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| ONR Project assessment report  Heysham 1 and Hartlepool – Graphite Safety Case  Agreement to NP/SC 7824 - Consolidated Seismic Safety Case for the Graphite Core, Core Restraint and Core Support Structure (HRA EC No: 371983 Revision 000 HYA EC No: 372009 Revision 000) |



ONR Project assessment report

**Project name**: Heysham 1 and Hartlepool – Graphite Safety Case

**Report title**: Agreement to NP/SC 7824 - Consolidated Seismic Safety Case for the Graphite Core, Core Restraint and Core Support Structure (HRA EC No: 371983 Revision 000 HYA EC No: 372009 Revision 000)

**Dutyholder/Applicant**: EDF Energy Nuclear Generation Limited

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# Executive summary

**Title**

Agreement to NP/SC 7824 – Heysham 1 and Hartlepool Power Stations, Consolidated Seismic Safety Case for the Graphite Core, Core Restraint and Core Support Structure (HRA EC No: 371983 Revision 000 and HYA EC No: 372009 Revision 000).

**Permission Requested**

EDF Energy Nuclear Generation Limited (EDF NGL), under arrangements made under Licence Condition 22(1) of Schedule 2 attached to Nuclear Site Licences 59 and 60 (for Hartlepool (HRA) and Heysham 1 (HYA), respectively), applied for Review and Consideration from the Office for Nuclear Regulation (ONR) for NP/SC 7824, “EC 371983/372009: Consolidated Seismic Safety Case for the Graphite Core, Core Restraint and Core Support Structure”

ONR subsequently notified EDF NGL, under the same arrangements made under Licence Condition 22(1), that the licensee shall not commence nor thereafter proceed with NP/SC 7824 without the Agreement of the ONR, which will be issued via a licence instrument following ONR’s assessment of NP/SC 7824.

**Background**

The graphite core of each of the reactors at Heysham 1 and Hartlepool power stations consist of a large assembly of graphite components that are keyed together to form channels for fuel assemblies and control rods. One of the fundamental nuclear safety requirements of the graphite core is to allow unimpeded movement of control rods and fuel assemblies.

It has long been understood that the irradiation of the graphite leads to dimensional and material changes. These changes could eventually lead to the generation of cracking in the fuel channel graphite bricks. There are two types of cracking:

* one associated with the early reactor life referred to as bore cracking; and
* another associated with the late reactor life referred to as keyway root cracking (KWRC).

Bore cracking is limited in nature, but keyway root cracking is an active mechanism late in the reactor life that can lead to wide-spread cracking of fuel channel graphite bricks. This cracking has the potential to affect the fundamental nuclear safety requirements of the core and consequently it needs to be demonstrated that these requirements continue to be met in normal operation, fault conditions and during and after a design basis seismic event.

The reactor cores at HYA and HRA are at an age, in terms of core burn-up, where keyway root cracking is predicted to occur. However, no keyway root crack has been observed to date in any of the reactors at HYA or HRA.

This Project Assessment Report (PAR) considers safety case NP/SC 7824 which consolidates the seismic safety case for the graphite core, Core Restraint Structure (CRS) and Core Support Structure (CSS) and aims to demonstrate that the risk posed by a seismic event is reduced to As Low as Reasonably Practicable (ALARP) until 14.65 TeraWatt day (TWd) at HYA and 15.15 TWd at HRA. NP/SC 7824 justifies the essential safety functions of the core are maintained during this period provided that the core remains ‘essentially intact’; defined as 10% axially cracked bricks in the central region of the core.

NP/SC 7824 consolidates significant work by EDF NGL since 2018 to improve the modelling and understanding of the seismic response of the pre-stressed concrete pressure vessel PCPV and the graphite cores at HRA/HYA. As a result of this work, several key changes have been made to the modelling, with the most significant being the coupling of the PCPV and the graphite core models, which results in damping between these components and reduces the overall magnitude of the core response to a seismic hazard.

NP/SC 7824 presents evidence of:

* Updated Damage tolerance assessments (DTA) for core states containing specific numbers and configurations of cracked bricks to demonstrate that the core essential functions will be maintained during and following a design basis seismic event.
* Updated assessments of the core restraint structure, the core support structure and civil engineering structures supporting the graphite core.

Compliance with the limits on the number of cracked bricks is maintained by regular core inspections throughout the validity period of the proposed case. Inspection findings will be reviewed by ONR where necessary to ensure compliance with the limits of the proposed safety case.

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

ONR’s assessment of NP/SC 7824 has focused on whether cracking predicted to occur in the graphite bricks that form the reactor core could compromise the key nuclear safety requirements of the Heysham 1 and Hartlepool reactor cores. Assessments have been carried out by ONR’s specialist inspectors from:

* Graphite Structural Integrity Specialism;
* Steel Structural Integrity Specialism;
* Civil Engineering Specialism;
* External Hazards Specialism; and
* Fault Studies Specialism.

**Matters arising from ONR's work**

Following assessment, all specialist inspectors consider that the issue of ONR’s Agreement to the implementation of the proposed safety case NP/SC 7824 is acceptable. In support of their assessments, ONR’s specialist inspectors have engaged with EDF NGL in technical discussions to ensure that key issues have been adequately addressed.

**Conclusions**

It is concluded that EDF NGL has provided an adequate justification underpinning NP/SC 7824, “Consolidated Seismic Safety Case for the Graphite Core, Core Restraint and Core Support Structure” for Heysham 1 and Hartlepool reactors up to core burn-ups of 14.65 TWd and 15.15 TWd, respectively, and that a Licence Instrument should be issued to EDF NGL.

**Recommendation**

I recommended that Licence instruments 639 and 576 are granted to Heysham 1 and Hartlepool Power Stations, respectively, Agreeing to the implementation of the proposed safety case NP/SC 7824.

Table 1: List of abbreviations.

|  |  |
| --- | --- |
| Term/Acronym | Description |
| ACI | American Concrete Institute |
| AFoE | Annual Frequency of Exceedance |
| AGR | Advanced Gas-cooled Reactor) |
| ASCE | American Society of Civil Engineers |
| ALARP | As low as is reasonably practicable |
| CSS | Core Support Structure |
| CRS | Core Restraint Structure |
| CSP | Core Support Plate |
| DCB | Doubly Cracked Brick: a brick containing exactly two full height, full thickness axial cracks) |
| DU | Distortion Utilisation |
| EA | Environment Agency |
| EC | Engineering Change |
| EDF NGL | EDF Energy Nuclear Generation Limited |
| HYA | Heysham 1 Power Station |
| HYB | Heysham 2 Power Station |
| HNB | Hunterston B Power Station |
| HPB | Hinkley Point B Power Station |
| HRA | Hartlepool Power Station |
| LC | Licence Condition |
| INSA | Independent Nuclear Safety Assessment |
| JCO | Justification for Continued Operation |
| KWRC | KeyWay Root Crack |
| LRK | Lower Radial key |
| MCB | Multiply Cracked Brick: a brick containing three or more full height, full thickness axial cracks. |
| NSC | Nuclear Safety Committee |
| ONR | Office for Nuclear Regulation |
| PAR | Project Assessment Report |
| PCPV | Pre-stressed Concrete Pressure Vessel |
| PSD | Primary Shutdown System |
| RGP | Relevant Good Practice |
| SAPs | Structure, system and component |
| PSA | Probabilistic safety analysis |
| PSR | Preliminary safety report |
| RGP | Relevant good practice |
| SAPs | Safety assessment principle(s) |
| SCAP | Safety Case Anomalies Process |
| SCB | Singly Cracked Brick: a brick containing exactly one full height, full thickness axial crack |
| SHWP | Seismic Hazard Working Party |
| SQEP | Suitably Qualified and Experienced Person |
| SSC | Structure, System and Component |
| SSD | Secondary Shutdown System |
| SSI | Soil Structure Interaction |
| TAG | Technical Assessment Guide(s) (ONR) |
| TOR  TSC  TSD  TQ  TWd  URK  URS | Torness Power Station  Technical Support Contract  Tertiary Shutdown System  Technical Query  TeraWatt Day  Upper Radial Key  Uniform Risk Spectra |

Table of contents

[Executive Summary 5](#_Toc135899541)

[List of Abbreviations 8](#_Toc135899542)

[1. Permission Requested 11](#_Toc135899543)

[2. Background 11](#_Toc135899544)

[2.1. General Description 11](#_Toc135899545)

[2.2. Extant Graphite Core Safety Case and Known Shortfalls 14](#_Toc135899546)

[2.3. Proposed Safety Case NP/SC 7824 16](#_Toc135899547)

[2.4. Summary 17](#_Toc135899548)

[3. Assessment and Inspection Work Carried out by ONR in Consideration of this Request 18](#_Toc135899549)

[3.1. Assessment Findings 19](#_Toc135899550)

[3.1.1. Graphite Structural Integrity Assessment (Ref. [20]) 19](#_Toc135899551)

[3.1.2. Steel Structural Integrity Assessment (Ref. [21]) 23](#_Toc135899552)

[3.1.3. Civil Engineering Assessment (Ref. [22]) 26](#_Toc135899553)

[3.1.4. External Hazards Assessment (Ref. [24]) 31](#_Toc135899554)

[3.1.5. Fault Studies Assessment (Ref. [23]) 33](#_Toc135899555)

[4. Matters Arising from ONRs Work 34](#_Toc135899556)

[5. Conclusions 35](#_Toc135899557)

[6. Recommendations 35](#_Toc135899558)

[References 36](#_Toc135899559)

**List of Figures:**

[Figure 1: Typical AGR Graphite Core Bricks](#_Toc135899560)

[Figure 2: Example of an AGR fuel element](#_Toc135899561)

[Figure 3: Key components and structures supporting the graphite core](#_Toc135899562)

[Figure 4: Example of an AGR keyway root crack in a fuel channel graphite brick](#_Toc135899563)

[Figure 5: Schematic of an LRK](#_Toc135899564)

[Figure 6: Core Restraint Structure (CRS)](#_Toc135899565)

[Figure 7: Illustration of the PCPV supporting walls](#_Toc135899566)

**List of Tables:**

[Table 1: Circulation (latest issue)](#_Toc135899567)

[Table 2: HYA and HRA crack configuration for GCORE base-line analysis (ref. [4])](#_Toc135899568)

# Permission requested

1. EDF Energy Nuclear Generation Limited (EDF NGL), under arrangements (ref. [1]) made under Licence Condition (LC) 22(1) of Schedule 2 attached to Nuclear Site Licences 59 and 60 (for Hartlepool (HRA) and Heysham 1 (HYA), 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 NP/SC 7824, “EC 371983/372009: Consolidated Seismic Safety Case for the Graphite Core, Core Restraint and Core Support Structure” (refs. [2] and [3]).
2. The proposed safety case (ref. [4]) is a Category 1 submission.
3. ONR subsequently notified EDF NGL (refs. [5] and [6]), under the same arrangements (ref. [1]) made by the licensee under LC 22(1) of Schedule 2 attached to Nuclear Site Licences 59 and 60 to control any modification or experiment carried out on any part of the existing plant or processes, that the licensee shall not commence nor there after proceed with NP/SC 7824 without the Agreement of the ONR, which will be issued via a licence instrument following ONR’s assessment of NP/SC 7824.

# Background

## General Description

1. Heysham 1 (HYA) and Hartlepool (HRA) Power Stations each have two advanced gas-cooled Reactors (AGRs). Each reactor core is made up of a large assembly of graphite bricks keyed together via a keying system as shown in Figure 1 to form channels for fuel assemblies and control rods. Each core contains around 3000 fuel channel graphite bricks. For brevity these bricks are referred to as fuel bricks. The core is supported by a steel structure and contained within a prestressed concrete pressure vessel (PCPV).
2. Ceramic uranium oxide fuel is contained within fuel assemblies in channels in the graphite core, see Figure 2. Control rods, containing boron, move within control rod channels in the graphite core to control the nuclear reaction and to shut-down and hold-down the reactor.
3. The control rods are the primary means of controlling the nuclear reaction and shutting down the reactor. They make up the primary shutdown system (PSD). At HYA and HRA, a nitrogen injection system is available as another means of shutting down the reactor and is referred to as the secondary shutdown system (SSD). The SSD is supported by a tertiary shutdown system (TSD) of boron bead injection to maintain long term hold-down.



Figure 1: Typical AGR Graphite Core Bricks

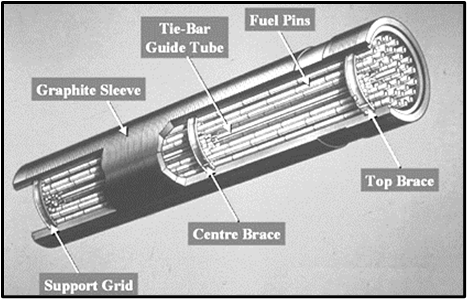


Figure 2: Example of an AGR fuel element

1. Figure 3 shows a schematic of the reactor vessel demonstrating the different structures supporting the graphite core.
2. The graphite core is supported by the core support structure (CSS) and the core restraint structure (CRS). The CSS and CRS are steel structures and they interface with the PCPV through the lower and upper radial keys (LRKs and URKs) and the core support pillars. The PCPV is supported by the pressure vessel support walls which are in turn supported by the foundations. The PCPV and its supporting structure are concrete structures.
3. All of the aforementioned structures work together to maintain the geometry of the core, for example, during a seismic event. Therefore, the behaviour of the graphite core during a seismic event requires a multi-disciplinary assessment involving: external hazards, civil engineering, structure integrity for steel and graphite components and fault studies for potential fault sequences and consequences.

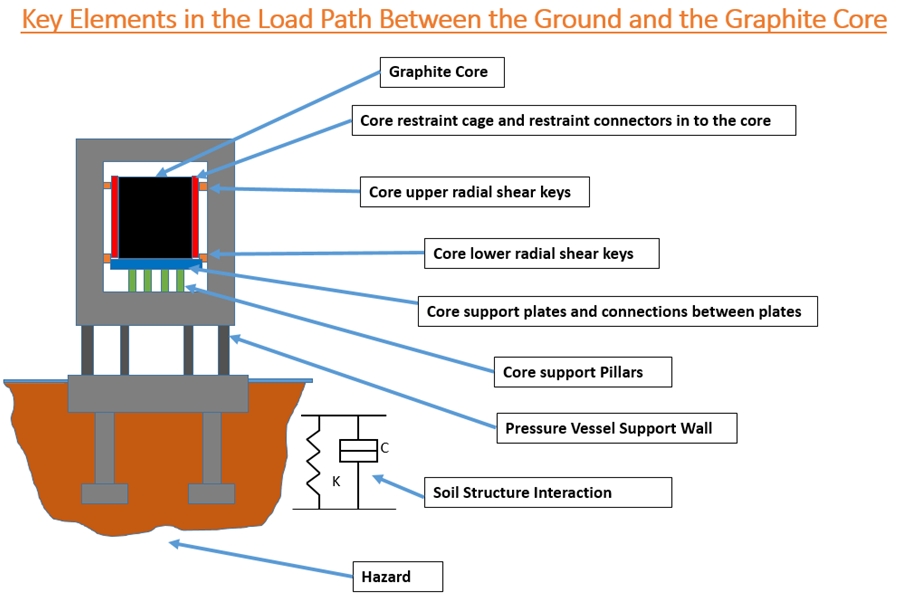


Figure 3: Key components and structures supporting the graphite core

1. It has long been understood that the irradiation of the graphite leads to dimensional and material properties changes of the graphite bricks. These changes could eventually lead to the generation of cracking in the fuel channel graphite bricks. There are two types of cracking:

* one associated with the early reactor life referred to as bore cracking; and
* another associated with the late reactor life referred to as keyway root cracking (KWRC). A KWRC could also bring forward cracking in a neighbouring fuel brick and this is referred to as ‘induced cracking’.

1. Bore cracking is limited in nature, as the tensile stresses at the brick bore reverse into compressive stresses as the reactor core ages, reducing the likelihood of crack initiation from the bore significantly.
2. The keyway root cracking is an active mechanism late in the reactor life that can lead to wide-spread cracking of the fuel bricks. This is because at high irradiation, i.e., later in the reactor life, tensile stresses are generated at the outer section of the brick wall where keyway features are present by design, see Figure 1. These keyway features at the brick periphery act as stress concentration sites where cracks could initiate from the keyway root and propagate through the brick wall to the bore leading to a keyway root crack. Figure 4 shows an example of a keyway root crack in a graphite brick, as seen from the fuel channel bore, during a core inspection.

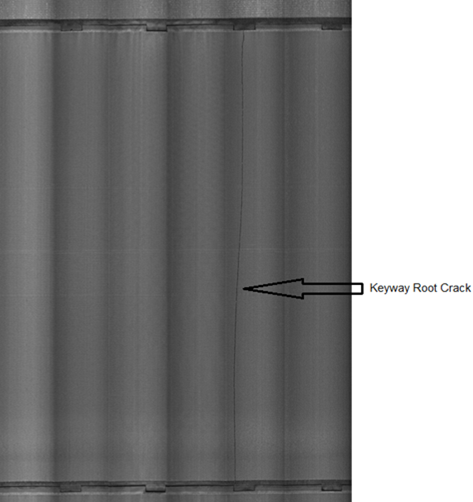


Figure 4: Example of an AGR keyway root crack in a fuel channel graphite brick

1. Keyway root cracking has been observed at other AGR stations: Hunterston B (HNB), Hinkley Point B (HPB), Heysham 2 (HYB) and Torness (TOR). The reactors at HYA and HRA are at an age, in terms of core burn-up, where keyway root cracking is predicted to occur. However, no KWRC has been observed to date in any of the reactors at HYA and HRA.
2. It is worth noting that the geometry of the fuel bricks at HYA and HRA is different from the other AGR reactors, as the HYA/HRA design features partial height keyways that do not span the full height of the bricks, see Figure 1. The designs of fuel bricks at the other reactors (HNB, HPB, HYB and TOR) feature full height radial keyways.

## Extant Graphite Core Safety Case and Known Shortfalls

1. The HRA/HYA reactors are currently operating under the extant graphite core safety case NP/SC 7570 (ref. [7]). This is a pre-keyway root cracking case that justifies operation up to a core state that is considered “essentially intact”. This is defined as a core containing up to 10% full-height axially cracked bricks.
2. As part of EDF NGL’s activities to develop a post-keyway root cracking case, EDF NGL carried out a review of the damage tolerance assessments of the extant case NP/SC 7570 and updated the models, where possible in line with current standards and expectations, for the pre-stressed concrete vessel (PCPV) and the graphite core (e.g., GCORE (an ABAQUS-Explicit model of the graphite core)).
3. As the review progressed and modelling work completed, EDF NGL identified a number of safety case shortfalls/anomalies associated with the seismic safety justification.
4. During the initial preparation of the proposed case NP/SC 7824, EDF NGL identified that the existing case NP/SC 7570 (ref. [7]) used best-estimate instead of upper-bound ground properties for the design basis seismic assessments. The best-estimate properties were used based on a judgement that the seismic response of the pre-stressed concrete pressure vessel (PCPV) and the graphite core was relatively insensitive to different ground properties. This was based on a sensitivity study that did not include explicit consideration of the PCPV and the core structure. Subsequent work by EDF NGL to include explicit consideration of the PCPV and the graphite core with upper bound properties led to challenging seismic assessment results. EDF NGL entered its safety case anomalies process (SCAP) and concluded that it was necessary to put in place revised arguments in the form of a Justification for Continued Operation (JCO) until NP/SC 7824 safety case was completed and implemented.
5. The arguments were initially presented in two JCOs. One JCO (EC 368026 & 368031, ref. [8]) covered the civil engineering considerations, i.e. the performance of the PCPV and supporting walls. The other JCO (EC 369005 & 369007, ref. [9]) covered the response of the graphite core. ONR reviewed these JCOs and concluded that the risk of continued operation remained tolerable and ALARP (refs. [10] and [11]).
6. In preparation for moving from NP/SC 7570 to NP/SC 7824, EDF NGL made a review of the load path from ground-to-graphite. That review identified two structural components that required a review of the components’ structural integrity arguments: firstly, the lower radial keys (LRKs); and secondly, the graphite-core restraint cage.
7. As these two issues were discovered at different points in time, EDF NGL firstly presented a JCO on the matter of the LRK components (EC 369656 & 369657, ref. [12]). Then, EDF NGL addressed the core restraint cage anomaly in a subsequent JCO (EC 371114/371115, ref. [13]). Both JCOs drew on multiple disciplinary arguments including graphite and steel structural integrity, civil engineering, external hazards and fault studies.
8. These cases, valid for an ‘essentially intact’ core state, are currently limited to 14 TWd at HYA and 14.5 TWd at HRA (approximately mid 2023).
9. ONR’s inspectors reviewed both JCOs and ONR decisions on continued operation were recorded in Decision Records (refs. [11] and [14])
10. Consequently, the proposed safety case NP/SC 7824 aims to consolidate the seismic safety case for the graphite core, CRS and CSS, thus pulling together developments over many years, roughly since 2018. EDF NGL claims that the proposed case will provide a complete and full justification to demonstrate that the risk posed by a seismic event is reduced to ALARP within the proposed burn-up and core state limits.

## Proposed Safety Case NP/SC 7824

1. The proposed safety case provides a seismic safety justification for operation with axially cracked fuel channel bricks, arising from both the bore cracking mechanism and the keyway root cracking mechanism. The number of cracked bricks considered by the case remains at the “10% level” associated with a core remaining “essentially intact” but includes sensitivity studies at higher levels of cracking.
2. Previous graphite post keyway root cracking cases for Hinkley Point B/Hunterston (HPB/HNB) and Heysham 2/Torness (HYB/TOR) provided safety justification for tolerance to cracking, i.e., damage tolerance assessments (DTA), for (a) normal operation and fault conditions and (b) an infrequent seismic event. The discoveries of the anomalies associated with the seismic justification have progressively caused delays in the production of evidence required to underpin the seismic justification in the proposed consolidated case. Therefore, EDF NGL decided to split the consolidated case into two cases:

* one addressing tolerance to cracking in normal operation and fault conditions which has been reviewed by ONR, See permissioning records PR-01072 and PR-01119 (ref. [15]); and
* the second is to address tolerance to cracking in an infrequent seismic event, which is the subject of this PAR.

1. The proposed safety case states that the fundamental nuclear safety requirements of the graphite core, CRS and CSS in response to a seismic event are to (ref. [4]):

* Allow the movement of control rods and fuel without significant delay or interaction as a result of core geometry,
* Allow operation of the secondary and tertiary shutdown systems,
* Direct gas flows to ensure adequate cooling of the fuel and core,
* Maintain integrity of core boundary,
* Provide neutron moderation and thermal inertia.

1. EDF NGL states that the first three of these requirements require the graphite core geometry to be maintained, specifically, the fuel and control rod channels to be adequately straight and free from significant discontinuities and obstructions. The fourth is related to the integrity of the CRS and CSS. The proposed case focuses on the potential for core distortion to affect control rod entry and on the integrity of the CRS / CSS in a seismic event. Movement and integrity of fuel during and following a seismic event is also considered. Integrity of the CRS / CSS is essentially unaffected by ageing, but updated assessments are provided based on new understanding.
2. The proposed safety case supports operation up to core burn-up limits of 14.65 TWd at HYA and 15.15 TWd at HRA.
3. One of the main modelling changes that the proposed case introduces is the dynamic coupling of the graphite core model to the Pre-stressed Concrete Pressure Vessel (PCPV) model. This modelling change has led to reduced core distortion leading to improved margins for control rod entry. EDF NGL had previously decided to decouple the models due to their complexity. The PCPV construction for HYA/HRA which includes shear keys at its base is different to other stations, namely, HYB/TOR and HPB/HNB, where the seismic models are coupled. In advance of the formal safety case submission and potential life extension decisions, EDF NGL requested a preliminary review from ONR of the supporting references covering this aspect of the modelling (ref. [16]).
4. ONR’s inspectors considered the modelling changes regarding the coupling of the core to the PCPV to be important to the upcoming safety case. Therefore, a preliminary review of the changes being proposed by EDF NGL was undertaken during early engagement. This was done to give us more time to influence potential necessary improvements with regards to this significant modelling development.
5. ONR’s civil engineering specialist inspectors, with support from other specialisms as needed, carried out a review of the coupled modelling supporting references and raised a number of technical queries (TQs) which were recorded in the TQ Tracker for the consolidated seismic safety case (ref. [17]). EDF NGL has provided adequate responses to these queries with further work committed to be completed as part of the production of this case. ONR’s civil engineering specialist inspectors were satisfied in principle with the use of the coupled modelling approach in the safety case. A summary of the ONR’s preliminary review and ONR’s position is recorded in the ONR’s reply letter to EDF NGL in ref. [18]. ONR’s assessment of the proposed safety case built on this preliminary review work.
6. ONR’s External Hazards Specialist Inspector has previously carried out an assessment of the Hazard definitions used for HYA and HRA as part of ONR’s considerations of the JCOs mentioned above. The external hazards assessment is recorded in ref. [19]. The specialist inspector was content the hazard definitions used were adequate to support the safety case. EDF NGL claims that the hazard definitions in the proposed safety case have not been revised for this case. ONR’s assessment of the proposed safety case also built on this previous assessment work.

## Summary

1. The proposed seismic safety case for the graphite core, core restraint and core support structure (ref. [7]) aims to demonstrate that the risk posed by a seismic event is as low as reasonably practicable (ALARP) until core burn-up limits of 14.65 TWd and 15.15 TWd are reached at HYA and HRA, respectively. These burn-ups are valid for an ‘essentially intact’ core state only (up to 10% of bricks in the central region of the graphite core, or 227 axially cracked bricks in total), which is ensured by graphite inspection.
2. The main aspects of the proposed safety case and the sections of this report in which they are discussed are as follows:

* Dynamic coupling of the PCPV and graphite core which replaces the separate graphite core and PCPV models; see Sections 3.1.1.1 and 3.1.3.5.
* Modelled core state and cracking configurations, see Section 3.1.1.2.
* The potential extent of core distortion in a seismic event, see Section 3.1.1.4.
* Structural integrity and representation of the core support structure (CSS) and core restraint structure (CRS), see Sections 3.1.2 and 3.1.3.4.
* Soil Structure Interaction (SSI), see Section 3.1.3.1.
* Non-linear concrete modelling and representation of interactions between the PCPV and its supporting walls, see Section 3.1.3.3.
* Hazard definition by the Seismic Hazard Working Party (SHWP) with 90% scaling to account for geometric mean, see Section 3.1.4.
* Assessment of fault consequences due to a LRK failure, see Section 3.1.5.

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

1. In accordance with the regulatory permissioning plan (PR-01153 and PR-01154), ONR has carried out the following specialist assessments/reviews:

* a Structural Integrity (Graphite) Specialist Assessment recorded in an assessment report type ‘Major’ (ref. [20]);
* a Structural Integrity (Steel) Specialist Assessment recorded in an assessment report type ‘Major’ (ref. [21]);
* a Civil Engineering Specialist Assessment recorded in an assessment report type ‘Major’ (ref. [22]);
* a Fault Studies Specialist Review recorded in an assessment report type ‘Other’ (ref. [23]); and
* an External Hazards Specialist Review recorded in an assessment report type ‘Other’ (ref. [24]).

1. It should be noted that ONR specialist inspectors have engaged with EDF NGL in detailed technical discussions and have raised and resolved a number of technical queries (ref. [17]) throughout their assessments of NP/SC 7824. 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.

## Assessment Findings

### Graphite Structural Integrity Assessment (Ref. [20])

1. The graphite structural integrity specialist inspector has targeted specific areas of the proposed case to ensure EDF NGL has adequately demonstrated unimpeded entry of control rods during a 1 in 10,000 year seismic event, these included consideration of the following areas:

* The validity and confidence of using the coupled model from a graphite structural integrity perspective.
* The adequacy of crack configurations and the core age used in the seismic DTA.
* The uncertainties that have been considered.
* The potential extent of core distortion in a seismic event.

#### Validity and Confidence of Using the Coupled Model

1. The specialist inspector states that in preparing a graphite core DTA case for HYA/HRA in anticipation of keyway root cracking, EDF NGL reviewed its existing GCORE model of the PCPV and graphite core. This GCORE model incorporated representations of both the PCPV and the graphite core simultaneously, but it did not meet the standard set by the keyway root cracking cases for the HPB/HNB reactors. In addition, it was recognised that modifications were needed to the civil engineering aspects of the PCPV representation. The modification to the civil engineering aspects of the PCPV representation were at the time incompatible with the graphite core representation, and to update the model, EDF NGL made the decision to separate the model into two. One model captured the seismic response of the PCPV, and a second captured the seismic response of the graphite core.
2. This meant that there would be no dynamic feedback effect between the graphite core mass and the PCPV mass. Given that the mass of the graphite core was small compared to the mass of the PCPV building, EDF NGL considered this would be a conservative change, or at least an inconsequential one.
3. The graphite bricks which make the outer rings and upper and lower layers of the graphite core, known as the reflector, are made from lower graphite grades than the active region and consequently started operation with a lower strength. For the separated model it was ultimately demonstrated by EDF NGL that large numbers of keying system failures in the reflector region were being predicted due to the low strength and the loads generated by the seismic event. These predicted failures led to a substantial increase in predicted core distortions leading to a potential hinderance to a significant number of control rods.
4. This led EDF NGL to re-consider its decisions, in particular the separation of the original model. EDF NGL was able to address the incompatibility between the PCPV and the graphite core models to recombine them back into one “coupled model”. This coupled-model predicted a greatly reduced degree of damage to the keying system and subsequently predicted all control-rod channel distortions were inside the distortion limit.
5. The specialist inspector states that EDF NGL has demonstrated confidence in the coupled model through a three-step process, firstly by developing an analytical solution of the response of two interacting masses representing the core and the PCPV, secondly by developing a simple numerical coupled model by embedding a simple mass representing the graphite core in the PCPV model and thirdly developing the fully coupled GCORE model. The frequency responses from the different models were comparable, which the specialist inspector considers to strengthen EDF NGL’s position that the use of the coupled model is entirely reasonable.
6. Overall, the specialist inspector is content that EDF NGL has provided sufficient evidence to give adequate confidence that the use of the coupled model is appropriate.

#### The Adequacy of Crack Configurations and the Core Age Used in the Seismic DTA

1. The crack configuration and core age used in the DTA set the limit of validity for the proposed case. Any damage observed or predicted to exist within the graphite core which exceeds the crack configuration would not be covered by the case. Similarly, the core age is expressed in terms of overall core burn-up and regardless of what damage is present in the graphite core, EDF NGL cannot operate beyond that burn-up under this case.
2. EDF NGL has set the crack configuration to provide a safety case coverage for the discovery of a variety of possible configurations of cracked bricks in the core up to the core age specified by the validity. Table 2 shows the crack configuration for the base line GCORE analysis, in terms of the numbers of singly cracked bricks (SCB), doubly cracked bricks (DCB) and multiply cracked bricks (MCB).

Table 2: HYA and HRA crack configuration for GCORE base-line analysis (ref. [4])

|  |  |  |
| --- | --- | --- |
| Cracked Brick Type | HYA | HRA |
| SCBs | 173 | 174 |
| DCBs | 59 | 60 |
| DCBs (bore cracked) | 50 | 100 |
| MCBs | 17 | 17 |
| **Total** | 299 | 351 |

1. It should be noted that Table 2 shows a larger number of bore cracked DCBs at HRA than at HYA to reflect the in-core observations to date.
2. EDF NGL has defined a distribution of crack openings at 1mm intervals from 1mm to 20mm openings at the brick periphery. The specialist inspector considers this is a reasonable range of openings to consider. However, of the 173 and 174 SCBs for HYA and HRA, approximately half is of an opening that is likely to be inconsequential to core distortion. The other half consists of a roughly even spread of openings.
3. The specialist inspector remains content with the overall arrangement of the crack configuration presented in the case.
4. In terms of core age, the specialist inspector states that EDF NGL’s GCORE DTA has assessed the graphite core performance at a core age approximately six months more advanced than the validity date. The specialist inspector considers that this margin provides some control over the uncertainties associated with defining the core age. The specialist inspector is therefore content with the stated validity limit on core age.

#### The Uncertainties that Have Been Considered in the Analysis

1. The specialist inspector states that the sensitivity studies supporting the DTA must explore within the bounds of reasonable uncertainty the potential challenge against the conclusions drawn from the baseline studies. Whilst EDF NGL has carried out a range of sensitivity studies, the specialist inspector targeted those studies which have the greatest potential to challenge the DTA conclusions, these included: core age, crack configuration, extent of cracking (i.e., larger numbers of cracked bricks) and keying system capacities.
2. The specialist inspector is content that the sensitivity studies on core age, crack configuration and extent of cracking are adequate to cover the uncertainties associated with these parameters.
3. EDF NGL’s choice of sensitivity studies for the keying system capacities is to adopt an approach of separating the keying system into the different types of horizontal connections, i.e. those between fuel-bricks and interstitial-bricks, and those between fuel-bricks and fuel-bricks; and those in the reflector. Each type is then considered by a separate sensitivity study. This is a new approach, it was not adopted for any of the HPB/HNB DTAs or the latest HYB/TOR DTA. Amongst other sensitivity studies on clearances and capacities, previous DTAs have included a global 20% capacity reduction in the entire keying system. A global 20% reduction is not quantified against some particular uncertainty, it is arbitrary and is considered as a reasonable magnitude. It is the specialist inspector’s view that such a study acknowledges the potential for overestimating the capacity or the proximity to a tolerance boundary of a system which is complex, uncertain, approximate and highly influential to the DTA conclusions and therefore should be included.
4. Therefore, the specialist inspector did not concur with EDF NGL’s view that the keying system capacities can be separated into independent parts and the sensitivity to each part is considered independently. The specialist inspector has required EDF NGL to make the ‘20% reduction’ study as per pervious cases, e.g., the HPB/HNB DTA methodology.
5. Since EDF NGL ultimately made the ‘20% reduction’ study, which did not challenge the control rod entry margins, the specialist inspector is consequently content with the scope of the sensitivity studies supporting the DTA.
6. To ensure that the requirement for a global reduction sensitivity study for the keying system capacities is taken forward and referenced in future safety cases, the specialist inspector has raised Regulatory Issue RI-11392.

#### The Potential Extent of Core Distortion in a Seismic Event

1. EDF NGL uses the GCORE model to predict the core distortion during the seismic event. The core distortions predicted by GCORE are quantified in terms of a metric known as the distortion utilisation (DU). The DUs are calculated from the GCORE channel distortion predictions by another EDF NGL’s code called LEWIS which quantifies the severity of the control-rod channel distortion into a single number, the DU. The DU calculation is essentially the fraction of the channel’s distorted shape amplitude which would cause a three-point contact between the control rod and its channel wall. For example, if the DU is 0.5 then the channel’s distorted shape would have to double in amplitude to cause a three-point contact between the control rod and the control rod channel wall. Therefore, the specialist inspector applied an acceptance criterion that DUs must be less than 1, which is consistent with the intention of the ONR TAG (ref. [25]) in terms of unimpeded movement of the control-rods.
2. The specialist inspector notes that three-point contact at a DU of 1.0 does not equate to a control failing to enter the core. For instance, the peak DU is only short-lived, it lasts for only a fraction of a second during the seismic event, the remainder of the time the DU is usually much smaller. However, any DU exceeding 1.0 infers that some forcible interaction occurs between the control-rod and the interstitial channel wall and the consequences of that must be well understood, before the specialist inspector could consider assessing such instances.
3. GCORE and LEWIS have been developed over many years by EDF NGL, and in particular via the HPB/HNB safety cases, to date their principles and performance have been subject to substantial validation activities and substantial scrutiny by ONR. The specialist inspector has therefore focused on the adequacy of the DUs and the amount of in-event keying system damage predicted by the DTA.
4. The specialist inspector states that the extent of core distortion shown for the baseline condition is low and is not significantly perturbed by the sensitivity studies. An exception is the 40% integral key/keyway capacity reduction in the active core which showed a marked but still acceptable increase in distortion (i.e., DU remained less than 1.0). Integral key/keyways refer to part of the keying system and represent the keys and keyways between the fuel-bricks and interstitial-bricks.
5. The specialist inspector considers that the extent of keying system damage is low and consistent with the predicted core distortions. There is no disproportionate change in the keying system damage observed which would undermine the scope of the studies.
6. Overall, the specialist inspector is content that the case has demonstrated sufficient tolerance to core distortion at the 10% cracking level.

#### Graphite Structural Integrity Conclusion

1. To conclude, the graphite structural integrity specialist inspector is content that EDF NGL’s proposed safety case is adequate and the risks have been reduced to ALARP for the defined validity of the safety case. It is judged that the proposal is sufficient, from a graphite structural integrity perspective, to justify the issue of a Licence Instrument for ONR’s Agreement, under arrangements made under Licence Condition 22(1), to the implementation of NP/SC 7824 by Heysham 1 and Hartlepool Power Stations.

### Steel Structural Integrity Assessment (Ref. [21])

1. The graphite core is supported by the core support structure (CSS) and the core restraint structure (CRS, also referred to as the restraint cage) within the PCPV. These steel structures and components (SSCs) are key elements as they act as the load path between the graphite core and the PCVP transferring seismic loads during a seismic event.
2. The steel structures are fundamental to the ability of the core to support safe shutdown and holddown and maintain core geometry to ensure that there is acceptable cooling for in-situ fuel and core components. Therefore, appropriate representation of the SSCs in GCORE and the demonstration of acceptable margins against failure for these SSCs are important aspects of the proposed graphite core safety case NP/SC 7824.
3. Consequently, the steel structural integrity specialist inspector targeted their assessment of the proposed safety case on the demonstration of structural integrity for the following SSCs:

* The lower and upper radial keys (LRKs and URKs);
* The core restraint structure (CRS); and
* The core support structure (CSS).

1. The specialist inspector sought to establish whether EDF NGL has provided suitable evidence to support the structural integrity classification for the key SSCs and whether the standard of the assessment is consistent with this classification. They have assessed the adequacy of predicted margins to failure for these components. They have also sought to determine how the mechanical behaviours of the SSCs have been represented in the whole core model and whether the licensee’s evidence to support the modelling was appropriate.

#### The Lower and Upper Radial Keys (LRKs and URKs)

1. There are 3 LRKs and 3 URKs that connect the CSS and the CRS to the PCPV. The LRKs (and the URK) are arranged at 120 degrees from each other, and, despite the name, these radial keys are designed to prevent movement and transfer loads in the circumferential direction only. A schematic of an LRK is shown in Figure 5.
2. EDF NGL makes a high integrity claim for the LRKs and URKs. The seismic loads on the LRKs bound those of the URKs. Hence, the specialist inspector has focused on the integrity of the LRKs.
3. The specialist inspector has considered different aspects of EDF NGL’s arguments with regards to the structural integrity claims on the LRKs and URKs. These included the classification of the LRKs/URKs, the standards of assessment used to support the integrity of the LRKs/URKs, material properties used in the analysis, the bounding analysis and the available margins to failure in a seismic event.



Figure 5: Schematic of an LRK

1. The specialist inspector is content that the classification of high integrity, the use of ASME III standards and the material properties used for the analysis are appropriate.
2. The specialist inspector is of the view that EDF NGL’s methodology and the margins against failure demonstrated for the LRKs are acceptable. The specialist inspector notes that the seismic analyses are based on upper bound seismic inputs and lower bound materials properties for the support stool (a part of the LRK), whose load capacity is most limiting. The specialist inspector is content that the analysis is consistent with relevant ONR Safety Assessment Principles (SAPs) expectations (ref. [26]).

#### Core Restraint Structure (CRS)

1. The CRS is composed of a metallic ‘cage’ and core restraint links connecting the cage to the graphite core. The cage is made of lateral beams which are bolted to vertical beams, known as the stanchions. Each lateral beam is approximately 2.36 meter long. The stanchions are about 11 meter long. The cage is restrained at the top by the top stiff ring (TSR). The bottom of the cage is bolted to the core support plates (CSPs). The TSR and CSPs are connected to the PCPV by the three URKs and the three LRKs. Figure 6 shows an illustration of the CRS.

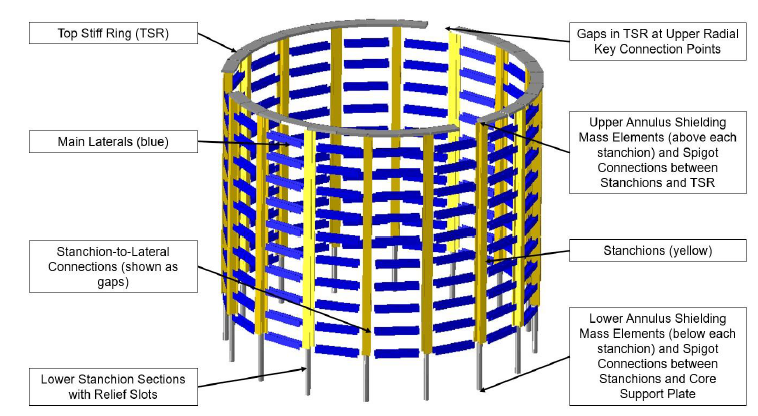


Figure 6: Core Restraint Structure (CRS)

1. The specialist inspector focused their assessment on the lateral beam to stanchion connection as the seismic analysis predicts significant plasticity in some of these connections.
2. The specialist inspector is content that only a small number of connections were predicted to yield at the top and bottom of the cage and that the extent of yielding was unlikely to affect the overall elastic-plastic behaviour of the cage.
3. The specialist inspector is satisfied that EDF NGL has provided satisfactory demonstration that the margins against failure of a lateral beam are acceptable and that the elastic-plastic properties for the cage in the GCORE model appear to be appropriate.
4. Overall, the specialist inspector concludes that the cage modelling and its representation in the GCORE model are appropriate and consistent with ONR’s expectations in relevant SAPs (ref. [26]).

#### Core Support Structure (CSS)

1. The HYA/HRA graphite cores are supported by the core support plates (CSPs) which are in turn supported by an array of 138 pillars. The pillars have spherical ends bearing on hardened steel pads which allow for small amount of rotation of the pillars whilst maintaining the CSPs horizontal. A dowelled connection joins the core support pillars to the CSPs via a connector plate.
2. The core support pillars are attached to the CSPs via 38 support pillar permanent connectors, 20 secondary connectors and 8 expansion link connectors. The licensee modelled the connections in GCORE using user-defined elements. The licensee determined the elastic-plastic behaviour for these user-defined elements using a more detailed finite element model of the dowelled connection.
3. The specialist inspector has considered the adequacy of EDF NGL’s analysis of the doweled connections and the available margins against failure. They also assessed the margins against instability of the core support pillars.
4. The specialist inspector did not identify any significant shortfalls in EDF NGL’s assessment of the dowelled connection between the CSPs and the core support pillars. The specialist inspector is content that EDF NGL has provided a satisfactory demonstration of the structural integrity of the core support pillars and their connection to the CSPs. The specialist inspector also judges that the elastic-plastic properties appeared to have been adequately implemented into GCORE.

#### Steel Structural Integrity Conclusion

1. To conclude, the steel structural integrity specialist inspector is content that EDF NGL’s proposed safety case is adequate and the risks have been reduced to ALARP for the defined validity of the safety case. It is judged that the proposal is sufficient, from a steel structural integrity perspective, to justify the issue of a Licence Instrument for ONR’s Agreement, under arrangements made under Licence Condition 22(1), to the implementation of NP/SC 7824 by Heysham 1 and Hartlepool Power Stations.

### Civil Engineering Assessment (Ref. [22])

1. The civil engineering specialist inspector has focused on the following principal areas of the proposed safety case:

* Soil Structure Interaction (SSI) properties and consideration of geotechnical uncertainties.
* Properties of the bearing pads.
* The non-linear concrete model behaviour, associated uncertainties and appropriateness of PCPV-related parameters.
* Civil engineering aspects of the core restraint structure (CRS) and core support structure (CSS).
* The dynamic coupling of pre-stressed concrete pressure vessel (PCPV) and graphite core model to gain confidence that the modelling approaches align with relevant good practice (RGP).

#### SSI Properties

1. The specialist inspector notes the difference in design between the HYA rectors and the HRA reactors. The HYA design has a raft foundation which is founded directly on bedrock. The HRA design has a piled foundation due to differing ground conditions to those of HYA.
2. The specialist inspector has considered EDF NGL’s assessments that define the soil structure interaction (SSI) for each station.
3. The specialist inspector is content that EDF NGL has incorporated sufficient conservatisms in the modelling of the soil structure interaction (SSI) used in the GCORE coupled model.

#### Properties of the Bearing Pads

1. The specialist inspector has considered EDF NGL’s assessment of the bearing pads with regards to available RGP and standards.
2. Based on sampling a number of relevant references, the specialist inspector judges that the properties and integrity of the bearing pads are acceptable.
3. However, the specialist inspector notes that the thread of evidence is disjointed and difficult to follow.
4. Hence, the specialist inspector makes the following observation:

*“Observation 1: Given the assumptions that have been made, the inability to carry out testing and examination in line with BS EN 15129, ageing and degradation issues; if in the future the duty holder were to consider extending the current working life beyond 2024, that clarification is sought on bearing make up and geometry and this is reflected in the calculations and the FE modelling.”*

1. This observation will be communicated to EDF NGL via Level 4 normal business interactions to seek improvements for potential future safety cases. Nonetheless, the specialist inspector remains content that EDF NGL’s justification for the bearing pads in the proposed safety case is acceptable.

#### Non-linear Concrete Model, Associated Uncertainties and Appropriateness of PCPV Parameters

1. For both HYA and HRA, the PCPV is supported by two rings of supporting walls via the bearing pads. Figure 7 illustrates the inner and outer walls. The top of the inner wall features crenels and merlons. The PCPV has shear keys that locate at the crenels of the inner wall.

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Figure 7: Illustration of the PCPV supporting walls

1. In a seismic event, it is anticipated that the PCPV shear keys will interact with the merlons of the supporting wall, affecting the seismic movement of the graphite core.
2. The specialist inspector has considered EDF NGL’s representations of the different civil structures with a focus on the shear keys/merlon interactions in the GCORE coupled model.
3. The specialist inspector has also utilised two Technical Support Contracts (TSCs) at strategic points within the model development to review key aspects of the modelling.
4. The specialist inspector notes that engineering judgement has been called upon to cover some areas of limited information. However, the specialist inspector is content that EDF NGL has used conservative parameters and the available margins are sufficient to cover the uncertainty associated with the areas of limited information.

#### Core Restraint Structure (CRS) and Core support Structure (CSS)

1. The pre-stressed concrete pressure vessel (PCPV) interfaces with the graphite core via key elements as presented in Figure 3. These key elements are the lower and upper radial keys (LRKs and URKs). The radial keys have been considered by the steel structural integrity specialist inspector as they are metal components, see Section 3.1.2. However, at the point where these elements interface with the PCPV, it is necessary to demonstrate the appropriateness of civil engineering aspects. The civil engineering specialist inspector has sampled this area as part of their assessment of the proposed safety case.
2. The specialist inspector has sought to gain adequate confidence in the primary load path, particularly focusing on the embedment of the LRKs within the PCPV. They have further considered the supporting check calculations undertaken to justify parameters assumed in the modelling.
3. The specialist inspector notes that due to the nature of the embedment, it is not possible or representative to strictly adopt all aspects of the relevant design code (ref. [27]). However, the specialist inspector considers that the judgements made and checks undertaken by EDF NGL are appropriate and support the conclusions of the assessment, providing adequate justification with respect to the robustness of the embedment.
4. Overall, the specialist inspector is content with the claims, arguments and evidence presented with respect to the primary load path and interface between the LRK and PCPV.

#### Dynamic Coupling of Pre-Stressed Concrete Pressure Vessel (PCPV) and Graphite Core Model

1. This safety case submission presents an updated coupled analysis approach where the PCPV and graphite core are dynamically coupled. This replaces the previous separate graphite core and PCPV models, as explained earlier in this report. This is a key area of the proposed safety case and it represents an interface between the graphite structural integrity and the civil engineering assessments. The graphite structural integrity consideration of the coupled model has been summarised in Section 3.1.1.1.
2. The proposed safety case reflects an improved understanding of the damping effect between the components and how this reduces the overall magnitude of the core response to the seismic hazard.
3. The specialist inspector has sought to gain confidence in the validation, verification, and qualification undertaken to support the use of the coupled model. The specialist inspector notes that EDF NGL has completed an “independent” assurance panel review of the coupling approach; the specialist inspector has considered the findings of this review.
4. The specialist inspector’s review of the qualification of the coupled model has indicated some differences are observable in the PCPV rotational (torsional) accelerations and that these are attributed to the non-linear behaviour of the shear keys.
5. The specialist inspector has investigated the observed increased rotational (torsional) response further due to the high utilisation of the radial keys (~0.95). The relevant codes and standards (ref. [28]) include general requirements for ‘actual’ and ‘accidental torsion’ to be considered.
6. Whilst the specialist inspector is content that ‘actual torsion’ is likely to be captured by the model, ‘accidental torsion’ requires additional analysis tasks to be undertaken. This is particularly important where there are potential uncertainties around the centre of mass or centre of rigidity and/or where non-linear yielding of load path elements (e.g., the shear keys or the radial keys) may cause the migration of these points. The consideration of ‘accidental torsion’ in the analysis ensures that these and other aspects (e.g., seismic waves not propagating vertically, rotational components of ground motion) are conservatively accounted for.
7. The specialist inspector could not see evidence within the safety documents or references of ‘accidental torsion’ being considered in accordance with RGP and raised a TQ with respect to this.
8. EDF NGL’s responses confirmed that ‘accidental torsion’ had not been considered. However, in response to the TQ, an assessment was conducted in accordance with RGP (ref. [28]) and reported in a supplementary calculation note (ref. [29]).
9. Based on their sample of the information in the documents and the TQ responses provided, the civil engineering specialist inspector is satisfied that the qualification reports provide adequate evidence of validation and verification. The specialist inspector also considers the uncertainties in the coupled response are adequately offset by conservatisms in the analysis approach.

EDF NGL’s “Independent” Review of the Coupled Modelling Approach (ref. [30])

1. The specialist inspector states that EDF NGL has convened a panel of seven suitably qualified and experienced (SQEP) independent people. The review was scoped around the following questions:

* *“Review of the new PCPV and graphite core coupling; do you consider the coupling has been correctly implemented and the revised behaviour is understood?*
* *Considering the assurance that has already taken place; do you consider the assurance has any significant gaps?*
* *Assessing the total implementation and analysis of the response of the graphite core to a seismic event; do you consider it suitable and conservative to support the safety case assessment? Noting this same assessment route will be used for a revised lifetime.”*

1. A series of documents were released to the panel for review and meetings subsequently held to identify questions and discuss these with the responsible authors and engineers.
2. The specialist inspector states that the Independent Assurance Panel review appears to meet the expectations of the relevant SAPs and represents a thorough and robust review.
3. A few issues were raised by the panel but these are not considered to significantly affect the claims, arguments and evidence of the proposed safety case, but are areas where the panel judge that further clarity would be advantageous.
4. EDF NGL has subsequently provided an updated Issue 2 of the Independent Assurance Review (ref. [31]), which includes additional information and specific responses to each of the panel's concerns. It is noted that based on the additional information provided, the review panel is now satisfied that the overall approach and its implementation are suitable and conservative to support safety case assessment.
5. It is the specialist inspector’s opinion that based on the updated Issue 2 of the Independent Assurance Panel review report, the points of concern raised by the panel have now been adequately addressed by EDF NGL to the panel’s satisfaction. The formal close out of the Independent Assurance Review is noted as a positive development which provides additional confidence in the overall suitability of the analysis approach and its conservative implementation in support of the safety case assessment. Hence, the specialist inspector makes the following observation:

*“Observation 2: The formal close out of a Level 3 Independent Assurance Review is noted as a positive development, which provides additional confidence in the overall suitability of the analysis approach and its conservative implementation in support of the safety case assessment.”*

#### Civil Engineering Conclusion

1. To conclude, the civil engineering specialist inspector is content that EDF NGL’s proposed safety case is adequate and the risks have been reduced to ALARP for the defined validity of the safety case. It is judged that the proposal is sufficient, from a civil engineering perspective, to justify the issue of a Licence Instrument for ONR’s Agreement, under arrangements made under Licence Condition 22(1), to the implementation of NP/SC 7824 by Heysham 1 and Hartlepool Power Stations.

### External Hazards Assessment (Ref. [24])

1. EDF NGL has utilised the Uniform Risk Spectra (URS) developed by the Seismic Hazard Working Party (SHWP) in the 1990s to define the seismic hazards for each station. The URS were based on site specific hazard evaluations and are different for each station.
2. EDF NGL has used the URS with an annual frequency of exceedance (AFoE) of 1 x 10-4 /yr (1 in 10,000 year) to define an infrequent design basis seismic event.
3. EDF NGL has generated five ground motions for each station based on spectral matching of time histories from real earthquake records to the site-specific URS. These ground motions with 90% scaling (i.e., 10% reduction) of the horizonal components to account for the geometric mean effect are used as input to the analysis of the graphite core response to a seismic event.
4. ONR has previously accepted through a targeted external hazard assessment (ref. [19]) the use of the 90% SHWP infrequent URS as an adequately conservative characterisation of the seismic hazard at the HRA and HYA sites to support continued operation. However, the margins in the 90% infrequent URS are uncertain and do not provide support for reducing conservatism elsewhere in the analysis. The specialist judged that deviations from this position were likely to require further justification to support continued operation.
5. The external hazards assessment (ref. [24]) of the proposed safety case NP/SC 7824 has specifically targeted this aspect to ensure that the seismic input motions used are adequate representation of the seismic hazard design basis events for both sites and that they have not been changed from those previously assessed by ONR in ref. [19].
6. The specialist inspector has also considered the adequacy of the cliff-edge and beyond design basis analyses and the interfaces between NP/SC 7824 and the overarching seismic safety cases for HYA and HRA.
7. The external hazards assessment has found that NP/SC 7824 uses the infrequent SHWP URS, scaled to 90%, as the seismic hazard design basis event. As ONR has previously assessed this and found it to meet the expectations of relevant SAPs (ref. [26]), the specialist inspector judges that the 90% infrequent URS remains an adequately conservative representation of the seismic hazard for HYA and HRA stations.
8. The specialist inspector states that the beyond design basis analyses are provided for events of 1 in 20,000, 40,000 and 100,000 years frequency of exceedance. The specialist inspector is content that these analyses demonstrate that margin exists for both HYA and HRA.
9. The specialist inspector considers that the proposed case NP/SC 7824 does not provide an adequate cliff-edge analysis, and does not meet the expectations of SAP EHA.7. The damage tolerance analysis that underpins NP/SC 7824 does not explore events more onerous than the design basis with other input parameters defined conservatively. However, the specialist inspector judges that there is unlikely to be a cliff-edge given the margins demonstrated by the design basis and beyond design basis damage tolerance analyses.
10. The specialist inspector has found that the safety case thread between NP/SC 7824 and the overarching seismic safety cases for HYA and HRA is not clear, and not traceable at the current time. However, the specialist inspector is content that the EDF NGL has provided sufficient evidence to demonstrate that NP/SC 7824 does not challenge the claims, arguments and evidence in the overarching seismic safety cases for HYA and HRA.
11. Overall, from an external hazards perspective, it is judged that the case presented in NP/SC 7824 and supporting documentation has adequately addressed the external hazards aspects. The case demonstrates that nuclear safety risks resulting from seismic hazards on the graphite cores have been reduced as low as reasonably practicable.

#### External Hazards Conclusion

1. To conclude, the external hazards specialist inspector is content that EDF NGL’s proposed safety case is adequate and the risks have been reduced to ALARP for the defined validity of the safety case. It is judged that the proposal is sufficient, from an external hazards perspective, to justify the issue of a Licence Instrument for ONR’s Agreement, under arrangements made under Licence Condition 22(1), to the implementation of NP/SC 7824 by Heysham 1 and Hartlepool Power Stations.

### Fault Studies Assessment (Ref. [23])

1. The fault studies specialist inspector has carried out a targeted review of the proposed safety case NP/SC 7824 focusing on aspects that are most relevant to fault studies, these include:

* The functionality of the primary shutdown system in a seismic event;
* The analysis of lower radial key failure consequences; and
* The justification that adequate cooling for in-situ fuel and core components is maintained in a seismic event.

1. The specialist inspector states that the maximum predicted values of control rod channel distortion for all cases are significantly less than 1.0, demonstrating that the original design intent and claimed reliability of the PSD is maintained in the analysed seismic events. Assessment of the adequacy of the evidence supporting these claims, incorporating the seismic hazard definition and core modelling are considered within the external hazards, civil engineering and structural integrity disciplines. The specialist inspector is content, provided that these disciplines are content with the adequacy of the modelling results, that there is no impact on the extant fault studies supporting operation of HYA/HAR and as such the potential impact of a seismic event on PSD functionality does not need to be considered further from the perspective of fault studies.
2. I am content that the conclusions of the assessments from the different disciplines presented in the previous sections of this PAR confirm the adequacy of the claims and evidence related to the claimed reliability of the PSD as assumed by the fault studies specialist inspector.
3. The specialist inspector notes that in the event that the seismic modelling is inadequately conceived or executed, such that some or all of the control rods fail to enter the core, there is redundancy within the PSD (as not all rods are needed to achieve shutdown), and diversity provided by the seismically qualified secondary shutdown system (SSD). The specialist inspector judges that this provides an adequate level of defence-in-depth to protect against the risk of conceptual errors in the modelling.
4. The specialist inspector states that in the event of failure of a lower radial key (LRK) as a result of a seismic event, there is the potential for a partial or complete collapse of the core support plate. Whilst EDF NGL’s arguments are focussed primarily on demonstrating the low frequency of such an event, the potential fault studies consequences have also been analysed to support the justification for a high integrity claim on the lower and upper radial keys (LRKs and URKs).
5. A partial or complete collapse of the core support plate (CSP) could potentially lead to dose band 5 consequences, although this is not inevitable even for a whole core support plate collapse. The avoidance of these consequences is primarily reliant on the integrity of the LRKs in an infrequent seismic event, and if a LRK fails, the ability of the buffer stops and reactor structure to prevent disengagements of CSP pillars. The buffer stops are components of the LRKs that would engage in case of large radial movement following a LRK failure.
6. The structural integrity claim on the LRK in a seismic event falls within the scope of the structure integrity (steel) assessment, which has been presented earlier in this PAR. However, the required level of integrity for this component is an interface area between fault studies and structure integrity.
7. EDF NGL has made a ‘high integrity’ claim, a classification associated with the consequences of failure, on the LRK. Both inspectors have worked together to cover this interface. The structural integrity specialist inspector is content the likelihood of LRK failure in an infrequent seismic event is ‘very low’, and the likelihood of CSP pillar disengagement following LRK failure is ‘low’ (ref. [32]). The fault studies specialist inspector is content that the principal argument for the LRK being a ‘high integrity’ component (as opposed to a ‘highest reliability component’), is satisfied by the confidence that the probability of LRK failure in an infrequent seismic event is sufficiently low. If a LRK were to fail, the buffer-stops and reactor structure might prevent disengagement of the CSP pillars, providing further defence in depth.
8. Consequently, the fault studies specialist inspector considers that the fault sequence frequency of LRK failure leading to significant radiological consequence in an infrequent seismic event is sufficiently low to be beyond the design basis and the specialist inspector concurs with EDF NGL’s claim that the risk from this fault sequence is tolerable and ALARP.
9. For fuel cooling, the specialist inspector is content that EDF NGL has provided adequate justification that fuel sleeve gapping resulting from a seismic event is not a significant threat to nuclear safety.
10. Overall, from a fault studies perspective, it is judged that the case presented in NP/SC 7824 and supporting documentation is adequate to support continued operation of HYA and HRA reactor for the identified period of validity.

#### Fault Studies Conclusion

1. To conclude, the fault studies specialist inspector is content that EDF NGL’s proposed safety case is adequate and the risks have been reduced to ALARP for the defined validity of the safety case. It is judged that the proposal is sufficient, from a fault studies perspective, to justify the issue of a Licence Instrument for ONR’s Agreement, under arrangements made under Licence Condition 22(1), to the implementation of NP/SC 7824 by Heysham 1 and Hartlepool Power Stations.

# Matters arising from ONR’s work

1. All ONR specialist inspectors agree that the proposed safety case modification of NP/SC 7824 (ref. [4]) is acceptable. On that basis, I have prepared licence instruments 639 and 576 for Agreement to NP/SC 7824: Heysham 1 and Hartlepool Consolidated Seismic Safety Case for the Graphite Core, Core Restraint and Core Support Structure EC 372009 (HYA) and 371983 (HRA). These have been written according to ONR guidance for derived power arrangements (ref. [33]).
2. Some Recommendations and Observations were raised by the specialist inspectors which are discussed in this report. None of the recommendations or observations prevent Agreement to NP/SC 7824.
3. I have liaised with the Environment Agency (EA) and they have confirmed that they have no objections to the operation of Heysham 1 and Hartlepool reactors to a core burn-up of 14.65 TWd at HYA and 15.115 TWd at HRA (ref. [34]).
4. I have confirmed that EDF NGL has followed its own due process. An Independent Nuclear Safety Assessment (INSA) statement for NP/SC 7824 has been submitted (ref. [2]) and Nuclear Safety Committee (NSC) meeting minutes have been submitted in support of the case (ref. [35]).

# Conclusions

1. Based on the work carried out by ONR, I have concluded that the proposed safety case NP/SC 7824 has been adequately justified by EDF NGL and that Licence Instruments should be issued to HYA and HRA Agreeing to implementation of NP/SC 7824.

# Recommendations

1. I recommend that ONR should issue Licence Instruments 639 and 576 to Heysham 1 and Hartlepool Power Stations, respectively, to Agree to the implementation of NP/SC 7824.
2. I also recommend that ONR should maintain regulatory oversight and routinely monitor progress against the assessment recommendations and observations identified by the specialist inspectors, these are:

* Regulatory Issue raised by the graphite structural integrity specialist inspector (see para. 56): RI-11392, title: “Graphite core seismic tolerance sensitivity studies, inclusion of a global capacity reduction into the safety case (HYA & HRA)”.
* Observation 1 raised by the civil engineering specialist inspector (see para. 90): “Given the assumptions that have been made, the inability to carry out testing and examination in line with BS EN 15129, ageing and degradation issues; if in the future the duty holder were to consider extending the current working life beyond 2024, that clarification is sought on bearing make up and geometry and this is reflected in the calculations and the FE modelling.”

# References

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