Office for Nuclear Regulation

ONR Assessment Report

Heysham 2 and Torness – EC 371321 / 371221 Long Term KWR Cracking Safety Case Graphite Assessment

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Project Name: Heysham 2 and Torness

Report Title: EC 371321 / 371221 Long Term KWR Cracking Safety Case Graphite Assessment

Authored by: [redacted]

Report Issue No: 01

Document ID: ONRW-2126615823-2466

Publication Date: April 24

Executive Summary

EdF NGL, the Licensee, has prepared a new safety case, EC 371321/371221, justifying the damage tolerance of the graphite cores at Heysham 2 (HYB) and Torness (TOR) with greater levels of core damage than the existing case NP/SC 7810.

The case is needed because the lead reactors at HYB and TOR are approaching the core-burn up limit [redacted] This report contains my assessment of EC 371321/371221 safety case.

My assessment will feed into a decision on whether the hold point against the implementation of EC 371321/371221 can be lifted. My view will be combined with assessment from Fault Studies and External Hazards to form a holistic view of the risks posed by operation to a higher core burn-up and by implication a higher number of keyway root (KWR) cracked bricks.

I have assessed, from a graphite structural integrity perspective, whether the licensee has provided sufficient justification why cracking of the fuel bricks, within the levels anticipated by EC 371321/371221, will not degrade the safe shut down margins or the protection systems.

From this assessment I have made the following key observations.

- The licensee has built upon the analysis methods and arguments within NP/SC 7810. I have reviewed the developments made by the licensee based on improved knowledge. I am content that the licensee has deployed appropriate analysis approaches to evaluate the response of the graphite cores at HYB /TOR to higher levels of core burn-up.

- [redacted] Therefore I am content that the licensee has considered a core state which is conservative within the limits of EC 371321/371221.

- The licensee acknowledges that the analysis of the response of the core state is based upon judgements and have conducted a suite of sensitivity studies that the licensee claims will evaluate these uncertainties. I am content that the licensee has completed sufficient sensitivity studies to reveal and characterise the dominant uncertainties in the supporting analyses. I am content that these sensitivity studies do not undermine the claims, arguments within EC 371321/371221.

- There is the possibility that the core state that evolves will differ from that assumed in the analyses which underpin EC 371321/371221. To mitigate this uncertainty, the licensee will make regular inspections to monitor the graphite degradation process and check the safety case assumptions against the inspection observations [redacted]. I am content that the licensee plans will reveal deviations from the assumed degradation in a timely manner.

- I have considered the effect of core distortion on the levels of fuel sleeve gapping within the core, and I am content that these levels are below the total and individual limits prescribed. The consequences of the estimated fuel sleeve gapping will be assessed by the Fault Studies inspector.

- I have reviewed the potential for interstitial brick gapping as a result of normal operation and frequent faults and hazards. I have noted that the licensee has included the retarding effect of creep within its estimation of interstitial brick gapping. I am of the view that creep is a complex topic and is difficult to validate in this context and hence I am of the opinion it can't be supported. [redacted] The Fault Studies inspector considered this increase and was content it would not have a meaningful reduction in the claimed capability of the SSD system.

- During my assessment of EC 371321/371221 the licensee identified errors within the supporting analyses which could affect the results underpinning this case. The licensee was content that any impact would be minimal, referencing a sensitivity study, but has also commissioned an additional GCORE sensitivity study to confirm this position. I was content that the licensee's position was reasonable noting the results of the original sensitivity study. Within the period before the new sensitivity results will be reported (~2 months) I am content that the amount of additional cracking accumulated will be insignificant and not pose a risk to the shutdown capability. Hence, I view that it is not proportionate to delay this assessment until this new sensitivity study is completed. To track and manage this uncertainty have raised a recommendation, captured within ONR Issue 11953, which will be discussed during routine regulatory engagements.

To conclude, I am satisfied, from a graphite integrity perspective, the licensee has provided an adequate safety case demonstrating the safety of its operations. I have no objection to the implementation of EC 371321 / 371221. [redacted], it will be necessary to monitor inspection results to ensure that the evolution of the core state remains broadly in line with the assumed evolution used within EC 371/321 / 371221. I am content this will occur through routine regulatory interactions.

Recommendations

To track and manage the uncertainty caused by the additional GCORE sensitivity study I have raised the following recommendation which is captured within ONR Issue 11953 and will be managed through routine regulatory interactions.

- The licensee should share the new HYB/TOR GCORE analyses completed as a result of the brick temperature and channel spigot / recess capacity errors. The licensee should also confirm that these new results do not undermine the claims and arguments presented within EC 371321/371221.

- The licensee should conduct an additional sensitivity study (similar to that completed for the HRA/HYA DTA) to confirm the judgement that the failure of interstitial brick spigot/recess connections does not meaningfully impact the claim on control rod insertion.

List of Abbreviations

ALARP	As low as is reasonably practicable
AGR	Advanced Gas-cooled Reactor
CTE	Coefficient of Thermal Expansion
DCB	Doubly Cracked Brick
DTA	Damage Tolerance Assessment
DTB	Damage Tolerance Boundary
DU	Distortion Utilisation
FEA	Finite Element Analysis
GAP	Graphite Assessment Panel
GTAC	Graphite Technical Advisory Committee
EIM	EDF Integrated Methodology
HNB	Hunterston B
HOW2	ONR's Management System Platform
HSE	Health and Safety Executive
HPB	Hinkley Point B
HYB	Heysham 2
IAEA	International Atomic Energy Agency
INSA	Independent Nuclear Safety Assessment
JPSO	Justified Period of Safe Operation
KWR	Keyway Root
LSK	Layer Spanning Key
MCB	Multiply Cracked Brick
NSI	Nuclear Safety Issue
ONR	Office for Nuclear Regulation
PCPV	Pre-stressed Concrete Pressure Vessel
PSD	Primary Shut Down
RGP	Relevant Good Practice
RTD	Run Time Damage
SAP	Safety Assessment Principle(s)
SCB	Singly Cracked Brick
SR	Seal Ring
SRGW	Seal Ring Groove Wall
SSD	Secondary Shut Down
TAG	Technical Assessment Guide(s) (ONR)
TOR	Torness
TQ	Technical Query
TSC	Technical Support Contractor
TSD	Tertiary Shut Down
TWd	Terra Watt day

Contents

1. Introduction

1. EDF Energy Nuclear Generation Limited, known hereon as the licensee, justifies the damage tolerance of the graphite cores at Heysham 2 (HYB) and Torness (TOR) power stations through the existing Category 1 safety case NP/SC 7810 [1]. [redacted]

2. The licensee has prepared a new safety case, EC 371321 / 371221 [2], justifying the damage tolerance of the graphite cores [redacted] there will continue to be a margin between the anticipated core stated and that which has been shown to be tolerable, otherwise known as a Justified Period of Safe Operation (JPSO).

3. EC371321 / 371221 builds upon arguments and evidence presented within NP/SC 7810 and it will act as an overarching safety case along with the seal ring groove wall (SRGW) debris safety case (NP/SC 7819 [3]) and the graphite weight loss safety case [4]. Operational limits will not be set directly by these safety cases but rather an operational safety case will be written following each graphite inspection. The operational case will use the latest graphite core inspection results to predict, to a statistical high confidence, the core state at the end of a proposed operating period and show margin to the limitations within NP/SC 7819 (SRGW), EC371321 / 371221 (Damage Tolerance) and EC 371193 / 371194 (Weight Loss).

4. My assessment has focused on the graphite structural integrity related aspects of EC 371321/371221. Specifically, I have assessed, from a graphite structural integrity perspective, whether the licensee has adequately described the impact of graphite degradation on the performance of the primary and secondary shut down systems. Using this assessment I have formed a judgement on whether the licensee has produced an adequate safety case as laid down by Licence Condition (LC) 23(1).

1.1. Background

5. The graphite core of Advanced Gas-cooled Reactors (AGRs) is made of a large number of graphite bricks used as a moderator, structural components and neutron reflectors in the peripheral regions of the core (Figure 1). As graphite is irradiated in the reactor, it experiences dimensional changes due to the effects of irradiation on the internal structure of graphite. [redacted]

[redacted]

[redacted] [redacted]

7. ONR has an expectation that during normal operation and all design basis faults and hazards the reactor can be shut down and held down in a safe manner. The Primary Shut down System (PSD) is through the insertion of control rods into dedicated interstitial channels, known as control rod channels. These act to absorb the neutrons within the core and stop the nuclear chain reaction. The licensee can also inject nitrogen and or boron beads into dedicated interstitial channels to perform a similar function. These are known as secondary (SSD) and tertiary (TSD) shut down systems

respectively. The SSD and TSD are only deployed if the PSD has failed to perform as required.

8. For normal operation, frequent faults and non seismic related hazards the licensee claims protection through the PSD and SSD. For a design basis seismic event the licensee claims protection through the PSD only. For design basis seismic event, as the consequences of the PSD failing to perform are intolerable, the ONR has the expectation that all of the control rods go all the way in, all of the time.

[redacted]

[redacted]

1.2. Scope

11. This report covers my assessment of the graphite related aspects of licensee's safety case in NP/SC 7810 [1] for the graphite cores at HYB and TOR power stations.

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

- Consideration of SRGW debris on fuel movement which has been considered as part of ONR's assessment of NP/SC 7819 [3].

2. Assessment Standards and Interfaces

13. This section identifies the scope of the assessment and the standards and criteria that have been applied.

2.1. Standards

14. The relevant standards and criteria adopted within this assessment are principally the Safety Assessment Principles (SAP) [6], internal ONR TAGs, 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. National and international standards and guidance have been referenced where appropriate within the assessment report. Relevant good practice, where applicable, has also been cited within the body of the assessment.

2.2. Safety Assessment Principles (SAPs)

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

2.3. Technical Assessment Guides (TAGs)

16. The following TAG has been used as part of this assessment [7]:

- ONR-TAST-GD-029 Revision 4 Graphite Reactor Cores

2.4. National and International Standards and Guidance

17. 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 my assessment.

2.5. Integration with Other Assessment Topics

18. My assessment forms part of the ONR's decision on whether to agree to EC 371321/371221 [2]. This assessment integrates with the external hazards and fault studies assessment topics.

19. The licensee states that it has not changed the seismic input motion or Pre-stressed Concrete Pressure Vessel (PCPV) buildings model. ONR has decided that an assessment of these aspects within EC 37132/371221 by External Hazards or Civil Engineering specialist inspectors is not necessary.

My assessment therefore interfaces with the previous External Hazards [8] and Civil Engineering [9] assessment of NP/SC 7810.

20. The external hazards assessment [10] of EC371321/371221 has considered the impact of the increased core burn-up on beyond design basis and lack of cliff edge whilst the fault studies assessment has drawn on my views with regard to the predictions of [redacted]

2.6. Use of Technical Support Contractors

21. As part of the ONRs ongoing regulation of AGR graphite core structural integrity, TSCs are utilised to develop modelling methods independent of the licensee and provide broader advice on graphite integrity. I have consulted with technical support contractors (TSCs) on current graphite issues at a number of meetings, and where TSCs have been consulted for this assessment, it has been made clear in the appropriate sections of this report.

22. The TSCs are statistical experts from the Health and Safety Executive, analytical and materials experts from the University of Manchester and the University of Birmingham and independent experts on the Graphite Technical Advisory Committee (GTAC).

3. Dutyholder’s Submission

3.1. Nuclear Safety Issues

23. The licensee claims that the specific nuclear safety issues (NSI) addressed by EC 371321 / 371221 [2] relate to the potential for fuel brick cracking and associated fragments and debris to:

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

3.2. Safety Case Structure

3.2.1. Principles

25. The license issued the first complete graphite core safety case for HYB / TOR within NP/SC 7663 . NP/SC 7663 justified the ability to shut down and hold down the nuclear reaction during a design basis seismic event whilst the core was essentially intact.

26. [redacted] Following the issuance of NP/SC 7663 the graphite weight loss aspects and damage tolerance has continued to be developed and operation has subsequently been justified through dedicated safety cases.

27. Due to infrequent nature of the design basis earthquake event only one line of protection is claimed by the licensee to shut down and hold down the nuclear reaction. This is the ability to insert all of the control rods, all of the way, all of the time. [redacted]

28. [redacted]

[redacted]

29. The licensee issued NP/SC 7810 [1] which removed the requirement for an essentially intact core. Instead, NP/SC 7810 introduced the concept of a Justified Period of Safe Operation (JPSO). The JPSO is a period of operation where there will remain adequate margin to the Damage Tolerance Boundary (DTB). The DTB is the core state at which the licensee believes it has demonstrated sufficient confidence that all of the control rods will go in all the way all of the time. This approach has been used across the AGR fleet.

30. [redacted]

31. [redacted]

32. The licensee is again providing evidence that at the older core age the impact of the DTB on the other aspects such as fuel cooling and SSD system performance is acceptable.

3.2.2. Claims and Arguments

33. Within EC 371321 / 371221 the following claims and arguments are presented:

- Claim 1: Robust Shutdown and Hold Down via the PSD is maintained with Increased Core Ageing and Distortion
    - Argument 1.1: Degradation of the core over an operating period can be predicted with allowance for uncertainties.
    - Argument 1.2: The damage tolerance of the core is established for normal operations and plant faults.

  - Argument 1.3: The damage tolerance of the core is established for seismic loading.
  - Argument 1.4: The integrity of the core restraint and core support structure, during normal operation and plant faults, and following a seismic event will be maintained.
  - Argument 1.5: An appropriate inspection strategy has been defined to inform predictions of core state.
  - Argument 1.6: Setting of valid operating periods will be carried out through successive operational safety cases.
  - Argument 1.7: There are appropriate monitoring techniques available to detect core distortion.

- Claim 2: Fuel and Core Component Cooling Remains Acceptable in Normal Operation, Fuel Handling and Faults including Seismic Hazards
  - Argument 2.1: Graphite core ageing will not be detrimental to core and fuel cooling flows.
  - Argument 2.2: Appropriate monitoring techniques are available to detect fuel cooling shortfalls.
  - Argument 2.3: Graphite core ageing will not significantly increase fuel handling risk.
  - Argument 2.4: Appropriate monitoring techniques are available to detect changes in channel geometry that would impede free movement of the fuel.

- Claim 3: Radiological Risk Remains ALARP
  - Argument 3.1: The SSD provides defence in depth against plant faults (i.e. non-seismic).
  - Argument 3.2: The inspection and monitoring strategy is consistent with reducing the risk to ALARP.
  - Argument 3.3: There are no additional reasonably practicable measures that can be taken to reduce the risk further.
  - Argument 3.4: The radiological risk associated with graphite core ageing is acceptable for operation to a core burn-up [redacted]

3.2.3. Safety Case Validity

34. It is stated by the licensee that EC 371321/371221 [2] is valid up to a burn-up of [redacted]

- [redacted]
    - [redacted]
    - [redacted]
- [redacted]
    - [redacted]
    - [redacted]
    - [redacted]

35. The licensee has noted that at the moment the forecasts for cracked brick opening contains a large degree of uncertainty as they do not filter out predictions, known as conditioning, which do not match the observed crack openings. The licensee plans to incorporate this capability within an upcoming update to CrackSim. Until this update has been implemented the licensee has stated that the forecasts will continue to be robust for at least 6 months beyond the next inspection point.

36. The licensee has considered the impact of debris on fuel movement as part the dedicated safety case considering SRGW debris (NP/SC 7819, [3]).

3.3. INSA

37. The licensee's Independent Nuclear Safety Assessment (INSA) accepted that the safety case EC 371321/371221 was consistent with their expectations .

3.4. Modelling Approaches

38. The licensee has used analytical models to predict the response to the degraded graphite core to design basis operation, faults and hazards. The following sub-sections describe the key inputs and approaches.

3.4.1. Core State

39. [redacted]

40. [redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]

41. [redacted]

42. [redacted]

43. [redacted]

44. [redacted]

3.4.2. Brick Temperatures

45. The stress analyses used a set of field variables from which the material property evolutions are estimated. The field variables are irradiation temperature, weight loss and dose. [redacted]

3.4.3. Material Properties / Keyway Clearances

46. [redacted]

47. [redacted]

48. [redacted]

49. [redacted]

50. [redacted]

51. [redacted]

3.4.4. AGRIGID

3.4.4.1. Generic Methodology

52. [redacted]

3.4.4.2. Modifications from NP/SC 7810

53. [redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

[redacted]

3.4.5. GCORE

3.4.5.1. Generic Methodology

54. [redacted]

3.4.5.2. Modifications from NP/SC 7810

55. [redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]

3.5. Distortion Metrics

56. [redacted]

3.5.1. Core Distortion

57. [redacted]

3.5.2. Fuel Sleeve Gapping

58. [redacted]

[redacted]

59. [redacted]

- [redacted]

- [redacted]

- [redacted]

60. [redacted]

3.5.3. Interstitial Brick Gapping

61. At HYB / TOR, the licensee states that if insufficient control rods enter the core when a reactor trip is demanded the Secondary Shutdown (SSD) system is activated. It is claimed that the SSD system provides a second line of protection against frequent faults and hazards, and to provide defence in depth.

62. [redacted]

63. [redacted]

- [redacted]

- [redacted]

64. [redacted]

- [redacted]
- [redacted]
- [redacted]

4. ONR Assessment

4.1. Assessment Strategy

65. [redacted]

66. To form a judgement under the expectations of LC 23(1) and whether the licensee has produced an adequate safety case I have considered the relevant NSIs repeated in Section 3. To determine which areas, in my opinion, represent the greatest risk to nuclear safety. I have chosen to focus on the ability to shut down and hold down during all foreseeable events (e.g. design basis). This includes consideration of those aspects of graphite ageing that could affect the operation of the PSD and SSD.

67. Failure of the PSD system during an infrequent seismic event would lead to intolerable consequences, hence a high level of confidence is required. The SSD is claimed as a second line protection system for normal operation and frequent faults. An aging graphite core could affect the speed at which the nuclear reaction is shut down. A delay in shutting down the core could challenge fuel clad temperature limits.

68. I am also interested in those aspects of graphite core degradation that will affect the cooling of the fuel. Cooling problems could be present for a period of time before any issues are detected. This could threaten the fuel clad integrity or fuel stringer tie bar temperature limits. I am interested in the calculation of potential distortions of the fuel element graphite sleeves. The consequence of any fuel cooling issues will be considered by the fault studies inspector.

69. As part of my graphite assessment of EC 371321/371221 [2] I have therefore focused on the following areas:

- Whether the licensee has adequately demonstrated that “all the rods will go in all the way all the time” such that confidence in the PSD can be taken for an infrequent (e.g. 1 in 10,000 year event) seismic event.

- Whether the licensee has adequately estimated the fuel sleeve gapping during normal operation and fault (excluding seismic events) such that the impact on fuel cooling can be determined.

- Whether the licence has adequately estimated the interstitial brick gapping within the SSD system channels such that the effect on the shut down and hold down can be evaluated.

- Whether, from a graphite perspective, the licensee has demonstrated risks from operation with a higher level of brick cracking remain ALARP.

70. To answer these points, I have targeted the models that the licensee has developed and the results which underpin the claims and arguments.

71. I note that that the licensee claims that the seismic input motion and PCPV buildings model has not changed within EC 371321/371221. Hence, I am focussing the response of the graphite core to the applied input motion.

4.1.1. Assumptions

72. The analyses being presented by the licensee utilise methods [redacted], which have already been considered by ONR . It is not my intention to re-open the assessment of the generic principles and the approaches developed by the licensee in those cases. Instead, I am focussing on those key differences which have been made to them for the since the implementation of NP/SC 7810.

4.1.2. Safety Case Coverage

73. There are a suite of safety cases which will justify continued operation with an ageing graphite core. If implemented EC 371321/371221 [2] will sit in parallel with NP/SC 7819 [3] and Weight Loss safety case [4] where the operational limits will be set to comply with the more onerous limitation of each case. It is important that all relevant risks have adequate safety case coverage to ensure operation is justified.

74. Whilst each safety case considers specific risks there is some overlap between NP/SC 7819 and EC 371321/371221, namely the evaluation of the risks from debris. It is important that these cases are clear on their own coverage and provide a link to the other cases so that any outstanding points are captured.

75. [redacted]

76. As part of the ONR assessment of NP/SC 7810 ONR raised the following recommendation which was captured within ONR Issue 10776:

> "To support the validation of the core distortion analyses in normal operation, the licensee should consider the benefits of measuring the bore diameter of the control rod channels at HYB /TOR. If it is deemed not appropriate to conduct these inspections the licensee should provide a robust ALARP argument."

77. Through routine engagements ONR received confirmation that it was the licensee's intention to collect channel bore measurement data from one control rod channel each statutory outage . With this information the issue was closed. The license had intended to complete the first activity at the HYB R8 outage in May of 2023 but difficulties within the control systems prevented this activity. The next opportunity will be the TOR R1 statutory outage in April 2024.

78. Within ONR's assessment of NP/SC 7819 a number of a recommendations were raised. One these recommendations was relevant to the response of the core and is repeated below for information:

> "The licensee should provide the remnant strength of [redacted]

79. [redacted]

4.2. Assessment

80. My assessment has built up through the consideration of different areas. Within Section 4.2.1 I will consider the core state and how the licensee has characterised the uncertainty in core state. Within Section 4.2.2 I will consider how the inputs have evolved from NP/SC 7810 and how uncertainties have been addressed. I consider the licensee's position on the response of the core during normal operation within Section 4.2.3. I consider the response to design basis seismic events within Section 4.2.4. Within Section 4.2.5 I consider the proposed inspection strategy to give confidence in the core degradation. Finally, within Section 4.2.6 I consider whether there are other actions the licensee could take to reduce risks further.

4.2.1. Core State

81. [redacted]

82. [redacted]

83. [redacted]

84. [redacted]

85. [redacted]

4.2.2. Component Properties

4.2.2.1. Brick Temperatures

86. [redacted]

[redacted]

87. [redacted]

88. [redacted]

89. [redacted]

90. [redacted]

4.2.2.2. Bricks Properties

91. [redacted]

92. [redacted]

- [redacted]
- [redacted]
- [redacted]

- [redacted]
- [redacted]
- [redacted]

93. These sensitivities are intended to test the key uncertainties and are equivalent to that completed previously (NP/SC 7810, [1]) hence I am content it is appropriate.

4.2.2.3. Restraint Beam Pins

94. [redacted]

95. [redacted] I am content these sensitivity studies provide sufficient information to gauge whether the baseline runs are appropriately pessimistic.

4.2.3. Normal Operation and Fault (excluding Seismic)

4.2.3.1. AGRIGID Model

96. [redacted]

97. I am content that the modifications are reasonable to improve the accuracy of the model.

4.2.3.2. Core Distortion

98. [redacted]

[redacted]

99. [redacted]

100. [redacted]

101. [redacted]

- [redacted]
- [redacted]
- [redacted]

102. [redacted]

103. [redacted]

104. [redacted]

105. [redacted]

4.2.3.3. Fuel Sleeve Gapping

106. [redacted]

107. [redacted]

108. [redacted]

109. [redacted]

110. [redacted]

111. [redacted]

4.2.3.4. Interstitial Brick Gapping

112. [redacted]

- [redacted]
- [redacted]
- [redacted]

113. [redacted]

114. [redacted]

- [redacted]
- [redacted]
- [redacted]

115. [redacted]

[redacted]

116. [redacted]

117. [redacted]

118. [redacted]

4.2.3.5. Summary

119. During the normal operation and plant faults the licensee is seeking to justify the ability of the two lines of protection, namely the PSD and SSD. It is my expectation that during normal operation and frequent plant faults there is no significant degradation of the ability to shut down and hold down the reactor due to graphite degradation.

120. In the majority the licensee has tried to keep the approach consistent with that used within NP/SC 7810 and show that the increased core age does not degrade confidence that the reactor can be shut down and held down. Those areas where modifications have been made the licensee argues that these are to improve the accuracy of the modelling approach and increase the robustness of the predictions. I am content that the modifications sampled are soundly based.

121. The key example is the change in the modelling of the layer spanning keys. [redacted] I support the licensee's attempts to improve the detail in which these are modelled. The licensee is aware that this change if inappropriately conceived and implemented could induce false confidence in the ability to shutdown and hold down the core. I am content that the licensee has conducted adequate sensitivity studies to identify any cliff edge in response. Hence, I am content that the predictions can be viewed as adequate.

122. The results have indicated that for normal operation and plant faults there is no impingement on the PSD system by the degradation of the graphite core. Despite the increased core age, the results suggest the risk to the PSD system are not significantly increased. [redacted]. Hence, I am content that, from a graphite structural integrity perspective, the risk posed by the anticipated core degradation, within the scope of EC 371321 / 371221 (Ref. 2), to control rod entry during normal operation and plant faults is tolerable.

123. [redacted] In addition, I am content the sensitivity studies will encompass the uncertainties in the calculations.

124. [redacted]

125. [redacted] I am content that an adequate methodology has been used and hence the values predicted can be viewed as reliable. The Fault Studies inspector is considering the implication of the value of fuel sleeve gapping quoted by the licensee in EC 371321/371221 [2].

126. So, in conclusion, I am content that within the scope of EC 371321 / 371221 [redacted] there is clear evidence that the anticipated graphite degradation should not impinge on control rod entry or induce a degree of interstitial brick gapping which would impair SSD functionality. I am also

content that if the analyses are ill-conceived or ill-founded then there is margin against the limits presented by the licensee and as such the risks posed by uncertainties are tolerable.

4.2.4. Seismic Response

4.2.4.1. GCORE Model Developments

127. [redacted]

128. I am content that the modifications are reasonable to improve the accuracy of the model.

4.2.4.2. Core Distortion

129. The safety case aims to show that safe shutdown of the reactor in a design basis earthquake can be achieved through consideration of GCORE predictions. Sensitivity studies further explore the influence of key parameters on those predictions.

130. [redacted]

131. [redacted]

132. [redacted]

[redacted]

133. [redacted]

134. [redacted]

135. [redacted]

136. This argument relies on judgements which causes uncertainty to exist. I am of the opinion that the licensee should conduct a similar sensitivity study to confirm that that the judgements made above are valid. Noting the isolated failure observed and the current condition of the graphite cores at HYB/TOR I do not think it is proportionate to with hold lifting of the regulatory hold point until these runs have been completed. I will capture this observation within the following recommendation which will raised within ONR Issue 11953 and be tracked through normal regulatory interactions:

- The licensee should conduct an additional sensitivity study (similar to that completed for the HRA/HYA DTA) to confirm the judgement that the failure of interstitial brick spigot/recess connections does not meaningfully impact the claim on control rod insertion.

137. [redacted]

138. [redacted]

139. [redacted] I will monitor the resolution of this action and any impact on the response of the core. I am content that the risk raised by this outstanding issue is acceptable as the removal of the constraint induced by the SRGW is conservative. Hence ONR Issue 11708 does not pose a challenge to the implementation of EC 371321/371221.

4.2.4.3. Key Disengagement

140. [redacted]

141. [redacted]

[redacted]

142. [redacted]

143. [redacted] Hence, I am content that this modelling approach is acceptable for these analyses.

144. [redacted]

145. [redacted]

146. [redacted] I am content that there is not likely to be a cliff edge in key disengagements if the inputs into the baseline runs were ill conceived.

4.2.4.4. Beyond Design Basis

147. [redacted] The External Hazards Inspector stated that this was a sufficient increase to investigate lack of cliff edge . All other inputs were kept the same as the baseline run.

148. [redacted]

[redacted] The DU values are still below unity, and this provide confidence that there is a lack of cliff edge in terms of core distortion just beyond the design basis.

149. [redacted]

150. [redacted]

151. I am content that the beyond design basis runs show that there is confidence of lack of cliff edge beyond the design basis. Whilst the results indicate that there is a point where control entry may be challenged there is margin to accommodate uncertainties in the selection of the seismic hazard.

4.2.4.5. Summary

152. The core state at the end of the safety case period of operation [redacted] is uncertain. The evolution of graphite material properties is complex and uncertain. Whilst improvements to the modelling approach have been made to increase the representative nature of the simulation the licensee is still forced to make approximations and rely on judgements introducing uncertainty.

153. As the entire route is so complex it is not feasible to fully characterise the impact of these uncertainties. The licensee never claims that the analyses are bounding or that they have used an accurate representation of the core state at the end of the operating period. It is the licensee's approach to test their approach and identify cliff edges which could introduce the potential impedance of the control rods.

154. [redacted] Hence, whilst it is claimed that from the results presented there is confidence control rods are not impeded it is not a guarantee.

155. The licensee then runs a suite of sensitivity studies on areas where it believes that the end result could be affected. I am content that the scope of the sensitivity studies is reasonable and has not highlighted a cliff edge in PSD functionality.

156. [redacted] The licensee claims that if the cracking is lower there is greater confidence that control rods will not be impeded. Hence, the margin in forecasted cracking against that analysed is used as a protection against the uncertainties within the analysis and forecasting approaches.

157. Given the sensitivity studies performed and the anticipated margin between the analysed and forecasted core states I am content that there is reasonable confidence all of the control rods will go in all the way all of the time within the operational period justified by EC 371321/371221.

4.2.5. Monitoring and Inspection

158. As noted during my assessment, the licensee has analysed a core state which includes more degradation than the anticipated core state within the validity of EC 371321/371221 [redacted] The only way to reduce this uncertainty is through regular inspection of the graphite channels.

159. The licensee has included a section on the proposed inspection strategies at the time EC 371321/371221 was written. [redacted]

160. [redacted] This has provided the licensee with vital information to develop their models and forecasts. I am content that this approach is reasonable.

161. I am also aware that as the level of cracking increases the licensee is reviewing the inspection strategy. I am content that ONR will be provided with appropriate visibility of any revisions to the inspection strategy through routine regulatory engagements.

162. Finally, the licensee notes that as a result of ONR Issue 10776 they have developed the capability to measure the bore diameter of the control rod channels. This will provide confirmation of modelling assumptions and provide additional confidence in the predictive capability.

4.2.6. ALARP

163. The licensee states that EC 371321 / 371221 [2]considers the potential for the fundamental safety functions of the graphite core to be challenged as a result of brick cracking, distortion and debris. The licensee argues that the safe operation of the reactor within the validity of EC 371321 / 371221 [redacted] has been justified.

164. The licensee states that as part of the previous case (NP/SC 7810 [1]) additional activities that could reduce the risk further were considered. From a graphite perspective the following were relevant:

- Use Failure Modes & Effects Analysis (FMEA) techniques to increase the level of understanding of core distortion mechanisms (in this case, brick cracking) in turn increasing confidence in the existing modelling regime.

- Diverse set of input data for core analysis models such that no single set of input data is relied upon for one or more core analysis routes i.e. material input data.

[redacted]

[redacted]

[redacted]

165. The licensee states that the process of brick cracking is well established across the AGR fleet. The licensee claims that forecasts to date for HYB/TOR have been generally accurate and hence confidence is gained that the KWR cracking process is understood and a FMEA would provide little benefit [redacted] Hence, I am content that due to the licensee's success in predicting the majority of the cracking observed a FMEA would not provide significant benefit.

166. The licensee states that there are already diverse methods within the generation of analysis inputs and hence the licensee feels there is no requirement to pursue this option. I am content that the licensee has indeed alternative means of calculating several analysis inputs which do highlight differences which are then resolved.

167. The licensee has implemented a brick cracking / debris census which is recording the relevant cracking (KWR crack and SRGW cracking) and the secondary fragments generated as a result of KWR cracking.

168. [redacted] The safety case states that the first was to be conducted at the HYB R8 periodic outage in 2023. This did not happen due to technical issues, the next opportunity is at the TOR R1 periodic outage in April 2024.

169. [redacted] I am content that it is not appropriate to pursue this option as the additional lifts put the fuel at a level of risk and the information that could be obtained on KWR cracked bricks is unlikely to offset those risks.

170. The licensee has concluded that all reasonably practicable options to ensure risk arising from core distortion and cracking are underway or have been identified for further investigation. I am content that the licensee within EC 371321 / 371221 has, from a graphite perspective, reached an adequate position and hence the risks have been reduced ALARP.

4.3. Safety Case Anomaly

171. During my assessment of EC37321/371221 [2] the licensee uncovered an error within the analysis that supports the similar DTA for Heysham 1 and Hartlepool. During the licensee's review of the error (a process known as the Safety Case Anomaly Process (SCAP)) the licensee identified that the error could also affect the analyses underpinning EC 371321/371221 .

172. The issues that had been identified were as follows:

- [redacted]
- [redacted]

173. [redacted]

174. Whilst the licensee has considered that there is minimal impact, they have commissioned a new set of GCORE analyses to confirm these assumptions which are due to complete after the issue of my assessment.

175. Noting the sensitivity study results I am content that the licensee's position is reasonable. Specifically, that the wholesale reduction in capacities has had minimal impact on the key metrics (e.g. DU). I support the licensee's action to test this assumption through new GCORE runs. These runs will not be available until after my assessment has completed. I view that given the sensitivity run already completed it is not proportionate to hold my assessment until these runs have completed. To manage and track the uncertainty caused by the issues found and the new GCORE runs I have raised the following recommendation:

176. The licensee should share the new HYB/TOR GCORE analyses completed [redacted] The licensee should also confirm that these new results do not undermine the claims and arguments presented within EC 371321/371221.

177. This recommendation will be captured within ONR Issue 11953 and will be managed through routine regulator interactions.

4.4. ONR Assessment Rating

178. I consider that the claims, arguments, and evidence laid out in EDF NGL's safety case [2] were adequate to justify that the risk from the graphite core degradation anticipated, from a graphite perspective, is acceptable for the proposed period of validity at HYB and TOR power stations. The technical quality of the submission was sufficient, and the information provided in the references sampled and responses to technical queries was compelling; as such I rate the submission, GREEN in line with the assessment rating table in Appendix 1 of NS-TAST-GD-096.

5. Conclusions and Recommendations

5.1. Conclusions

179. I have assessed, from a graphite perspective, the licensee's safety submission (EC 371321/371221 [2]) justifying operation of the reactors at HYB / TOR with increasing core damage up to a core burn-up of [redacted] This safety case argues that within the operating period the reactor can be shut down and held down during all foreseeable faults and hazards.

180. The licensee is using the "justified period of safe operation" principle where a margin between the forecasted core state and that shown to be tolerable is claimed. I have assessed, from a graphite perspective, whether the licensee has provided sufficient justification why the degradation of the graphite core will not impinge on the operation of the protection systems.

181. From this assessment I have made the following key observations:

- The licensee has built upon the analysis methods and arguments within NP/SC 7810. I have reviewed the developments made by the licensee based on improved knowledge. I am content that the licensee has deployed appropriate analysis approaches to evaluate the response of the graphite cores at HYB /TOR to higher levels of core burn-up.

- [redacted] Therefore, I am content that the licensee has considered a core state which is conservative within the limits of EC 371321/371221.

- The licensee acknowledges that the analyses of the response of the core state are based upon judgements and have conducted a suite of sensitivity studies that the licensee claims will evaluate these uncertainties. I am content that the licensee has completed sufficient sensitivity studies to reveal and characterise the dominant uncertainties in the supporting analyses. I am content that these sensitivity studies do not undermine the claims, arguments within EC 371321/371221.

- There is the possibility that the core state that evolves will differ from that assumed in the analyses which underpin EC 371321/371221. To mitigate this uncertainty, the licensee will make regular inspections to monitor the graphite degradation process and check the safety case assumptions against the inspection observations prior to reaching the [redacted] burn-up limit. I am content that the licensee plans will reveal deviations from the assumed degradation in a timely manner.

- I have considered the effect of core distortion on the levels of fuel sleeve gapping within the core, and I am content that these levels are below the total and individual limits prescribed. The consequences of the estimated fuel sleeve gapping will be assessed by the Fault Studies inspector.

- I have reviewed the potential for interstitial brick gapping as a result of normal operation and frequent faults and hazards. [redacted] The Fault Studies inspector considered this increase and was content it would not have a meaningful reduction in the claimed capability of the SSD system.

- During my assessment of EC 371321/371221 the licensee identified errors within the supporting analyses which could affect the results underpinning this case. The licensee was content that any impact would be minimal, referencing a sensitivity study, but has also commissioned a GCORE sensitivity study to confirm this position. I was content that the licensees' position was reasonable noting the results of the original sensitivity study. Within the period before the new sensitivity results will be reported (~2 months) I am content that the amount of additional cracking accumulated will be insignificant and not pose a risk to the shutdown capability. Hence, I view that it is not proportionate to delay this assessment until this new sensitivity study is completed. To track and manage this uncertainty have raised a recommendation, captured within ONR Issue 11953, which will be discussed during routine regulatory engagements.

182. To conclude, from graphite structural integrity perspective, I am satisfied from a graphite integrity perspective the licensee has provided an adequate safety case demonstrating the safety of its operations. I have no objection to the implementation of of EC 371321 / 371221. Whilst there is a margin between the core state prediction at [redacted] and the DTB, it will be necessary to monitor inspection results to ensure that the evolution of the core state remains broadly in line assumed evolution used within EC 371/321 / 371221. I am content this will occur through routing regulatory interactions.

5.2. Recommendations

183. To track and manage the uncertainty caused by the additional GCORE runs I have raised the following recommendation which is captured within ONR Issue 11953 and will be managed through routine regulatory interactions.

- The licensee should share the new HYB/TOR GCORE analyses completed as a result of the brick temperature and channel spigot / recess capacity errors. The licensee should also confirm that these new results do not undermine the claims and arguments presented within EC 371321/371221.

- The licensee should conduct an additional sensitivity study (similar to that completed for the HRA/HYA DTA) to confirm the judgement that [redacted]

References

Appendix 1 – Relevant SAPs 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. 7	Engineering principles: graphite reactor cores: component and core condition assessment	Analytical models should be developed to enable the prediction of graphite reactor core material properties, displacements, stresses, loads and condition.
EGR. 8	Engineering principles: graphite reactor cores: component and core condition assessment	Predictive models should be shown to be valid for the particular application and circumstances by reference to established physical data, experiment or other means.
EGR. 9	Engineering principles: graphite reactor cores: component and core condition assessment	Extrapolation and interpolation from available materials properties data should be undertaken with care, and data and model validity beyond the limits of current knowledge should be robustly justified.
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. 11	Engineering principles: graphite reactor cores: defect tolerance assessment	The safe working life of graphite reactor cores should be evaluated.

EGR. 12	Engineering principles: graphite reactor cores: defect tolerance assessment	Operational limits (operating rules) should be established on the degree of graphite brick ageing, including the amounts of cracking, dimensional change and weight loss. To take account of uncertainties in measurement and analysis, there should be an adequate margin between these operational limits and the maximum tolerable amount of any calculated brick ageing.
EGR. 13	Engineering principles: graphite reactor cores: defect tolerance assessment	Data used in the analysis should be soundly based and demonstrably conservative. Studies should be undertaken to establish the sensitivity to analysis parameters.
EGR. 14	Engineering principles: graphite reactor cores: monitoring	The design, manufacture, operation, maintenance, inspection and testing of monitoring systems should be commensurate with the duties and reliabilities claimed in the safety case.
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.