Office for Nuclear Regulation

Agreement to EC 367341 - Justification for Return to Service of Hunterston B R4 to Operate to a Core Burn-Up of 16.25 TWd

Hunterston B Power Station
Project Assessment Report

Project Assessment Report ONR-OFD-PAR-20-012
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EXECUTIVE SUMMARY

Title

Agreement to EC 367341 - Justification for Return to Service of Hunterston B R4 to Operate to a Core Burn-Up of 16.25 TWd

Permission Requested

Under EDF Energy Nuclear Generation Limited's (EDF NGL) arrangements made under Licence Condition 22(1), ONR requested engineering change (EC) 367341 which is the safety case for the Justification for Return to Service of Hunterston B Reactor 4 to operate to a core Burn-up of 16.25 TWd (equivalent to approximately 6 months operation), for Review and Consideration. Following Review and Consideration ONR placed the following hold point:

Hold Point 20-015-001 – To be released via an Agreement following assessment of EC 367341, NGL should not re-start Hunterston B Reactor 4 until this hold point is lifted.

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. 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.

This Project Assessment Report (PAR) considers EC 367341 which justifies the return to service of Hunterston B Reactor 4 to operate to a core burn-up of 16.25 TWd. The purpose of the EC is to review the findings of Hunterston B Reactor 4 inspections completed in January and February 2020 to confirm that they are within expectations and support safe operation to a core burn-up of 16.25 TWd. Due to the shared reactor design and similar core age, this proposal draws on the arguments and evidence in NP/SC 7766 which justified a similar period of operation for Hunterston B Reactor 3. ONR's assessment of NP/SC 7766 concluded that sufficient evidence to demonstrate that the fundamental nuclear safety requirements would be met had been provided by EDF NGL and ONR agreed to operation of Hunterston B Reactor 3 up to 16.425 TWd. EC 367341 aims to demonstrate that the Damage Tolerance Assessments (DTA) presented in NP/SC 7766 are valid for Hunterston B Reactor 4 and justify operation of Reactor 4 up to a core burn-up of 16.25 TWd.

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 and taking into account the previous assessment carried out on Hunterston B Reactor 3, an assessment has been carried out by a specialist graphite structural integrity inspector.

Taking into account the previous assessment of NP/SC 7766, the specialist inspector focussed their assessment of EC 367341 on the following aspects:

- Equivalence of Hunterston B Reactor 4 and Reactor 3 core behaviours and applicability of NP/SC 7766 to Hunterston B Reactor 4.
- Hunterston B Reactor 4 core state predications and adequacy of margins to the currently established damage tolerance limit (CEDTL) presented in NP/SC 7766.

Matters arising from ONR's work

Following assessment of EC 367341 the specialist structural integrity inspector supports the issue of ONR’s Agreement to the proposed EC 367341. In support of their assessment, the ONR’s specialist inspector has engaged with EDF NGL in technical discussions to ensure that key issues have been adequately addressed.

Specialist assessment supports 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 predicted to occur during the next operating period to a core burn-up of 16.25 TWd.

Conclusion

It is concluded that the operation of Hunterston B Reactor 4 to a core burn up of 16.25 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 567 is granted to Hunterston B which releases hold point 20-015-001 to allow the implementation of Engineering Change 367341.

LIST OF ABBREVIATIONS

AGR	Advanced Gas Cooled Reactor
ALARP	As Low As is Reasonably Practicable
AR	Assessment Report
CEDTL	Currently Established Damage Tolerance Limit
DCB	Doubly Cracked Brick
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
SCB	Singly Cracked Brick
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.
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.
Induced Cracks	Opening of cracked fuel bricks which causes adjacent fuel bricks to also crack.
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).
Singly Cracked Brick (SCB)	Singly axially Cracked Brick (i.e. a brick containing exactly one full height, full thickness axial crack).
TWd	Terawatt-Day (core burn-up. In practice one years' operation at 80% power is slightly under 0.5 TWd.

TABLE OF CONTENTS

Figures

Tables

1. PERMISSION REQUESTED

1. Under EDF Energy Nuclear Generation Limited's (EDF NGL) arrangements made under Licence Condition 22(1) (Ref. 1), ONR requested EC 367341 which is the safety case for the Justification for Return to Service of Hunterston B Reactor 4 to operate to a core Burn-up of 16.25 TWd (Ref. 2), (~6 months operation), for Review and Consideration (Ref 3). Following Review and Consideration ONR placed the following hold point:

Hold Point 20-015-001 – To be released via an Agreement following assessment of EC 367341, NGL should not re-start Hunterston B Reactor 4 until this hold point is lifted (Ref 4).

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.

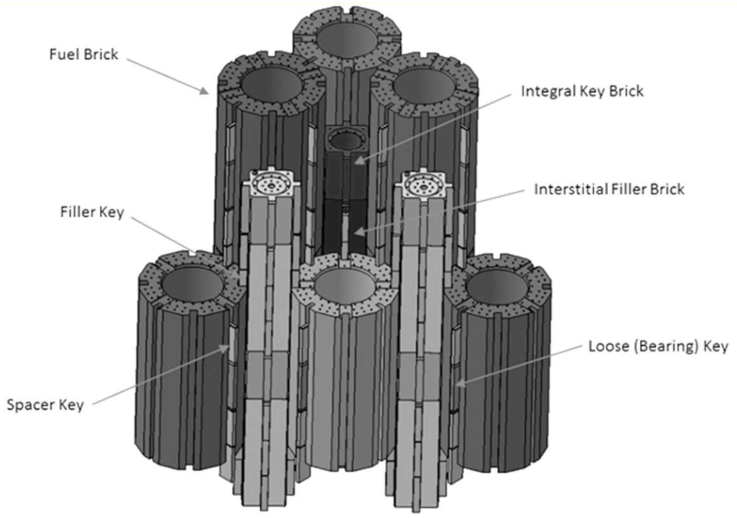

Figure 1 – Graphite Core Arrangement

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.

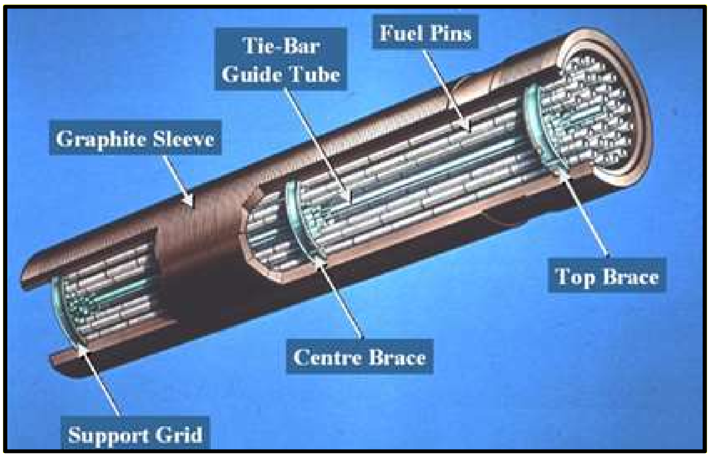

Figure 2 – Fuel Element Example

4. Each reactor has 81 control rods that are used to manage the power in the reactor 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. 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.

[1] A full height KWRC was first observed in Reactor 4 in 2014 in a high shrinkage brick.

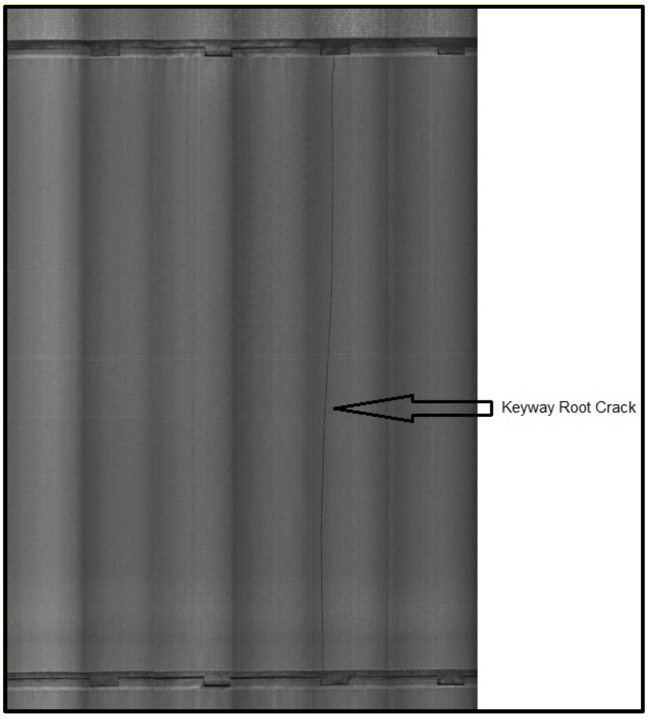

Figure 3 – Keyway Root Crack Example

7. Hunterston B Reactor 4 was shut down for graphite core inspections in October 2018. The inspections showed that cracking was within the safety case limits but that any further operation would need to be justified in a new safety case. Subsequently ONR Agreed (Ref. 5) to NP/SC 7785 (Ref. 6) which justified operation a core burn up of 16.025 TWd (~4 months operation).

8. EDF NGL returned Hunterston B Reactor 4 back to service in August 2019 under NP/SC 7785. Following a four month operating period it was shut down in December 2019 for core inspections and to develop a new safety case.

9. EDF NGL carried out inspections of the Hunterston B Reactor 4 graphite core in January and February 2020 in order to determine the progression of the core damage. Following these inspections, EDF NGL produced the proposed safety case, EC 367341 (Ref. 2), to return Hunterston B Reactor 4 back to service and operate up to a core burn up of 16.25 TWd (equivalent to approximately 6 months further operation). Following this period of operation, the graphite core will then be subject to further inspections. Any further operation will be dependent on the inspections demonstrating that cracking of the graphite core is within expectations and ONR's assessment of, and Agreement to, a new safety case that justifies a further period of operation.

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

10. 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.

11. EDF NGL's proposal EC 367341 (Ref. 2) draws on the arguments and evidence in the Category 1 paper NP/SC 7766 (Ref. 7) which justified a period of operation for Hunterston B Reactor 3. ONR's assessment of NP/SC 7766 was reported in References 8, 9 and 10. ONR's assessment concluded that NP/SC 7766 provided sufficient

evidence to demonstrate that the fundamental nuclear safety requirements would be met and agreed to operation of Hunterston B Reactor 3 up to a core burn-up of 16.425 TWd (~6 months operation).

12. The focus of ONR's assessment of EC 367341 (Ref. 2) has been on the graphite structural integrity aspects of the safety case. In addition to assessment by a graphite structural integrity inspector, assurance has been provided by specialist civil engineering and fault studies inspectors that the recent assessments carried out on the safety case for the return to service of Hunterston B Reactor 3 (NPSC 7766 Ref. 8 and 10) are equally applicable to Hunterston B Reactor 4 and that no further assessment is required (Ref. 11 and 12). This is because the main difference between Hunterston B Reactor 3 and Hunterston B Reactor 4 is the presence of a small but limited population of high shrinkage bricks (HSBs) in Hunterston B Reactor 4 whose effect needs to be accounted for in the graphite structural integrity assessment.

13. Based on the previous assessments of NP/SC 7766, EC 367341 has been subject to specialist assessment by graphite structural integrity. The scope of the graphite structural integrity assessment is described in section 3.1.1 below. It should also be noted that, in order to support the assessment of EC 367341 the specialist graphite structural integrity inspector has engaged with the EDF NGL and has raised and resolved a number of technical issues during their assessment. This report does not attempt to summarise all of the questions raised and answers provided.

3.1 ASSESSMENT FINDINGS

3.1.1 STRUCTURAL INTEGRITY - GRAPHITE ASSESSMENT

14. Taking into account the previous assessment of NP/SC 7766 (Ref. 9) The specialist inspector focussed their assessment (Ref. 13) of EC 367341 on the following aspects:

- Equivalence of Hunterston B Reactor 4 and Reactor 3 core behaviours and applicability of NP/SC 7766 to Hunterston B Reactor 4.
- Hunterston B Reactor 4 core state predications and adequacy of margins to the Currently Established Damage Tolerance Level (CEDTL) presented in NP/SC 7766.

15. The specialist inspector is content that the damage tolerance assessment (DTA) arguments and evidence presented in NP/SC 7766 are equally valid for Hunterston B Reactor 4. This is because the main difference between Hunterston B Reactor 3 and Hunterston B Reactor 4 is the presence of a small but limited population of around 30 high shrinkage bricks (HSBs) in Hunterston B Reactor 4 whose effect is limited.

16. The specialist inspector is content that EDF NGL has carried out an adequate graphite core inspection of Hunterston B Reactor 4 in January and February 2020 following a 4 month period of operation to allow appropriate core state predictions. Those inspections did not observe any new doubly or multiply cracked bricks.

17. The specialist inspector is content that EDF NGL's core state predictions for Hunterston B Reactor 4 are based on the latest inspection results and account for the presence of high shrinkage bricks appropriately. The specialist inspector takes confidence from the core state sensitivity studies provided by EDF NGL and from the similarity of EDF NGL's predictions to the core states predicted by ONR's independent advisors. The specialist inspector is therefore content that EDF NGL has presented adequate and conservative cracking predictions over the proposed 6 months of further operation for Hunterston B Reactor 4.

18. By accounting for the presence of the small population of high shrinkage bricks in its core state predictions, EDF NGL predicts slightly higher numbers of doubly cracked bricks (DCBs) and multiply cracked bricks (MCBs) in Hunterston B Reactor 4 when compared to Hunterston B Reactor 3. Consequently, the margin to the CEDTL in terms of the numbers of DCBs and MCBs is slightly smaller for Hunterston B Reactor 4 than for Hunterston B Reactor 3. However, EDF NGL's Hunterston B Reactor 4 predicted core state after 6 months of further operation show that there remains a substantial margin to the CEDTL of NP/SC 7766 (See table 1 below).

Comparison of the predicted core states to the Seismic DTA CEDTL			
Cracked Brick Type	**6 month**	**12 month**	**CEDTL**
All	767	936	1331
SCB < 6mm	585	647	Bounded by SCB ≥ 6mm
SCB 6mm-12mm	79	166	831
SCB > 12mm	29	33	200
DCB	52	60	200
MCB	22	30	100
DCB+MCB	74	90	300

Table 1: Core state predicted after 6 and 12 months of operation at 99.9% confidence level

19. The predicted core states after 6 months and 12 months of further operation shown in Table 1 demonstrate that there is a significant margin to the CEDTL with regards to the numbers of DCBs, MCBs and SCBs with crack openings larger than 6mm and 12mm. Bricks with small crack opening (less than 6mm), which dominate the total number of predicted cracked bricks, have little effect on the core distortion as they would behave much like intact bricks. This position has been applied in previous safety cases and the specialist inspector is content that SCBs with narrow crack opening have little effect on control rod channel distortion. The core state predictions for 12 months' operation are provided as an indication of the rate of crack development.

20. EDF NGL provided additional evidence specific to Hunterston B Reactor 4 to demonstrate the available margins to the CEDTL when taking account of the potential for in-event cracking generating additional DCBs and MCBs during a seismic event. The potential effect of in-event cracking is accounted for using the same approach as NP/SC 7766, by adding 100 additional DCBs + MCBs to the Hunterston B Reactor 4 predicted core state. Even with the additional DCB + MCBs there is a substantial margin between the CEDTL and the Hunterston B Reactor 4 core state at a 99.9% confidence level for DCBs and MCBs after accounting for in-event cracking. This margin is similar to that presented for Hunterston B Reactor 3 under NP/SC 7766 however EDF NGL argues that the estimated figure of 100 additional in-event DCBs and MCBs for Hunterston B Reactor 3 is bounding for Hunterston B Reactor 4. In the specialist inspector's view, the following reasons support the argument that the Hunterston B Reactor 4 in-event cracking is bounded by Reactor 3:

- The Reactor 4 core burn-up is less than Reactor 3, so the end-face key/keyway capacities are likely to be higher in Reactor 4.
- The number of SCBs in Reactor 4 is lower than that of Reactor 3, so there are fewer bricks ready to convert to DCBs/MCBs during a seismic event in Reactor 4 than in Reactor 3.

21. After assessing the additional evidence, the specialist inspector is satisfied that sufficient margins between the 6 month core state and the CEDTL have been adequately demonstrated when taking account of in-event cracking.

22. To conclude, the specialist inspector is satisfied that EDF NGL has provided adequate evidence with respect to the structural integrity of the graphite core to support the return to service of Hunterston B Reactor 4 and operation up to a core burn-up of 16.25 TWd.

4. MATTERS ARISING FROM ONR'S WORK

23. The ONR specialist structural integrity inspector supports agreement to the proposed safety case EC 367341 (Ref. 2). On that basis I have prepared a licence instrument for Agreement to EC 367341, Justification for Return to Service of Hunterston B Reactor 4 to Operate to a Core Burn-Up of 16.25 TWd. 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.

24. I have liaised with the Scottish Environmental Protection Agency (SEPA) and they have confirmed that they have no objections to the operation of Hunterston B Reactor 4 to a core burn up of 16.25 TWd. (Ref. 14).

25. I have confirmed that EDF NGL has followed its own due process. An INSA statement has been submitted in support of EC 367341 (Ref. 15).

5. CONCLUSION

26. I conclude that, based on the assessment and conclusions made by the ONR specialist structural integrity inspector and the evidence from regulatory interactions with EDF NGL, operation of Hunterston B Reactor 4 up to a core burn up of 16.25 TWd has been adequately justified by EDF NGL.

6. RECOMMENDATIONS

27. I recommend that licence instrument 567 is granted to Hunterston B to implement EC 367341.

7. REFERENCES

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4. HNB71307N Review and Consideration of EC No.: 367341 – Justification for Return to Service of Hunterston B R4 to Operate to a Core Burn-Up of 16.25 TWd, 5 September 2020, CM9 2020/184113

5. 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

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11. Email from [redacted] – RE: HNB R4 Return to Service – 06/07/2020, CM9 2020/203421

12. Email from [redacted] – RE: HNB R4 Return to Service 24/08/2020 CM9 2020/253334

13. ONR-OFD-AR-20-040, EC367341 - Justification for Return to Service of Hunterston B R4 to Operate to a Core Burn-Up of 16.25 TWd - Graphite Structural Integrity Assessment, 2020/261731

14. Email from [redacted] to [redacted] RE: EC367341 - Justification for Return to Service of Hunterston B R4 to Operate to a Core Burn-Up of 16.25 TWd, 03/09/2020, CM9 2020/263115

15. EDF Energy Nuclear Generation Ltd – Milestone Full INSA Statement – Hunterston B EC No./Rev No.: 367341/000 Version No.: 02, Justification for Return to Service of Hunterston B R4 to a Burn-Up of 16.25 TWD – 2020/267126