Office for Nuclear Regulation

| ASSESSMENT REPORT | | | |
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† *Where required in accordance with ONR How2 BMS Document NS-TAST-GD-085 Revision 6*
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**Operating Facilities Programme**

# Heysham 1 Reactor 1 2017 Periodic Shutdown - Assessment of the Results of the Graphite Core Inspections

Assessment Report ONR-OFP-AR-16-069
Revision 0
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## EXECUTIVE SUMMARY

During the 2017 Heysham 1 Reactor 1 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 1 2017 periodic shutdown are acceptable and do not challenge safe operation. I judge that this is a claim that has been adequately demonstrated. I also note that the Independent Nuclear Safety Assessor is in agreement.

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. 36 specimens have been trepanned from the core during this shutdown, which exceeds the minimum safety requirement by 6 specimens. The trepanned specimens will be analysed in due course and will provide further data informing the current weight loss predictions. 17 channels were measured and visually inspected, which is 7 more measured channels than required by the safety case and provides confidence that the safety case requirement of 60 visually inspected channels over a 3 year period can be achieved. The inspections of the fuel channel bores support the claim that the core condition does not challenge safe operation.

The current safety case places a limit on the active core weight loss of 12% which means Heysham 1 Reactor 1 cannot operate beyond 12900GWd, which equates approximately to the end of 2019 and is prior to the next scheduled periodic shutdown in May 2020. To provide for the opportunity of securing operation beyond this limit, NGL must proceed with its current plan to submit to ONR during 2017 a justification to increase the 12% limit.

To conclude, I am satisfied with the claims, arguments and evidence presented by the Licensee in respect of the present condition of the graphite core in Reactor 1 at Heysham 1 power station. I have therefore assigned an ONR assessment rating of green.

I have found no impediment, in terms of graphite structural integrity, to ONR granting consent to return to service.

## LIST OF ABBREVIATIONS

| | |
|---|---|
| EC | Engineering Change document |
| GCPT | NGL Graphite Core Project Team |
| HOW2 | ONR HOW2 Business Management System |
| HYA | Heysham 1 Nuclear Power Station |
| INSA | Independent Nuclear Safety Assessor |
| LC | Licence Condition |
| NICIE | New In-Core Inspection Equipment Mark 2 |
| NGL | EDF-Energy Nuclear Generation Limited |
| ONR | Office for Nuclear Regulation |
| R1 | Reactor 1 |
| SAP | Safety Assessment Principle(s) |
| TAG | Technical Assessment Guide(s) (ONR) |

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### Table(s)

# 1 INTRODUCTION

1 During the 2017 Heysham 1 (HYA) Reactor 1 (R1) periodic shutdown, the graphite reactor core has undergone surveys, as required by the graphite core safety case [1, 2 & 3]. The Licensee, EDF-Energy Nuclear Generation Limited (NGL), has produced an Engineering Change document (EC) [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 R1 is set out below:

- TV inspections of 60 fuel channels per station every three years.
- Channel bore measurement inspections of 10 fuel channels at every periodic shutdown (3-yearly) on each core.
- Trepanning of a minimum of 30 samples, with a target of 36 samples from at least 6 fuel channels, subject to reasonable practicability, at every periodic shutdown (3-yearly).
- TV inspection of 1 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).

## 1.1 Background

4 This report assesses the findings of the graphite core inspections of HYA R1 during the 2017 periodic shutdown, which are presented in the EC [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 guide NS-PER-GD-014 [5]. The ONR Safety Assessment Principles (SAP) [6], together with supporting Technical Assessment Guides (TAG) [7], have been used as the basis for this assessment.

## 1.2 Scope

5 The scope of this report covers the extent to which the results of the visual and dimensional graphite core inspections from the HYA R1 2017 periodic shutdown challenge the graphite safety case. Assessment of these results will culminate in a recommendation to ONR on the decision to consent a return to service of HYA R1.

## 1.3 Methodology

The methodology for the assessment follows HOW2 guidance on mechanics of assessment within the ONR [8]. This assessment has been focussed primarily on the results of the graphite core inspections during the HYA R1 2017 periodic shutdown as detailed in the EC [4].

# 2 ASSESSMENT STRATEGY

6 The intended strategy for assessment of the EC 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

7 The relevant standards and criteria adopted within this assessment are principally the SAPs [6], relevant national and international standards and relevant good practice informed from existing practices adopted on UK nuclear licensed sites.

## 2.2 Safety Assessment Principles

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

## 2.3 Out of Scope Items

9 The following items are outside the scope of the assessment.

10 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 the GCPT.

## 3 LICENSEE'S SAFETY CASE

11 During the HYA R1 periodic shutdown inspections were performed within selected channels of the graphite core to determine:

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

12 This assessment compares the first three of these results above against relevant sections of the HYA graphite core safety case [1, 2 & 3] to determine whether they pose any challenge to the return to service of HYA R1 for a further three years of operation. Results from item 4 above 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. The relevant limits of the graphite core safety case are summarised below:

- The current estimate of stress reversal for the graphite bricks at HYA R1 is not before 12600GWd. The current core burn-up for reactor 1 is 11491GWd, the approximate annual rate of burn-up is 500GWd, and therefore, there is significant margin to the predicted onset of stress reversal. Furthermore, the current safety case is valid up to the predicted onset of keyway root cracking predicted at a core burn-up not before 14400GWd.
- 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.
- Currently the most limiting graphite weight loss limit is the average core weight loss and is 12% mean weight loss in the active core [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 Heysham trepanning campaigns [2]. However, as part of the EC, NGL have revised the weight loss forecasts with samples up to and including the 2015 Heysham trepanning campaigns [9]. The revised predictions forecast that the 12% weight loss limit will be reached at a burn-up of 12900GWd, and estimates that this will be reached by the end of 2019, which is before the next scheduled periodic shutdown planned for May 2020. NGL has stated as part of the EC that during 2017 NGL will propose an increase in the 12% limit to 17%. NGL currently forecast that the 17% limit will be reached by a burn-up of 17050GWd [9], which equates to 2027 [4] and is well beyond the May 2020 periodic shutdown.

13 In addition to the limits within the graphite core safety case, I note that NGL produce reports detailing it's expectations of the graphite core inspections based on the results of previous inspections [10 & 11]. 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 one or two new singly axially cracked bricks and up to one new doubly axially cracked brick will be found. Up to 7 new singly axially cracked bricks and up to 2 new doubly axially cracked bricks would be in-line with expectations.
- Maximum expected brick ovality is 1.1mm for central channels and 2.4mm for edge channels based on the historical maximum observed ovality in 2013. An ovality of >5mm would challenge understanding.
- The maximum mid-brick shrinkage for a central channel is expected to be 1.89% ±0.42. The maximum observed shrinkage thus far being 1.94% in 2013. A mid-brick shrinkage of >4.1% would challenge understanding.
- Maximum expected brick bow is 0.87mm for central channels and 2.17mm for edge channels, based on the maximum historically observed brick bow in 2013. A brick bow of >1.5mm for central channels and >5mm for edge channels would challenge understanding.
- Maximum expected channel bow for central and edge channels is 6.4mm and 4.4mm respectively based on the maximum historically observed channel bow in 2004 for central channels and 2010 for edge channels. A channel bow of >14mm would challenge the understanding.
- Channel tilts have no implications for fuel stringer movements by themselves. However, the maximum expected channel tilt for central and edge channels is 12.6mm and 9.3mm respectively based on the maximum historically observed channel tilt in 2013 and 2010 respectively.

## 4 ONR ASSESSMENT

14 This assessment has been carried out in accordance with HOW2 guide NS-PER-GD-014, “Purpose and Scope of Permissioning” [5].

### 4.1 Scope of Assessment Undertaken

15 The scope of the assessment covers the extent to which the results of the visual and dimensional graphite core inspections at HYA R1 2017 periodic shutdown challenge the existing graphite core safety case [1, 2 & 3]. The assessment of these results will culminate in a recommendation to ONR on the decision to consent to the return to service of HYA R1.

### 4.2 Assessment

#### 4.2.1 Remote Visual Inspections

16 Seventeen fuel channels and one control rod channel were inspected, which is consistent with the Maintenance Schedule requirements. All 17 fuel channels were inspected visually and measured dimensionally using the New In-Core Inspection Equipment Mark 2 (NICIE) tool. Inspection of an eighteenth channel had been attempted, channel 1W23, but inspections encountered problems with the NICIE hoist and subsequently only achieved 2 out of the 6 scans required for a complete inspection of that channel. Subsequently, NGL have not counted channel 1W23 as part of the inspected channels, but inspection of the channel has been recorded and processed through the Graphite Assessment Panel (GAP). I have recorded the findings of the graphite inspections under Trim reference 2017/105369 [12] and included a summary of the inspection findings in Table 2.

17 Pre-shutdown expectations were that it was most likely that 1 or 2 new singly axially cracked bricks and up to one doubly axially cracked brick would be found. This is entirely consistent with the finding of 2 new singly axially cracked bricks and no doubly axially cracked bricks.

18 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. However, NGL claim the full height axial cracks observed in channel 1L41 and 1M31 indicate the bricks are not significantly beyond stress reversal, if at all. 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’s claim is reasonable.

19 When I take in to account 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 provide a challenge to the safety case.

#### 4.2.2 Channel bore measurements

20 Channel bore measurements cover brick shrinkage, bore ovality, brick bow, channel bow and channel tilt. These quantities are compared to expectations published prior to the inspection [11] and against levels that would challenge understanding, see Section

3. I have reviewed the inspections findings [12] and I am content that the findings support the argument made by NGL that the measured core, channel and brick distortions are within expectations and do not present a challenge to safe operation.

### 4.2.3 Trepanning Campaign

21 Thirty-six specimens were trepanned from six fuel channels (1F31, 1G11, 1L13, 1M31, 1R33 and 1S13), this exceeds the minimum requirements of the safety case and meets NGL's target. The results from the trepanned specimens will add further insight into the through thickness weight loss behaviour of the graphite, and help to inform future models predicting the rate of whole core graphite weight loss.

### 4.2.4 Graphite Weight Loss

22 The current safety case limit for the active core weight loss is 12%, which is predicted to be reached at a core burn-up of 12900GWd, or approximately by the end of 2019. I note the weight loss limit will subsequently be reached before the next scheduled periodic shutdown in May 2020. Therefore operation beyond 12% active core weight loss must be supported by an appropriately permissioned modification to the existing safety case. NGL has stated in the EC [4] that work is underway to increase the 12% limit to 17% and will be presented in a safety case before the end of 2017. 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.

### 4.2.5 Completion of the periodic shutdown related documentation

23 I have assessed the EC [4] that summarises the results of the graphite inspections at HYA R1 during the 2017 periodic shutdown and reviewed the INSA statement [13]. I have compared the inspection findings with the current graphite safety case [1, 2 & 3] and assessed them against the relevant SAPs [6]. Overall, the EC makes the single claim that 'the results of the graphite core inspections at the Heysham R1 2017 periodic shutdown are acceptable and do not challenge safe operation'. I judge that this is a claim that has been adequately demonstrated. I also note that the Independent Nuclear Safety Assessor is in agreement. Furthermore, I confirm that the graphite inspection requirements of the safety case have been met.

## 4.3 ONR Assessment Rating

24 I consider the graphite core maintenance schedule commitments have been met. I am satisfied with the claims, arguments and evidence presented by the Licensee in respect of the present condition of the graphite core in Reactor 1 at Heysham 1 power station. I have therefore assigned an ONR assessment rating of green in accordance with the ONR assessment rating guide [14].

# 5 CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

25 This report presents the findings of the ONR assessment of 'Justification for the Return to Service of Heysham 1 Reactor 1 following the Graphite Core Inspections at the 2017 Periodic Shutdown' [4].

26 To conclude, I am satisfied with the claims, arguments and evidence laid down within EC [4]. NGL has carried out a scope of inspection and trepanning that are its safety case commitments. The extent of bore cracking shown by the HYA R1 core inspections in 2017 is consistent with expectations. HYA R1 lags other, older, AGR reactors in terms of neutron dose and would not be expected to show evidence of stress reversal.

27 The current safety case places a limit on the active core weight loss of 12% which means HYA R1 cannot operate beyond 12900GWd, which equates approximately to the end of 2019 and is prior to the next scheduled periodic shutdown in May 2020. To provide for the opportunity of securing operation beyond 2019, NGL must proceed with its current plan to produce a safety case to increase the 12% operating limit.

28 I attach an assessment rating of green as I consider the safety case commitments to have been met and the claim to be supported by the inspection evidence.

29 I have found no impediment, in terms of graphite structural integrity, to ONR granting consent to return to service.

## 5.2 Recommendations

30 My recommendations are as follows.

31 Recommendation 1: I recommend the project inspector provides consent to the return to service of Reactor 1 of Heysham 1 power station.

## 6 REFERENCES

1. NP/SC 7570 Heysham 1 (HYA) and Hartlepool A (HRA) Graphite Core Safety Case – Version 02, [redacted], 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, [redacted], *TRIM 2013/334877*.

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

4. EC 360346 version 02, Justification for the Return to Service of Heysham 1 Reactor 1 following the Graphite Core Inspections at the 2017 Periodic Shutdown, TRIM *2017/120780*.

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, 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 2013/204124*.

9. FNC 53835-015 95016V, Updated ACWL Forecasts for Heysham A Using Latest Available Trepanning Data, [redacted] & [redacted], *TRIM 2017/106361*.

10. QRS-3007M-2, Application of Statistical Models for Brick Cracking to Heysham 1 R1Inspections in February 2017, Pre-Inspection Report, *TRIM 2017/105338*.

11. DAO/REP/JIEC/310/AGR/17, A Statement of Expectations for the Channel Bore Measurement of Fuel Channels during the Planned 2017 Core Inspections, January 2017, *TRIM 2017/105332*.

12. Heysham 1 Reactor 1 Graphite Inspection Results 2017. *TRIM 2017/105369*.

13. Independent Nuclear Safety Assessor Statement for EC 360346 version 02, 22/3/17, [redacted]. *TRIM 2017/120806*.

14. ONR Assessment Rating Guide Table – *TRIM 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:**<br>**Safety case** | The safety case should demonstrate that either:<br>a) the graphite component or structure is free of defects that could impair its safety functions;<br>OR<br>b) the safety functions of the graphite components or structure are tolerant of those defects that might be present. |
| EGR.4 | **Engineering principles: graphite components and structures: design**<br>**Inspection and surveillance** | Features should be provided to:<br>a) facilitate inspection during manufacture and service; and of materials behaviour.<br>b) permit the inclusion of surveillance specimens for monitoring |
| EGR.15 | **Engineering principles: graphite components and structures: examination, inspection, surveillance, sampling and testing**<br>**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 Inspections Findings

| Channel | Central/Edge | New/Repeat | Cracked Brick Observations |
|---|---|---|---|
| 1F15 | Central | New | No cracked bricks |
| 1F31 | Central | Repeat from 2006 | No cracked bricks |
| 1G07 | Central | Repeat from 2006 | Layer 10: two short partial circumferential cracks (new since 2006)<br>Layer 9: one short partial axial crack with a branch (new since 2006) |
| 1G11 | Central | Repeat from 2006 | No cracked bricks |
| 1G23 | Central | New | No cracked bricks |
| 1J33 | Central | New | No cracked bricks |
| 1L13 | Central | New | No cracked bricks |
| 1L41 | Edge | Repeat from 2007 | Layer 10: one full height axial crack (new since 2007) |
| 1M03 | Edge | Repeat from 2007 | No cracked bricks |
| 1M19 | Central | New | Layer 9: one partial lasso crack<br>Layer 8: one partial circumferential crack |
| 1M31 | Central | New | Layer 10: one full height axial crack |
| 1P11 | Central | New | No cracked bricks |
| 1R21 | Central | New | No cracked bricks |
| 1R33 | Central | Repeat from 2006 | No cracked bricks |
| 1R37 | Central | Repeat from 2006 | No cracked bricks |
| 1S13 | Central | Repeat from 2006 | No cracked bricks |
| 1S29 | Central | New | No cracked bricks |