Agreement to NP/SC 7785 Hunterston B Power Station - Return to service safety case for Reactor 4 following core inspection results in 2018

Hunterston B Power Station
Project Assessment Report

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EXECUTIVE SUMMARY

Title

Agreement to NP/SC 7785 Hunterston B Power Station - Return to service safety case for Reactor 4 following core inspection results in 2018.

Permission Requested

Under their arrangements made under Licence Condition 22(1), EDF Energy Nuclear Generation Limited (EDF Energy NGL) has requested that the Office for Nuclear Regulation (ONR) issues an Agreement to NP/SC 7785, which is the safety case for return to service of Hunterston B Reactor 4 following inspection of the graphite core in 2018.

Background

The fundamental nuclear safety requirements of the graphite core of an Advanced Gas Cooled Reactor (AGR) are to:

- Allow unimpeded movement of control rods and fuel.
- Direct gas flows to ensure adequate cooling of the fuel and core.
- Provide neutron moderation and thermal inertia.

It has long been understood that irradiation of the fuel channel graphite bricks will eventually lead to shrinkage and cracking of these bricks late in reactor lifetime. Such cracking is termed keyway root cracking. This has the potential to challenge the nuclear safety requirements above and consequently it needs to be demonstrated that these fundamental requirements continue to be met in normal operation, fault conditions and after a design basis seismic event.

Keyway root cracking was first observed in Hunterston B Reactor 4 in August 2014, although this was in one of a small number of bricks with a high shrinkage, known to be more susceptible to cracking. The first observation in the main population of graphite fuel bricks was at Hunterston B Reactor 3 in October 2015, and then in September 2017 in Reactor 4. Hunterston B Reactor 3 is the lead reactor across the AGR fleet in terms of keyway root cracking. Since then, continued reactor operation has been under a safety case that allowed up to 700 axially cracked bricks, known as the “Currently Established Damage Tolerance Limit”. To ensure a further safety margin, a lower operational limit (the “Operational Allowance”) of 350 axially cracked bricks was imposed to ensure that the upper safety limit (700 axially cracked bricks) was not challenged. In order to monitor the core condition and the number of cracks, the reactor cores have been regularly inspected. Inspection results and modelling are used to determine an appropriate period of safe operation to the next core inspection.

Inspection of the Hunterston B Reactor 3 graphite core in March 2018 identified cracking which was in excess of the operational allowance of 350 axially cracked bricks but well within the upper safety case limit of 700 axially cracked bricks. As a result, Hunterston B Reactor 3 remains shut down. EDF Energy NGL has recently presented a safety case to ONR that aims to justify further operation of Reactor 3, which will be assessed by ONR in due course.

The extent of cracking identified within Reactor 3 resulted in an earlier than originally planned inspection of the Reactor 4 graphite core in October 2018. The inspection confirmed expectations that, due to the lower core burn-up, Reactor 4 had fewer cracked bricks than Reactor 3 and that Reactor 4 remained within the operational allowance of 350 cracked bricks. However, it was evident that continued operation of Reactor 4 would mean that it would soon exceed this limit and consequently Reactor 4 has remained shut down whilst EDF Energy NGL developed a safety case to justify further operation. NP/SC 7785 presents this safety case and was provided to ONR in March 2019.

This Project Assessment Report (PAR) considers the proposal (NP/SC 7785) from EDF Energy NGL for return to service of Hunterston B Reactor 4 following its graphite core inspections for operation up a core burn-up of 16.025 TWd. This equates to approximately 4 months continuous operation at power. The safety case is based upon an increase in the operational allowance to 700 axial cracks and an upper safety limit of 1331 axially cracked bricks. The safety case also takes into account graphite bricks with two axial cracks (doubly cracked bricks) and the potential for bricks with three or more axial cracks (multiply cracked bricks). EDF Energy NGL's view is that these changes are justified through developments in the assessments used to predict how a cracked core will perform under normal operation, faults and seismic loading (known as Damage Tolerance Assessments). This includes the use of a revised core input seismic motion following an update to the Hunterston B buildings model, used to predict the behaviour of the core during an earthquake. The safety case also addresses the implications of the production of small pieces of graphite debris, produced by cracking, on fuel cooling and fuel handling.

A key aspect of the safety case is that the Reactor 4 core state, in terms of the predicted level of cracking following around 4 months of operation, is broadly comparable to the current Reactor 3 core state, as established by inspections in 2018.

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

Based on the potential for cracked bricks to affect the fundamental nuclear safety requirements of the Hunterston B Reactor 4 core, the following assessments of NP/SC 7785 have been completed by ONR specialist inspectors:

- Civil Engineering
  - Assessment of a new analysis model for the pre-stressed concrete pressure vessel.
- Structural Integrity (graphite)
  - Assessment of the revised core state predictions including induced cracking and multiply cracked bricks.
  - Increasing the safety case allowances for cracked brick numbers, the operational allowance and currently established damage tolerance level.
- Fault Studies
  - Assessment of the requirement to allow unimpeded movement of control rods and fuel.
  - Assessment of the requirement to direct gas flows to ensure adequate cooling of the fuel and core.
  - Assessment of the requirement to provide neutron moderation and thermal inertia.
- External Hazards
  - Assessment of the capability of the nitrogen hold down system following a seismic event.

Matters arising from ONR's work

Following assessment of NP/SC 7785 all specialist inspectors consider that the issue of ONR's Agreement to the proposed modification of NP/SC 7785 is acceptable. In support of their assessments ONR's specialist inspectors have engaged extensively with EDF Energy NGL in technical discussions over the last year to ensure that key issues have been adequately addressed.

In particular, the assessments support EDF Energy NGL's case that the fundamental safety functions of the graphite core are not affected by the level of cracking in the core now or that predicted to occur during the next operating period to a core burn-up of 16.025 TWd. A key consideration has been whether keyway root cracking could lead to core distortion and impede the insertion of control rods to shut down the reactor. The specialist inspector's assessment is that the supporting analyses show control rod channel distortions will not impede control rod entry in normal operation and in a 1 in 10,000 year seismic event and are therefore acceptable. The specialist inspector's assessment is also that the channel distortions allow a safety margin for unimpeded control rod entry to be maintained, even when the possibility of more severe but less likely distortions are considered. These conclusions take into account the potential for production of more complex crack morphologies (multiply cracked bricks) and the expected low level of graphite debris that could be present during this operating period.

ONR's assessment identified that revised operating procedures in the event of detection of increased activity levels in the reactor coolant would be a reasonably practicable improvement to mitigate the consequences of graphite debris. It has been confirmed that these have been implemented.

The assessments have identified some issues to be taken forward and addressed by future safety cases (i.e. those justifying a further period of operation beyond a core burn-up of 16.025 TWd) but none of these prevent ONR's Agreement to the restart of Hunterston B Reactor 4. The progress and closure of these issues will be tracked via the ONR issues database.

Conclusion

It is concluded that the restart of Hunterston B Reactor 4 and operation up to a core burn-up of 16.025 TWd has been adequately justified by EDF Energy NGL and that a Licence Instrument should be issued to EDF Energy NGL.

Recommendations

It is recommended:

That licence instrument 561 is granted to Hunterston B to allow implementation of safety case NP/SC 7785.

LIST OF ABBREVIATIONS

AGR	Advanced Gas Cooled Reactor
ALARP	As Low As is Reasonably Practicable
AR	Assessment Report
BDB	Beyond Design Basis
BMS	Business Management System
CEDTL	Currently Established Damage Tolerance Limit
DCB	Doubly Cracked Brick
DHD	Diverse Hold Down
DTA	Damage Tolerance Assessments
EDF	Électricité de France
EC	Engineering Change
FHA	Full Height Axial
HSB	High Shrinkage Brick
HOW2	(ONR) Business Management System
IJCO	Interim Justification for Continued Operation
JPSO	Justified Period of Safe Operation
KWRC	Keyway Root Crack
LC	Licence Condition
LI	Licence Instrument
LLB	Lower Lower Bound
MCB	Multiply Cracked Brick
NGL	EDF Energy Nuclear Generation Ltd
N_2	Nitrogen
OA	Operational Allowance
ONR	Office for Nuclear Regulation
PAR	Project Assessment Report
PCPV	Pre-stressed Concrete Pressure Vessel
PRY	Per Reactor Year
PSD	Primary Shutdown
RTS	Return to Service
SCB	Singly Cracked Brick
SSC	Structure, System and Component
TWd	Terawatt Days
UB	Upper Bound

GLOSSARY OF TERMS

Term	Definition
Currently Established Damage Tolerance Level (CEDTL)	The level of brick cracking and crack opening that has currently been assessed and demonstrated to be tolerable, i.e. that does not challenge the fundamental nuclear safety requirements of the core.
Doubly Cracked Brick (DCB)	Doubly axially Cracked Brick (i.e. a brick containing exactly two full height, full thickness axial cracks).
Debris / Fragments	Brick fragments are pieces of graphite brick that remain approximately in position as part of the fuel or control rod channel. Pieces of brick that come free from the channel wall are debris.
Eccentric Annulus	The fuel stringers sit in channels in the graphite core formed by the fuel channel bricks. When a fuel stringer is in situ there is a gap between the inside surface of the fuel channel and the outer surface of the fuel sleeve, this gap is called the annulus. If the fuel stringer does not sit in the centre of the fuel channel or if the fuel stringer becomes distorted such that it is not straight then one side of the annulus could have a larger gap than the other side, this is called an eccentric annulus. An eccentric annulus can lead to asymmetric cooling of the fuel sleeve due to the larger gaps on one side of the fuel sleeve than the other.
Fuel Sleeve	Each fuel element consists of 36 fuel pins arranged in a circular grid and held in place by the lower support grid and two braces. A cylindrical graphite sleeve surrounds the 36 fuel pins with the lower support grid and the braces fitting into grooves on the inside of the graphite sleeve holding the arrangement together.
Full Height Axial	Full height axial crack, extending from top to bottom of a graphite brick.
Sleeve Gapping	The fuel elements are arranged into stringers with 8 fuel elements stacked vertically. The graphite fuel sleeves have grooves in the top and bottom edges so that the top of one fuel sleeve interfaces with the bottom of the sleeve above creating a seal which resists the flow of coolant gas. If the fuel stringer is moved such that it is not straight then the interfaces between the fuel element sleeves could begin to open up on one side leading to gaps and a loss of the gas seal, this could lead to gas flow through the fuel sleeve interfaces disrupting the intended coolant flow.
GCORE	A computer program used to generate finite element models of the graphite core for displacement and loading analysis for the seismic hazard.
High Shrinkage Brick (HSB)	High shrinkage bricks are a small number of bricks that, based on conditions during production, may exhibit high shrinkage behaviour and be at risk of early KWRC compared to the main population of bricks.
Hold Down	Ensures that the reactor remains sub-critical following the decay of Xenon 135.
Induced Cracks	Opening of cracked fuel bricks which causes adjacent fuel bricks to also crack.
Keyway Root Cracking	Cracking initiating from a keyway root of a fuel moderator brick,

(KWRC)	caused by a combination of internally generated shrinkage and thermal stresses and propagating the full height and full thickness of the brick.
Multiply Cracked Brick (MCB)	Multiply axially Cracked Brick (i.e. a brick containing three or more full height, full thickness axial cracks).
Operating Allowance (OA)	The operating limit for the state of the core (in terms of brick cracking and crack opening) which is not to be exceeded during a period of reactor operation and which has been demonstrated to be safe and provides margin to the CEDTL.
Singly Cracked Brick (SCB)	Singly axially Cracked Brick (i.e. a brick containing exactly one full height, full thickness axial crack).

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1. PERMISSION REQUESTED

1. Under derived powers made under Licence Condition 22(1) (Ref. 1), EDF Energy Nuclear Generation Limited (NGL) has requested (Ref. 2) that the Office for Nuclear Regulation (ONR) issue Agreement to NP/SC 7785 (Ref. 3), which is the safety case for the return to service of Hunterston B Reactor 4 following inspection of the graphite core in 2018, for operation up to a core burn-up of 16.025 TWd, which is around 4 months operation.

2. BACKGROUND

2. Hunterston B power station has two advanced gas cooled reactors (AGR) termed Reactors 3 and 4. Each reactor core is made up of around 3,000 graphite fuel bricks measuring 825mm high and 460mm external diameter which are connected together by keys and keyways (see figure 1), bound by a steel restraint system and contained within a concrete pressure vessel which is over three metres thick.

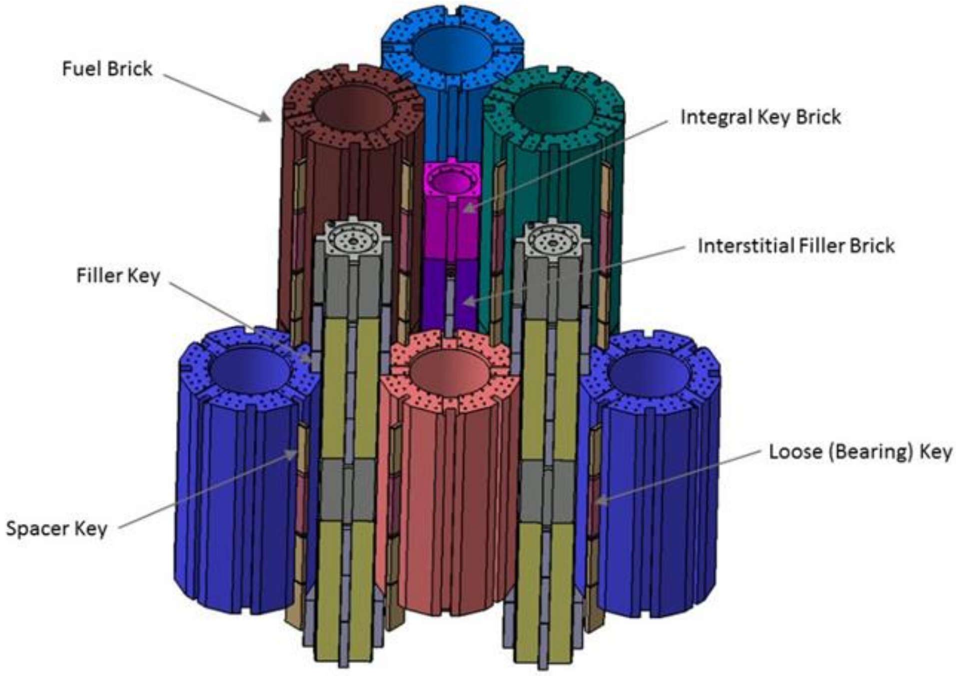

Figure 1 – Graphite Core Arrangement

3. 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 the reactor.

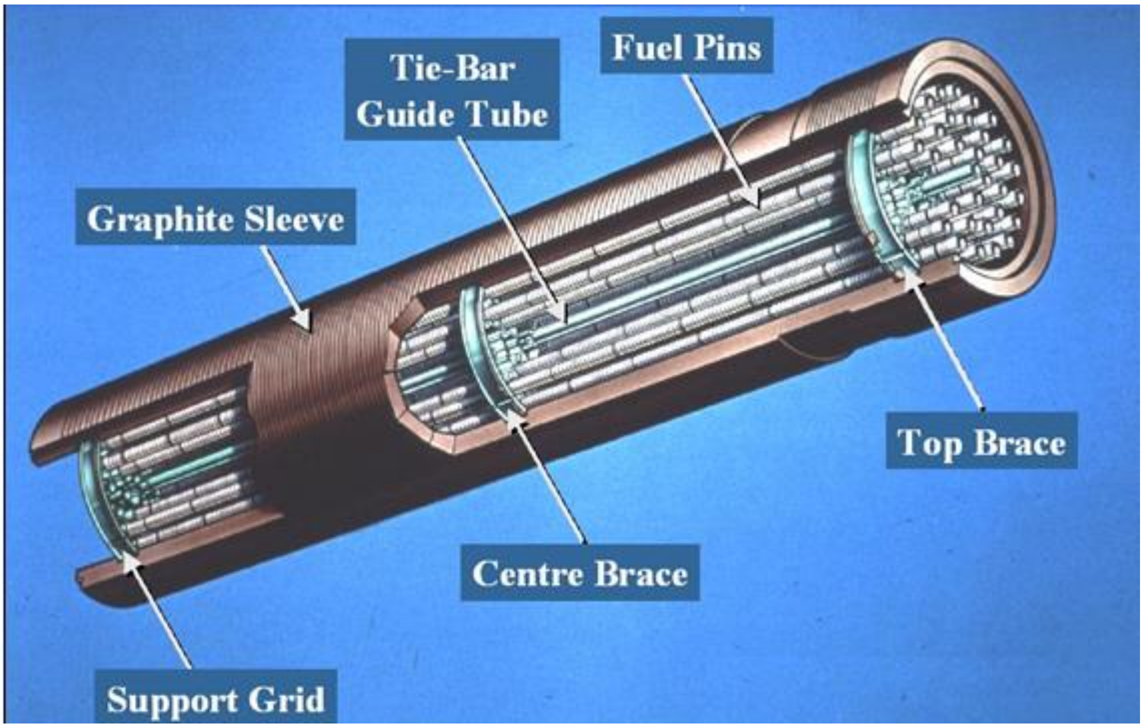

Figure 2 – Fuel Element Example

4. Each reactor has 81 control rods that are used to manage the power in the reactor. 37 control rods are used to control reactor power and day to day operation of the reactor; the remaining control rods are used to shutdown the reactor. 12 of these rods are referred to as super articulated control rods. The super articulated control rods are more flexible than the standard control rods which would enable them to enter channels with higher distortion than standard control rods. The super articulated control rods alone are able to shut down the reactor with longer term hold down of the reactor being provided by a nitrogen injection system. The super articulated control rods and the nitrogen injection system are provided as defence in depth and the safety case presented by the licensee is based on all of the control rods going into the core when required.

5. The fundamental nuclear safety requirements of a graphite core, in normal and fault conditions, are to:

- Allow unimpeded movement of control rods and fuel.
- Direct gas flows to ensure adequate cooling of the fuel and core.
- Provide neutron moderation and thermal inertia.

6. It has long been understood that irradiation of the fuel channel graphite bricks will lead to shrinkage and cracking of the bricks late in reactor lifetime. Such cracking is termed keyway root cracking (KWRC) as it initiates due to stresses which concentrate at the keyways on the outer diameter of the bricks. Figure 3 shows an example of a keyway root crack in a graphite brick, as seen from the fuel channel bore, from a core inspection. Keyway root cracking has the potential to challenge the above requirements and consequently the safety case needs to demonstrate that there are no significant implications for these nuclear safety requirements arising from keyway root cracking in order to permit further operation.

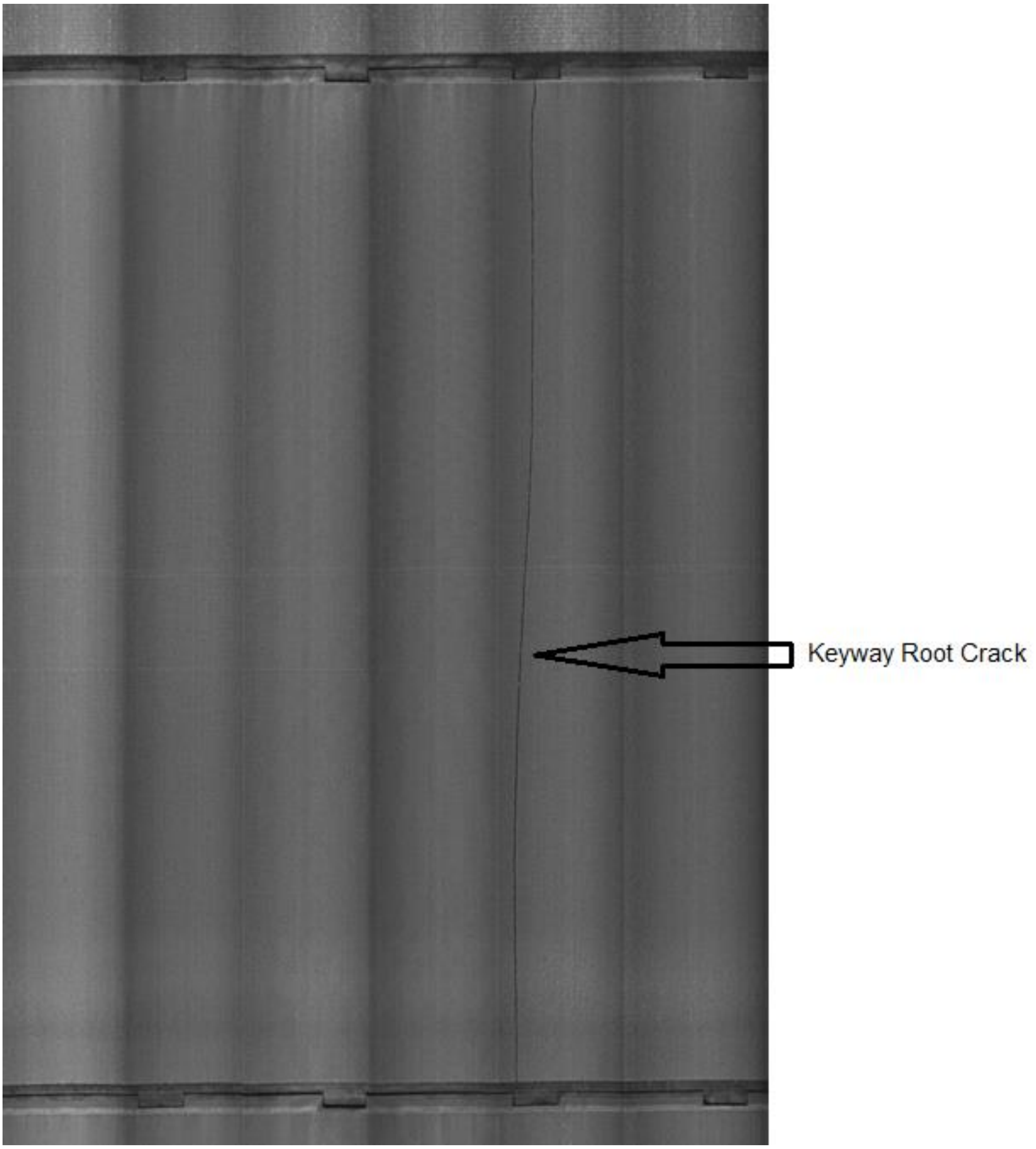

Figure 3 – Keyway Root Crack

7. Keyway root cracking was first observed in the main population of graphite moderator fuel bricks at Hunterston B Reactor 3 in October 2015, and September 2017 in Reactor 4[1]. Since then continued operation has been under a safety case, known as NP/SC 7716, which allowed for up to 700 axial cracks (includes keyway route cracking and induced cracks), referred to as the Currently Established Damage Tolerance Level. This is the level of cracking at which it has currently been established that there is no detriment to the nuclear safety functions of the graphite core. To provide a safety margin to the currently established damage tolerance level, a lower Operational Allowance (OA) of 350 axial cracks was also set within which it was intended to

[1] A full height KWRC was first observed in 2014 in a high shrinkage brick.

operate. In order to monitor the core condition and the number of cracks, the reactor cores have been regularly inspected. Inspection results and modelling are used to determine an appropriate Justified Period of Safe Operation (JPSO). The most recent operational safety case for Hunterston B Reactor 4 is presented in EC 362229 (Ref 4), which justified operation following the 2017 statutory outage to May 2019 (with a corresponding core burn-up of 16.160 TWd).

8. Inspection of the Hunterston B Reactor 3 graphite core in March 2018 identified cracking in excess of the OA of 350 axially cracked bricks, but well within the CEDTL of 700 axially cracked bricks[2]. As a result, Hunterston B Reactor 3 remains shut down. EDF Energy NGL has been developing a safety case to justify further operation of Reactor 3 and a safety case has recently been provided to ONR which will be assessed in due course.

9. The extent of cracking identified within Reactor 3 raised the potential for Reactor 4 to also exceed the OA within its JPSO. In response, an Interim Justification for Continued Operation (IJCO) EC363693 (Ref. 5) was provided, which justified continued operation until a core burn-up of 15.9 TWd. At this core burn-up, it was predicted that the upper bound (99.9% calculational confidence) number of axially cracked bricks in Hunterston B Reactor 4 would be approaching, but remain below the OA of 350 cracked bricks. In October 2018 when the Reactor 4 core burn-up reached 15.89 TWd, Reactor 4 was shut down and a graphite core inspection was performed. The results of this inspection demonstrated that the number of axial cracks in Reactor 4 was 319 at a 99.9% calculational confidence, i.e. below the OA in the NP/SC 7716 safety case (see table 1).

Brick Type	**R4 Current (15.89 TWd)**	**NP/SC 7716 OA**	**NP/SC 7716 CEDTL**
FHA Cracked Bricks (includes Doubly and Multiply cracked)	319	350	700
FHA Cracked Bricks in Channels with HSB (note 1)	114	-	-
SCB open by 6 to 12mm (at brick periphery)	79	350	700
SCB open by more than 12mm (at brick periphery)	14	100 (no more than 20 bricks > 18mm)	210 (no more than 40 bricks > 18mm)
DCB (includes MCB)	44	180	350
MCB	8	**Note 2**	

Table 1 – Comparison of whole Core Current Brick Cracking and NP/SC 7716 (99.9% calculational confidence)

Note 1: These are included within the full height axial (FHA) cracked brick total number, and are not in addition to the total FHA cracked brick number.

Note 2: NP/SC 7716 does not include an OA for MCBs, though its precursor safety cases considered isolated occurrences.

The terms Full Height Axial (FHA), Singly Cracked Brick (SCB), Doubly Cracked Brick (DCB) and Multiply Cracked Brick (MCB) are defined in the glossary.

10. The proposal under consideration in this Project Assessment Report (NP/SC 7785, Ref. 3), submitted by EDF Energy NGL, is intended to justify the Return to Service (RTS) of Reactor 4 following graphite core inspections in October 2018 for a further operational period up to a core burn-up of 16.025 TWd (approximately 4 months of

[2] Core cracking is calculated using “CrackSim” which is a statistical process model. The model is informed by inspection results and mechanistic understanding of graphite cracking processes. The model can be used to make predictions of the maximum extent of cracking in the core to a given confidence level.

operation). The safety case is essentially an extension to the current safety case NP/SC 7716, but with changes made to both the OA and the Currently Established Damage Tolerance Limit (CEDTL). The proposal presents new evidence, particularly in respect of developments in the Damage Tolerance Assessments (DTA) and the use of a revised core input seismic motion. The tolerability of Multiply axially Cracked Bricks (MCBs – discussed in paragraph 38) is also incorporated into the OA supported by an appropriate CEDTL for MCBs (see table 2). In addition, Table 3 shows the predicted whole core brick cracking over the next 3, 4, 6 and 9 months.

11. The proposal aims to demonstrate that:

- The core state at the end of the proposed JPSO (to 16.025 TWd) is within the OA at 99.9% calculational confidence.
- The Reactor 4 core state (in terms of the predicted level of cracking following 4 months of operation) remains broadly within the current Reactor 3 core state, as established by its 2018 inspections.

Cracked Brick Type	**OA**	**CEDTL**
Total number FHA cracked bricks	700	1331
SCBs open by 6 to 12mm [a]	350	700
SCBs open by more than 12mm [a]	100	200
DCBs + MCBs	200	400
MCBs	100	200

Table 2 – NP SC 7785 Proposed OA and CEDTL

[a] The crack openings dimension is appropriate to the brick periphery (keyway tips).

	R4 3 months (15.99 TWd)	**R4 4 Months (16.025 TWd)**	**R4 6 months (16.10 TWd)**	**R4 9 months (16.21 TWd)**
FHA Cracked Bricks (includes DCB and MCB)	442	**467**	544	647
FHA Cracked Bricks (in channels with HSB, **Note 1**)	126	**130**	139	153
SCB open by 6 to 12 mm (at brick periphery)	106	**112**	127	158
SCB open by more than 12mm (at brick periphery)	22	**24**	29	36
DCB (includes MCB)	55	**59**	65	78
MCB	11	**12**	17	24

Table 3 – Predicted Whole Core Brick Cracking (99.9% Calculational Confidence)

Note 1: These are included within the FHA cracked brick total number and, are not in addition to the total FHA cracked brick number.

12. The safety case proposed by EDF Energy NGL is based on the following two Claims:

- **Claim 1**: Graphite core degradation over the proposed JPSO will not undermine the required reliability of the Primary Shutdown (PSD) system for shutdown and hold down during normal operation and plant faults and the seismic hazard or prevent the graphite core from meeting its other fundamental nuclear safety requirements (fuel movement and fuel cooling).
- **Claim 2**: All reasonably practicable measures have been taken in order to ensure that the risk associated with continued operation of Hunterston B Reactor 4 is As Low As Reasonably Practicable (ALARP).

3. ASSESSMENT AND INSPECTION WORK CARRIED OUT BY ONR IN CONSIDERATION OF THIS REQUEST

13. As described in Section 2 the fundamental nuclear safety requirements of a graphite core, in normal and fault conditions, are to:

- Allow unimpeded movement of control rods and fuel.
- Direct gas flows to ensure adequate cooling of the fuel and core.
- Provide neutron moderation and thermal inertia.

14. Based on the nature of the proposal and the potential for cracking to impact on the fundamental safety functions of the graphite core, NP/SC 7785 has been subject to assessment by inspectors in the following specialisms:

- Civil Engineering
- Structural Integrity – Graphite
- Fault Studies
- External Hazards

15. The scope of these assessments is described below. It should also be noted that, in order to support the assessment of NP/SC 7785, ONR specialist inspectors have engaged extensively with the EDF Energy NGL in technical discussions over the last year and raised and resolved a significant number of technical issues. This report does not attempt to summarise all the questions raised and answers provided.

<u>Civil Engineering</u>

16. A seismic event has the potential to lead to core distortion and one or more control rods failing to insert into the core. The case presented by EDF Energy NGL seeks to demonstrate that core distortion under seismic faults will not prevent control rod insertion. The evidence presented describes a number of improvements to the seismic modelling of the core, including an updated core boundary input motion.

17. The core boundary seismic motion used for previous assessments was based on a seismic analysis performed in support of the first Periodic Safety Review (approximately 20 years ago). EDF Energy NGL has recently identified unrealistic constraints in this legacy model and now considers that these cause unrealistic and excessive seismic motion in the Pre-stressed Concrete Pressure Vessel (PCPV). This safety case describes a new analysis model of the PCPV, referred to as the new buildings model, which has been developed to update the core boundary input motion for the graphite core assessments.

18. The new buildings model has therefore been assessed by a specialist civil engineering inspector (Ref.6).

<u>Structural Integrity – Graphite</u>

19. The most recent inspection results on Hunterston B Reactor 3 revealed that opening of cracked fuel bricks was causing adjacent fuel bricks to also crack; this is termed “induced cracking” and required EDF Energy NGL to update its core state prediction methods. The inspections also showed instances of fuel bricks containing one or two full-height axial cracks with additional partial-height axial cracks emanating from the brick ends. This indicated the potential for bricks to crack in to three or more vertical parts if those partial-height cracks were to grow to full-height; such a potentially cracked brick is referred to as a multiply-cracked brick (MCB). Further to these observations, brick cracking was also found in some instances to be generating graphite debris, i.e. small pieces of graphite separating from the brick, the implications of which would need addressing in any return to service case. Consequently the safety

case provided by EDF Energy NGL aims to justify a further period of operation with MCBs and graphite debris in addition to increasing the existing OAs and CEDTL for singly cracked bricks (SCBs) and doubly cracked bricks (DCBs).

20. Damage to core components, for example, cracking of moderator fuel bricks, could potentially affect the geometry of the graphite core during normal operation, faults and seismic events. Damage to core components could also affect the calculated margins for control rod entry, impacting the first of the graphite core fundamental nuclear safety requirements listed above. The safety case aims to demonstrate that there remains sufficient margin to ensure unimpeded control rod entry.

21. The graphite structural integrity assessment (Ref. 7) has therefore focussed on the following aspects of the safety case:

- The revised core state predictions which include induced cracking and MCBs;
- The increased safety case allowances for cracked brick numbers, i.e. the OA and CEDTL;
- The justification for safe operation with MCBs and graphite debris;
- The improvements to the graphite core seismic tolerance arguments.

22. The above aspects of the case submitted by EDF Energy NGL have therefore been assessed by a specialist graphite structural integrity inspector.

<u>Fault Studies</u>

23. Based on the fundamental nuclear safety requirements of the graphite core and the potential impact on these of the presence of cracked bricks, the fault studies assessment has focussed on the following (Ref. 8):

- Assessment of the requirement to allow unimpeded movement of control rods and fuel:
  - Control rod movement
  - Fuel movement
- Assessment of the requirement to direct gas flows to ensure adequate cooling of the fuel and core:
  - The effects of changes in coolant flow paths due to cracking
  - The effects of channel distortion – eccentric annulus
  - The effects of channel distortion – sleeve gapping
  - The potential effects of debris
- Assessment of the requirement to provide neutron moderation and thermal inertia:
  - The potential effects of brick cracking on the neutron flux distribution

<u>External Hazards</u>

24. Whilst EDF Energy NGL has produced a case which demonstrates that, during normal operation and design basis faults or in the event of a seismic event, all of the control rods will be inserted into the core, a nitrogen hold-down system has been claimed as a defence in depth measure. The capability of the nitrogen hold down system following a seismic event has therefore been assessed by a specialist external hazards inspector (Ref. 9).

3.1 ASSESSMENT FINDINGS

3.1.1 CIVIL ENGINEERING ASSESSMENT

25. From a civil engineering perspective, the most significant risks addressed by the case relate to the justification that core distortion will not prevent successful insertion of the

control rods during and following a seismic event. This justification is based on the revised seismic modelling of the pre-stressed concrete pressure vessel (PCPV).

26. The civil engineering inspector has assessed the claims and supporting arguments with civil engineering content and sampled the supporting evidence (Ref 6). The assessment focused on the revised modelling of the PCPV. The inspector also attended technical meetings with EDF Energy NGL as part of the assessment process and raised a significant number of assessment queries, which in general were adequately addressed. Those queries that were not fully addressed are covered by the specialist inspector's recommendations, but were not considered significant enough to prevent a return to service of Hunterston B Reactor 4.

27. The civil engineering inspector found that, overall, the safety case as presented was valid, robust, integrated and balanced. It was judged that there were certain areas within the case that lacked the intelligibility, completeness and evidential basis expected by ONR's guidance for assessment of safety cases. The specialist inspector considered that these areas were important, but was satisfied that there was sufficient evidence from the licensee's further modelling work, provided in response to their technical queries, to judge that the risk associated with any changes to the safety case claims resulting from these enhancements and additions was acceptably small. Expectations regarding these matters are captured in CE Recommendation 5 below.

28. The key assessment findings are summarised below.

- It was judged that the modelling approach was conventional and in general accordance with relevant good practice.
- The changes to the restraints in the existing model in order to de-couple the PCPV from the Reactor Building have been adequately justified.
- The seismic input motion is considered conservative within the frequency range of significance for the core.
- For frequency ranges of significance to the core response, there was a significant reduction in core seismic input motion for the best estimate model compared with the legacy best estimate model.
- The best estimate material properties for the concrete structure, bearings, rock and backfill are deemed adequate.
- A limited, though acceptable, sensitivity study has been undertaken that considered the effects of uncertainty due to variation in key material properties.
- In order to address queries, EDF Energy NGL supplied additional evidence taken from its updated modelling work for the PCPV and graphite core. It was noted that this material is preliminary in nature but was judged to be adequate as additional supporting evidence to the present safety case.
- The most onerous case for channel distortion margins was obtained from a combination of upper bound properties for the rock, backfill and bearings. However, the safety case claims in relation to the core are based on a best estimate analysis, which may be un-conservative. This was raised as CI Recommendation 2 and has been considered further in the ONR graphite assessment (see paragraph 36).
- Insufficient evidence was presented that the bearings could fulfil their safety functional requirements or that the bearings complied with current codes and standards. The specialist inspector judged that the final calculations will demonstrate that the bearings can fulfil their safety functional requirements. CI Recommendation 4 has therefore been raised in order to track the licensee's progress in resolving this shortfall. The civil engineering specialist judged that this is not required prior to return to service of Hunterston B Reactor 4.
- The walk-down to confirm the as-built details important to the analysis had not been reported in a manner that could be used as evidence in the safety case. However the civil engineering specialist was content that as-built details had

been checked and judged that the enhanced reporting was not required prior to return to service of Hunterston B Reactor 4. This shortfall was captured as part of CI Recommendation 5.

- The effect of the changes to the PCPV modelling on other Structures, Systems and Components (SSC) and safety cases (for example that of structures connected to the PCPV) requires further investigation. This work is needed to demonstrate that the SSCs can fulfil their safety functional requirements over the full range of seismic loading. In response to the specialist inspector's queries, the licensee confirmed that the revised modelling generally resulted in less onerous load effects on other SSCs than resulted from the previous PCPV modelling. Some of the loads on the Long Travel Girders that support the Charge Machine Gantry may increase, but the specialist inspector was satisfied that EDF Energy NGL can make an adequate case that the girders and supporting columns will remain within their structural capacity. The specialist inspector was content that this matter is being followed up by the licensee and judged that the work is not required to be complete prior to return to service of Hunterston B Reactor 4. The specialist inspector has raised CI Recommendation 6 in order to track the licensee's progress.
- A number of areas were identified where the intelligibility and evidential basis of the PCPV analysis could be improved. The risk associated with any changes resulting from these enhancements and additions was judged to be acceptably small.

29. The civil engineering specialist inspector concluded that, from a civil engineering perspective, they are satisfied with the claims, arguments and evidence laid down within the licensee's safety case. A number of aspects of the PCPV analysis and its reporting require further work and these have been captured in CE Recommendations 4, 5 and 6.

30. Recommendations for ONR are:

- **CE Recommendation 1 –** From a civil engineering perspective, it is recommended that ONR should issue a Licence Instrument granting Agreement to the safety case under Licence Condition 22(1).
- **CE Recommendation 2 –** The ONR graphite assessment should take into account when assessing core margins for seismic events that the GCORE analysis reported in the safety case is based on the use of the best estimate PCPV model only. Sensitivity studies have indicated that the upper bound PCPV model is bounding for PCPV accelerations of significance to the core and for core distortion margins (this is addressed in section 3.1.2, paragraph 35).
- **CE Recommendation 3 –** When assessing future safety cases, the ONR graphite and civil engineering assessments should take into account that further changes to core damage models may lead to alterations in the natural frequency of the core. Such changes may require the licensee to carry out additional sensitivity studies to demonstrate that the most onerous combination of PCPV model variables has been considered.

31. Recommendations for the licensee are given below. These Recommendations are being tracked via regulatory issue 7168 but are judged not to prevent restart of Hunterston B Reactor 4.

- **CE Recommendation 4 –** The licensee should demonstrate to ONR that the bearings supporting the PCPV have adequate capacity under seismic loading.
- **CE Recommendation 5 –** In its final modelling report the licensee should provide evidence that the following matters arising from ONR's assessment of the preliminary PCPV modelling have been adequately addressed:

- Uncertainty and bias when using theoretical formulae for compression stiffness of the bearings
- Uncertainties in the damping properties for compression of the bearings
- Justification that the Hinkley Point C (HPC) backfill properties are relevant to Hunterston B
- Evidence that confirms that the bi-linear backfill soil springs used in the preliminary model have been replaced and that a lower lower bound (LLB) backfill case to address gapping has been included in the sensitivity studies
- Detailed reporting of site walk-downs at both Hunterston B and Hinkley Point B that confirm the physical and geometric assumptions made in the analysis
- Numerical quantification of the Central Block displacements
- Expanded reporting of verification and validation of the final model compared with that provided for the preliminary model
- Comparisons of the vertical motion into the core for the legacy model, preliminary model and final models
- Consideration of the effects of a Beyond Design Basis (BDB) seismic event, including increased displacements and possible closure of joints that may challenge the modelling assumptions of an isolated structure
- Reporting of enhanced sensitivity studies reflecting the further work done since the preliminary analysis was completed
- Justification that an upper bound (UB) case with LLB backfill is bounded by the UB case regarding its effects on the graphite core
- Justification that Structure-Soil-Structure Interaction (SSSI) is not significant

- **CE Recommendation 6 –** The licensee should review all relevant safety cases that may be affected by the changes to the PCPV seismic modelling and confirm to ONR that any adverse effects on other SSCs have been adequately justified.

32. To conclude, from a civil engineering perspective, the specialist civil engineering inspector is satisfied with the claims, arguments and evidence laid down within the EDF Energy NGL's safety case. It is judged that the proposal is adequate to justify the issue of a Licence Instrument to signify ONR's Agreement under arrangements made under Licence Condition 22(1) that Hunterston B Reactor 4 can return to service for a period of operation up to a core burn of 16.025 TWd.

3.1.2 STRUCTURAL INTEGRITY - GRAPHITE ASSESSMENT

33. Based on the fundamental nuclear safety requirements of a graphite core, the specialist structural integrity inspector assessed the revised core state predictions and concluded that they are content that the phenomena of induced cracking and the potential for MCBs has been conservatively included using a sufficient scope of inspection evidence (Ref. 7). The extensive inspection of the leading reactor (Hunterston B Reactor 3), and the targeted inspection of a number of High Shrinkage Bricks (HSB) in Hunterston B Reactor 4, has provided important additional confidence in the prediction of the Hunterston B Reactor 4 core state at the end of its four-month operating period. This is an important factor in the acceptance of the safety case claims because EDF Energy NGL predictions of core degradation have been shown in the absence of leading data to be not wholly accurate when data became available.

34. The specialist inspector agrees that the Licensee has shown that the small number of more advanced crack morphologies predicted to exist by the end of the four month operating period means the rate of generation of graphite fragments and debris is likely to be low during that period. Based on the evidence presented, the specialist inspector

considers that a partial coolant blockage of fuel element 1 (the lowest in the fuel stringer) with sufficient debris to challenge fuel cooling in that channel is a very low frequency event for the proposed four month period of operation. However, because there is significant uncertainty in determining the true likelihood, a precautionary approach should be taken. The specialist inspector has therefore recommended that when considering this case the fault studies inspector should treat the initiating event frequency of a blockage at the fuel element 1 grid, which has the potential to cause a fuel clad melt as a 10^{-4} pry design basis event. This is discussed in more detail in paragraph 48.

35. It is judged by the specialist inspector that graphite debris will become more frequent during operation beyond the current core condition of Hunterston B Reactor 3 which is the lead reactor in terms of cracking. A recommendation has therefore been made (SI Recommendation 4) that before any further permission for operation is requested for Hunterston B Reactors 3 or 4; EDF Energy NGL should provide more robust arguments for mitigating the risks posed by graphite debris, and for the determination of graphite debris production and its migration.

36. The inspector notes that EDF Energy NGL has expended substantial effort in developing the graphite core seismic tolerance arguments. This has been in two major respects: firstly, the treatment of component failures during a seismic event; and secondly, updating the predicted seismic input motion to the graphite core. The specialist inspector is content that the revised treatment of component failures represents an improved methodology and satisfies the recommendations made by ONR's previous assessment of NP/SC 7716 (Ref. 10). The updated seismic input motion has been assessed by a civil engineering specialist inspector; the inspector was satisfied but CE Recommendation 2 in paragraph 30 recommended that the specialist structural integrity inspector take into account the effect of an upper bound seismic input case on the channel distortions. The specialist structural integrity inspector took these considerations into account and concluded that they are content with the seismic tolerance claims.

37. The specialist inspector is content that the supporting analyses show control rod channel distortions are acceptable in normal operation and in a 1 in 10,000 year seismic event for the OA's and CEDTL's defined in Table 2. The specialist inspector is also content that the channel distortions allow a safety margin for unimpeded control rod entry to be maintained, even when the possibility of more severe but less likely distortions are considered. It is important to recognise that EDF Energy NGL has evaluated the OA and CEDTL at a core age of 17 TWd, which would need approximately two full power years of operation to reach. The OA and CEDTL do not represent a prediction of the cracked brick configuration at 17 TWd; they are intended to represent a bounding level of damage which is then evaluated with graphite material properties at a bounding core age, i.e. 17 TWd.

38. The specialist structural integrity inspector has sampled the peak channel distortion predicted from the whole core models for different future core states. It is noted that in some cases there are outliers outside of the majority of predictions. Whilst the peak channel distortion for such outliers is below the level of concern, the specialist inspector judges that, going forward, they should be explained. The specialist inspector is content however that the low distortions allow a safety margin for unimpeded control rod entry to be maintained even when the possibility of more severe, but less likely, distortions are considered. The specialist inspector has recommended that any request for further operation should reinforce the evidence that outlier configurations that could challenge unimpeded control rod entry in normal operations are sufficiently unlikely and raised SI Recommendation 2.

39. The specialist inspector is content that the approximate methods (referred to as proxy-MCBs) for predicting the influence of MCBs on free movement of control rods and fuel have been done conservatively, but only with respect to channel distortion. In extreme cases, MCBs might be capable of creating local sites of fuel stringer ledging or snagging; this has been considered by the fault studies inspector (paragraph 47). Whilst content with the approximate method of the MCB implementation in this case, the specialist inspector has recommended that EDF Energy NGL should set out a plan to move to a more accurate implementation. See SI Recommendation 1 below.

40. The specialist inspector is content that the licensee has conservatively accounted for the effect of core distortion on fuel movement and fuel sleeve gapping.

41. To conclude, from a structural integrity perspective, the specialist structural integrity inspector is satisfied with the claims, arguments and evidence laid down within the EDF Energy NGL's safety case. It is judged that the proposal is adequate to justify the issue of a Licence Instrument to signify ONR's Agreement under arrangements made under Licence Condition 22(1) that Hunterston B Reactor 4 can return to service for a period of operation up to a core burn of 16.025 TWd.

42. Recommendations for the licensee are given below. These Recommendations are judged not to prevent restart of Hunterston B Reactor 4.

SI Recommendation 1: Before any further permission for operation of HNB R4 is requested, NGL should set out a plan to replace the implementation of proxy-MCBs in the whole core models with a full MCB representation.

SI Recommendation 2: Whilst I am content with the arguments presented for channel distortion, I consider it reasonable to expect future safety cases to reinforce the supporting evidence that outlier configurations that would approach a control rod channel distortion utilisation of 1 in normal operation are sufficiently unlikely.

SI Recommendation 3: It is recommend that the fault studies inspector's assessment takes into account the judgement that the likelihood of debris significantly blocking the fuel element 1 grid should be treated as a design basis event with a potential frequency of 10^{-4} pry during the next four months of operation of HNB R4.

SI Recommendation 4: Before any permission for operation of HNB R4 beyond the proposed operating period is requested, NGL should introduce to the safety case more robust arguments for mitigating the risks posed by graphite debris and for the determination of graphite debris production and its migration.

43. SI Recommendation 3 is addressed in paragraph 51

44. The remaining recommendations will be tracked via regulatory issue 7332.

3.1.3 FAULT STUDIES ASSESSMENT

45. The specialist fault studies inspector has focussed on making a judgement on whether or not EDF Energy NGL has adequately demonstrated that the safety functions of the graphite core will be fulfilled over the proposed 4 month operating period (Ref 8). Whilst the report has considered the effects of graphite brick cracking on all of the safety functions of the graphite core, the two safety functions with the greatest potential to be affected by graphite brick cracking are: allowing unimpeded movement of the fuel and control rods, and directing coolant flow to ensure adequate cooling of the fuel and core components. Consequently the fault studies assessment has focussed on these two safety functions.

Allowing unimpeded movement of the fuel and control rods

46. Cracking of the graphite core has the potential to increase the freedom of movement of the graphite components within the core and thus lead to greater core distortion. The control rods and the fuel are inserted into the graphite core through channels in the graphite bricks and thus significant core distortion could lead to impeded movement of the control rods and the fuel as the channels become increasingly distorted.

47. The inspector noted that the safety case presented by EDF Energy NGL presents arguments and evidence to demonstrate that the movement of control rods and fuel would not be impeded in normal operation, in faults, or following a seismic event, during the proposed 4 month period of operation.

48. The free movement of control rods during normal operation and seismic events has been assessed by the ONR structural integrity inspector who judged that that the conclusions of NGL's predictions of control rod channel distortions – that no control rod would be impeded in normal operation or seismic events – could be supported. Considering the free movement of control rods following plant faults, the specialist inspector concluded that EDF Energy NGL has presented adequate arguments and evidence to demonstrate that the free movement of control rods will be maintained following plant faults, such that the shutdown function is not threatened.

49. EDF Energy NGL concedes that there may be an increase in the risk of fuel becoming snagged whilst it is being moved. The specialist fault studies inspector therefore examined a sensitivity study presented by EDF Energy NGL which demonstrates that there are large margins to the risk target limits in respect of the potential for dropped fuel caused by fuel snagging. The fault studies inspector additionally challenged EDF Energy NGL to demonstrate that there were no further improvements which could be made to reduce the risk associated with fuel snagging. The fault studies report concludes that the arguments and evidence presented by EDF Energy NGL adequately demonstrated that the risks associated with fuel snagging over the proposed 4 month operating period have been reduced so far as is reasonably practicable.

50. The fault studies inspector therefore concluded that EDF Energy NGL has demonstrated that the nuclear safety function of the graphite core to allow unimpeded movement of control rods and fuel, will be adequately fulfilled over the proposed 4 month operating period (up to a core burn up of 16.025 TWd), and that EDF Energy NGL has taken all reasonably practicable measures to reduce the risk associated with impaired movement of fuel and control rods.

Directing coolant flow to ensure adequate cooling of the fuel and core components

51. The fault studies inspector noted that the safety case provided by EDF Energy NGL presents arguments and evidence to demonstrate that the disruption to gas flow paths within the core will not significantly affect the cooling of fuel and core components such that temperature limits are threatened, during the proposed 4 month period of operation.

52. Increased cracking of the graphite bricks has the potential to change the gas flow paths within the core; this could reduce the cooling of core components and fuel. The specialist inspector examined the evidence presented by EDF Energy NGL to demonstrate that the increased coolant flow from the arrow head passageways to the fuel channel annulus due to graphite brick cracking is acceptable. It was also judged that NGL has satisfactorily demonstrated that the effect on fuel temperatures is small and negative, and that EDF Energy NGL has adequately demonstrated that the thermally induced stresses in the fuel sleeve would be reduced.

53. In assessing the effects of core distortion, the specialist inspector concluded that the evidence presented by NGL adequately demonstrates that the effects of eccentricity of the fuel channel annulus on fuel temperatures are acceptable, and that there is no threat to the integrity of the fuel sleeve.

54. The fault studies inspector concluded that it has been demonstrated that the changes to gas flow paths due to graphite brick cracking will not present a threat to the fuel and core component temperature operating limits over the proposed 4 month operating period.

55. Core distortion has the potential to impinge upon fuel stringers leading to gaps opening up between the sleeves of the fuel elements in the fuel stringer and disrupting the flow of coolant within the stringer. The fault studies assessment examines the arguments and evidence presented by EDF Energy NGL and concludes that the effects of sleeve gaps will not threaten fuel clad temperature limits within the proposed 4 month operating period.

56. Graphite brick cracking has the potential to produce debris, which could cause a partial blockage within a fuel stringer leading to impaired fuel cooling. The specialist fault studies inspector has examined the evidence presented by EDF Energy NGL and concluded that although EDF Energy NGL did not demonstrate that all barriers to a radiological release were preserved (fuel clad melt), there is sufficient mitigation (by way of the reactor pressure vessel and activity monitoring) to determine that the resultant mitigated risk was acceptable as assessed against ONR’s risk targets, provided that the risks had been reduced so far as is reasonably practicable.

57. Notwithstanding the above the specialist inspector concluded that there is still uncertainty associated with the point at which fuel clad melt would occur following a partial blockage of coolant in a fuel stringer. The inspector has therefore made the following recommendation:

- **FS Recommendation 1**: For inclusion in future safety cases justifying the operation of the Hunterston B Reactor 4 graphite core, NGL should perform further analysis of the effects of a blockage at the element 1 support grid in order to establish the point at which fuel clad melt temperatures would be reached.

58. The fault studies assessment also considers EDF Energy NGL’s analysis of whether there are any reasonably practicable improvements which could be made to reduce the risk associated with graphite debris, and concluded that EDF Energy NGL considered all potential measures to reduce risk, and demonstrated to the satisfaction of the specialist inspector that there were no reasonably practicable measures which could be taken other than the implementation of power reduction if background activity increases in line with the levels specified in Ref 11.

59. The inspector therefore made a Recommendation that EDF Energy NGL should implement the technical specification changes proposed by the generic failed fuel safety case (Ref. 12) prior to the restart of reactor 4 which ensures actions to reduce reactor power in the event of a rise in activity levels in line with Technical Specification 8.1.3 (Ref 11).

- **FS Recommendation 2**: The changes to Technical Specification 8.1.3 proposed in NP/SC 7653 should be implemented at Hunterston B prior to restart of Reactor 4.

60. The specialist inspector considered the effects of graphite brick cracking and core distortion on the capability of the core to fulfil its safety function of directing gas flows to

ensure cooling of the fuel and core. This specialist inspector concluded that EDF Energy NGL has presented adequate arguments and evidence to demonstrate that the safety function will be fulfilled over the proposed 4 month operating period.

61. Within EDF Energy NGL's safety case, consideration of cooling following a seismic event was limited to consideration of the integrity of the fuel sleeve and did not consider the effects on fuel sleeve gapping. In the specialist inspector's opinion, due to the low control rod channel distortions predicted following a seismic event, and the evidence presented by NGL to demonstrate tolerance to sleeve gapping at power, the lack of discussion of sleeve gapping during post-trip cooling following a seismic event does not present an issue for permissioning of this safety case.

62. The specialist inspector concluded that EDF Energy NGL should include consideration of fuel channel distortions and hence fuel sleeve gapping following a seismic event in future graphite safety cases, and has made a recommendation in this regard.

- **FS Recommendation 3**: NGL should include consideration of fuel channel distortions following a seismic event and its effect on fuel sleeve gapping in future graphite safety cases

Provide neutron moderation and thermal inertia

63. The specialist inspector notes that there is no plausible effect on the thermal inertia of the graphite core due to graphite brick cracking. Graphite weight loss does affect the mass of the graphite core, and thus its thermal inertia, however the effects of graphite weight loss are outside of the scope of the return to service safety case. In addition to this, weight loss continues to be lower than the operating rule limits for weight loss at Hunterston and there is no change to the limit on graphite weight loss being proposed in EDF Energy NGL's safety case.

64. The graphite bricks provide moderation of the neutrons. The fault studies inspector therefore considered that it was plausible that the presence of cracks in the graphite bricks could lead to a radial asymmetry in the thermal neutron flux in a fuel channel. The inspector asked EDF Energy NGL whether the potential for this effect had been considered, and whether it would have any effect on the assumptions of reactivity faults in which the symmetry of channel power is a factor.

65. In response EDF Energy NGL stated that the small scale moderator density variation would have a negligible effect on the thermal flux distribution as the neutron slowing down length in an AGR is much larger than the length of graphite brick cracks, and thus the potential effect could be discounted. The specialist inspector judged this to be a logical argument, and concluded that the presence of graphite brick cracks would not have any significant effect on the neutron moderation provided by the graphite core.

66. In summary the specialist inspector judged that EDF Energy NGL has adequately demonstrated that the safety function of the graphite core to provide neutron moderation and thermal inertia is unaffected by the presence of graphite brick cracking.

Conclusion

67. The fault studies inspector concluded that EDF Energy NGL has demonstrated that the nuclear safety functions of the graphite core to:

- allow unimpeded movement of control rods and fuel,
- direct gas flows to ensure adequate cooling of the fuel and core,
- provide neutron moderation and thermal inertia,

will be adequately fulfilled over the proposed 4 month operating period, and that EDF Energy NGL has taken all reasonably practicable measures to reduce the risk associated with cracking of the graphite core.

68. To conclude, subject to adequate closure of FS Recommendation 2, the specialist fault studies inspector is satisfied with the claims, arguments and evidence laid down within EDF Energy NGL's safety case. It is judged that the proposal is adequate to justify the issue of a Licence Instrument to signify ONR's Agreement under arrangements made under Licence Condition 22(1) that Hunterston B Reactor 4 can return to service for a period of operation up to a core burn of 16.025 TWd.

69. The outstanding Recommendations and requirements for further technical work are being tracked via regulatory issues 7291, 7292 and 7300.

3.1.4 EXTERNAL HAZARDS ASSESSMENT

70. The scope of the external hazards assessment (Ref. 9) was limited to seismic hazards with respect to the Diverse Hold Down (DHD) Nitrogen system, which is claimed as defence in depth. The sampling strategy focused on five shortfalls in the safety case for the diverse hold down system at Hunterston B, which had been identified in a previous ONR assessment, 'Review of ONR Seismic Assessment of Hunterston B Nitrogen Plant, 15.1.15 - 20.6.18' (Ref.13). These shortfalls are discussed below.

Provide a bottom line seismic design basis which corresponds to an event with conservatively predicted probability of exceedance of 10^{-4} pa at Hunterston B.

71. The DHD system has been qualified for the infrequent (10^{-4} pa) bottom line event defined by the Principia Mechanica Limited (PML) design response spectrum for a hard site, scaled to a Zero Period Acceleration (ZPA) of 0.14 g, which is conservative at Hunterston B for frequencies below 26 Hz. The items which can be affected by frequencies greater than 26 Hz are principally C&I systems. The C&I systems required for the DHD system to perform its safety function are qualified against a DB seismic event. The specialist inspector is therefore content that this assessment of the seismic design basis is adequate for the RTS safety case. The specialist inspector concluded therefore that EDF Energy NGL has made an adequate argument with regards to the characterisation and substantiation of the bottom line seismic design basis for the DHD system.

Clarify the claims that are now being made for the DHD system.

72. The specialist inspector concluded that EDF Energy NGL has adequately clarified the claims on the DHD system. Which are as follows:

- The DHD system has been qualified to withstand the 10^{-4} pa (bottom line seismic event) with significant beyond design basis capability and the absence of cliff-edge effects.
- A best estimate of hazard level whereby the safety functions of the DHD system could be challenged is greater than twice the seismic hazard design basis level.

Substantiate the DHD system against the relevant seismic claims.

73. The components of the system are as follows:

- Civil structures.
- Nitrogen Plant Items, including liquid nitrogen (LN) vessels.
- Inside Battery Limits (ISBL) Pipework - comprising all N_2 plant associated with and founded on the new foundation slab external to the main buildings.

- Outside Battery Limits (OSBL) Pipework - comprising N_2 plant located between the ISBL and the Reactor Building, i.e. primarily in piping trench.
- Injection and Blowdown Pipework - comprising N_2 plant located inside the Reactor Building (entering at Ground Level) up to the PCPV injection points including all diverse branch and ring-main routes.
- Cabling Routes.
- C&I Components.

74. EDF Energy NGL has confirmed that the Hunterston B raft foundation has been designed to withstand the plant seismic loads that are due to the bottom line seismic event at the Hinkley Point B site. The compatibility of the Hinkley Point B seismic loads with the Hunterston B site specific seismic response has been assured by modification of the Hunterston B seismic response by replacing the ground between the underside of the raft foundation and the underlying bedrock with a mass of concrete. This is shown to reduce the enhancement to the seismic loads due to the Hunterston B soil structure interactions to provide a generally conservative design.

75. The specialist inspector concluded that NGL has adequately substantiated the DHD system against the relevant seismic claims.

<u>Demonstrate that there are acceptable margins against beyond design basis (BDB) seismic events for the systems claimed for hold down</u>

- A minimum overall BDBE margin of 2.1 (relative to seismic loading) was obtained for the liquid nitrogen vessels.
- A margin in excess of 2 was obtained for C&I equipment functionality associated with the DHD system by shake table testing.
- Based upon Electric Power Research Institute (EPRI) guidance for BDBE assessment, the seismic fragility assessment indicates a minimum combined seismic margin of 2.12 for seismic walkdown compliant bottom line plant items located in the main buildings.
- EDF Energy NGL have justified that BDBE margins >2 are inherently available for the new N_2 plant related civil structures using seismic walkdown qualification techniques. Similarly, it is claimed to be reasonable to confer an overall BDBE margin ≥2 for the structural performance of the main buildings where the physical route of the N_2 system is located, i.e. where building structures have the potential to impact DHD system pipework and cabling routes. The claims in this bullet point were reviewed by ONR's Civil Engineering and External Hazards Professional Lead who concluded that there is sufficient confidence not to undertake any further significant assessment of this.

76. The specialist inspector concluded therefore that acceptable margins against BDB seismic events have now been adequately demonstrated.

<u>Identify and assess adjacent plant with the potential to fail and cause damage to the DHD system in a seismic event. Demonstrate that credible failures do not undermine the seismic claims for the DHD system.</u>

77. The licensee provided confirmation that the DHD system, including allowance for interactions from nearby plant, is seismically adequate with outliers and recommendations from the earlier walkdowns completed.

78. The specialist inspector judged that a walkdown process carried out by EDF Energy NGL was adequate, in line with relevant good practice (RGP) and has been adequately implemented with respect to assessing interactions from plant adjacent to the DHD system and resolving the identified outliers.

79. The specialist assessor therefore concluded that the five shortfalls previously identified and listed above, have now been adequately addressed. The assessment supports the adequacy of the EDF Energy NGL's bottom line seismic design basis for the Hunterston B site, the claims made on the diverse hold down system and its qualification against the claims. These conclusions also cover margins against beyond design basis seismic events and the assessment of interactions from plant adjacent to the diverse hold down system.

80. To conclude, from an external hazards perspective, the specialist external hazards inspector is satisfied with the claims, arguments and evidence laid down within EDF Energy NGL's safety case. It is judged that the proposal is adequate to justify the issue of a Licence Instrument to signify ONR's Agreement under arrangements made under Licence Condition 22(1) and that Hunterston B Reactor 4 can return to service for a period of operation up to a core burn of 16.025 TWd.

4. MATTERS ARISING FROM ONR'S WORK

81. All ONR specialist inspectors consider agreement to the proposed safety case modification of NP/SC 7785 (Ref.3) to be acceptable . On that basis I have prepared a licence instrument to enable the return to service of Hunterston B Reactor 4 up to a core burn of 16.025 TWd. This has been written according to ONR guidance (Ref.14) and is of routine type, for which the text and format have been agreed with the Government legal department. Further legal checking of this licence instrument is therefore unnecessary.

82. I have liaised with SEPA who have confirmed that they have no objections to a return to service for Reactor 4 at Hunterston B (Ref. 15).

83. I have confirmed that EDF Energy NGL have followed their own due process. An INSA statement for the case has been submitted (Ref 16) and Nuclear Safety Committee (NSC) meeting minutes have been submitted (Ref 17).

84. A number of recommendations were raised by specialist inspectors which are discussed in this report. The only recommendation that needs to be addressed prior to return to service is discussed below. None of the other recommendations prevent the restart of Hunterston B Reactor 4.

85. FS Recommendation 2, which was raised by the fault studies inspector, recommends that the changes to Technical Specification 8.1.3 proposed in NP/SC 7653 should be implemented at Hunterston B prior to restart of Reactor 4.

86. I have confirmed with EDF Energy NGL that the relevant changes to Technical Specification 8.1.3 equivalent to those proposed in NP/SC 7653 have now been implemented (Ref. 18).

87. I am therefore content that this Recommendation has been addressed.

5. CONCLUSION

88. I conclude that, based on the assessments and conclusions made by the ONR specialist inspectors and the evidence from regulatory interactions with EDF Energy NGL, that Hunterston B Reactor 4 can return to service for a period of operation up to a core burn up of 16.025 TWd.

6. RECOMMENDATIONS

89. I recommend that licence instrument 561 is granted to Hunterston B to implement NP/SC 7785.

7. REFERENCES

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2. NSL HNB5055R, Request for Agreement Under Arrangements Made Under Licence Condition 22(1), EC 364115 Return to Service Case for R4 Following Core Inspection Results in 2018 (CM9 2019/162165)

3. NP/SC 7785 Hunterston B Power Station – Return to Service Safety Case For R4 Following Core Inspection Results in 2018 – EC No 364115, Revision 000, Proposal Version No:11 (CM9 2019/149729)

4. EC 362229 Rev 000 Proposal Version 3, Justification for Continued Operation following the Graphite Core Inspections at Hunterston B R4 in September 2017 (60-day EC), January 2018

5. IJCO EC363693 Rev 000, Hunterston B Interim Justification for Continued Operation of the R4 Graphite Core following the Core Inspection Results at R3 in 2018, June 2018

6. ONR-OFD-AR-18-085 Revision 0 – Return to service safety case for Reactor 4 following core inspection results in 2018 - NP/SC 7785, Civil engineering assessment (CM9 2019/90351)

7. ONR-OFD-AR-19-007 Revision 1 – Return to service safety case for Hunterston B Reactor 4 following core inspection results in 2018 (NP/SC 7785), Graphite structural integrity assessment (CM9 2019/221481)

8. ONR-OFD-19-029 Revision 0 – Fault Studies Assessment of the Hunterston B R4 Return to Service Safety Case Following Core Inspection Results in 2018 (CM9 2019/176010)

9. ONR-OFD-AR-19-003 Revision 0 – Return to service safety case for Reactor 4 following core inspection results in 2018 - NP/SC 7785, Seismic Assessment for Diverse Hold Down System, (CM9 2019/100264)

10. ONR-OFP-AR-16-053, Safety case for the graphite core and core restraint: Operation after the onset of keyway root cracking, January 2016 (CM9 2016/228144)

11. Hunterston B Power Station – Technical Specification 8.1.3 – Control of Failed Fuel – Issue 3, June 2019 (CM9 2019/197954)

12. NP/SC 7653 In-Reactor Detection and Management of AGR Fuel Failures Occurring During Normal Operation, January 2015 (CM9 2015/54498)

13. Review of ONR Seismic Assessment of Hunterston B Nitrogen Plant, 15.1.15 - 20.6.18, 22 June 2018 (CM9 2018/196129)

14. NS-PER-IN-001. Preparation and Issue of Licence Instruments. Revision 8. (CM9 2017/8970)

15. Email from [redacted] to [redacted], Return to service of HNB R4, received 16 August 2019

16. Full INSA Approval Statement – Return to Service Safety Case for R4 Following Core Inspection Results in 2018 CM9 (2019/149729)

17. EDF Energy Nuclear Generation Ltd, Hunterston B Nuclear Safety Committee Minutes of the Meeting, 07 March 2019 (CM9 2019/80805)

18. Email from [redacted] to [redacted] – HNB Tech Spec 8.1.3 – 10/07/2019 (CM9 2019/197965)