Office for Nuclear Regulation

Agreement to NP/SC 7766 Stage Submission 1: An Operational Safety Case for Hunterston B R3 to a Core Burn-up of 16.425 TWd Following the 2018 Graphite Core Inspection Outage

Hunterston B Power Station
Project Assessment Report

Project Assessment Report ONR-OFD-PAR-20-004
Revision 0
27 August 2020

Published 08/2020

EXECUTIVE SUMMARY

Title

Agreement to NP/SC 7766 Stage Submission 1: An Operational Safety Case for Hunterston B R3 to a Core Burn-up of 16.425 TWd Following the 2018 Graphite Core Inspection Outage

Permission Requested

Under its arrangements made under Licence Condition 22(1), EDF Energy Nuclear Generation Limited (EDF NGL) has requested that the Office for Nuclear Regulation (ONR) issues an Agreement to NP/SC 7766, which provides a safety case for the operation of Hunterston B Reactor 3 to a core burn-up of 16.425 TWd (~6 months operation) following the 2018 graphite core inspection outage.

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 must be demonstrated that these fundamental requirements continue to be met in normal operation, fault conditions and after a 1 in 10,000 year 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.

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 (OA) of 350 axially cracked bricks but well within the Currently Established Damage Tolerance Level (CEDTL) of 700 axially cracked bricks. As a result, Hunterston B Reactor 3 has remained shut down. Hunterston B Reactor 3 is the lead reactor with respect to brick cracking and as such, in the interim period, ONR has agreed to further operation of Hunterston B Reactor 4 and Reactors 3 and 4 of its sister station Hinkley Point B under separate safety cases.

This Project Assessment Report (PAR) considers the proposal (NP/SC 7766) from EDF NGL for return to service of Hunterston B Reactor 3 following its graphite core inspections for operation up to a core burn-up of 16.425 TWd or around 6 months continuous operation at power.

The previous graphite core safety case for Hunterston B Reactor 3 set an OA and determined a CEDTL in terms of the number and size of graphite brick cracks for which safe operation was justified. EDF NGL has changed its approach in NP/SC 7766 in that an OA is no longer defined although a CEDTL is retained. This does not undermine the robustness of the NP/SC 7766 methodology because damage tolerance arguments are still made for the CEDTL and a substantial margin is still demonstrated between the predicted core state after 6 months operation and the CEDTL.

The safety case is based upon a CEDTL of 1331 axially cracked bricks and 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). The provision of the case is in line with EDF NGL's strategy of developing the safety case to allow for higher levels of damage as the core ages. EDF NGL's view is that the changes are justified through developments in the assessment methodologies used to predict how a cracked core will perform under normal operation, faults and seismic loading (known as Damage Tolerance Assessments). This includes an update to the Hunterston B buildings model which is 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.

NP/SC 7766 aims to provide justification for operation of Hunterston B Reactor 3 for a further 6 months. The case is based on:

1. A conservative core state prediction is made, with high confidence that this will not be exceeded in the proposed period of operation.
2. It is demonstrated that the core can adequately perform its nuclear safety duties, for a greater level of core damage than that predicted (the CEDTL).
3. A margin is demonstrated between bullet point 1 and 2 above.

The graphite core will then be subject to further inspections and a new safety case will be required justifying any further operation beyond this 6 month period.

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 3 core and taking into account the previous assessment carried out on Hunterston B Reactor 4 and Hinkley Point B reactors, the following assessments of NP/SC 7766 have been completed by ONR specialist inspectors:

- The civil engineering assessment has focussed on the revised modelling of the pre-stressed concrete pressure vessel (PCPV) and is based on a previous assessment of similar modelling carried out in support of the Hunterston B Reactor 4 return to service safety case (NP/SC 7785).

- The graphite structural integrity assessment focussed on gaining:

    - Confidence that at the end of the 6 month operating period the number and type of cracked bricks has been conservatively defined.
    - Confidence that the likelihood of graphite debris generation is acceptable.
    - Confidence that the damage tolerance analysis bounds the 6 month core state and supports the unimpeded movement of fuel and control rods.

- The fault studies assessment focussed on:

    - 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.

Matters arising from ONR's work

Following assessment of NP/SC 7766 all specialist inspectors consider that the issue of ONR's Agreement to the proposed modification of NP/SC 7766 is acceptable. In support of their assessments, ONR's specialist inspectors have engaged extensively with EDF NGL in technical discussions to ensure that key issues have been adequately addressed.

Specialist assessments support EDF 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 16.425 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 or in a 1 in 10,000 year seismic event and are therefore acceptable. These conclusions take into account the potential for production of more complex crack morphologies (multiply cracked bricks), cracking which may occur during a seismic event and the low level of graphite debris expected to be present during this operating period.

The assessments have identified some recommendations 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 16.425 TWd) but none of these prevent ONR's Agreement to the restart of Hunterston B Reactor 3. The progress and closure of these issues will be tracked via the ONR issues database.

Conclusion

It is concluded that the operation of Hunterston B Reactor 3 to a core burn up of 16.425 TWd has been adequately justified by EDF NGL and that a Licence Instrument should be issued to EDF NGL.

Recommendations

It is recommended:

That licence instrument 565 is granted to Hunterston B to allow implementation of safety case NP/SC 7766.

LIST OF ABBREVIATIONS

AGR	Advanced Gas Cooled Reactor
ALARP	As Low As is Reasonably Practicable
AR	Assessment Report
BCD	Burst Can Detection
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
EFK	End Face Key
FHA	Full Height Axial
HSB	High Shrinkage Brick
JPSO	Justified Period of Safe Operation
KWRC	Keyway Root Crack
LC	Licence Condition
LI	Licence Instrument
MCB	Multiply Cracked Brick
NGL	Nuclear Generation Ltd
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
RKW	Radial Keyways
RTS	Return to Service
SCB	Singly Cracked Brick
SSC	Structure, System and Component
SS1	Stage Submission 1
TWd	Terawatt Days

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.
Damage Tolerance Assessment	A prediction of channel distortions in two scenarios, the full-power normal operating condition and a 1 in 10,000 year seismic event.
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.
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 cause adjacent fuel bricks to also crack.
JPSO	Justified Period of Safe Operation. A period of operation during which it has been demonstrated that the graphite core will remain in a safe condition.
Keyway Root Cracking (KWRC)	Cracking initiating from a keyway root of a fuel moderator brick, 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)	Previously 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).
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.
TWd	Terawatt-Day a core burn-up. In practice one years' operation at 80% power is slightly under 0.5 TWd.

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1. PERMISSION REQUESTED

1. Under derived powers made under Licence Condition 22(1) (Ref. 1), EDF Energy Nuclear Generation Limited (EDF NGL) has requested (Ref. 2) that the Office for Nuclear Regulation (ONR) issue an Agreement to NP/SC 7766 (Ref. 3), which provides a safety case for the operation of Hunterston B Reactor 3 to a core burn-up of 16.425 TWd (~6 months operation) following the 2018 graphite core inspection outage.

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 3000 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.

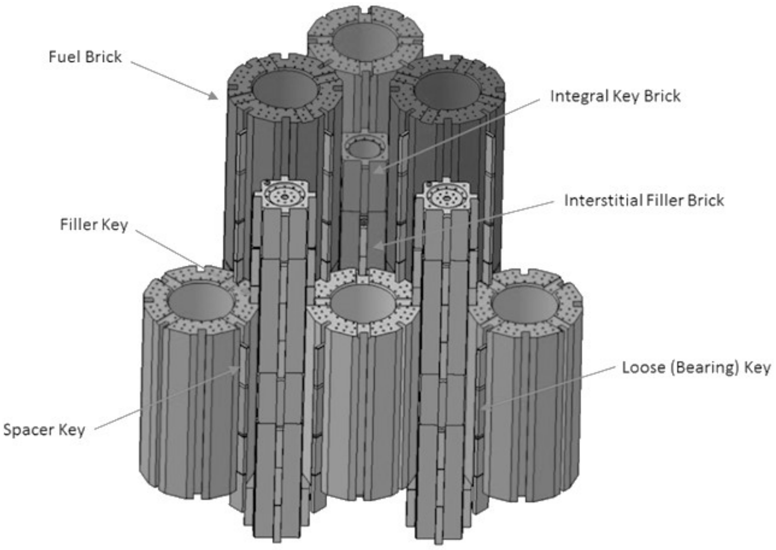

Figure 1 – Graphite Core Arrangement

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.

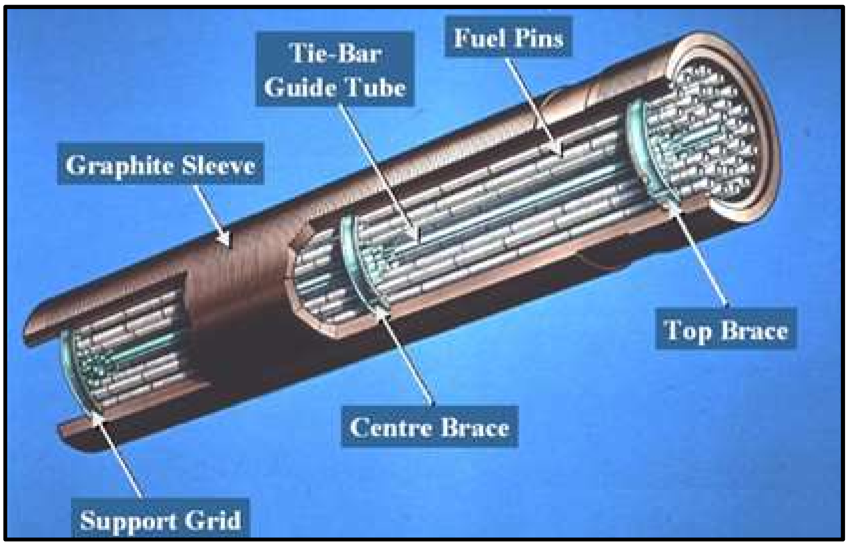

Figure 2 – Fuel Element Example

4. Each reactor has 81 control rods that are used to manage the power in the reactor by absorbing neutrons. 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 their channels in the unlikely event of a higher core distortion. 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, is 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 leads 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 below 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 safety requirements above and consequently the safety case needs to demonstrate that there are no significant implications for the nuclear safety requirements arising from keyway root cracking in order to permit further operation.

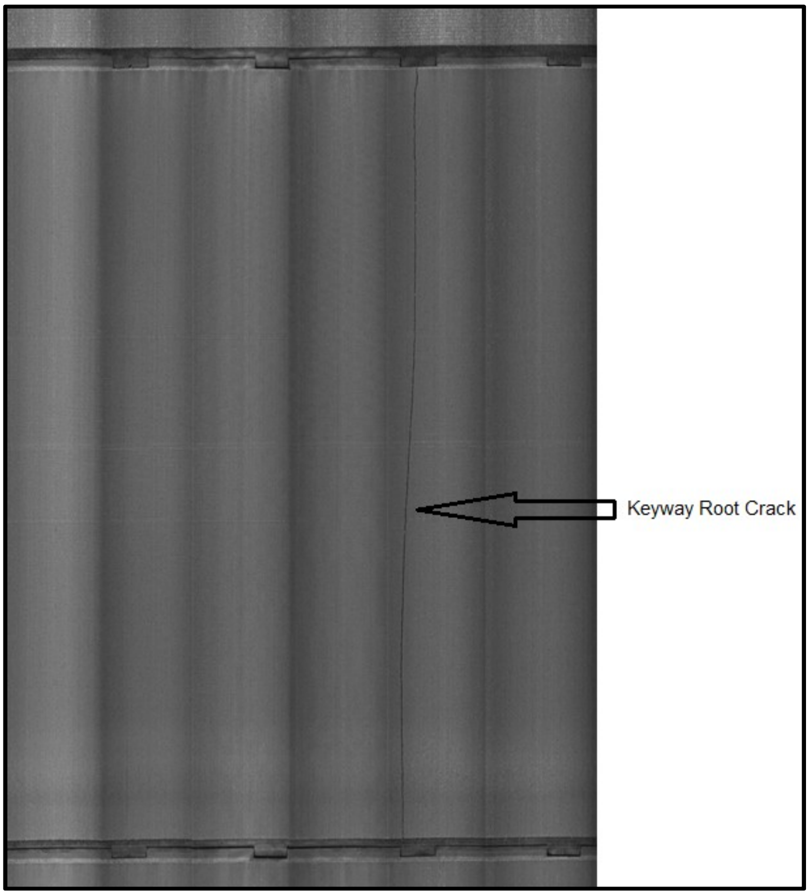

Figure 3 – Keyway Root Crack Example

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 in Reactor 4[1] in September 2017. Prior to its shutdown in March 2018, Hunterston B Reactor 3 operated, under a safety case, known as NP/SC 7716, which allowed for up to 700 axial cracks, referred to as the Currently Established Damage Tolerance Level (CEDTL). This was the level of cracking for which it had been demonstrated that there is no detriment to the nuclear safety functions of the graphite core. This was in line with EDF NGL's strategy of justifying higher levels of damage as the core ages through developments in the assessment methodologies. To provide a safety margin to the CEDTL, a lower Operational Allowance (OA) of 350 axial cracks was also set within which it was intended to 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). Of the 350 axially cracked bricks:

- no more than 100 were to be singly axially cracked bricks open by more than 12mm,
- no more than 20 were to be are singly cracked bricks open by more than 18mm,
- and, no more than 180 were to be doubly axially cracked bricks.

8. In addition, the safety case was limited to core burn-up of no more than 16.7 TWd.

9. 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 has remained shut down pending a safety case justifying further operation. The OA was exceeded because the core state predictions at that time did not account for the potential for cracks to be induced in adjacent bricks by keyway root cracks. Induced cracking is now included in the core state predictions.

10. The purpose of NP/SC 7766 is to justify return to service of Hunterston B Reactor 3 for a further operating period of ~6 months (to a core burn-up of 16.425 TWd). The graphite core will then be subject to further inspections. Any further operation would be dependent on the inspections demonstrating that cracking of the graphite core is within expectations and development of a new safety case to justify further operation.

11. Hunterston B Reactor 4 was shutdown for graphite core inspections in October 2018. The inspections showed that cracking was within the OA but that any further operation would need to be justified in a new safety case. ONR agreed (Ref. 4) to such a safety case which justified operation a core burn up of 16.025 TWd (~4 months operation). This enabled Hunterston B Reactor 4 to operate up to a similar core state as Reactor 3 when shutdown in March 2018. A similar safety case was also agreed for Hinkley Point B to core burn ups of 16.775 TWd and 17.031 TWd for Reactor 4 and Reactor 3 respectively (Ref. 5). Following operation of these reactors, graphite core inspections were carried out to confirm understanding of crack progression. The inspection data obtained following the periods of operation was all within expectations predicted by modelling. These reactors remain shutdown pending new safety cases justifying any further operation.

12. Much of the work that justified operation of Hunterston B Reactor 4 up to 16.025 TWd remains relevant to the safety case (NP/SC 7766) provided for Hunterston B Reactor 3 and addressed in this PAR. Key developments since ONR agreed to the operation of

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

[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.

Hunterston B Reactor 4 up to 16.025 TWd and where they are discussed in this PAR are listed below:

- The prediction of the reactor building response to the seismic ground motion uses upper-bound building properties instead of best-estimate properties (see paragraph 22).
- The 'final' version of the reactor building response to the seismic ground motion is used instead of the 'preliminary' version, accounting for recommendations by independent peer review (see paragraph 18).
- The rocking motion of the building has been included to the graphite core seismic input (see paragraph 32).
- End-face key/keyway capacities are reduced by 45% (see paragraph 32).

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 7766 has been subject to assessment by inspectors in the following specialisms:

- Civil Engineering
- Structural Integrity – Graphite
- Fault Studies

15. The scope of these assessments is described for each specialism in section 3 below. It should also be noted that, in order to support the assessment of NP/SC 7766, ONR specialist inspectors have engaged with the EDF NGL in numerous detailed technical discussions and have raised and resolved a number of technical issues throughout their assessments. This report does not attempt to summarise all of the questions raised and answers provided.

16. An assessment was previously completed under NP/SC 7785 (Ref. 6) with respect to the diverse hold down (DHD) Nitrogen system, which is claimed by EDF NGL as defence in depth. The assessment supported the adequacy of the 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 and these conclusions remain applicable.

3.1 ASSESSMENT FINDINGS

3.1.1 CIVIL ENGINEERING ASSESSMENT

17. From a civil engineering perspective, the most significant nuclear safety risk addressed by the safety case relates to the justification that core damage and distortion will not prevent acceptable control rod entry during and following a seismic event. This justification is based on the revised seismic modelling of the pre-stressed concrete pressure vessel (PCPV).

18. The specialist civil engineering inspector has assessed the claims and supporting arguments with civil engineering content and sampled the supporting evidence (Ref. 7). The assessment has focused on the revised modelling of the PCPV and is based on previous assessments of a similar preliminary version of modelling carried out in support

of the Hunterston B Reactor 4 return to service safety case (NP/SC 7785) (Ref. 8) and the safety case to increase the graphite core operating allowance for the Hinkley Point B reactors (NP/SC 7792) (Ref. 9). During those assessments a number of recommendations were raised, which have since been adequately addressed.

19. The specialist civil engineering inspector is satisfied with the claims, arguments and evidence presented in the safety case. The key assessment findings are summarised below.

20. The specialist inspector considers that the PCPV modelling used to derive the core boundary seismic motion for input to the graphite core analysis has remained unchanged from that used in safety case NP/SC 7792 in relation to the Hinkley Point B reactors. The main conclusions from ONR's assessment of NP/SC 7792 were:

- The PCPV modelling approach was conventional and in general accordance with relevant good practice.
- The changes to the restraints in the existing model, made 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.
- The material properties for the concrete structure, bearings, rock and backfill are deemed adequate and a limited, though acceptable, sensitivity study has been undertaken that considered the effects of uncertainty due to variation in key material properties.

21. As concluded in ONR's assessment of NP/SC 7792, it is considered that the modelling is adequate, and equally applicable to the Hunterston B reactors. The specialist inspector further considers that the claims on the PCPV modelling in the current safety case have been adequately substantiated.

22. As indicated above (paragraph 20 - 4th bullet point), previous assessments have been based on best estimate properties for the PCPV model with sensitivity studies to address uncertainty due to variation in key material properties. The current safety case NP/SC 7766, has now utilised a core boundary seismic motion derived using upper bound PCPV properties, which is considered appropriate and meets with ONR's expectations.

3.1.1.1 CIVIL ENGINEERING CONCLUSION

23. To conclude, the civil engineering inspector is satisfied with the claims, arguments and evidence laid down within EDF NGL's safety case. It is judged that the proposal is adequate 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) that Hunterston B Reactor 3 can return to service for a period of operation up to a core burn of 16.425 TWd.

3.1.2 STRUCTURAL INTEGRITY - GRAPHITE ASSESSMENT

24. The specialist structural integrity inspector focussed their assessment (Ref. 10) of NP/SC 7766 on three fundamental structural integrity aspects of the safety case, and on resolving the remaining two Recommendations made by the previous assessment of the Hunterston B Reactor 4 return to service case (NP/SC 7785 Ref. 11). An outline of the scope of the assessment is as follows:

- Confidence that at the end of the 6 month operating period the number and type of cracked bricks has been conservatively defined.
- Confidence that the likelihood of graphite debris generation is acceptable.
- Confidence that the damage tolerance analysis bounds the 6 month core state and supports the unimpeded movement of fuel and control rods.

3.1.2.1 OA AND CEDTL

25. EDF NGL has changed the approach it used in its previous safety case methodology by no longer defining an operational allowance (OA). Previously, EDF NGL has set the OA as an arbitrary core state that operation during the period would not exceed before further inspections were made. EDF NGL also set a second core state known as the currently established damage tolerance level (CEDTL) that was defined such that there was a margin between the OA and CEDTL in terms of cracked brick numbers. EDF NGL then showed that the safety case was valid up to the CEDTL, thereby demonstrating a substantial margin beyond the OA and mitigating any residual uncertainty in the core state predictions.

26. NP/SC 7766 has removed the OA and instead defined a 6 month and 12 month core state setting a safety case validity limit of 6 months. In the specialist structural integrity inspectors view this does not undermine the robustness of the NP/SC 7766 methodology because damage tolerance arguments are still made for the CEDTL and a substantial margin is still demonstrated between the predicted core state after 6 months operation and the CEDTL.

3.1.2.2 CORE STATE PREDICTIONS

27. The core state predictions presented in NP/SC 7766 are based on a methodology that was previously assessed via the Hunterston B Reactor 4 return to service safety case and take account of the brick cracking observations from the extended inspections undertaken on Reactor 3 since March 2018. The predictions account for the generation of induced cracks, and the likelihood of doubly cracked and multiply cracked bricks being formed. Further brick cracking observations that had not been available during EDF NGL's development of NP/SC 7766 became available from the January 2020 inspection of Hunterston B Reactor 4. Although from Reactor 4, the observations nevertheless increased the pool of relevant data beyond those available to NP/SC 7766.

28. To ensure NP/SC 7766 was assessed in the light of the latest information available, the specialist inspector requested that EDF NGL update the Reactor 3 NP/SC 7766 core state predictions taking into account the January 2020 Reactor 4 observations. A good comparison to core state prediction by ONR's advisors who are independent of the licensee provides further confidence in the core state predictions. Based on this, the specialist structural integrity inspector is content that appropriate core states have been predicted by NGL with sufficient confidence and are bounded by the damage tolerance assessments (DTA), see table 1 on page 18.

Comparison of the predicted core states to the DTA			
Cracked Brick Type	Including the R4 2020 observations		Seismic DTA
	6 month	12 month	CEDTL
All	781	943	1331
SCB 6-12mm	109	224	831
SCB > 12mm	22	28	200
DCB	40*	54*	200
MCB	9	14	100
DCB+MCB	49	68	300

*The value stated is not an explicit calculation of the number of DCBs at 99.9% confidence interval. It is an approximation, derived from taking the 99.9% prediction of MCBs from the 99.9% prediction of DCB+MCBs.

Table 1: Comparison of the revised core state predictions to the CEDTL

29. The core state predictions for 12 months' operation are provided as an indication of the rate of crack development. It is important to recognise that singly cracked bricks (SCB) with crack openings up to 6mm have very little impact on core distortion and behave essentially as intact bricks (Ref. 12). With respect to core distortion SCBs with openings greater than 6mm, doubly cracked bricks (DCB), and multiply cracked bricks (MCB) are of greater significance. Table 1 demonstrates that there are substantial margins to the CEDTL after 6 months' operation for SCBs with openings greater than 6mm, DCBs and MCBs. It is also worth noting that significant margins exist for the predicted core state after 12 months' operation.

3.1.2.3 DAMAGE TOLERANCE ASSESSMENT

30. The damage tolerance assessment (DTA) focuses on the prediction of channel distortions in two scenarios: the full-power normal operating condition and a 1 in 10,000 year seismic event. Although EDF NGL has submitted separate safety cases for Reactor 4 and Reactor 3, the two reactors are common in design and EDF NGL considers the two reactors share common graphite material properties and ageing processes. The specialist structural integrity inspector is in agreement with EDF NGL that this is the case and that aspects of their previous assessment of NP/SC 7785 continue to be directly relevant to this assessment of Reactor 3. Where appropriate, the specialist structural integrity inspector has therefore drawn on the previous assessment of NP/SC 7785 instead of repeating that assessment. In particular, the specialist inspector is content that there is sufficient equivalence between Reactor 3 and Reactor 4 that the Reactor 4 normal operating condition DTA that has been accepted under the NP/SC 7785 case is applicable to NP/SC 7766.

31. In terms of the seismic DTA, EDF NGL identified two issues that needed to be addressed by NP/SC 7766. Firstly, that the seismic input to the graphite core needed to include the rocking motion of the building and secondly, a reduction in the load capacity of the end-face keying system. It is also noted that NP/SC 7766 implements upper bound seismic building properties, which conservatively increases the severity of the seismic input to the graphite core. The use of upper bound building properties in NP/SC 7766 has been separately assessed by a specialist civil engineering inspector (see paragraph 22).

32. During the development of a revised building model, EDF NGL identified that the graphite core would be subject to both translational and rocking motions in a seismic

event, but that rocking motion had not previously been adequately captured by the graphite core model. The effect of the rocking motion on the graphite core response is potentially significant and was first introduced by EDF NGL in the Hinkley Point B safety case (NP/SC 7792) and was assessed by ONR in Reference 13. During the development of methodologies to support these safety cases, EDF NGL also identified that the capacity of graphite brick end face keys (EFKs) was not sufficiently conservative and could be up to 45% lower than previously considered. This reduction in EFK capacity was first addressed by ONR in the assessment of NP/SC 7792. When the reduced EFK capacity is combined with the additional rocking motion and upper bound properties the number of overloaded EFKs during a seismic event, was substantially increased over previous Hunterston B cases. This necessitated a more in-depth evaluation of the consequences of overloaded EFKs during a seismic event. This was referred to as in-event cracking which is discussed in section 3.1.2.4.

33. Channel distortion predictions from the revised seismic DTA are presented for the CEDTL. The specialist inspector has considered the seismic DTA and they judge that the core state shows acceptable channel distortion margins for control rod insertion. A difference between NP/SC 7766 and previous cases is that NP/SC 7766 does not demonstrate margin beyond the CEDTL with respect to brick cracking. The CEDTL defined by NP/SC 7766 appears to be a limit of tolerance; albeit noting that is within the constraint of the conservative scope and assumptions in the analysis.

34. The safety case has not sought to quantify those conservatisms and the specialist inspector has instead sought to be assured that the margin between the 6 month core state and the CEDTL is sufficient. This, in conjunction with the consequences of the revised seismic DTA, led the specialist into considerable regulatory interaction with EDF NGL on an issue that has become known as in-event cracking.

3.1.2.4 IN-EVENT CRACKING

35. In-event cracking is the methodology implemented in NP/SC 7766 that addresses the increased damage to the graphite core keying system as a result of the seismic DTA revisions, i.e. the increased seismic input and the reduced end-face key load bearing capacities. In-event cracking considers an alternative outcome to keying system failures previously considered. Specifically, end-face key failures could manifest as additional cracked bricks (instead of local failure of the key or keyway) in sufficient numbers to change the core state during the seismic event.

36. With the in-event cracking assumption, a 1 in 10,000 year seismic event during the 6-month operating period could lead to a reduction in margin to the CEDTL. It was therefore necessary for EDF NGL to confirm that the in-event core state still provided sufficient margin to the CEDTL, and in a more substantive manner than initially presented in NP/SC 7766. EDF NGL developed the in-event cracking methodology to show that should a 1 in 10,000 year seismic event occur in the 6-month operating period, the core state at 6-months combined with in-event cracking would ensure that a sufficient margin still exists between the in-event core state and the CEDTL.

37. Based on its methodology, EDF NGL claim that up to an additional 100 DCBs/MCBs could occur during the 1 in 10,000 year seismic event, when accounting for both EFK and radial-key/keyway (RKW) overloads. EDF NGL added this to the revised prediction of 49 DCBs/MCBs (see table 1). This gives an approximate in-event core state of 150 DCBs/MCBs at the end of the 6-month core state, and thus a substantial margin remains when compared to the 300 DCBs/MCBs at the CEDTL. It is also noted that EDF NGL's predictions did not include a number of conservatisms that in the specialist structural integrity inspector's opinion would significantly reduce the 100 additional DCBs/MCBs.

38. After assessing the in-event cracking methodology, and taking account of the uncertainties and inherent conservatisms in the methodologies, the specialist structural integrity inspector was satisfied that sufficient margins between the 6 month core state and the CEDTL have been adequately demonstrated when taking account of in-event cracking.

39. The specialist inspector did however identify room for improvement in the ageing methods employed for predicting keying system load capacities. This did not amount to a shortfall in NP/SC 7766 but was an opportunity for improvement should those methods be deployed in future cases.

40. This is addressed by **NP/SC 7766 SI Recommendation 1:** If the revised capacity methodology is to be used in future safety cases, EDF NGL must show high confidence in the virgin end-face key capacity being taken forward. EDF NGL must also refine the methodology for co-location of the combined irradiation and seismically induced stresses with ageing of the graphite strength.

41. The specialist inspector is subsequently content that channel distortion margins for control rods are acceptable and has confirmed that substantial core state margin continues to exist between the in-event core state and the CEDTL.

3.1.2.5 MATERIAL MODEL

42. EDF NGL's graphite material model provides an important input to NP/SC 7766 and has been subject to assessment by a specialist inspector (Ref. 14). The specialist inspector concluded the effect of uncertainties associated with the clearances and load bearing capacities of the keying system on the safety case claims should be considered. The specialist structural integrity inspector has considered these aspects and concluded that the NP/SC 7766 claims are not undermined by those uncertainties.

3.1.2.6 FUTURE CASES

43. It is the view of the specialist inspector however, that EDF NGL's safety case methodology is approaching its limit of viability in NP/SC 7766 due to the assumptions and conservatism that constrain it. It is their view that a safety case that seeks operation beyond NP/SC 7766 would need to reduce those conservatisms in some way. Under those circumstances, it is the specialist inspector's view that EDF NGL should identify the major conservatisms and uncertainties and should seek to quantify their combined effect on the graphite core's tolerability to ageing.

44. This is addressed by **NP/SC 7766 SI Recommendation 2**: Safety case arguments for operation beyond NP/SC 7766 should identify the major conservatisms and uncertainties and seek to quantify their combined effect on the DTA.

3.1.2.7 BRICK FRAGMENTS AND DEBRIS

45. Inspections have shown that brick cracking can generate brick fragments by branching of cracks. If those fragments become mobile in the coolant gas flow, where they become known as graphite debris, there is a potential concern that debris may migrate to safety significant locations and impede fuel cooling. The overall risk to fuel cooling from graphite debris is covered by a separate fault studies assessment (Ref. 15) which is discussed in section 3.1.3.2, but the likelihood of debris production and its migration to safety significant locations was considered by the specialist structural integrity inspector. The bulk of those considerations were originally made in the Hunterston B Reactor 4 return-to-service structural integrity assessment report (Ref. 11) and limited to being bounded by the Hunterston B Reactor 3 operational experience. In their assessment, the specialist inspector concluded that the likelihood of graphite debris migrating to safety significant locations should be considered as a design basis event with a potential

frequency of 10^{-4} per year. The inspector also concluded that since Hunterston B Reactor 3 is not bounded in terms of brick cracking by the operational experience of any other AGR, the case for a further period of operation of Reactor 3 (NP/SC 7766) must provide more robust arguments than had been presented for Hunterston B Reactor 4.

46. It is the view of the specialist inspector that NP/SC 7766 has provided arguments on the likelihood of fragment generation that are more robust via a review of all graphite fragment and debris observations. A primary observation of the review is that fragments have only become mobile once there is significant crack opening around the fragment. The review concluded that the majority of fragments in Reactor 3 would not have sufficient crack opening conditions to be released for at least 12 months of operation.

47. The specialist inspector concluded the likelihood of graphite debris partially blocking the fuel element 1 grid should be maintained as a design basis event with a potential frequency of 10^{-4} per year during the next 6 months of operation of Hunterston B Reactor 3. The specialist structural integrity inspector confirmed that the fault studies assessment report made due consideration of this potential event frequency as part of their assessment of NP/SC 7766 see section 3.1.3.2.

3.1.2.8 EXISTING STRUCTURAL INTEGRITY RECOMMENDATIONS

48. This section reviews the status of recommendations made by ONR in the previous assessment of the Hunterston B Reactor 4, safety case (Ref. 11).

49. **NP/SC 7785 SI Recommendation 1** was for EDF NGL to update ONR on the progress made in the development of the damage tolerance modelling of MCBs beyond that of proxy-MCBs used in NP/SC 7785. EDF NGL has now addressed this recommendation by presenting a comparison of proxy-MCBs and its improved representation of MCBs in its whole core models (Ref. 16). The comparison showed that proxy-MCBs gave conservative results with respect to the improved representation of MCBs. However, EDF NGL stated that improvements in the MCB methodology will feature in follow-on safety cases and not NP/SC 7766. The specialist inspector also noted that the extent to which proxy-MCBs are used in NP/SC 7766 to support the CEDTL is no greater than was accepted in NP/SC 7785 and, overall, it is considered acceptable for NP/SC 7766 to continue with the use of proxy-MCBs, pending the introduction of developments to the modelling of MCBs in follow-on safety cases.

50. **NP/SC 7785 SI Recommendation 3** advised the ONR fault-studies assessment on matters of graphite debris in relation to the assessment of NP/SC 7785 and is therefore now closed. Only Recommendations 2 and 4 are taken forward here and are discussed below.

51. **NP/SC 7785 SI Recommendation 2**: concerned potential outliers and stated: 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.

52. NGL responded to Recommendation 2 with a further series of sensitivity studies which reproduced the ten distributions and then extended the ten distributions to fifty to determine if additional ‘outliers’ were generated, none were. The specialist structural integrity inspector is content to accept this suggests the ‘outlier’ is not straightforward to achieve and not a common occurrence.

53. It is the specialist structural integrity inspector’s view that ‘outlier’ distributions of cracked bricks that double the normal operating condition distortions normally presented in the case are plausible. It is also their view that such ‘doubling-outliers’ for the core states assessed in NP/SC 7766, whilst not a common occurrence, are likely enough in normal

operation to need mitigation in the form of a substantial safety margin. It is their view that the channel distortion margins presented in NP/SC 7766 for the normal operating condition are large enough that they can absorb a potential doubling of the channel distortion whilst still retaining a substantial margin.

54. The recommendations raised under the Hunterston B Reactor 4 assessment were tracked by Regulatory Issue 7332. Based on the above, the specialist structural integrity inspector is content that Recommendation 2 has been satisfactorily addressed.

55. **NP/SC 7785 SI Recommendation 4**: concerned graphite debris and stated: Before any permission for operation of HNB R4 beyond the proposed four-month 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.

56. It is the view of the specialist inspector that EDF NGL has further supported the arguments for the likelihood of debris production with evidence that is more robust, and that the specialist inspector's conclusions from the assessment of Reactor 4 can be maintained. Namely that the likelihood should be treated as a design basis event with a potential frequency of 10^{-4} per year over the next 6 months of operation of Hunterston B Reactor 3.

57. EDF NGL's review of graphite debris does not significantly add to the existing arguments for the likelihood of graphite debris migration, this is not surprising given their qualitative nature. It is important then to acknowledge the qualitative nature of the arguments for the likelihood of graphite debris migrating to safety significant locations, and consequently that more emphasis should be placed on the potential consequences and debris production arguments.

58. The structural integrity recommendations raised under the Hunterston B Reactor 4 assessment were tracked by Regulatory Issue 7332. Based on the above, the specialist inspector is content that Recommendation 4 has been satisfactorily addressed. Regulatory issue 7332 can now be closed.

3.1.2.9 STRUCTURAL INTEGRITY CONCLUSION

59. The specialist structural integrity inspector is satisfied with the claims, arguments and evidence provided by EDF NGL. It is judged that the proposal is adequate from a structural integrity perspective to justify the issue of a Licence Instrument for ONR's Agreement under arrangements made under Licence Condition 22(1) that Hunterston B Reactor 3 can return to service for a period of operation up to a core burn of 16.425 TWd.

60. Recommendations NP/SC 7766 SI 1 and 2 will be tracked by regulatory issue 8234.

3.1.3 FAULT STUDIES ASSESSMENT

61. The specialist fault studies inspector focussed their assessment (Ref. 15) on determining whether EDF NGL had adequately demonstrated that the safety functions of the graphite core will be fulfilled over the proposed ~6 month operating period up to 16.425TWd. The specialist inspector has taken into account the recent ONR fault studies assessment of the Hunterston B Reactor 4 graphite core safety case NP/SC 7785 (Ref. 17).

62. The assessment focussed on:

- 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 including:
  - 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.

3.1.3.1 ASSESSMENT OF THE REQUIREMENT TO ALLOW UNIMPEDED MOVEMENT OF CONTROL RODS AND FUEL

Control Rod Movement

63. The specialist inspector judged that consideration of whether NP/SC 7766 had adequately demonstrated that the control rods insert in normal operation and following a seismic event is the main focus of the ONR graphite specialist inspector's assessment report and raised the following recommendation:

64. **NP/SC 7766 FS Recommendation 1**: Prior to ONR agreeing to the modifications to the safety case described in Reference 3, the project inspector should confirm that the graphite specialist inspector is satisfied that EDF NGL has adequately demonstrated that all control rods will insert in normal operation and following a design basis seismic event. I have confirmed this position with the specialist structural integrity inspector (Ref. 19).

65. The specialist fault studies inspector also noted that EDF NGL reviewed the potential for control rod insertion to be impeded during plant faults and concluded that for all but a potential depressurisation fault due to a control rod standpipe failure the control rods would have inserted into the core by the time any core distortion occurred. The specialist inspector judged that the arguments and evidence presented in by EDF NGL are the same as those presented in NP/SC 7785, these arguments and evidence were assessed by ONR and the assessment report concluded that EDF NGL's arguments could be supported.

66. EDF NGL states that an interstitial channel standpipe failure could lead to core distortion prior to the control rods inserting, but state that the integrity of the interstitial channel graphite bricks would mean that any resulting core distortion would not be significant. The assessment of NP/SC 7785 considered that further technical work which was being undertaken by EDF NGL to better understand the effects on core distortion of a depressurisation fault should be included in future safety cases for the operation of Hunterston B Reactor 4 beyond the 4 month operating period proposed in that case. Regulatory issue 7300 was raised to track the progress of the technical work.

67. The results of the technical work undertaken by EDF NGL which addresses regulatory issue 7300 concludes that consideration of the flow paths within the core indicated that there would not be significant core distortion following an interstitial channel standpipe failure. The evidence presented whilst qualitative in nature, relies on well-established understanding of the characteristics of choked fluid flow, and in the specialist fault studies inspector's view it provides evidence to support EDF NGL's arguments on the core distortion effects of a control rod standpipe failure. EDF NGL suggests that further computational analysis of the situation would provide additional confidence in the conclusions and as such the specialist fault studies inspector intends to keep regulatory issue 7300 open pending further discussions with EDF NGL.

68. The specialist fault studies inspector's views of the conclusions of NP/SC 7766 are largely independent of the core condition as long as the interstitial channel bricks in the affected channel remain intact; as there is no systematic cracking predicted in interstitial channels, and currently no cracks have been observed in interstitial channels. The specialist inspector noted that the potential consequences of a standpipe failure fault, if the interstitial channel integrity was compromised, could be significant and has confirmed with the graphite specialist inspector that there is confidence that interstitial channel integrity is very unlikely to be compromised by core degradation over the proposed ~6 month operating period.

69. In the specialist inspectors view EDF NGL has provided sufficient evidence to demonstrate that there will be no impediment to the free movement of control rods for all plant faults.

Fuel movement

70. Graphite brick cracking has the potential to increase the core distortion which may impede the movement of fuel. Additionally debris produced due to graphite brick cracking could cause an obstruction and lead to fuel snags or ledges. If fuel were to become stuck during fuel movement then there is an increased probability of the fuel being dropped which could lead to fuel damage and a release of radioactive isotopes into the primary circuit.

71. The ONR assessment of NP/SC 7785 concluded that EDF NGL had demonstrated that a hypothetical ten-fold increase in fuel snag frequency was still tolerable. In the specialist fault studies inspector's view this is equally applicable to Hunterston B Reactor 3 as the fuel route risk is comparable across the two reactors and was calculated as risk per reactor year (i.e. based on the risk of refuelling operations over a year, not over the four month period justified in NP/SC 7785).

72. In the specialist fault studies inspector's view, the graphite specialist inspector should be satisfied that EDF NGL has adequately demonstrated that there would not be a significant increase in fuel snag frequency from core distortion or graphite debris over the proposed ~6 month operating period prior to ONR agreeing to NP/SC 7766. The following Recommendation was therefore raised:

73. **NP/SC 7766 FS Recommendation 2**: Prior to ONR agreeing to the modifications to the safety case described in Reference 3, the project inspector should confirm that the graphite specialist inspector is satisfied that NGL have adequately demonstrated that there will be no significant increase in fuel snag frequency from core distortion or graphite debris (compared to that presented in the most recent HNB R4 safety case) over the proposed JPSO up to 16.425TWd. I have confirmed this position with the specialist structural integrity inspector (Ref. 19).

74. The specialist fault studies inspector concluded that the approach taken in the Hunterston B Reactor 3 safety case is consistent with the approach taken in NP/SC 7785 (Ref. 18) The specialist inspector has considered the effect of the more advanced core state for Hunterston B Reactor 3 and considers EDF NGL's judgement that the risks associated with fuel handling have been reduced as low as reasonably practicable (ALARP) to be valid.

3.1.3.2 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

75. The arguments and evidence presented in NP/SC 7766 (Ref. 3) are the same as those presented in NPSC 7785 (Ref. 18). The fault studies assessment (Ref. 17) of the NP/SC

7785 examined the arguments and evidence relating to the effects of brick cracking on the arrow head to annulus flow (see figure 4), and concluded that EDF NGL had adequately demonstrated that the effects of increased arrow-head to annulus flow due to brick cracking are acceptable and are independent of the number of brick cracks. The specialist inspector therefore concluded that the effects of arrow-head to annulus flow do not present an impediment to the operation of Hunterston B Reactor 3 for the proposed ~6 month period (up to a core burn-up of 16.425TWd).

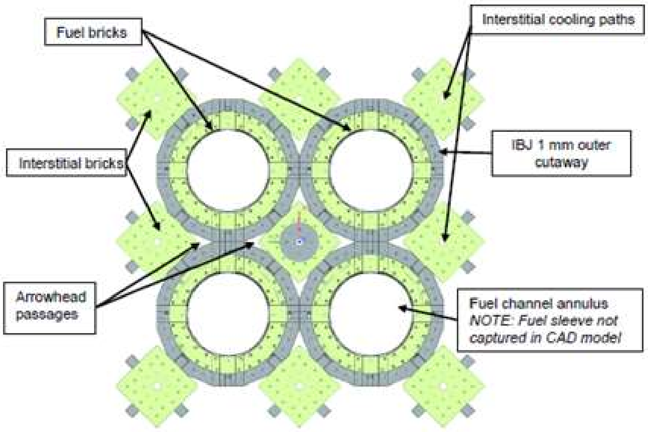

Figure 4 – Plan view of graphite core showing arrowhead passages, and annulus with no fuel stringer in-situ

The effects of channel distortion – eccentric annulus

76. The arguments and evidence presented in NP/SC 7766 are the same as those presented in NP/SC 7785 and seek to demonstrate that the peak fuel temperature and peak fuel channel brick temperature are within acceptable limits, and that the fuel sleeve temperature does not reach a point at which the sleeve integrity would be threatened.

77. ONR's previous fault studies assessment (Ref. 17) of NP/SC 7785 examined the arguments and evidence relating to the effects of an eccentric annulus on fuel clad and fuel sleeve temperatures and judged that the effects of annulus eccentricity were acceptable, and that EDF NGL had taken adequate account of the effects of annulus eccentricity in fault conditions. The specialist fault studies inspector therefore concludes that EDF NGL's safety case for Hunterston B Reactor 3 NP/SC 7766 demonstrated that the effects of an eccentric annulus on fuel sleeve and fuel clad temperatures are acceptable. These conclusions are independent of the condition of the graphite core as the consequence assessment has considered a bounding condition.

The effects of channel distortion – sleeve gapping

78. The ONR fault studies assessment (Ref. 17) of NP/SC 7785 (Ref. 18) examined the methodology employed by EDF NGL to determine the effects of sleeve gapping on the fuel clad temperatures, and concluded that the methodology was appropriate and that adequate verification and validation of the methodology had been demonstrated along with sensitivity studies. Application of the methodology to Reactor 4 concluded that the sleeve gap flow resistances introduced significant uncertainty such that it highlighted that further validation of the sleeve gap flow resistances would be required should sleeve gapping in excess of 4mm be predicted.

79. The specialist fault studies inspector judged that this conclusion also applies to Hunterston B Reactor 3. However, as NP/SC 7766 has shown that the sleeve gapping is not predicted in excess of 4mm, the specialist inspector concluded that EDF NGL has

adequately demonstrated that the effects of sleeve gapping are acceptable over the proposed ~6 month operating period (up to a core burn-up of 16.425TWd).

The potential effects of debris

80. The fault studies assessment of NP/SC 7785 recommended (Recommendation 1) that further work would be required to reduce the uncertainty on the amount of blockage that would be required to lead to fuel clad melt before operation of Hunterston B Reactor 4 could be justified beyond the current Hunterston B Reactor 3 core state, and regulatory issue 7291 was raised to track the work and progress on the issue.

81. In order to address the recommendation from the assessment of NP/SC 7785, EDF NGL commissioned two independent studies aimed at reducing the uncertainties associated with the thermal effects of a fuel element blockage. The results of the independent studies indicated that fuel element blockages of ~17% of the flow area would not lead to fuel clad melt as was assumed from the linear extrapolation of the rig test data, and would not lead to fuel clad temperatures in excess of the station operating limits. The studies also examined the effects of a fuel element blockage of ~24% flow area, and concluded that the resulting heat transfer impairment would only be marginally worse than that at ~17% blockage, suggesting the presence of a significant margin to fuel clad melt.

82. Based on the assumption that the probability of a fuel element flow obstruction will not significantly increase over the proposed operating period, and that the consequences of a fuel element flow obstruction are significantly reduced from that considered previously, the specialist inspector judged that EDF NGL has adequately demonstrated that the risks from graphite debris have been reduced so far as is reasonably practicable for the proposed operating period (up to 16.425TWd). The specialist fault studies inspector therefore raised recommendation 3 below.

83. **NP/SC 7766 FS Recommendation 3**: Prior to ONR agreeing to the modifications to the safety case described in Reference 3, the project inspector should confirm that the graphite specialist inspector is satisfied that EDF NGL has adequately demonstrated that there will be no significant increase in the probability of fuel element flow obstruction from graphite debris (compared to that presented in the most recent HNB R4 safety case) over the proposed JPSO up to 16.425TWd. I have confirmed this position with the specialist structural integrity inspector (Ref. 20).

3.1.3.3 ASSESSMENT OF THE REQUIREMENT TO PROVIDE NEUTRON MODERATION AND THERMAL INERTIA

84. The specialist fault studies inspector noted that there is no plausible effect on the thermal inertia of the graphite core due to graphite brick cracking.

85. Other plausible effects on the neutron flux distribution from graphite brick cracking were examined in the ONR fault studies assessment of NP/SC 7785 (Ref. 17), which concluded that EDF NGL had adequately demonstrated that the safety function of the graphite core to provide neutron moderation was unaffected by the presence of graphite brick cracking. This conclusion applies equally to Reactor 3 for the proposed operating period (up to a core burn-up of 16.425TWd).

3.1.3.4 EXISTING FAULT STUDIES RECOMMENDATIONS

86. This section reviews the status of existing recommendations made by ONR in the fault studies assessment NP/SC 7785 (Ref. 17).

87. **NP/SC 7785 FS Recommendation 1** of ONR's fault studies assessment of NP/SC 7785 recommended that "For inclusion in future safety cases justifying the operation of the

Hunterston B Reactor 4 graphite core, EDF 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."

88. Regulatory issue 7291 was raised to track the work on the topic. The specialist fault studies inspector judges that the recommendation has been adequately fulfilled, as EDF NGL has taken all reasonably practicable steps to reduce the uncertainties in the time since the recommendation was made. The regulatory issue will remain open pending further discussion with EDF NGL on potential further work that would be reasonably practicable in the future. This does not present an impediment to permissioning of NP SC 7766.

89. **NP/SC 7785 FS Recommendation 2** of ONR's fault studies assessment of NP/SC 7785 recommended 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." This recommendation was fulfilled prior to the restart of Hunterston B Reactor 4, and the Technical Specification change applied to both Hunterston B reactors.

90. **NP/SC 7785 FS Recommendation 3** of ONR's fault studies assessment of NP/SC 7785 recommended that "NGL should include consideration of fuel channel distortions following a seismic event and its effect on fuel sleeve gapping in future graphite safety cases." Regulatory issue 8212 was raised to track the work on this topic but consideration of fuel channel distortions following a seismic event was not included in Reference 3, and thus the recommendation has not yet been completed, however EDF NGL has provided an extract of a report in development which provides additional arguments related to this topic. The specialist fault studies inspector has not assessed these arguments in detail as they are not yet presented in a published report, but they judge that they appear to be a reasonable basis upon which to fulfil the recommendation.

91. As EDF NGL is working on addressing Recommendation 3 from Reference 17 and as this was not judged to be a significant shortfall when the recommendation was made, the specialist fault studies inspector judged that whilst EDF NGL had not yet completed work to address the recommendation, it does not represent an impediment to permissioning. The same recommendation has been made in Reference 15 (see NP/SC 7766 FS Recommendation 4 below) to ensure that the issue retains focus.

92. **NP/SC 7766 FS Recommendation 4**: NGL should include consideration of fuel channel distortions following a seismic event and its effect on fuel sleeve gapping in future graphite safety cases.

3.1.3.5 FAULT STUDIES CONCLUSION

93. I have discussed NPSC 7766 FS Recommendations 1-3 with specialist graphite structural integrity inspectors and I can confirm that they agree with the assumptions made by the specialist fault studies inspector in the recommendations above (Refs. 19 and 20).

94. NP/SC 7766 Recommendation 4 is being tracked by the specialist inspector via regulatory issue 8212.

95. It is judged therefore that the proposal is adequate 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) that Hunterston B Reactor 3 can return to service for a period of operation up to a core burn of 16.425 TWd.

4. MATTERS ARISING FROM ONR'S WORK

96. All ONR specialist inspectors consider agreement to the proposed safety case modification of NP/SC 7766 (Ref. 3) to be acceptable. On that basis I have prepared a licence instrument for Agreement to NP/SC 7766 Stage Submission 1: an Operational Safety Case for Hunterston B Reactor 3 to a Core Burn-up of 16.425 TWd Following the 2018 Graphite Core Inspection Outage. This has been written according to ONR guidance 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.

97. The Structural Integrity Graphite Assessment Reports (Ref's 10 and 14) assigned Amber ratings to NP/SC 7766 in judging the original submission against the ONR assessment rating guide (Appendix 1 of Ref. 21). These ratings reflect the significant interaction and additional evidence required by ONR to complete its assessment of NP/SC 7766. The ratings do not imply a shortfall in the adequacy of the overall safety case once the additional evidence provided by EDF NGL is taken into account.

98. A number of Recommendations were raised by specialist inspectors which are discussed in this report. These Recommendations include those which require the project inspector to confirm assumptions made in the specialist fault studies assessment which I can confirm has been done. None of the other recommendations prevent the restart of Hunterston B Reactor 3 but they will be tracked via ONR regulatory issues.

99. Due to the length of time that the reactor has been shutdown, the statutory outage which was due to be completed during the period has not followed the routine process that ONR would anticipate. I have therefore liaised with the outage project inspector regarding the conclusions of this PAR. Please see Reference 22 for more information on the statutory outage.

100. ONR has liaised with the Scottish Environmental Protection Agency (SEPA) and it has confirmed that it has no objections to the operation of Reactor 3 at Hunterston B to a core burn up of 16.425 TWd. (Ref. 23).

101. I have confirmed that EDF NGL has followed its own due process. An INSA statement for NP/SC 7766 has been submitted (Ref. 24) and Nuclear Safety Committee (NSC) meeting minutes have been submitted (Ref. 25).

5. CONCLUSION

102. I conclude that, based on the assessments and conclusions made by the ONR specialist inspectors and the evidence from regulatory interactions with EDF NGL, operation of Hunterston B Reactor 3 up to a core burn up of 16.425 TWd has been adequately justified by EDF NGL.

6. RECOMMENDATIONS

103. I recommend that licence instrument 565 is granted to Hunterston B to implement NP/SC 7766.

7. REFERENCES

1. BEG/SPEC/DAO/020, Nuclear Generation Limited, Company Specification, Modification process, Revision 009, July 2019

2. NSL HNB50566R Request for Agreement under Arrangements Made under Licence Condition 22(1), EC 363560 Graphite Core safety Case. NP/SC 7766 Stage Submission 1: An operational Safety Case for Hunterston B R3 to a Core Burn-up of 16.425 TWd Following the 2018 Graphite Core Inspection Outage, 6th May 2020, 2020/136956

3. NP/SC 7766 (EC 363560) version 10, Hunterston B Power Station, Graphite Core Safety Case NP/SC 7766 Stage Submission 1, An operational safety case for Hunterston B R3 to a core burn-up of 16.425TWd following the 2018 graphite core inspection outage, CM9 2020/124498

4. ONR-OFD-PAR-19-004, Agreement to NP/SC 7785 Hunterston B Power Station - Return to service safety case for Reactor 4 following core inspection results in 2018 Revision 0, CM9 2019/169056

5. ONR-OFD-PAR-19-010 Revision 0, Agreement to NP/SC 7792 Hinkley Point B Power Station - Justification for an increase in the operational allowance for the Hinkley Point B graphite cores for core ages up to 17.2 TWd, CM9 2019/265361

6. 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

7. ONR-OFD-AR-20-002 Revision 0, Civil engineering assessment, Graphite Core Safety Case NP/SC 7766 Stage Submission 1: An Operational Safety Case for Hunterston B R3 to a Core Burn-Up of 16.425TWd following the 2018 Graphite Core Inspection Outage, CM9 2020/109854

8. 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

9. ONR-OFD-AR-19-041 – Justification for an increase in the Operational Allowance for the Hinkley Point B Graphite Cores for Core Ages up to 17.2 TWd - NP/SC 7792 – Civil Engineering Assessment, CM9 2019/268654

10. ONR-OFD-AR-19-053 Revision 0, Graphite Core Safety Case NP/SC 7766 Stage Submission 1: An operational safety case for Hunterston B R3 to a core burn-up of 16.425TWd following the 2018 graphite core inspection outage, Graphite structural integrity assessment, CM9 2019/264245

11. 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

12. Atkins report 5152292/350/009 Issue 02, Hunterston B Reactor 3: Return to Service 2018 Seismic Assessment Sensitivity Study, April 2018, CM9 2018/140613.

13. ONR-OFD-AR-19-073, Revision 0, NP/SC 7792 V09 Hinkley Point B – Graphite Structural Integrity Assessment, CM9 2019/355116

14. ONR-OFD-AR-19-093 Revision 0, Assessment of EDF’s graphite materials properties model in NP/SC 7766 V10 SS1 (Operation of HNB R3 to a burn up of 16.425TWd) and

implications for the predicted brick stresses, dimensions and overall damage tolerance assessment, CM9 2020/151688

15. ONR-OFD-AR-20-003 Revision 0, Fault Studies Assessment of Hunterston B Power Station Reactor 3 Graphite Core Safety Case, Graphite Core Safety Case. NP/SC 7766 Stage Submission 1: An Operational Safety Case for Hunterston B R3 to a Core Burn-up of 16.425TWd Following the 2018 Graphite Core Outage, CM9 2020/131280

16. EDF - ONR-OFD-CR-20-060 - Realistic and Proxy MCBs - 09/04/2020 - [redacted] CM9 reference 2020/111854

17. 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

18. EDF NGL Safety Case: NP/SC 7785 Hunterston B Power Station Return to Service Safety Case for R4 Following Core Inspection Results in 2018, May 2019, EC No 364115 Rev 00 Version 11. CM9: 2019/149727

19. Email from [redacted] to [redacted] – RE: Fault Studies Recommendations – NPSC 7766 – 22/07/2020 CM9 2020/226045

20. Email from [redacted] to [redacted] - RE: Fault Studies Recommendations - NPSC 7766 - 31/07/2020 CM9 2020/231253

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