Office for Nuclear Regulation

ONR Permissioning Decision Record

Heysham 2 and Torness – Graphite Safety Case

Review and Consideration of EC 371321/371221 - Safety Case for Operation with Keyway Root Cracking Beyond a Core Burn-up of 16.5 TWd

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Project name:

Heysham 2 and Torness – Graphite Safety Case

Report title:

Review and Consideration of EC 371321/371221 - Safety Case for Operation with Keyway Root Cracking Beyond a Core Burn-up of 16.5 TWd

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Contents

1. Permission requested

1. EDF Energy Nuclear Generation Limited (EDF), under arrangements made under Licence Condition (LC) 22(1) of Schedule 2 attached to Nuclear Site Licences 60 and Sc.14 (for Heysham 2 (HYB) and Torness (TOR), respectively) to control any modification or experiment carried out on any part of the existing plant or processes, applied for Review and Consideration from the Office for Nuclear Regulation (ONR) for "EC: 371321/371221 Safety Case for Operation with Keyway Root Cracking Beyond a Core Burn-up of 16.5 TWd" (refs. [1] and [2]) , as requested by ONR in refs. [3] and [4]. For clarity, TWd refers to terawatt days, which is the core burn-up and in practice one year of operation is roughly equivalent to 0.5 TWd.

2. The proposed safety case (refs. [1] and [2]) is a Category 2 submission. An Independent Nuclear Safety Assessment (INSA) statement has been submitted in support of the proposed case (refs. [1] and [2]).

3. In line with ONR's procedures, this permissioning decision record (PDR) documents ONR's view on the adequacy of the proposed safety case. ONR will also produce formal letters to communicate ONR's decision to the stations.

2. Background

4. The graphite cores at HYB and TOR are currently operating under the extant graphite safety case for keyway root cracking NP/SC 7810 (ref. [5]), which was assessed and permissioned by ONR (ref. [6]). This case justified operation, through damage tolerance assessments (DTA), up to 16.5 TWd and with an increasing numbers of keyway root cracks (KWRCs) in the graphite bricks of the channels where the fuel assemblies are placed. For brevity, these graphite bricks are colloquially referred to as "fuel bricks".

5. The reactors at HYB and TOR are approaching the 16.5 TWd operational limit. Hence, EDF is proposing to extend the operating period from 16.5 TWd to 18 TWd or approximately 3 calendar years of continuous operation within the proposed safety case EC 371321/371221.

6. The proposed safety case EC 371321/371221 re-evaluates the core response at a burn-up of 18.5 TWd but limits operation up to 18 TWd. This is to provide a 0.5 TWd margin, equivalent to about one year of continuous operation.

7. The proposed safety case maintains a similar core state with 100% of the central region of the core containing cracked fuel bricks as the extant case NP/SC 7810. However, with the extended burn-up, EDF has included a small population (~10%) of multiply cracked fuel bricks (MCBs), in contrast to the extant case NP/SC 7810 where only singly and doubly cracked fuel bricks

(SCBs and DCBs) were modelled. EDF models MCBs as quadruply cracked bricks (QCBs).

8. For clarity, an SCB is a fuel brick containing a full height axial crack along one of its axial keyways, a DCB is a fuel brick containing two full height axial cracks at 180º from each other (i.e., the brick is split into two halves), and an MCB is a brick with three or more full height axial cracks. A QCB is an MCB with four full height axial cracks at 90º from each other (i.e., the bricks is divided into four quarters). Figure 1 shows simplified representations of an SCB, a DCB and a QCB which is a form of an MCB.

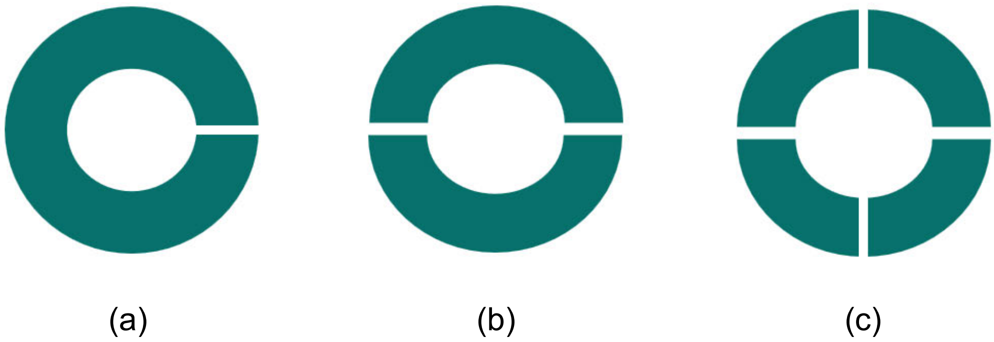

Figure 1. Simplified representations of (a) SCB, (b) DCB and (c) QCB.

9. The proposed safety case EC 371321/371221 is based on the principles of the extant case NP/SC 7810. The main aspects of the proposed safety case are:

- New damage tolerance assessments at an older core age of 18.5 TWd.
- Inclusion of QCBs in the core models.
- Other developments related to graphite core models.
- No changes were made to the seismic input motion or the prestressed concrete pressure vessel (PCPV) parameters of the models from those used within the extant case NP/SC 7810.

10. EDF demonstrates compliance with the graphite safety cases through regular core inspections. Following each graphite core inspection, a Justified Period of Safe Operation (JPSO) will be defined as to not exceed any limit in the graphite safety cases. This includes limits enforced by the proposed safety case and the parallel extant graphite safety cases covering the Seal Ring Groove Wall (SRGW) Debris and graphite weight loss.

11. ONR examines the results of the graphite inspections as part of normal regulatory business to ensure compliance with the graphite safety cases.

3. Assessment and inspection work carried out by ONR in consideration of this request

12. In accordance with the regulatory permissioning plan (PR-01365 and PR-01366), ONR has carried out the following specialist assessments/reviews:

- a structural integrity (graphite) specialist assessment recorded in an assessment report type 'Major' (ref. [7]);
- a fault studies specialist assessment recorded in an assessment report type 'Other' (ref. [8]); and
- an external hazards specialist assessment recorded in an assessment report type 'Other' (ref. [9]).

13. It should be noted that ONR's specialist inspectors have engaged with EDF in detailed technical discussions and have raised and resolved a number of technical queries (ref. [10]) throughout their assessments of the proposed case. This report does not attempt to summarise all the questions raised and answers provided. However, they are captured in the relevant specialist assessment reports where necessary.

14. ONR's assessment of the proposed safety case has focused on:

- any significant developments/changes to the methods supporting the extant safety case NP/SC 7810; and
- The adequacy of the results and evidence to support the proposed safety case claims.

3.1. Assessment findings

3.1.1. Structural integrity (graphite) assessment (ref. [7])

15. The graphite structural integrity specialist inspector has focused their assessment of the proposed safety case on EDF's considerations of the effects of keyway root cracking of the fuel bricks on:

- the operation of the primary shutdown system (PSD);
- the operation of the secondary shutdown system (SSD); and
- cooling of the fuel in the core.

16. The specialist inspector states that EDF has presented damage tolerance assessments (DTA) of the graphite cores for (a) normal operation and fault conditions and (b) an infrequent (1 in 10,000 years) seismic event for core states containing 100% cracked fuel bricks in the central core (i.e., all the 1656 bricks in layers 3 to 8 and rings 1 to 9).

17. In addition to singly cracked bricks (SCB) and doubly cracked bricks (DCBs) that were analysed in the extant case NP/SC 7810, EDF has included multiply cracked bricks (MCB) in the proposed safety case. MCBs are modelled as quadruply cracked bricks (QCBs), i.e., a brick in four quarters.

18. The numbers and types of cracked bricks considered in the DTA are used to define a damage tolerance boundary (DTB). The DTB is set to 1656 cracked fuel bricks of which:

- ~1050 SCBs;
- ~440 DCBs; and
- 166 MCBs.

19. The DTA are assessed at a core burn-up of 18.5 TWd and a limit on operation of 18 TWd is introduced by EDF, providing a margin of 0.5 TWd, which is roughly equivalent to a calendar year of continuous operation.

20. For normal operation and faults and for an infrequent seismic event, the specialist inspector is content that the proposed safety case has provided sufficient evidence to support that the PSD ability to shutdown and holddown the reactor will not be affected by the graphite core at the DTB as defined above. That is, the graphite core with cracking up to the DTB will not impede the movement of the control rods.

21. The specialist inspector considers that EDF has provided sufficient sensitivity studies to cover the uncertainties in the models and to demonstrate a lack of cliff-edge effects in the core response.

22. The specialist inspector notes that the SSD capability and similarly the fuel cooling could be affected by core distortion as gaps could develop between the bricks of the SSD channels and similarly between the fuel sleeves. The specialist inspector is content that the proposed safety case has provided appropriate evidence which considers the potential gaps that could be developed for a core at the DTB. The consequences of these potential gaps have been considered by the fault studies specialist inspector and found to be acceptable (see Section 3.1.2 below).

23. The specialist inspector has observed that a single spigot/recess failure within a control rod channel is predicted to fail in a single seismic analysis run out of 15 baseline runs. For clarity, each graphite brick of the interstitial channels

(that includes the control rod channels and SSD channels) have a spigot at one end and a recess at the other; the spigot of each brick sits within the recess of another brick which together form a continuous channel shape. EDF argues that this potential failure is unlikely to happen in a seismic event as the spigot/recess capacity of a control rod channel is larger than the spigot/recess capacity assumed in the analyses.

24. In the analyses, EDF adopts the lowest capacity from the different types of interstitial channels; those include the control rod channels and the SSD channels among other types. The spigot/recess capacity for the SSD channel is lower than the spigot/recess capacity for the control rod channel. As there are no control rods in SSD channels, a spigot/recess failure in an SSD channel is less of a concern. Due to its lower value, the SSD spigot/recess capacity was adopted for all the interstitial channels including the control rod channels.

25. Although, the specialist inspector is content with EDF’s justification, they note a similar case for Heysham 1 (HYA) and Hartlepool (HRA) reactors, where similar spigot/recess failures were predicted. In that instance, EDF provided an additional sensitivity study to demonstrate the failure of interstitial spigot/recess connections does not have a meaningful impact on the control rod insertion. Therefore, the specialist inspector makes a recommendation for EDF to consider carrying out a similar sensitivity study specific to HYB/TOR. This recommendation will be recorded in regulatory issue IR-11953 and will be tracked through normal regulatory business.

26. The specialist inspector states that during ONR’s assessment of the proposed safety case, EDF uncovered an anomaly within the analysis that supports the similar DTA case for Heysham 1 and Hartlepool. During the licensee’s review of the anomaly (a process known as the Safety Case Anomaly Process (SCAP)), the licensee identified that the anomaly could also affect the analyses underpinning the proposed safety case for HYB/TOR (EC 371321/371221). The anomaly is associated with the effect of temperature on the weight loss predictions in the core upper layers and the SSD channels, which in turn affects the keying system capacities and spigot/recess capacities in these locations.

27. The specialist inspector states that EDF judges that the effect on the HYB/TOR DTA is negligible, because a sensitivity study where all capacities within the graphite core were reduced by 20% showed minimal impact on core distortion. Nonetheless, EDF has commissioned a new set of analyses to confirm this judgement, which are due to complete after the conclusion of ONR’s assessment of the proposed safety case.

28. The specialist inspector is content with EDF’s position supported by the 20% reduction sensitivity study. They are also supportive of EDF’s decision to carry out new analyses to confirm this position. It is the specialist inspector’s opinion that it would be disproportionate to hold back the permissioning of the proposed safety case until these analyses have been completed.

29. To manage and track the findings of the new analyses, the specialist inspector makes a recommendation for EDF to share the results of the new HYB/TOR analyses and to also confirm that these new results do not undermine the claims and arguments presented within the proposed safety case EC 371321/371221. This recommendation will be captured within ONR Issue 11953 and will be managed through normal regulatory business.

30. Overall, the specialist inspector concludes that EDF has provided an adequate safety case and therefore has recommended, from a graphite structural integrity perspective, that ONR allows the stations to proceed with the implementation of the proposed safety case as described in EC 371321/371221.

3.1.2. Fault studies assessment (ref. [8])

31. The fault studies specialist inspector targeted their assessment of the proposed safety case on the claims that could affect fault sequences in terms of progression and consequences, these included:

- Impact on functional capability of the primary shutdown system (PSD)
- Impact on fuel cooling
- Impact on functional capability of the secondary shutdown system (SSD)

32. The specialist inspector considers that the bulk of the fault studies related evidence has been assessed by ONR previously in the context of the extant safety cases for keyway root cracking NP/SC 7810, the seal ring groove wall debris NP/SC 7819 and the assessment and closure of Regulatory Issue RI-10793. This regulatory issue was raised to track EDF's modern standards assessment of the effects of the SSD channel gapping on the SSD capability.

33. The specialist inspector is content that the consequences of (a) fuel sleeve gapping affecting fuel cooling and (b) the SSD channel gapping affecting the SSD capability considered in the extant safety cases, which have previously been assessed by ONR, remain valid for the proposed safety case,.

34. The specialist inspector did not identify any shortfalls in the proposed safety case that warrants any regulatory action.

35. The specialist inspector therefore has recommended, from a fault studies perspective, that ONR allows the stations to proceed with the implementation of the proposed safety case as described in EC 371321/371221.

3.1.3. External hazards assessment (ref [9])

36. The external hazards specialist inspector states that the proposed safety case uses the same design basis earthquake (DBE) as the extant case NP/SC 7810

and the results of the damage tolerance assessment (DTA) associated with the DBE are similar to those reported in the extant case NP/SC 7810. That is, margins on control rod entry have not changed significantly for the DBE.

37. However, the specialist inspector notes that there has been more significant changes in the DTA results for analyses beyond design basis (BDB) and that there is an absence of a clear analysis demonstrating lack of cliff-edge beyond the DBE. Hence, the specialist inspector focused their assessment on the adequacy of the evidence for earthquake events more onerous than the design basis; that is, the demonstration of tolerance to beyond design basis earthquake (BDBE) and the demonstration of a lack of cliff-edge effect just beyond the DBE.

38. The specialist inspector states that the DTA reported in the proposed safety case EC 371321/371221 provides a suite of analyses for the DBE seismic hazard input (i.e., an annual frequency of occurrence of 1 in 10,000 years), and BDBEs comprising 1 in 20,000 years, 1 in 40,000 years and 1 in 100,000 years seismic events.

39. The design basis analysis (DBA) uses conservative assumptions for inputs, including those relating to the Pre-stressed Concrete Pressure Vessel (PCPV) and soil-structure interactions. On the other hand, the BDBA is performed on a best estimate basis, with less onerous PCPV properties. The specialist inspector judges the analysis assumptions are aligned with the expectations of the relevant SAPs for DBA and BDBA.

40. When assessing the extant case NP/SC 7810, the specialist inspector made the judgement that there was an absence of cliff-edge effects based on the margins demonstrated by the design basis analysis (DBA) and beyond design basis analysis (BDBA). However, for the proposed case, the results of the BDBA show increasing distortion utilisation of some of the control rod channels, which indicates entry may be impeded for earthquake events beyond the design basis for some of the control rods.

41. The BDBA results show that graphite distortions increase as the hazard severity increases, indicating approximately linear core behaviour. The specialist inspector judges that EDF has provided an adequate suite of BDBA, which meet the expectations of the relevant SAPs.

42. However, the specialist inspector sought clarity on the demonstration of a lack of cliff-edge effect just beyond the design basis earthquake via technical query (TQ) EX-01 (see ref. [10]). This is because:

- Although the BDBA uses earthquake events significantly higher than the DBA, the BDBA uses best-estimate PCPV parameters while the DBA uses conservative PCPV parameters, which makes a like-for-like comparison difficult to interpret.

- The BDBA results show higher control rod channel distortion, which makes forming an informed judgement on lack of cliff-edge effect difficult.

43. EDF consequently provided an analysis that uses the same conservative parameters used for the DBA and the DBE scaled up by 1.11 to demonstrate a lack of cliff-edge just beyond the DBE.

44. Following their assessment of EDF's new analysis, the specialist inspector judges that EDF has provided adequate evidence to demonstrate an absence of cliff-edge effects and that a small increase in the design basis event severity does not lead to a disproportionate increase in radiological consequences.

45. The specialist inspector therefore has recommended, from an external hazards perspective, that ONR allows the stations to proceed with the implementation of the proposed safety case as described in EC 371321/371221.

4. Matters arising from ONRs work

46. All ONR specialist inspectors, who assessed the case, agree that the proposed safety case modification of EC 371321/371221 (refs. [1] and [2]) is acceptable. On that basis I have prepared formal letters to allow the stations to proceed with the implementation of EC 371321/371221, subject to EDF's company processes and arrangements. The letters have been written according to ONR guidance for derived power arrangements (ref. [11]).

47. Some recommendations were raised by specialist inspectors which are discussed in this report. None of the recommendations prevents the lifting of the holdpoints.

48. I have confirmed that EDF NGL has followed its own due process. An INSA statement for EC 371321/371221 has been submitted (refs. [1] and [2]).

5. Conclusions

49. Based on the work carried out by ONR, I have concluded that the proposed safety case EC 371321/371221 has been adequately justified by EDF and that formal letters should be issued to HYB and TOR to allow the stations to proceed with the implementation of EC 371321/371221 subject to EDF's company processes and arrangements.

50. Core inspections will take place regularly and the results of these inspections will be examined by ONR to ensure compliance with the safety case.

6. Recommendations

51. I recommend that ONR should issue formal letter to Heysham 2 and Torness Power Stations, respectively, to allow the stations to proceed with the implementation of EC 371321/371221, subject to their company processes and arrangements.

102. I also recommend that ONR should maintain regulatory oversight and routinely monitor progress against the assessment recommendations identified by the specialist inspectors.

References

[1] EDF, Letter from HYB (NSL HYB/51163N) Requesting Review and Consideration for EC 371321, ONRW-2019369590-6301.

[2] EDF, Letter from TOR (NSL/TOR/50759) Requesting Review and Consideration for EC 371221, ONRW-2019369590-4540.

[3] ONR, Letter to HYB (HYB70953R) Requesting Review and Consideration of EC 371321/371221, ONRW-2019369590-3606.

[4] ONR, Letter to TOR (TOR71458R) Requestion EC 371321/371221 for Review and Consideration, ONRW-2019369590-3605.

[5] EDF, NP/SC 7810, Graphite Core: Safety Case for Operation After the Onset of Keyway Root Cracking, EC 366563/366568, CM9: 2022/1150.

[6] ONR, Project Assessment Report ONR-OFD-PAR-22-004 Rev 0, Agreement to NP/SC 7810, CM9: 2022/32318.

[7] ONR, AR-01309, Graphite Structural Integrity Assessment of EC 371321/371221, ONRW-2126615823-2634.

[8] ONR, AR-01383, Fault Studies Assessment of EC 371321/371221, ONRW-2126615823-2308.

[9] ONR, AR-01399, External Hazards Assessment of EC 371321/371221, ONRW-2126615823-2241.

[10] Technical Queries (TQ) Tracker for EC 371321/371221, CM9: 2023/62003.

[11] ONR, OF-OR-IN-001 - Operating Reactors LC22 Permissioning Instruction, March 2023, CM9: 2021/65766.