn-up not before 14400GWd (Reference 1). The number of doubly axially cracked bricks must constitute less than 10% of the whole core. The case proposes that prior to stress reversal, any number of singly axially cracked bricks can be tolerated.

3.3.2 Graphite weight loss

21. Currently the most limiting graphite weight loss limit is the average core weight loss and is 12% mean weight loss in the active core (Reference 2). Previous predictions have forecast the 12% limit to be reached at a core burn-up of 12400GWd, based on trepanned samples up to and including the 2008 HYA trepanning campaigns (Reference 2). However, NGL have updated the weight loss forecasts with samples up to and including the 2015 HYA trepanning campaigns in Reference 10. The revised calculations forecast that the 12% weight loss limit will not be reached until a burn-up of 12900GWd. Assuming an increase in the core burn-up of 526GWd per year and the current core burn-up of 11861GWd, NGL predicts that the 12% limit would be reached in 2020, which is before the next scheduled periodic shutdown planned for 2021.

22. To support operation beyond 2020, NGL revised the calculation methodology for the active core weight loss in Reference 11 and now predicts that the 12% limit will not be reached before a core burn-up of 14250GWd. NGL has also submitted a revised safety case to propose an increase in the 12% limit at HYA to 17% in Reference 12. NGL currently forecast that the 17% limit will be reached by a burn-up of 17050GWd using

the methodology in Reference 10 and 19750GWd using the methodology in Reference 11. Both estimates are well beyond the next periodic shutdown in 2021 and the currently planned date for end of generation for the station.

23. The results from the graphite weight loss measurements from the trepanned samples will not be processed in time to affect the decision on restart. Instead the estimated weight loss will be based on the most recent available trepanned sample results.

3.4 Expectations

24. In addition to the limits within the graphite core safety case, I note that NGL produce reports in advance of each periodic shutdown detailing its expectations of the graphite core inspections based on the results of previous inspections (References 13 and 14). These documents state a bound at which results would challenge NGL's understanding of core behaviour and thus require further investigation. Although not an operating limit any result which challenges NGL's understanding of core behaviour could potentially affect their safety case. The pre-shutdown expectations are summarised below:

- Based on three different model predictions the most likely expectation is 2 to 3 new singly axially cracked bricks and up to 1 new doubly axially cracked brick will be found. Up to 8 new singly axially cracked bricks and up to 4 new doubly axially cracked bricks would be in-line with expectations; see Reference 13.
- The maximum mid-brick shrinkage in a peak-rated layer is expected to be 2.04%. A mid-brick shrinkage of >4.1% would challenge understanding; see Table 1 of Reference 14.
- Maximum expected brick ovality is 1.75mm for central channels and 2.84mm for edge channels based on the historical maximum observed ovality. An ovality of >5mm would challenge understanding; see Table 2 of Reference 14.
- Maximum expected brick bow is 0.80mm for central channels and 1.83mm for edge channels. A brick bow of >1.5mm for central channels and >5mm for edge channels would challenge understanding; see Table 3 of Reference 14.
- Maximum expected channel bow for central and edge channels is 8.3mm and 5.6mm respectively. A channel bow of >14mm would challenge the understanding; see Table 4 of Reference 14.
- Channel tilts have no implications for fuel stringer movements by themselves. However, the maximum expected channel tilt for central and edge channels is 13.5mm and 13.6mm respectively; see Table 5 of Reference 14.

3.5 Outage intentions

25. According to the outage intentions document (Reference 15), the current Maintenance Schedule (MS) in Engineering Changes (ECs) 354994 & 354995 (Reference 3) requires the following inspections during periodic shutdowns:

- TV inspections of sixty fuel channels per station every three years;
- Channel bore measurement inspections of ten fuel channels at every periodic shutdown (three-yearly) on each core;
- TV inspection of one control rod channel at every periodic shutdown;
- Trepanning of a minimum of thirty samples, with a target of thirty-six samples from at least six fuel channels, subject to reasonable practicability, at every periodic shutdown (three-yearly).

26. Prior to the periodic shutdown, NGL issued the intended scope of inspections which is summarised below for the graphite core (Section 4.7.1 of Reference 15):

- TV inspection of nineteen fuel channels;
- Channel bore measurement of ten channels;

- Trepanning of thirty-six graphite specimens (six samples from six channels);
- Visual inspection of one control rod channel.

3.6 Graphite Assessment Panel

27. NGL uses the New In-Service Inspection Equipment Mk II (NICIE2) tool to visually inspect and measure the fuel channels at HYA. NICIE2 is equipped with a camera, transducers and 'feelers' which measure the channel tilt and bore dimensions.

28. To analyse and sentence the results of the graphite core inspections, the licensee set up a Graphite Assessment Panel (GAP) which is composed of personnel having been accredited as Suitably Qualified and Experience Person ('SQEP'). The members of the GAP are engineers and managers from the station, from the Central Technical Office (CTO) at Barnwood and from contractors involved with these inspections.

29. Following the inspection of each channel, the information is first gathered into GAP sheets. These GAP sheets are reviewed by the GAP during the meeting. The results of the visual inspections, the dimensional measurements and any defect found during the inspections are reviewed, sentenced and endorsed by the GAP members. The minutes of the GAP meeting, along with the GAP sheets, are produced and approved documents which are usually referenced in the safety case for the return-to-service of the reactor. The GAP minutes therefore provide a reasonably accurate representation of the inspection findings. A copy of the GAP sheets and of the GAP minutes is available in Reference 16.

30. According to the third GAP minutes in Reference 16, twenty fuel channels were selected for inspection, which is one more than stated in the outage intentions document in Reference 15. The channels selected for inspection are shown in Figure 1.

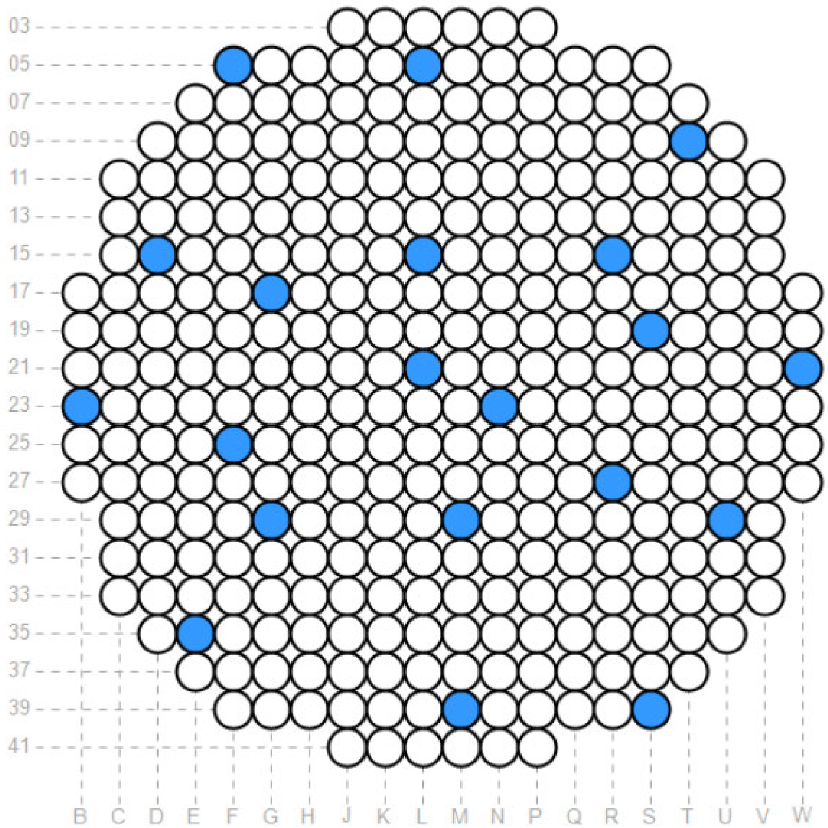

Figure 1: Core map showing the fuel channels inspected during 2018 HYA R2 periodic shutdown.

3.7 Engineering Change

31. At the time of the periodic shutdown, NGL produced Engineering Change (EC) 363869 which summarises the findings from the graphite inspections in Reference 4. A single claim is made in EC 363869 which states that '*The results of the graphite core inspections at the Heysham 1 R2 2018 periodic shutdown are acceptable and do not challenge safe operation'.* This claim is supported by the four following arguments:

- **Argument 1.1:** The results of the graphite core inspections are within expectations and no keyway root cracked bricks have been observed;
- **Argument 1.2:** The level of bore cracking is within expectation and does not challenge the number assumed in the current safety case;
- **Argument 1.3:** The axially bore cracked bricks have not started to open;
- **Argument 1.4:** The measured core, channel and brick distortions are within expectation.

32. I assess the claim, the arguments and supporting evidence in Section 4 below. To help me form the views in my assessment, I also considered the results of the inspections, as discussed at the GAP and recorded in the GAP minutes. I consider that the verified GAP minutes are an adequate formal statement of the findings.

4 ONR ASSESSMENT

33. 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

34. The scope of the assessment covers the extent to which the results of the visual and dimensional graphite core inspections at HYA R2 2018 periodic shutdown challenge the existing graphite core safety case (References 1, 2 and 3). The assessment of these results will result in a recommendation to ONR on the decision to consent to the return to service of HYA R2.

4.2 Remote Visual Inspections

35. The remote visual inspections are the TV inspections identified in the outage intentions document. Sixteen fuel channels and one control rod channel were visually inspected, which is consistent with the MS requirements. The sixty fuel channel inspections noted in the MS are for both reactors over a three year period and the sixteen channels inspected on this occasion support that overall requirement. All sixteen fuel channels were inspected visually using the New In-Core Inspection Equipment Mark 2 (NICIE2) tool, but only fifteen channels could be measured dimensionally due to intermittent gas coolant supply during the outage. No measurements were made from Channel B23, but visual records have been made of the defects found during the inspection.

36. The inspection of the channels has been recorded and processed through the Graphite Assessment Panel (GAP). I received a copy of the findings of the graphite inspections in Reference 16 and included a summary of the inspection findings in Table 2. The following new defects were found during the inspections:

- Four newly-observed full height axial bore cracked bricks in channels B23 layer 8, F25 layer 9, N23 layer 10 and W21 layer 10;
- Two newly-observed full circumferential bore cracked bricks (B23 layer 11 and G29 layer 9).

37. Two other cracks were previously observed bore cracks which have either grown or been reclassified (both D15 layer 10). No defect was observed in the control rod channel inspected (N22) although NGL reported the presence of a piece of debris in the debris pot, which is likely to be a metallic compound according to NGL (Reference 17). The piece of debris observed in N22 is shown in Figure 2 below.

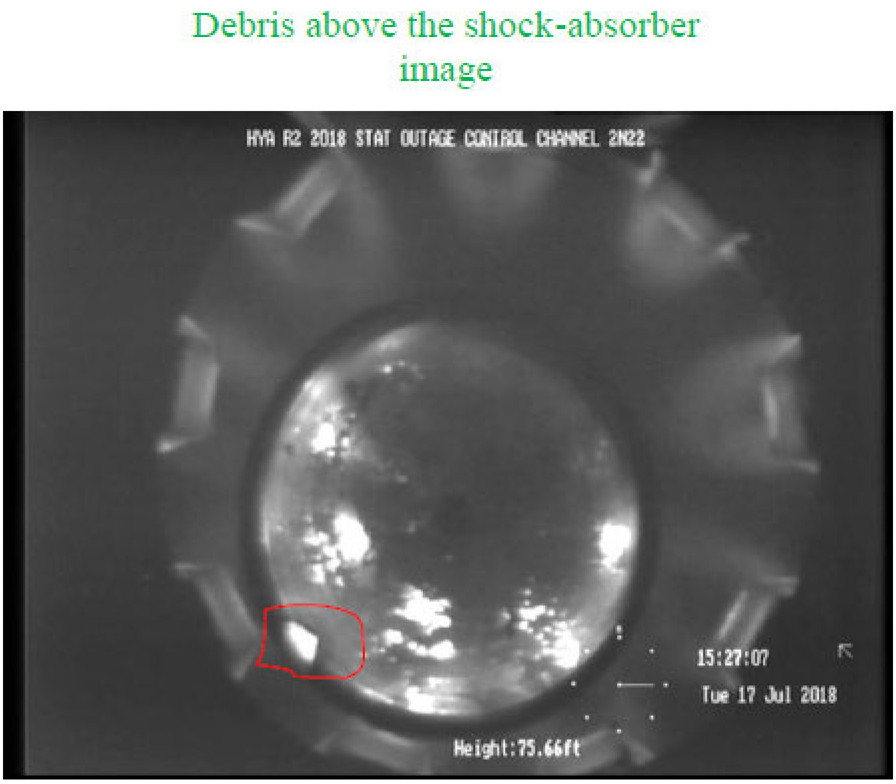

Figure 2: Piece of debris observed in debris pot in control rod channel N22.

38. I consider that the piece of debris which is visible in Figure 2 is small and unlikely to be significant (see evidence 1.2.1 of Reference 4). I therefore consider that this finding would not challenge the structural integrity of the core or the safety case and is acceptable.

39. Based on three different model predictions in Reference 13, the most likely expectation is 2 to 3 new singly axially cracked bricks and up to 1 new doubly axially cracked brick will be found. Up to 8 new singly axially cracked bricks and up to 4 new doubly axially cracked bricks would be in-line with expectations. Four new full-height axially cracked bricks have been observed during the outage, which is slightly more than expected from the best estimate models, but within the range provided at the beginning of the outage. No doubly axially cracked bricks have been observed during the inspection, which is consistent with expectations. I therefore consider that the number of full height axial cracks do not challenge the assumptions of the safety case.

40. The following fuel channels were re-inspected during the current outage:

- D15 (2008), F05 (1986), L05 (2015), L15 (2008), L21 (1988), M29 (2008), M39 (2015), R15 (2016), U29 (2008).

41. Of the nine channels being re-inspected during the outage, only channels D15 and M21 were known to contain a crack. No defects were found from the other channels. The measurements taken from channels D15 and M21 allow for the length and width of the cracks to be compared between the inspections.

42. The GAP sheet for channel D15 in Reference 16 states that the circumferential crack grew in length and in width. The length is not recorded in the GAP sheet but it is now fully circumferential. The circumferential crack appears to be ~0.5mm wider than in 2008, now up to 2.0mm. I do not consider the increase in the width of the crack observed to be significant and is unlikely to threaten the structural integrity of the core within the next period of operation.

43. In Reference 16, the GAP sheet for channel M29 indicates that the short circumferential crack in Layer 10 did not grow either in length or width since 2008. I therefore consider that this observation does not challenge the safety case assumptions.

44. The GAP sheet corresponding to Channel W21 in Reference 16 shows the presence of an axial crack in layer 10. Channel W21 is an edge channel for which a high channel tilt was measured from the bore (see Section 4.3 below). Figure 3 shows a visual representation of the crack observed during the inspection.

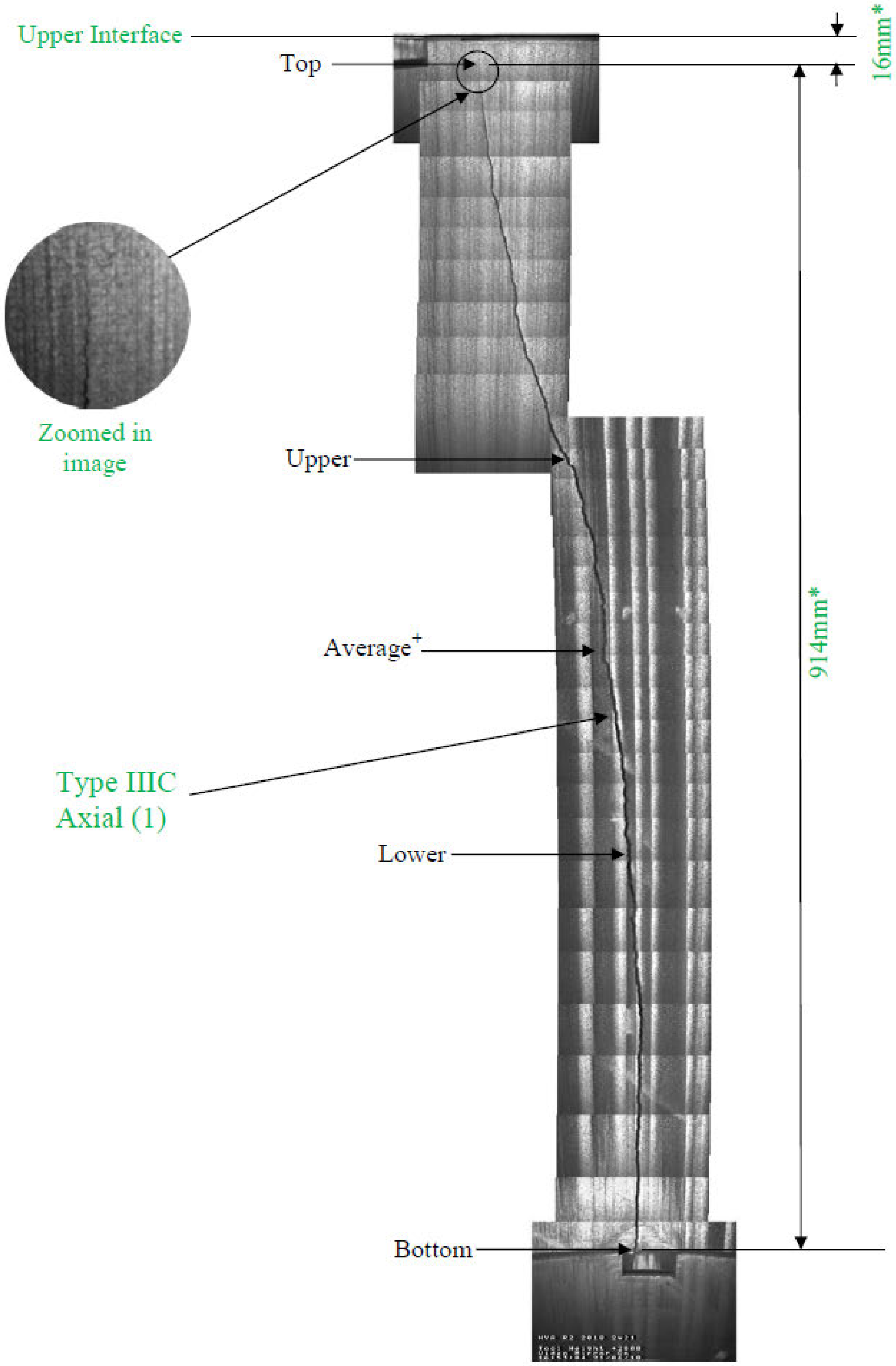

Figure 3: Axial crack observed in Channel W21, Layer 10.

45. As Figure 3 shows, the axial crack observed in Channel W21, Layer 10, seems to originate from the end face key at the interface between layer 9 and layer 10 and follows a generally upward path with a circumferential variation from the 170° position to 120° around the bore of the brick. NGL sentenced this crack as being bore-initiated, which the small 'lipping-in' in the cardioid plot seems to suggest in the GAP sheet (Reference 16). I consider that NGL's sentencing of the crack appears to be appropriate. Although the angle of the crack appears to be unusual, I consider that this observation does not challenge the safety case assumptions and can be categorised as an axial crack.

46. Stress reversal in irradiated graphite occurs after a period of time when the dimensions of the graphite stop shrinking and begin to expand and is thus a precursor to keyway root cracking. Evidence of the onset of stress reversal would represent a challenge to the current safety case as it would undermine the safety case prediction of the date of onset. Of the channels that had been inspected at previous periodic shutdowns, none had previously contained a full axial crack, therefore no direct evidence of crack opening due to stress reversal is available. I have reviewed the inspections findings and find that the characteristics of pre-stress reversal behaviour are present, such as lipping-in of the crack at the bore surface and therefore consider that NGL' sentencing of the cracks as bore cracks appear to be reasonable.

47. Considering the low number of full height axial cracks that have been identified, the associated brick distortions, and the apparent absence of keyway root cracking, I judge that the visual inspections do not challenge to the safety case assumptions.

4.3 Bore measurements

48. Of the sixteen fuel channels visually inspected, bore measurements were taken from 15 fuel channels. No measurement could be taken from Channel B23 due to intermittent coolant supply at the time of the outage. However, the MS requires that channel bore measurements of ten fuel channels are taken at every periodic shutdown (three-yearly) on each core. The fifteen fuel channels measured during the outage are therefore within the MS requirements, which I consider to be satisfactory.

49. Table 2 shows a summary of the bore measurements carried out during the outage, as provided by NGL in Reference 9. Table 3 summarises the maximum values of the bore measurements against the expected values stated in Section 3.4. Table 4 shows that the maximum mid-brick shrinkage in a peak-rated brick, the maximum brick bow and the channel tilts for edge channels appear to be higher than the historical values. Nevertheless, the measurements from the current inspections are all within the maximum value set by NGL prior to the outage. The brick and channel distortions measured were acceptable and within the safety case limits. The control rod channel did not reveal any defect.

50. The channel tilt measured in Channel W21, an edge channel (Figure 1), is 15.3mm in layer 11 and 15.2mm in layer 12 (evidence 1.4.1 of Reference 4). This is the highest channel tilt yet measured at HYA and amongst the highest in the fleet (Table 5 of Reference 14). Channel W21 has no previous inspection history. NGL's view in EC 363869 is that the channel tilt measured in Channel W21 is not significant compared to the channel length of 10 meters and considered the measurements to be within expectation. NGL also considered the channel bow to be relatively small (4.2mm maximum at layer 7), which indicates that keyway disengagement is therefore unlikely to have occurred in the vicinity of the channel. Figure 4 shows the historical channel tilt measurements at HYA 2 (from Reference 14). I added a circle to this graph to show the approximate region of the maximum channel tilt measured during the current periodic shutdown for reference, i.e. 15.3mm.

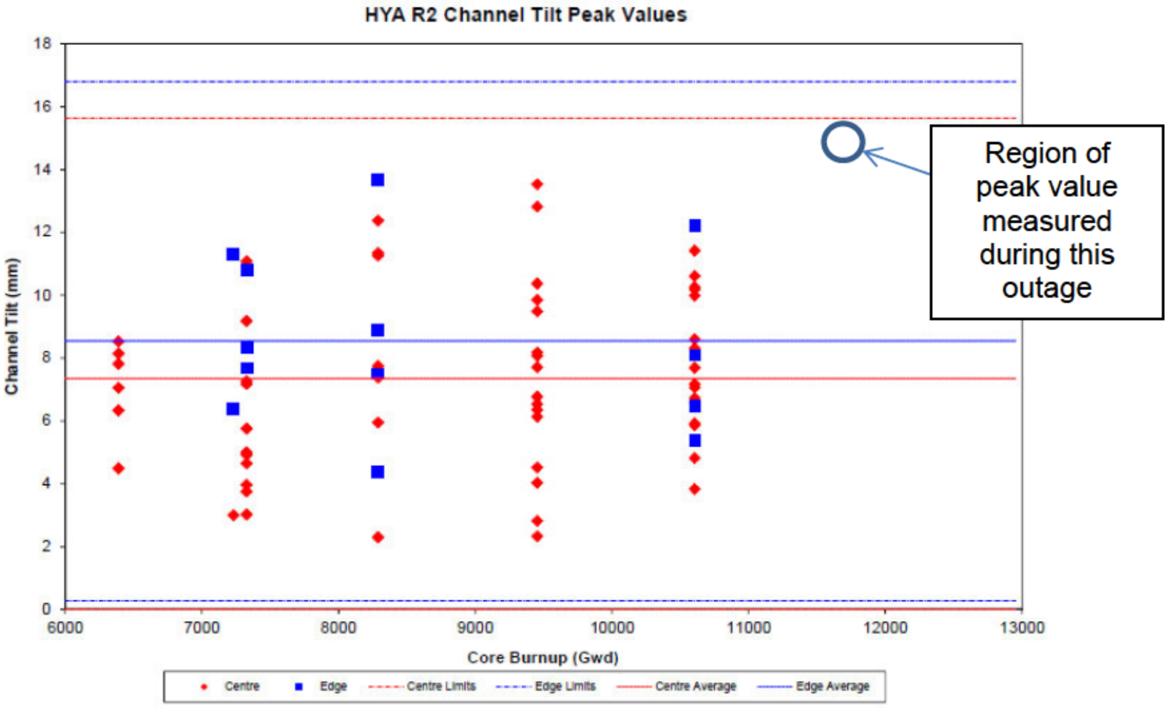

Figure 4: Historical channel tilt measurements at HYA R2.

51. Figure 4 shows that the latest channel tilt measurement of Channel W21 seems to be quite significant compared to similar historical measurements, although not outside expectations. Furthermore, higher channel tilts were measured at HRA. I also note that there is currently no safety case limit being applied to the maximum channel tilt value. I therefore consider that the maximum channel tilt value of 15.3mm measured for Channel W21 is unlikely to challenge the structural integrity of the core.

52. Overall, the measurements from the graphite core inspections appear to be within expectations and do not seem to challenge the assumptions of the safety case.

4.4 Graphite trepanning

53. Thirty-six trepanned samples were retrieved from the core during the outage (Reference 18). This corresponds to the target number in the MS requirement and is six samples more than the minimum requirement of thirty samples at each periodic shutdown. I therefore consider that that this is a good achievement and will provide significant extra data to support graphite weight loss predictions. The weight loss and materials properties data derived from the trepanned specimens will not be available for several months until the next GWL update. However, I have considered the latest GWL update using trepanned data up to 2015 in Section 4.5 below.

4.5 Graphite weight loss

54. The currently bounding safety case limit for graphite weight loss is the active core weight loss limit of 12% and was calculated to correspond to a core burn-up of 12400GWd (Table F6 of NP/SC 7623 in Reference 2). Assuming a core burn-up increase of 526GWd per year (assuming 90% availability), this core burn-up should be reached by the end of 2019.

55. Reference 10 revised the 12% active core weight loss to a core burn-up of 12900GWd, i.e. 2020. In a further revision to the active core weight loss estimates, NGL now predicts that the 12% active core weight loss limit will not be reached before a core burn-up of 14250GWd in Reference 11, i.e. 2023.

56. NGL has submitted NP/SC 7474 Addendum 2 to increase the 12% limit to 17% (Reference 19). NGL currently claims that a 17% limit on the active core weight loss is approximately equivalent to operation up to 2027, well beyond the next scheduled periodic shutdown. At the time of my assessment, NP/SC 7474 Addendum 2 was being considered by an ONR fault studies specialist.

57. At my request, NGL provided some information in Reference 20 to explain the changes to the forecasts between the safety case NP/SC 7623 in Reference 2 (12400GWd) to the 2017 estimates in Reference 10 (12900GWd). I did not request further information concerning the latest forecast in Reference 11 (14250GWd) as ONR requested a level 4 meeting to be organised in Reference 21.

58. In the 2017 forecasts (Reference 10), various parameters were changed with different effect on the active core weight loss estimate. According to NGL in Reference 20, the main changes to forecast in Reference 10 (2017) are mostly attributed to the lower methane and carbon monoxide concentrations assumed in the model and the exclusion of 1998 trepanning data with high rate of oxidation. However, a lower methane and carbon monoxide concentration would result in a decrease in the core burn-up rather than the increase observed. I therefore consider that other changes to the models are more likely to cause the changes in the forecast in Reference 10. This should be discussed with NGL, and a level 4 meeting has been requested in Reference 21.

59. In Reference 20, NGL states that '*Overall, it is judged that the calculations for the 12900 GWd forecast are conservative by a small amount, although there is no intentional additional conservatism applied*.'

60. To identify the areas of conservatisms in the model, I requested further justification to the graphite weight loss forecasts, which NGL responded in Reference 22. NGL believes that the extrapolation of graphite weight loss into the interstitial bricks is currently conservative. I am satisfied that the unverified graphs provided in Reference 22 seem to indicate that the calculation appears to be conservative. But I will consider this in more detail in future interactions with the licensee.

61. Based on the results of my assessment, I therefore consider that the current 12% active core weight loss limit is unlikely to be reached until 2020, as forecast in Reference 10. To support operation beyond 2020, NGL submitted safety case NP/SC 7474 Addendum 2 (Reference 19), which is being considered by a fault studies inspector. NGL also introduced a new methodology to revise the graphite weight loss forecasts in Reference 11. ONR requested further engagement with NGL in Reference 21.

62. I therefore consider that the graphite weight loss forecasts for HYA R2 do not prevent the return to service of the reactor.

4.6 Completion of the periodic shutdown related documentation

63. I have assessed the EC (Reference 4) that summarises the results of the graphite inspections at HYA R2 during the 2018 periodic shutdown. I have compared the inspection findings with the current graphite safety case (References 1, 2 and 3) and assessed them against the relevant SAPs (Reference 6). Overall, the EC makes the single claim that 'the results of the graphite core inspections at the HYA R2 2018 periodic shutdown are acceptable and do not challenge safe operation'.

64. I judge that this is a claim that has been adequately demonstrated. Furthermore, I confirm that the graphite inspection requirements of the safety case have been met. However, an Independent Nuclear Safety Assessment (INSA) 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.

4.7 ONR Rating

65. I reviewed the results of the graphite inspections carried out by the licensee during this periodic shutdown. Based on the results from my assessment, I consider that there are no outstanding actions that would prevent a return to service of HYA R2.

66. I have therefore attributed an overall ONR rating of ‘green’ – no formal action, based on the ONR rating guide table (Reference 23).

5 CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

67. During the 2018 Heysham 1 Reactor 2 periodic shutdown, the graphite reactor core has undergone surveys, as required by the graphite core safety case. The Licensee, EDF-Energy Nuclear Generation Limited, has produced an Engineering Change document that summarises the findings of the graphite inspection and claims that these support the overall graphite safety case.

68. As part of Licence Condition 30, I have assessed the Engineering Change document and compared the findings with the current graphite safety case and the relevant Safety Assessment Principles. Overall, the Engineering Change document makes the single claim that the results of the graphite core inspections at Heysham 1 Reactor 2 2018 periodic shutdown are acceptable and do not challenge safe operation. I judge that this is a claim that has been adequately demonstrated. 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.

69. The Licensee has carried out a scope of inspection and trepanning that satisfies its safety case commitments and demonstrates that the extent of bore cracking is consistent with expectations. Thirty-six specimens have been trepanned from the core during this shutdown, which exceeds the minimum safety requirement by six specimens. The trepanned specimens will be analysed in due course and will provide further data informing the current weight loss predictions. Sixteen fuel channels were visually inspected and the bore measurements from fifteen fuel channels were taken during the outage. A control rod channel was also visually inspected and did not reveal any defects at the bore. The inspections of the fuel channel and control rod channel bores are well within the safety case requirements and support the claim that the core condition does not challenge safe operation. In my assessment, I also consider that the 12% active core weight loss limit is unlikely to be reached until 2020 at the earliest. The licensee recently submitted a safety case to ONR to seek agreement to increase this limit to 17%. At the time of my assessment, this safety case was being considered by an ONR fault studies specialist.

70. In my opinion, the graphite core inspections results are within the bounds of NGL's safety case and do not present any impediment to return to service of HYA R2. I have no objection to the subsequent PAR recommending that consent is given to return Heysham 1 Reactor 2 back to service.

5.2 Recommendations

71. To ONR Project Inspector:

- Recommendation 1: Based on my assessment of the Heysham 1 Reactor 2 2018 Graphite Core Inspection Results and Justification for Return to Service, I have not found any reason to prevent me recommending that consent is given to Heysham 1 Reactor 2 return back to service.
- Recommendation 2: At the time of my assessment, an Independent Nuclear Safety Assessment certificate was not available. The Project Inspector should therefore ensure that this certificate is available and in agreement with the views in the Engineering Change document.
- Recommendation 3: that the PAR reflects that the current limit of 12% associated with steam-ingress reactivity faults could be reached in 2020 and that NGL has submitted a revised safety case, which will require ONR's approval, to raise this limit from 12% to 17%. NGL has also introduced a new

graphite weight loss methodology which needs to be discussed in a level 4 meeting being planned with NGL.

6 REFERENCES

1. NP/SC 7570 Heysham 1 (HYA) and Hartlepool A (HRA) Graphite Core Safety Case – Version 02, July 2012. (TRIM 2012/412486).

2. NP/SC 7623 Version 04 AGR Core safety case for 43% graphite weight loss for HPB, HNB, HYA, HRA September 2013 Verified 18 July 2013. (TRIM 2013/334877).

3. EC 354994 & 354995, Heysham 1 and Hartlepool: More Flexible Inspection Requirements for the Graphite Core. (TRIM 2015/142871).

4. EC 363869, version 02, Justification for the Return to Service of Heysham 1 Reactor 2 following the Graphite Core Inspections at the 2018 Periodic Shutdown, TRIM 2018/259075.

5. ONR HOW2 Guide NS-PER-GD-014 Revision 4 - Purpose and Scope of Permissioning. July 2014. http://www.onr.org.uk/operational/assessment/index.htm

6. Safety Assessment Principles for Nuclear Facilities. 2014 Edition Revision 0. November 2014. http://www.onr.org.uk/saps/saps2014.pdf

7. Graphite Reactor Cores NS-TAST-GD-029 Revision 3. ONR. July 2014 http://www.onr.org.uk/operational/tech_asst_guides/index.htm

8. Guidance on Mechanics of Assessment within the Office for Nuclear Regulation (ONR) – TRIM Reference 2013/204124

9. Summary Channel Bore Measurements - HYA-R2-18-INS-00 Rev 1. (TRIM 2018/248173).

10. FNC 53835-015 95016V, Updated ACWL Forecasts for Heysham A Using Latest Available Trepanning Data. (TRIM 2017/106361).

11. FNC 53835-040-102713V. Graphite Weight Loss Calibration and Forecasts for HYA R2. (TRIM 2018/249694).

12. EDF - Hartlepool - NSLHRA51166R - LC 22(1) - NP/SC 7474 Addendum 2 Hartlepool/Heysham 1 Power Station Extension of the Safety Case for the Reactivity Effects of Boiler Tube Failure Faults to end of station Life (EC346746) - 30 April 2018. (TRIM 2018/180466).

13. Quintessa Pre-inspection statistical report. Graphite. Heysham A. 2018. QRS-3007N-11v1.0 with TR (HYA R2 Jul2018 pre). (TRIM 2018/247897).

14. DAO/REP/JIEC/333/AGR/18 Rev000. A Statement of Expectations for the Channel Bore Measurement of Fuel Channels during the Planned 2018 Core Inspections. February 2018. (TRIM 2018/248195).

15. Heysham 1 R2 2018 Periodic Shutdown Intentions document. (TRIM 2018/232534).

16. Graphite Assessment Panel (GAP) Sheets & Minutes. Heysham 1 (HYA) R2 2018 Graphite Inspections. (TRIM 2018/247381).

17. RE: HYA R2 Graphite Inspection Update & statistical pre-inspection report. 2018. (TRIM 2018/249089).

18. RE: HYA R2 Graphite Inspection Update & statistical pre-inspection report. (TRIM 2018/249474).

19. EDF - Hartlepool - NSLHRA51166R - LC 22(1) - NP/SC 7474 Addendum 2 Hartlepool/Heysham 1 Power Station Extension of the Safety Case for the Reactivity Effects of Boiler Tube Failure Faults to end of station Life (EC346746) - 30 April 2018. (TRIM 2018/180466).

20. RE: HYA R2 return to service: Active Core W.L. limits. (TRIM 2018/247472).

21. HYA R2 RTS: GWL limits on HYA reactors. (TRIM 2018/231579).

22. RE: HYA R2 return to service: Active Core W.L. limits. 03/08/2018. (TRIM 2018/255082).

23. ONR Assessment Rating Guide Table – TRIM Reference 2016/118638.

Table 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. 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.

Table 2

Summary of Inspection Findings

Channel	Central/Edge	New/Repeat	Cracked Brick Observations
B23	Edge	New	Layer 11: One short axial crack and one full-circumferential crack Layer 8: One full-height axial crack
D15	Central	Repeat (2008)	Layer 10: One full-circumferential crack, one full-height axial crack and one short axial crack
F05	Edge	New	None
F25	Central	New	Layer 9: One full-height axial crack
G17	Central	New	None
G29	Central	New	Layer 9: One full-circumferential crack
L05	Central	Repeat (2015)	None
L15	Central	New	None
L21	Central	Repeat (1988)	None
M29	Central	New	Layer 10: One short axial crack
M39	Central	Repeat (2015)	None
N23	Central	New	Layer 10: One full-height axial crack
R15	Central	New	None
R27	Central	New	None
U29	Central	Repeat (2008)	None
W21	Edge	New	Layer 10: One full-height axial crack
CR N22	Control Rod	New	None

Table 3

Summary of Fuel Channel Bore Measurements

CBM Results Summary

Channel	'Mid Brick' Layer 7 Diameter* (mm)	*Shrinkage* (%)*	Brick End Minimum Diameter* (mm)	*Maximum Shrinkage* (%)*	*Minimum Diameter Layer**	Maximum Ovality** (mm)	Maximum Brick Bow*** (mm)	Maximum Channel Bow*** (mm)	Maximum Channel Tilt*** (mm)
B23****	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D15	264.7	2.0	261.7	3.1	6	1	0	4	9
F05	265.8	1.6	262.6	2.7	7	1	**3**	6	10
F25	265.2	1.8	262.0	3.0	6	0	1	2	5
G17	264.2	2.2	261.5	3.2	7	0	1	4	7
G29	264.1	**2.2**	261.4	3.2	7	0	1	1	4
L05	264.6	2.0	261.7	3.1	10	1	1	6	11
L15	264.8	1.9	261.5	3.1	9	0	1	**6**	6
L21	264.3	2.1	261.3	**3.2**	8	0	0	5	7
M29	264.6	2.0	261.9	3.0	9	0	1	3	5
M39	264.6	2.0	261.7	3.1	6	1	1	5	10
N23	264.4	2.1	261.7	3.1	7	0	1	5	5
R15	264.8	1.9	261.6	3.1	8	0	0	6	12
R27	264.9	1.9	261.7	3.1	6	0	1	6	10
U29	264.9	1.9	261.4	3.2	9	1	1	5	11
W21	265.4	1.7	262.6	2.7	8	**2**	2	4	**15**
Average (central)	**264.6**	**2.0**	**261.6**	**3.1**		**1**	**1**	**5**	**8**
Standard Deviation (central)	0.3	0.1	0.2	0.1		0	0	2	3
Average (Single edge)	**265.4**	**1.7**	**262.6**	**2.7**		**2**	**2**	**4**	**15**
Standard Deviation (Single edge)	N/A	N/A	N/A	N/A		N/A	N/A	N/A	N/A
Average (Double edge)	**265.8**	**1.6**	**262.6**	**2.7**		**1**	**3**	**6**	**10**
Standard Deviation (Double edge)	N/A	N/A	N/A	N/A		N/A	N/A	N/A	N/A

Cells highlighted contain the maximum values

Cells highlighted refer to single edge channels

Cells highlighted refer to double edge channels

* Diameter data is taken from the North files only

** Ovality is the maximum value taken from all available scans

*** Bow /Tilt data is the maximum from all available and appropriate files/from at least three independent scan pairs.

**** Channel B23 measurement data was not acceptable and can not be used in this report.

Table 4

Bore Measurements and Expected Values

Parameter	**Historical maximum expected value**	**Maximum value set**	**Measurements from current inspections**
New singly axially cracked bricks	N/A	Up to 8	4
New doubly axially cracked brick	N/A	Up to 4	2
Maximum mid-brick shrinkage in a peak-rated layer	2.04%	4.1%	3.2%
Brick ovality for central channels	1.75mm	5mm	1mm
Brick ovality for edge channels	2.84mm	5mm	2mm
Brick bow for central channels	0.80mm	1.5mm	1mm
Brick bow for edge channels.	1.83mm	5mm	3mm
Channel bow for central channels	8.3mm	14mm	6mm
Channel bow for edge channels	5.6mm	14mm	6mm
Channel tilt for central channels	13.5mm	None applied	12mm
Channel tilt for edge channels	13.6mm	None applied	15mm