Office for
Nuclear Regulation

Operating Facilities

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 Civil Engineering Assessment

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EXECUTIVE SUMMARY

This report presents my assessment findings for the civil engineering aspects of EDF Energy Nuclear Generation Limited's (NGL's) proposal "Operational Safety Case for Hunterston B Reactor 3 to a Core Burn-Up of 16.425 TWd (Terra Watt days) following the 2018 Graphite Core Inspection Outage", presented in NP/SC 7766 Stage Submission 1.

In accordance with NGL's arrangements made under Licence Condition 22 (1), the safety case is Category 1 and therefore requires ONR's Agreement or Acknowledgement before it can be formally implemented.

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 stringers.
- 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, with the cracks initiating at the root of keyways in the bricks. Such cracking is termed keyway root cracking. This has the potential to challenge the nuclear safety requirements identified above and consequently it needs to be demonstrated that, even with cracked bricks, 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 the main population of graphite moderator fuel bricks at Hunterston B Reactor 3 in October 2015, and in September 2017 for Reactor 4. Since this time, the safety case for operation of the graphite cores at Hunterston B and Hinkley Point B has been based on determining an appropriate Justified Period of Safe Operation from core inspection results as set out in NP/SC 7716.

At present, Hunterston B Reactor 3 is shut down after graphite core inspections in the 2018 inspection outage observed a greater level of graphite brick cracking than was predicted prior to the outage. During this shutdown period a further programme of inspections has been carried out.

This new safety case justifies return to service of Hunterston B Reactor 3 for an operating period of approximately 6 months (to a core burn-up of 16.425 TWd). The graphite core will then be subject to further inspections. An updated safety case will be required for operation beyond this 6 month period.

The safety case covers all nuclear safety issues associated with the graphite core in normal operation, faults and hazards. For shutdown and holddown the safety case demonstrates that all control rods will enter the core with high confidence (based on appropriate margins) for all plant based faults and for the seismic hazard.

One of the key updates to the damage tolerance assessments introduced by this proposal is a revised seismic input motion at the boundary between the core and its supporting structure (the core boundary seismic motion). The core support structure is in turn supported by the Pre-stressed Concrete Pressure Vessel (PCPV). The core boundary seismic motion is less severe, but considered more representative, than that previously used in NP/SC 7716.

The core boundary seismic motion used for previous assessments was based on a seismic analysis performed in 1995 in support of the first Periodic Safety Review (and known as the 'legacy model'). NGL has identified unrealistic constraints in this legacy model and now considers that these cause unrealistic and excessive seismic motion in the PCPV computer model. This safety case describes a new analysis model of the PCPV, intended for use at both Hunterston B and Hinkley Point B Stations, which has been developed to update the core boundary input motion for the graphite core assessments.

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 PCPV. The safety case also provides a justification that holddown of a distorted core can be achieved using a diverse nitrogen injection system that has been seismically qualified.

I have assessed the claims and supporting arguments with civil engineering content and sampled the supporting evidence. My assessment has focused on the revised modelling of the PCPV and is based on my assessment of similar modelling carried out in support of the Hunterston B Reactor 4 return to service safety case (NP/SC 7785) and for the safety case to increase the graphite core operating allowance for the Hinkley Point B reactors (NP/SC/7792). During those assessments I raised a number of recommendations, which have since been adequately addressed.

I found that overall I was satisfied with the claims, arguments and evidence presented in the safety case. My key assessment findings are summarised below.

- I consider 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. As concluded in ONR's assessment of NP/SC 7792, I consider the modelling to be adequate and equally applicable to the Hunterston B reactors. I further consider that the claims on the PCPV modelling in the current safety case have been adequately substantiated.

- Previous assessments have noted that the graphite core modelling has been based on best estimate properties for the PCPV model despite sensitivity studies demonstrating that the upper bound properties resulted in more onerous core distortion during a seismic event. The current safety case has now utilised a core boundary seismic motion derived using upper bound PCPV properties, which I consider appropriate and meets with my expectations.

- I consider the claims on the civil engineering structures comprising the diverse holddown (nitrogen) system have been adequately substantiated.

To conclude, from a civil engineering perspective I am satisfied with the claims, arguments and evidence laid down within the Licensee's safety case. Overall, I judge the proposal adequate to justify the issue of a Licence Instrument to signify ONR's Agreement under arrangements made under Licence Condition 22 (1) and have recommended that ONR issue such an Agreement.

Based on my findings, overall I judge that the licensee's submission should be rated as Green with respect to the ONR Assessment Rating Guide.

LIST OF ABBREVIATIONS

ABSC	ABS Consulting Ltd
ACI	American Concrete Institute
ACR	Articulated Control Rod
AGR	Advanced Gas Cooled Reactor
ALARP	As Low As is Reasonably Practicable
ASCE	American Society of Civil Engineers
BE	Best Estimate
BS	British Standard
CEDTL	Currently Established Damage Tolerance Level
CM	Content Manager
DTA	Damage Tolerance Assessment(s)
EC	Engineering Change
EDF	Electricite de France
GCORE	Graphite Core (finite element program) – see Glossary
HOW2	(ONR) Business Management System
HNB	Hunterston B Power Station
HPB	Hinkley Point B Power Station
Hz	Hertz
LB	Lower Bound
NGL	EDF Energy Nuclear Generation Ltd
OA	Operational Allowance
ONR	Office for Nuclear Regulation
PCPV	Pre-stressed Concrete Pressure Vessel
PML	Principia Mechanica Limited
PSD	Primary shutdown system
PSR1	The first Periodic Safety Review
R3/R4	Reactor 3/Reactor 4
RGP	Relevant Good Practice
RSI	Rock Structure Interaction
SACR	Super Articulated Control Rod(s)
SAP	Safety Assessment Principle(s) (ONR)
SSC	Structures, Systems and Components
TAG	Technical Assessment Guide(s) (ONR)
TWd	Terawatt days
UB	Upper Bound
UHS	Uniform Hazard Spectrum/Spectra

GLOSSARY

Term	Definition
CEDTL	Currently Established Damage Tolerance Level: 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.
DCB	Doubly axially Cracked Brick (i.e. a brick containing exactly two full height, full thickness axial cracks).
GCORE	A computer program used to generate ABAQUS finite element models of the graphite core for displacement and loading analysis for the seismic hazard.
Keyway Root Cracking	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.
LEWIS	Control rod entry margin is calculated by LEWIS and reported as the variable m3dsf (the maximum distortion scale factor on the given channel shape which just satisfies the geometrical no-overlap constraints between the assembly and the channel shape).
PML spectrum/input motion	A piecewise linear spectrum anchored at 0.14g. It is a generic UK wide design spectrum that does not contain any site-specific characterisation other than the general ground classification as “rock”. It was developed by Principia Mechanica Limited (PML) and was chosen as the 10^{-4} per annum seismic hazard spectrum for assessments carried out in support of PSR1.
SRL	Specified Rod Length – a method of assessing the level of distortion of an interstitial channel profile by identification of the minimum distance between an imaginary sensor rod and the interstitial channel’s instantaneous profile. This is used to identify channel profiles that would challenge the entry of 6-section control (sensor) rods into the core.
UHS	Uniform Hazard response Spectrum/Spectra - Response spectra derived so that the annual probability of exceeding the spectral quantity (acceleration, displacement, etc.) is the same for any spectral frequency.
3BL	3 Brick Length – a method of assessing the level of distortion of an interstitial channel profile by identification of the minimum distance between an imaginary control rod three brick lengths long and the interstitial channel’s instantaneous profile. This is used to identify channel profiles that would challenge the entry of 8-section control rods into the core.

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1 INTRODUCTION

1.1 Background

1. As the reactor has aged, cracks have begun to form in the graphite moderator bricks that make up the reactor core. Since the control rods are deployed down vertical channels within these stacked bricks, their insertion could be prevented if the cracking leads to excessive displacement of the bricks during an earthquake. Because of this cracking, the operational safety case for the core depends on repeated inspections and assessments of the graphite bricks.

2. This report presents the findings of my civil engineering assessment of the proposal entitled “An Operational Safety Case for Hunterston B R3 to a Core Burn-Up of 16.425TWd following the 2018 Graphite Core Inspection Outage” (hereinafter the safety case), as presented in Ref. 6 and supporting documentation provided by EDF Energy Nuclear Generation Ltd (NGL).

3. NGL has requested (Ref. 7) that the Office for Nuclear Regulation (ONR) provide Agreement of the proposal in accordance with the Licensee’s arrangements made under Licence Condition 22 (1). ONR has decided to assess the proposal and, subject to a satisfactory assessment outcome, to issue an Agreement via a Licence Instrument.

4. I undertook the assessment in accordance with the requirements of the ONR HOW2 Business Management System guide NS-PER-GD-001 (Ref. 1). The ONR Safety Assessment Principles (SAPs) (Ref. 2), together with supporting Technical Assessment Guides (TAGs) (Ref. 3), have been used as the basis for this assessment.

1.2 Scope

5. The scope of this report covers only the civil engineering aspects of the safety case. This consists of two main areas:

   - The revised seismic modelling for the Pre-stressed Concrete Pressure Vessels (PCPVs).
   - The nitrogen injection system (providing diverse holddown)

6. The seismic modelling has been carried out for the Hunsterston B (HNB) and Hinkley Point B (HPB) PCPVs and a single model produced that covers both stations. My assessment considers the adequacy of the seismic modelling for the PCPV structure, which provides seismic accelerations for subsequent use in the assessment of the graphite core using the GCORE finite element model (see Glossary). This assessment does not consider the derivation of the GCORE model or the adequacy of the results obtained from it, as these aspects are part of the graphite assessment.

1.3 Methodology

7. The methodology for the assessment follows HOW2 guidance on mechanics of assessment within ONR (Ref. 4).

8. Reliance has been placed, where applicable, on previous ONR assessments of the PCPV seismic modelling and the nitrogen injection plant.

9. I have rated the licensee’s submission in accordance with the ONR Assessment Rating Guide (Ref. 5).

2 ASSESSMENT STRATEGY

10. My strategy for the assessment of the safety case is set out in this section. This identifies the scope of the assessment and the standards and criteria that have been applied.

2.1 Standards and Criteria

11. The relevant standards and criteria adopted within this assessment are principally the Safety Assessment Principles (SAPs) (Ref. 2), internal ONR Technical Assessment Guides (TAGs) (Ref. 3), relevant national and international standards and relevant good practice informed from existing practices adopted on UK nuclear licensed sites. The key SAPs and any relevant TAGs are detailed within this section. National and international standards and guidance have been referenced where appropriate within the assessment report. Relevant Good Practice (RGP), where applicable, has also been cited within the body of the assessment.

2.2 Safety Assessment Principles

12. The key SAPs applied within the assessment are included within Table 1 of this report.

2.2.1 Technical Assessment Guides

13. The following TAGs have been used as part of this assessment (Ref. 3):

- NS-TAST-GD-005 Guidance on the Demonstration of ALARP
- NS-TAST-GD-013 External Hazards
- NS-TAST-GD-017 Civil Engineering
- NS-TAST-GD-051 The purpose, scope and content of Nuclear Safety Cases

2.2.2 National and International Standards and Guidance

14. The following principal standards and guidance have been used as part of this assessment (Refs 8 and 9):

- ASCE 4-16 – Seismic Analysis of Safety-Related Nuclear Structures, American Society of Civil Engineers (ASCE)
- ACI 349-13, Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary, American Concrete Institute (ACI)

2.3 Use of Technical Support Contractors

15. ABS Consulting (ABSC) has provided independent advice to ONR on the suitability of the updated PCPV model to provide adequately robust seismic input for use in the assessment of the graphite core. ABSC has produced a report (Ref. 10) which has been used in support of the assessment described in Sections 4.2 and 4.3 of this report. It should be noted that ABSC did not review the final version of the PCPV modelling report (Ref. 11) as referenced in the safety case, but an earlier version (Ref. 12). The differences between these versions of the modelling report are considered in Section 4.3.1.

2.4 Integration with Other Assessment Topics

16. This assessment is part of a suite of similar assessments being carried out by other ONR specialist inspectors who cover other technical disciplines and components and which will inform the Project Assessment Report. The civil engineering assessment

has been carried out in support of the graphite assessment, as described in Section 1.2.

2.5 Out of Scope Items

17. The seismic modelling of the Reactor Building remains unchanged from the previous Reactor Building safety case and is not reassessed. ONR has accepted (Ref. 20) the adequacy of a review undertaken by the Licensee into the effects on other SSCs (including the Reactor Building) of modelling the PCPV as an isolated structure. An area of further work concerning increased loading on the Charge Machine Gantry support structure was identified by the review and ONR is tracking progress in resolving this matter using Regulatory Issue 7503. This further work does not affect the safety cases for the graphite cores and hence is out of scope for this assessment.

18. The adequacy of the GCORE model and the assessment of the effects of the revised seismic motions on the GCORE model are considered out of scope for this report and are addressed in the graphite assessment report.

19. This assessment does not consider any changes to the characterisation of the seismic input motion, which remains the same as that used in the previous safety case. Although the revised modelling report includes examples of the effect of using Uniform Hazard Spectra (UHS) as seismic input motion, this is not claimed in the safety case and has not been formally assessed.

3 LICENSEE'S SAFETY CASE

3.1 Background

20. The graphite core supports the control of the nuclear fission process, by providing neutron moderation and thermal inertia. The graphite core must also maintain sufficient structural integrity to ensure that:

- The core geometry remains acceptable for the insertion of control rods and the movement of fuel.
- Fuel and core temperatures are maintained by normal gas flow patterns.

21. The graphite is subject to in-service degradation caused by neutron irradiation and radiolytic oxidation. This results in graphite weight loss, shrinkage and component strength reductions. Consequently, the graphite bricks are subject to dimensional change and a risk of cracking driven by shrinkage-induced stress.

22. Bricks forming the fuel channels (fuel bricks) and particularly those located in the central region of the core, are the most irradiated, and hence at highest risk of cracking. The bricks are connected by radial keys, which engage with keyway slots in adjacent bricks. Keyway Root Cracking (KWRC) (see Glossary) was first observed in the main population of graphite moderator fuel bricks at HNB Reactor 3 (R3) in October 2015, with the first doubly axially cracked brick (DCB) observed at HNB R3 in 2018. Brick cracking is a phenomenon which had been predicted to occur, and the safety case demonstrates that the graphite core can still perform its nuclear safety duties when accounting for conservatively predicted crack numbers and crack widths.

23. At present HNB R3 is shutdown after its planned graphite core inspections in the 2018 outage observed levels of cracking that were greater than expected. The extent of cracking, which has been further established by additional inspections performed during the outage, necessitates an updated safety case for further operation.

24. A safety case (Ref. 6) is presented to justify the return to service of HNB R3 for an operating period of approximately 6 months (to a core burn-up of 16.425 TWd). The graphite core will then be subject to further inspections. An updated safety case will then be required for operation beyond 6 months.

25. The justification in this proposal demonstrates that (i) the current state of the core is sufficiently understood based on the inspections that have been carried out, and (ii) that there is sufficient understanding of graphite degradation to make a conservative prediction of the whole core state at the end of the proposed operating period accounting for possible in-event cracking during a seismic event. It is then confirmed that safety margins are acceptable throughout the proposed period of operation, even in the event that core degradation occurs more quickly than predicted.

26. This safety case covers all nuclear safety issues associated with the graphite core in normal operation, faults and hazards. For shutdown and holddown, this safety case demonstrates that all control rods will enter the core with high confidence (based on appropriate margins) for all plant based faults and for the seismic hazard.

27. The updated case does not propose or justify any immediate physical modifications to the plant, or changes in the way in which it is operated. Modifications to improve the reliability of the nitrogen injection system and to improve future core inspections are proposed for further development, but are not considered to be required before return to service of R3.

3.2 Nuclear safety issues

28. The nuclear safety functions of the graphite core, in normal and fault conditions, are to:

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

29. Damage to core components, for example, cracking of moderator fuel bricks, can affect the geometric response of the graphite core during normal operation, faults and seismic events, and can affect the calculated margins for control rod entry, thus affecting the first of the graphite core fundamental nuclear safety requirements.

3.3 Claims, arguments and evidence

30. The safety case is presented based on five claims. Each of the claims has a series of arguments and pieces of evidence that support the claim and provide a safety justification for the proposals. The claims are:

- Claim 1: The effects of graphite core degradation on nuclear safety can be predicted with a suitable level of confidence (assessment methods).
- Claim 2: Following graphite core degradation over the proposed operating period, control rod entry, fuel handling and fuel cooling are robust against core distortion and debris under normal operation and non-seismic faults (application of the assessment methods)
- Claim 3: Graphite core degradation over the proposed operating period will not undermine the required reliability of the primary shutdown system (PSD) for shutdown and holddown under seismic faults
- Claim 4: The combination of super articulated control rods (SACR) and nitrogen is functionally capable of providing shutdown and holddown of a very distorted core
- Claim 5: This proposal is consistent with the ALARP principle

3.3.1 Claim 1

31. Claim 1 is primarily concerned with the assessment of graphite core condition and is supported by eleven arguments. The most relevant arguments to the civil engineering assessment, based on its importance in generating the input motion for the GCORE analysis are:

- Argument 1.5: Valid methods are available for adequately determining control rod channel distortion in a seismic event
- Argument 1.11: Sensitivities to modelling assumptions are accounted for in the methods deployed

32. The evidence presented in support of Argument 1.5 relates to the use of the GCORE software. GCORE comprises a number of toolsets which are used to create, solve and post-process finite element models which computationally predict the response of the reactor core to seismic excitation. GCORE intends to establish the channel distortions as they would be expected for a given seismic input motion (i.e. the most likely response). To predict the expected response, input parameters are generally set on a best estimate (BE) basis, but with uncertainties addressed conservatively. The exception to this is the PCPV model, which provides the seismic input motion to GCORE. This model uses upper bound (UB) soil, PCPV support bearing pad and soil back-fill properties.

33. A number of sensitivity studies using variants of the PCPV model have been performed to identify the most onerous combination of properties for graphite core distortion. It was found that assuming UB properties for all these parameters was the most conservative. The predicted distortions from GCORE are used as an input for the LEWIS method (see Glossary) to assess control rod and fuel channel functionality.

34. Argument 1.11 cites two pieces of evidence, one of which is related to the forward prediction of core state and hence out of scope of this assessment. Evidence 1.11.2 concerns sensitivities in the damage tolerance assessments (DTA) of the core. For the seismic DTA the results have been shown to be sensitive to the input motion applied to the PCPV. The seismic DTA will consider the possible effects of a beyond design basis event to demonstrate resilience against cliff edges. For each of the supporting DTAs there are suitable sensitivity studies.

3.3.2 Claim 2

35. This claim is concerned with normal operation and non-seismic faults and does not rely on the updated modelling of the PCPV, which was carried out to address seismic faults only. This claim and its supporting arguments and evidence are therefore not relevant to this assessment.

3.3.3 Claim 3

36. This claim is supported by five arguments, the most relevant to the civil engineering assessment being:

- Argument 3.2: The response of the graphite core to seismic excitation has been predicted with confidence
- Argument 3.3: All control rods will enter the core under bottom-line seismic faults

37. From the civil engineering perspective, the primary evidence supporting Argument 3.2 is Evidence 3.2.1, which describes a number of improvements to the PCPV seismic modelling. The GCORE modelling itself is out of scope as noted in Section 2.5.

38. Acceleration time histories for subsequent use in GCORE are extracted at the core boundary, which is taken to be the base of the boiler shield wall (Ref. 11), approximately 2.1m above the bottom of the PCPV cavity. The input motion is taken from seismic modelling of the PCPV with simplified representation of the graphite core and reactor internals. Previous GCORE models have applied the same seismic acceleration uniformly to the whole of the GCORE boundary. The current GCORE modelling (Ref. 14) applies input motion to a single point located at the base of the Boiler Shield Wall, in the plan centre of the core, and which includes rocking motions applied to the core boundary in addition to the horizontal motion considered in the previous HNB safety case (Ref. 21).

39. The core boundary input motion used for previous GCORE assessments (for R3), including those supporting NP/SC 7716 (Ref. 15), was based upon the PCPV response calculated by the ‘legacy’ Reactor Buildings seismic assessment (Ref. 23) that was performed in the 1990’s to support the first Periodic Safety Review (PSR1). Unrealistic constraints have been identified in the legacy model and these have been found to cause excessive PCPV motion. A new (‘final’) finite element model of the PCPV has therefore been developed (Ref. 11) to update the core boundary input motion for the GCORE assessments. In addition to removing the unrealistic constraint (interaction of the PCPV with the reactor building), the new model incorporates improvements to methodology and to the definition of the structure (PCPV bearings, and PCPV embedment in engineered backfill).

40. The current motion applied to the reactor core is a single unidirectional synthetic time history developed from the 0.14g hard-site Principia Mechanica Ltd (PML) design response spectra (see Glossary) , including the effects of PCPV rocking. The ground motion is considered synthetic, as it is not derived from the records of real earthquakes. The 0.14g PML synthetic time history is judged to provide a conservative and bounding surrogate for a site specific HNB hazard with a 10^{-4} probability of being exceeded in any one-year period (e.g. as would be developed by a Uniform Hazard Spectrum).

41. The core boundary time history produced for the final PCPV model, using upper bound parameters, is reduced in severity from the corresponding time history used in previous legacy assessments. This is mainly attributed to the legacy model including connections between the top of the PCPV and the reactor building, which unrealistically ties the structures together. The new model effectively considers the PCPV as being isolated from the reactor building, with its excitation (as would be expected) driven from its base. The inclusion of the improved representation of the PCPV foundation embedment is also contributory to the reduced core boundary motion that is calculated.

42. Evidence 3.2.2 relates to the GCORE assessments of channel distortions for a range of prescribed distributions and configurations of cracked bricks. The current GCORE assessments are reported in (Ref. 14) and summarised below.

- At the currently established damage tolerance level (CEDTL) the minimum margin of 1.06 (Distortion Utilisation of 0.94) is calculated against full insertion of a control rod (across all interstitial columns and for all times during the seismic event) using the conservative LEWIS method. This minimum margin occurs for a sensor rod during a very short extent of the seismic motion. At the CEDTL the minimum margin across the 10 core states assessed ranges from 1.06 to 1.80.
- At the CEDTL the minimum margin for articulated control rods (ACRs) and SACR is 1.36 and 2.51 respectively.
- Within each assessment run, there is a large spread of control rod entry margins, demonstrating a lack of cliff edge behaviour.
- Even with the substantially increased levels of cracking or connection failure, the margins upon control rod entry from the current assessment are better than those presented in NP/SC 7716 (Ref. 15). This is attributed to the reduction in core boundary motion provided in the final PCPV seismic model, even when using the upper bound PCPV motion.

43. With respect to Argument 3.3, the following criteria are established:

- 1) The current GCORE assessments are performed using :
  - Core cracking states which bound the bounding estimate of core cracking
  - Clearances and component strengths that are predicted at 17 TWd, which is later than the Justified Period of Safe Operation to 16.425 TWd
  - Upper Bound PCPV properties (including rocking) with adequate demonstration of control rod entry at the CEDTL.

- 2) Although based upon the conservative 0.14g PML hard site ground motion, the currently used core boundary motion does not comply with current codes and standards (since only a single synthetic time history is used). Studies in (Ref. 11) indicate that the time histories using real seismic data will however remain similar to that used.

- 3) There is adequate confidence in the GCORE modelling predictions for the core states and input motions assessed.
- 4) Control rod insertion is assessed against a conservative basis, returning adequate margins
- 5) Assessments confirm that the graphite core would be resilient to the more severe core boundary motion against best estimate PCPV assumptions.

44. On balance across each of the criteria above, the Licensee considers there to be a robust demonstration that the graphite core will not impede control rod entry even assuming the most onerous combination of building properties (UB properties in the PCPV model). Any weakness in complying with Criterion 2 is more than offset by the strength in meeting criteria 3, 4 and 5.

3.3.4 Claim 4

45. Claim 4 is supported by four arguments, only two of which are relevant to the civil engineering assessment:

- Argument 4.3: The seismically qualified nitrogen system will provide adequate holddown (long term)
- Argument 4.4: The protection is resilient to more severe levels of earthquake

46. For Argument 4.3, evidence is presented (Ref. 17 and 18) that the design and construction of the civil structures and foundations comprising the nitrogen system have been underwritten by seismic analysis in accordance with established codes and standards. Compared to the assessment of existing plant, the strategy chosen for the design of the nitrogen plant was more akin to that used for building a new power station, with the response of the foundation slab and mounted equipment being assessed on a pessimistic basis.

47. With respect to Argument 4.4, it is stated that Claim 3 has established the margins for control rod entry for the bottom-line seismic event, for a level of core damage which significantly exceeds the likely core state at the end of the operating period. The margins for control rod entry are all greater than 1 when assessing every interstitial channel, at every time step in the seismic event, and for all heights. These margins give confidence that there is resilience to a more severe level of earthquake.

48. It has also been identified that results from seismic assessment using the legacy core boundary motion demonstrate resilience to significantly more onerous seismic loading than the bottom-line seismic event.

49. It has been judged that there should be no cliff edge in buildings or plant response (for the nitrogen systems) such that there is a disproportionate increase in risk consequences just beyond the seismic hazard level used in the safety case.

3.3.5 Claim 5

50. Claim 5 is an overall claim that the proposal is consistent with the ALARP principle. The evidence presented focuses on physical modifications, operational changes or plant inspections to reduce risk or improve understanding of risk. Additional analysis and testing work (or similar) which could be carried out in support of Claims 1 – 4 is not considered in detail in this claim. The evidence presented is not therefore directly related to the civil engineering assessment.

51. Although not part of the formal evidence in support of Claim 5, ongoing work is identified to improve the understanding of graphite ageing mechanisms and to provide greater confidence in assessment techniques used to demonstrate tolerability to graphite ageing. This work includes improved seismic modelling by using real-record

seismic data (5 time histories for each of the targeted spectra) in accordance with ASCE 4-16 (Ref. 8).

3.4 Licensee's Commitments

52. The safety case has identified two commitments, but these are not within the scope of the civil engineering assessment.

3.5 Licensee's Conclusion

53. This proposal justifies the return to service of R3 from its 2018 graphite core inspection campaign, and continued operation for approximately 6 months, to a core burn-up of 16.425 TWd.

54. The safety case presents conservative predictions of the extent of cracking that may be present on return to service and following the proposed 6 months (approximately) of operation, including sensitivity studies to address the key uncertainties. Damage tolerance assessments confirm that the core can still adequately perform its nuclear safety duties for much greater levels of core damage. The Licensee considers that this margin provides very high confidence that the core state will remain within the assessed levels of damage, even if behaviour is outside expectations.

55. The damage tolerance assessments show appropriate margins for the key parameters for normal operation, fault loadings and the seismic hazard. Hence there is high confidence that all control rods will successfully enter the core in all credible faults and hazards, and that degradation of the core will not cause issues for fuel handling or fuel integrity.

56. There is further margin and no cliff-edge in reactivity control for larger core distortions due to the provision of control rods with additional articulation which can secure immediate shutdown and the seismically qualified enhanced nitrogen injection system which is functionally capable of securing long term holddown.

57. Overall, the Licensee considers that this proposal demonstrates that the nuclear safety risks associated with the graphite core for the proposed period of operation are acceptably low and ALARP.

4 ONR ASSESSMENT

58. My assessment has been carried out in accordance with HOW2 guide NS-PER-GD-001, “Purpose and Scope of Permissioning” (Ref. 1). In accordance with its arrangements, the Licensee has deemed the safety case a Category 1 submission. Based on the identified nuclear safety risks if inadequately conceived or executed, and the absence of a change in nuclear safety principles, I agree with its categorisation.

59. In my assessment, I refer to the claims, arguments and evidence provided by NGL, and I make my own judgement on how the claims have been substantiated within the safety case and the supporting documentation.

4.1 Scope of Assessment Undertaken

60. The general scope of my assessment is described in Section 1.2. The new PCPV modelling is common to both HNB and HPB (based on bounding soil properties) and has been used to support previous safety cases. My assessment is based on the following previous ONR assessments:

- ONR Assessment Report - Hunterston B - Return to service safety case for Reactor 4 following core inspection results in 2018 - NP/SC 7785 – Civil engineering assessment (Ref. 19)
- ONR Assessment Report - Hinkley Point B - 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 (Ref. 20)

61. The purpose of the revised PCPV seismic modelling has been described in Section 3.3.3. The model is used to derive a seismic input motion that can be used in the GCORE analysis to determine the effects of seismic events on the reactor core. The modelling is described in detail in Ref. 11.

62. The legacy PCPV model (Ref. 23) was based on the use of BE properties; however in the revised model the Licensee has studied the effects of variation in Rock Structure Interaction (RSI), backfill and bearing properties to create lower bound (LB) and upper bound (UB) model variants. For the LB and UB cases all of the RSI, backfill and bearing properties are combined at their lower bound or upper bound levels respectively.

63. The PCPV model has been developed in stages. ONR’s assessment (Ref. 19) of the HNB return to service safety case for Reactor 4 (Ref. 21) contained a detailed assessment of a preliminary version of the PCPV model (Ref. 13). This preliminary model, whilst having undergone verification within NGL, had not been amended to reflect external peer review comments. An updated ‘final’ PCPV model (Ref. 12) was used in support of the recent HPB graphite safety case (Ref. 22) and ONR’s assessment (Ref. 20) of this case gave detailed consideration to the changes made to the modelling between preliminary and final versions. The present safety case for HNB R3 (Ref. 6) is based on an updated modelling report (Ref. 11) revised to address a number of ONR comments. I consider that all ONR’s previous recommendations and comments have been adequately addressed.

64. This assessment will make use of the work done in previous ONR assessments. The approach to modelling of the PCPV has not changed since that assessed in Ref. 20 and will not be re-visited in this report. This report will consider the extent to which the safety case claims can be substantiated by the evidence provided.

65. Due to the legacy model (Ref. 23) including a connection between the PCPV and the Reactor Building Central Block, the revised finite element model is often referred to as the “buildings model” in the safety case and supporting documentation. In this report,

the model will be consistently referred to as the PCPV model as that is a more accurate description. In ONR's assessment of Ref. 19, it was accepted that modelling the PCPV as isolated from the Reactor Building was acceptable

66. The PCPV modelling report (Ref. 11) includes consideration of potential changes to the legacy ground motion defined in the extant safety case. Changes to the ground motion are proposed for a future long-term seismic safety case for the HNB and HPB PCPVs (as described under 'ongoing work' in the safety case) but these changes are not claimed in the safety case and are considered out of scope for this report (see Section 2.5).

67. My focus in this assessment has been on those aspects of Claims 1, 3 and 4 that I consider relevant to the civil engineering aspects sampled. Claims 1 and 3 relate to the updated PCPV seismic modelling. Claim 4 relates to the nitrogen injection system, for which I will make reference to previous ONR assessments (Ref. 24 and 25). Claims 2 and 5 are not directly relevant to my assessment and have not been assessed. I consider that other ONR assessors will adequately cover the evidence presented in support of the other claims.

68. The structure and content of the safety case has been assessed against ONR's safety case TAG (NS-TAST-GD-051, Ref.3).

4.2 Assessment of Claim 1

69. Claim 1 states that: "The effects of graphite core degradation on nuclear safety can be predicted with a suitable level of confidence."

70. The licensee presents eleven arguments in support of Claim 1. The arguments primarily relate to matters within the scope of ONR's graphite core assessment, but two of the arguments (1.5 and 1.11) concern interface issues between the GCORE analysis and PCPV modelling, hence I have chosen to sample them

4.2.1 Assessment of Argument 1.5: Valid methods are available for adequately determining control rod channel distortion in a seismic event; and Argument 1.11: Sensitivities to modelling assumptions are accounted for in the methods deployed.

71. These arguments are supported by a new sensitivity study into channel distortion (Ref. 26) that had not been formally reported at the time of ONR's assessment of the recent HPB graphite safety case (Ref. 22). Whilst this document relates to GCORE analysis, it does provide confirmation that a sensitivity study has been undertaken into the use of a wider range of PCPV model variants within GCORE. Previous safety cases have relied on the use of BE PCPV properties to support the GCORE work, despite analysis indicating that UB PCPV properties were the most onerous for predicted core distortion.

72. My assessment has been based on SAPs ECE.13 (use of data) and ECE.14 (sensitivity studies).

73. The sensitivity study has considered a CEDTL core state (i.e. at the tolerable limit of damage rather than an operating limit) with HPB graphite properties and the seismic input motion has been derived from the PCPV model using the following PCPV properties:

- Best Estimate SSI, fill and bearing properties
- Upper Bound SSI, fill and bearing properties
- Intermediate 1 - UB SSI; LB fill; UB bearing
- Intermediate 2 - UB SSI; BE fill; UB bearing

74. The rationale for the chosen intermediate PCPV properties is not stated in the report but was previously shared with ONR (Technical Queries CE1 and G1, Ref. 27). The cases chosen were those selected for further consideration from a wider study into critical combinations of PCPV properties. If each of the properties was varied in turn there would be at least 27 different sets of properties. If damping and stiffness properties within a property set were also considered as independent variables then the number of different sets of properties would again rise significantly. In order to reduce the non-linear GCORE analysis runs to a practical level, the Licensee has therefore selected two intermediate cases intended to provide a response between that found for BE and UB properties. It has been demonstrated (Ref. 11) that responses in the LB region are not critical for core distortion.

75. The Intermediate 1 case assesses the maximum stiffness / minimum damping combination close to the UB property set, whilst the Intermediate 2 case considers the second stiffest property set (the stiffest being UB). For Intermediate 1, the peak spectral response was at 2.1 Hz and for Intermediate 2 at 2.2 Hz, confirming that these cases gave an intermediate response between that for BE (1.8 Hz) and UB (2.4 Hz) properties.

76. A key measure of the effect of a seismic event on the GCORE modelling results is provided by plots of the “3BL” and “SRL” scores (see Glossary). These scores are a measure of interstitial channel distortion and are a method of assessing the minimum distance between a control rod and distorted channel (3BL) and between a sensor rod and distorted channel (SRL). The 3BL or SRL score is plotted against the percentage of channels where the score is below a particular threshold value. NGL considers that a 3BL or SRL score above unity provides an acceptable margin so that all control and sensor rods have unimpeded access throughout a seismic event.

77. The results of the HPB cumulative core distortion scores are shown in Figures 3 and 4 and show that the UB property set leads to the maximum core distortion, thus confirming previous data for the HNB R4 core (Ref. 11) that the UB property set is the most onerous for the core condition represented by the CEDTL. This meets the expectations of SAP ECE.13 that the data used should be demonstrably conservative, as the probability that the SSI, backfill and bearing properties all assume their UB values simultaneously is low.

78. I consider that although the number of sensitivity cases studied is relatively small, the chosen cases are appropriate, meet the expectations of SAP ECE.14 and have clearly identified the most onerous case as being a PCPV property set where all the parameters are set at their UB level. This UB property set has then been used to derive the seismic input motion for use in the GCORE analysis. In terms of an interface between the civil engineering and graphite core assessments, I therefore judge that the GCORE model has used valid seismic inputs, underpinned by sensitivity studies and that from a civil engineering perspective Arguments 1.5 and 1.11 are substantiated.

4.2.2 Claim 1 conclusion

79. Based on my sample of the arguments and evidence presented, I consider that from a civil engineering perspective, Claim 1 has been adequately substantiated.

4.3 Assessment of Claim 3

80. Claim 3 states that “Graphite core degradation over the proposed operating period will not undermine the required reliability of the Primary Shutdown System (PSD) for Shutdown and Holddown under seismic faults”.

81. The Licensee presents five arguments in support of Claim 3. I have carried out a high-level review of the arguments and their supporting evidence and decided to sample Arguments 3.2 and 3.3, which I consider the most relevant to the PCPV modelling. I am aware that other ONR assessors will consider the evidence presented in support of the other arguments.

4.3.1 Assessment of Argument 3.2: The response of the graphite core to seismic excitation has been predicted with confidence

82. The relevant evidence in support of this argument is Evidence 3.2.1: Updated core seismic input motion from the revised PCPV seismic modelling.

83. The evidence presented cites Revision 4 of the PCPV modelling report (Ref. 11). ONR has previously assessed Revision 2 of this report (Ref. 12) which was cited as evidence in relation to the HPB graphite safety case (Ref. 22), whilst noting the changes made between Revision 2 and Revision 4. The changes made between the two versions were assessed in Ref. 20, and were considered textual only and no changes to the modelling were carried out. As recorded in Ref. 20, based on SAPs AV.2, AV.5, ECS.3, ECE.13, ECE.14 and ECE.15, ONR was satisfied that the updated PCPV modelling was adequate and provides a suitably conservative seismic input motion for the detailed graphite core modelling using GCORE.

84. Based on the evidence presented in Figure 1, I agree with the argument that the core boundary seismic motion derived from the upper bound PCPV model, at frequencies corresponding to the peak core response (around 2.4 Hz) is less than that produced by the legacy analysis on which the previous safety case NP/SC 7716 (Ref. 15) was based. A margin therefore exists between the current seismic input motion and that used in previous safety cases.

85. I am therefore satisfied that the PCPV modelling used in support of the graphite core seismic modelling is suitably conservative and that from a civil engineering perspective Argument 3.2 is substantiated.

4.3.2 Assessment of Argument 3.3: All control rods will enter the core under bottom-line seismic faults

86. As described under Claim 1, the additional sensitivity studies into the effect of varying PCPV properties on core distortion have now been formally reported in Ref. 26. These identify that the UB property set results in the most onerous core distortion. I am satisfied that the most onerous seismic input motion is now being used to determine graphite core distortion and report margins for control rod entry.

87. The evidence in support of this argument notes that the currently used core boundary motion does not comply with current codes and standards (since only a single synthetic time history is used) and claims that studies in Ref. 11 indicate that the time histories using real seismic data will remain similar to that used.

88. In assessing this argument I have considered SAPs ECS.3 (codes and standards) and ECE.13 (validity of data). I consider that, as noted in the External Hazards TAG (Ref. 3), RGP (such as Ref. 8) is progressively moving away from the use of artificially generated records such as the synthetic PML ground motions on which the safety case is based. Their use is not precluded for linear analysis, provided the responses are consistent with those developed using modified real recorded motions. The Licensee has therefore undertaken work (Ref. 11) to compare the responses of the PCPV model using synthetic time histories developed to match the PML target response spectra against input motions derived from a range of real records. This approach is based on Ref. 8, which requires the use of a minimum of five ground motion histories for each direction of input considered (e.g. two orthogonal horizontal directions and one

vertical), with the mean response being used to derive in-structure response. The analysis carried out in Ref. 11 includes consideration of five real earthquake records matched to three different target spectra (modified PML spectra, mean HPB Uniform Hazard Spectra (UHS) and associated 84% confidence level HPB response spectra). The target spectra have been derived at the foundation level of the PCPV (or ground level for the modified PML spectra). For example, Figure 2 shows the core boundary secondary response spectra for the North-South direction for each of five earthquakes derived from real records and matched to the 84% confidence level HPB target response spectra. The secondary response spectra are presented for three different PCPV model variants, i.e. LB, BE and UB properties.

89. Comparison of Figure 1 (core boundary secondary response spectra obtained using the PML synthetic ground motion) and Figure 2 (core boundary secondary response spectra obtained using the 84% confidence level HPB target response spectrum), indicate a similar response for the critical UB case at the frequency for maximum core response (around 2.4 Hz). For Figure 1, the peak spectral acceleration is 6.8 m/s^2 compared with 6.4 m/s^2 for the most onerous set of modified real records in Figure 2. I agree that the synthetic PML ground motion gives core boundary responses that are consistent with those derived based on modified real recorded motions and is adequate for use in the essentially linear analysis of the PCPV model in the frequency range of interest to core response and hence is fit for purpose. The GCORE modelling, which uses seismic input from the PCPV model, is non-linear and for this work, the synthetic PML ground motions are inconsistent with the requirements of RGP. I therefore agree with the Licensee that there are weaknesses in this leg of the evidence (called Criterion 2 in the safety case, see Section 3.3.3).

90. The Licensee claims that any weakness in Criterion 2 is more than offset by strengths in Criteria 3, 4 and 5. These further criteria concern the confidence in the GCORE modelling predictions (Criteria 3), the conservatism in the control rod insertion assessment (Criteria 4) and the resilience of the core to beyond design basis seismic events (Criteria 5). Within the scope of this report, I agree that overall the seismic input motion to the core is suitably conservative as it is based on the PML spectrum (conservative at frequencies important to core response) and utilises a set of PCPV properties which are all combined to provide the most onerous seismic input for core distortion and damage. I therefore agree with the Licensee that any weakness in Criterion 2 is adequately offset by conservatism elsewhere and that the balance of uncertainty against conservatism meets the expectations of SAP SC.5. I also note that the Licensee has identified a programme of ongoing work to revise the input ground motions for the damage tolerance assessments to align with RGP, which should address this weakness in future cases.

91. Based on the use of the critical UB PCPV seismic input (as demonstrated by studies reported in Ref. 26), the safety case has provided evidence of core distortion margins greater than one for a core at the CEDTL (see Figures 3 and 4). From a civil engineering perspective I consider that this argument has been adequately substantiated.

4.3.3 Claim 3 conclusion

92. Based on my sample of the arguments and evidence presented, I consider that from a civil engineering perspective, Claim 3 has been adequately substantiated

4.4 Assessment of Claim 4

93. Claim 4 states that: “The combination of super articulated control rods (SACR) and nitrogen is functionally capable of providing shutdown and holddown of a very distorted core.”

94. Claim 4 is supported by four arguments, only two of which (Arguments 4.3 and 4.4) I consider relevant to the civil engineering assessment:

4.4.1 Assessment of Argument 4.3: The seismically qualified nitrogen system will provide adequate holddown (long term)

95. In my assessment I have focused on the claim that the design and construction of new civil structures and foundations for the nitrogen system has been underwritten by seismic analysis in accordance with established codes and standards. The main evidence for this claim is cited as NP/SC 7557 Stage Submission 3A (Ref. 17).

96. The evidence in support of this claim has previously been assessed by ONR (Ref. 24) in 2015. This assessment covered the following items:

- The reinforced concrete equipment raft comprising foundations and plinth supports for the nitrogen storage tanks, associated pumps, vaporisers and pipe work, and the Local Control Room.
- The civil design of trenches linking the proposed plant to the existing ring main, and housing.

97. The relevant claim on the civil structures was: “The proposed civil design will provide a raft with integrity which is adequate to support the plant, and to underwrite plant functionality during and after all relevant hazards.” The ONR assessment noted that “the designs have been prepared in accordance with all relevant civil engineering design codes”, and concluded ”I am able to judge that the safety case claims made for the civil engineering components of the proposed works are demonstrated.” I have no reason to question the judgements made in the previous assessment, but given the passage of time I have reviewed any more recent changes in applicable design codes in Section 4.5. This review did not identify any issues with the design substantiation.

98. I am satisfied that the evidence sampled has been previously assessed by ONR and judge that from a civil engineering perspective this argument has been adequately substantiated.

4.4.2 Argument 4.4: The protection is resilient to more severe levels of earthquake

99. This argument is concerned with the resilience of the primary shutdown and holddown systems against beyond design basis earthquakes. My assessment has considered SAPs EHA.7 and EHA.18.

100. The case acknowledges that there is not currently any explicit analysis of a more severe seismic ground motion (e.g. exceedance probability of 10^{-5} per annum). Instead alternative arguments are advanced to demonstrate resilience for earthquakes greater than the design basis earthquake, which is based on an exceedance probability of 10^{-4} per annum.

101. With respect to cliff edge effects within the PCPV modelling, ONR’s assessment (Ref. 20) concluded that “I am satisfied that there is an absence of cliff edge effects in the PCPV modelling and that the modelling meets the intent of SAP EHA.7.”

102. For a beyond design basis assessment, best estimate properties can be considered (SAP FA.15). The safety case has shown (see Figure 1), that there is a significant margin in terms of seismic input to the core between using BE and UB properties for the PCPV modelling, which provides a measure of confidence that the core will be resilient to greater levels of earthquake than the design basis earthquake.

103. The safety case also claims that results from GCORE seismic assessment using the legacy core boundary motion demonstrate resilience to significantly more onerous

seismic loading than the bottom-line (10^{-4} per annum) seismic event. I agree with the Licensee's claim that the legacy core boundary motion (as used for NP/SC 7716 assessments, based upon 0.14g PML ground motion) is more severe than the revised core boundary motion which has been developed from the updated PCPV modelling using the 0.14g PML ground motion (see Figure 1). At 2.4 Hz, which is an indicative linear frequency of the core response, the legacy spectral acceleration is around a peak of 10.5 m/s^2. By comparison, the acceleration is around 2 m/s^2 for the revised best estimate model and 6.8 m/s^2 for the UB model. Although the adequacy of the GCORE results is a matter for the graphite assessment, I judge that the use of the legacy core boundary motion to demonstrate resilience to a beyond design basis earthquake is an acceptable approach.

104. With respect to the diverse holddown system (nitrogen plant), a previous ONR assessment (Ref. 25) concluded "I judge that acceptable margins against beyond design basis seismic events have been adequately demonstrated". I do not consider it necessary to re-visit the previous ONR assessment.

105. Based on the evidence sampled, I consider that adequate consideration has been given to beyond design basis earthquakes and cliff edge effects and that this argument has been adequately substantiated.

4.4.3 Claim 4 conclusion

106. Based on my sample of the arguments and evidence presented, I consider that from a civil engineering perspective, Claim 4 has been adequately substantiated

4.5 Comparison with Standards, Guidance and Relevant Good Practice

107. In carrying out my assessment, I have considered the guidance in SAP ECS.3. Although this is an existing plant not designed to modern standards, the guidance in the ALARP TAG (Ref.3, Section 6.2) is that for an existing facility relevant good practice is established by using the standards that would be applied to a new design as a benchmark and subjecting any shortfalls to an ALARP test.

108. Compliance of the PCPV modelling work with standards, guidance and relevant good practice was considered in detail by ONR in Refs. 19 and 20. Based on the current evidence presented in the safety case, I have no reason to disagree with ONR's previous conclusion that the modelling was broadly compliant with the requirements of SAP ECS.3.

109. As noted in Section 4.4.1, ONR has previously concluded that the civil engineering design of the diverse holddown system meets the requirements of RGP. I note that the design was based on ACI 349-06, which has now been superseded by ACI 349-13 (Ref. 9). I judge that for this type of structure the change in code edition will have no material effect on the design and I have no reason to disagree with the previous ONR conclusion.

4.6 ONR Assessment Rating

110. In accordance with ONR's guidance (Ref. 4), the safety case has been rated based on the original submission without taking into account regulatory interventions undertaken by ONR.

111. I consider that the technical quality and detail in the safety case are adequate and in general accordance with the requirements of ONR SAPs and TAGs. The safety case was based on complex methods of assessment which were adequately underpinned and I consider it to have addressed the most significant risks arising from the seismic hazard.

112. Based on my findings, overall I judge that the licensee’s submission should be rated as Green with respect to the ONR Assessment Rating Guide (Ref. 5).

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

113. This report presents the findings of the ONR Civil Engineering Assessment of the proposal entitled "An Operational Safety Case for Hunterston B R3 to a Core Burn-Up of 16.425TWd following the 2018 Graphite Core Inspection Outage" (Ref. 6) and supporting documentation provided by the Licensee.

114. The intent of the proposal is to provide a justification for the return to service of HNB R3 for an operating period of approximately 6 months, following which the graphite core will be subject to further inspections. An updated safety case will then be required for operation beyond 6 months.

115. The safety case is structured around five claims. I have assessed the claims and supporting arguments with civil engineering content and sampled the supporting evidence. My assessment focused on the revised modelling of the PCPV, which provides seismic input into the graphite core modelling and hence is important to the demonstration of adequate core margins during a design basis seismic event. I also considered the claims on the civil engineering structures associated with the diverse holddown system.

116. In forming my judgement as to the adequacy of the Licensee's claims, arguments and evidence I have drawn on a number of previous ONR assessments. These previous assessments primarily related to the PCPV seismic modelling undertaken in support of other graphite core safety cases for Hunterston B and Hinkley Point B. I have also made reference to previous ONR assessments in relation to the diverse holddown system. The PCPV seismic modelling has been carried out so that it is equally applicable to the reactors at Hunterston B and Hinkley Point B.

117. I consider 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.

118. I therefore conclude that the PCPV modelling is adequate and that the claims made on the modelling in the current safety case have been adequately substantiated.

119. Previous assessments have noted that the graphite core modelling has been based on best estimate properties for the PCPV model despite sensitivity studies demonstrating that the upper bound properties result in more onerous core distortion during a seismic event. The current safety case has now utilised a core boundary seismic motion derived using upper bound PCPV properties, which I consider appropriate and meets with my expectations.

120. I consider that the claims on the civil engineering structures comprising the diverse holddown (nitrogen) system have been adequately substantiated.

121. To conclude, from a civil engineering perspective I am satisfied with the claims, arguments and evidence laid down within the Licensee’s safety case. Overall, I judge the proposal adequate to justify the issue of a Licence Instrument to signify ONR’s Agreement under arrangements made under Licence Condition 22 (1).

5.2 Recommendations

122. I have raised one recommendation for ONR:

- Recommendation 1 – From a civil engineering perspective, I recommend that ONR should issue a Licence Instrument granting Agreement to the proposal under Licence Condition 22 (1).

6 REFERENCES

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NS-TAST-GD-017 - Revision 3 - Civil Engineering
NS-TAST-GD-051- Revision 4 – The purpose, scope and content of safety cases
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6. NP/SC 7766 SS1, EC 363560 Revision 000, Proposal Version No: 10, Hunterston B Power Station - An Operational Safety Case for Hunterston B R3 to a Core Burn-Up of 16.425TWd following the 2018 Graphite Core Inspection Outage, EDF Energy, April 2020, CM 2020/124498.

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13. 5152292/350/019 Issue 2.0, HPB/HNB Seismic Assessment: PCPV Modelling, Atkins, August 2018, CM 2018/306583.

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16. DA/FEGO/CIVIL/TO/18/07, Technical Oversight – Hunterston B Seismic Hazard, EDF Energy, 2018, CM 2018/306582

17. NP/SC 7557 Stage Submission 3A EC 341414 003, Hunterston B Power Station. New Nitrogen Storage and Distribution Plant – Civil Engineering Design – CM 2013/379442

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19. ONR-AR-18-085 Revision 0, Hunterston B - Return to service safety case for Reactor 4 following core inspection results in 2018 - NP/SC 7785 – Civil engineering assessment, ONR, April 2019, CM 2019/90351.

20. ONR-AR-19-041 Revision 0, Hinkley Point B - 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, ONR, November 2019, CM 2019/268654.

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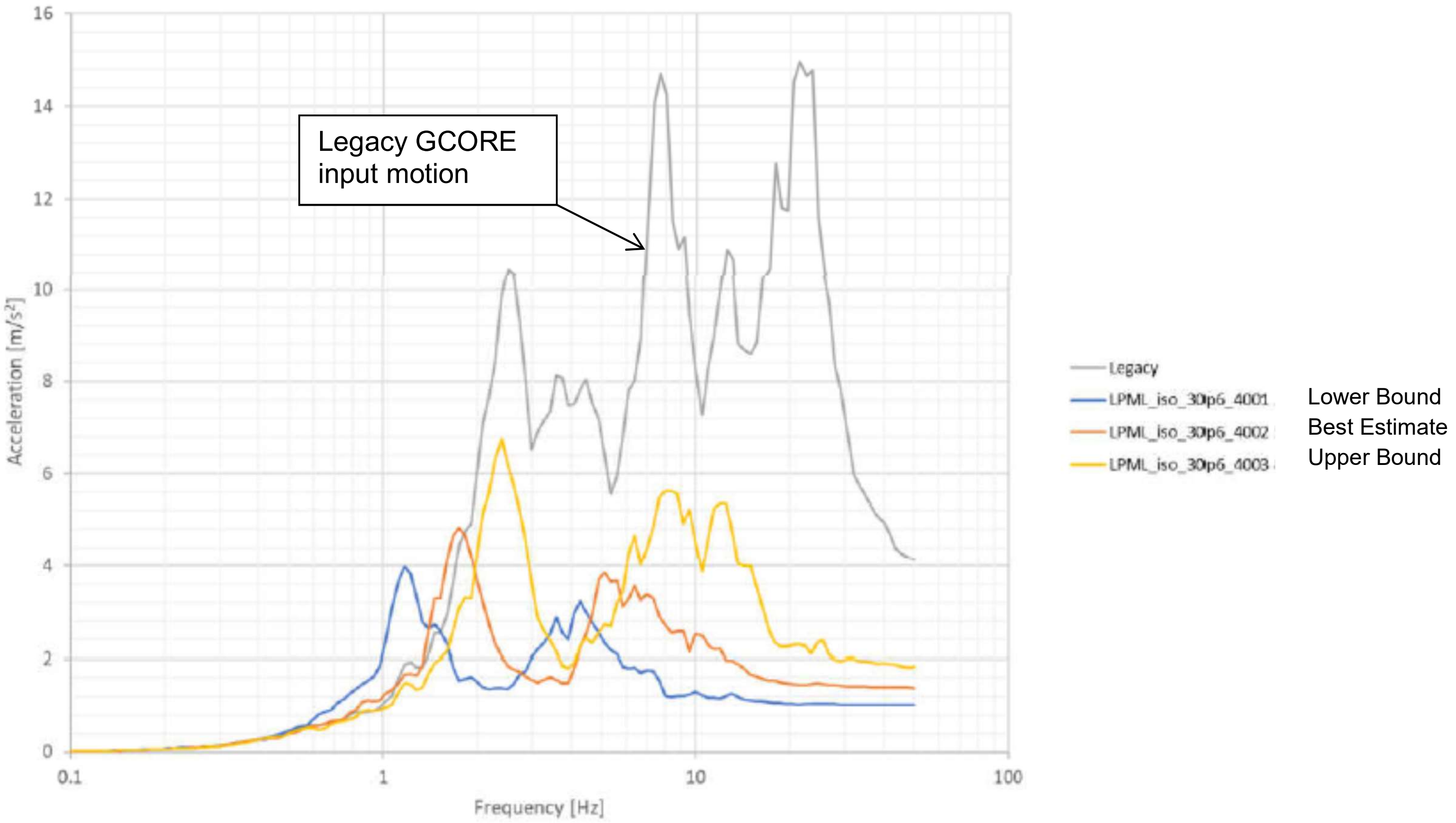
Table 1: Relevant Safety Assessment Principles considered during the assessment

SAP No	**SAP Title**	**Description**
AV.2	Fault analysis: assurance of validity of data and models: Calculation methods	Calculation methods used for the analyses should adequately represent the physical and chemical processes taking place.
AV.5	Fault analysis: assurance of validity of data and models: Documentation	Documentation should be provided to facilitate review of the adequacy of the analytical models and data.
ECE.13	Civil engineering: structural analysis and model testing: Use of data	The data used in structural analysis should be selected or applied so that the analysis is demonstrably conservative.
ECE.14	Civil engineering: structural analysis and model testing: Sensitivity studies	Studies should be carried out to determine the sensitivity of analytical results to the assumptions made, the data used, and the methods of calculation.
ECE.15	Civil engineering: structural analysis and model testing: Validation of methods	Where analyses have been carried out on civil structures to derive static and dynamic structural loadings for the design, the methods used should be adequately validated and the data verified.
ECS.3	Codes and Standards	Structures, systems and components that are important to safety should be designed, manufactured, constructed, installed, commissioned, quality assured, maintained, tested and inspected to the appropriate codes and standards.
EHA.7	Engineering principles: external and internal hazards: ‘Cliff-edge’ effects	A small change in design basis fault or event assumptions should not lead to a disproportionate increase in radiological consequences.
EHA.18	Engineering principles: external and internal hazards: Beyond design basis events	Fault sequences initiated by internal and external hazards beyond the design basis should be analysed applying an appropriate combination of engineering, deterministic and probabilistic assessments.
FA.15	Fault analysis: severe accident analysis: Scope of severe accident analysis	Fault states, scenarios and sequences beyond the design basis that have the potential to lead to a severe accident should be analysed.
SC.5	The regulatory assessment of safety cases: Optimism, uncertainty and conservatism	Safety cases should identify areas of optimism and uncertainty, together with their significance, in addition to strengths and any claimed conservatism.



Legacy GCORE input motion

Figure 1 – Secondary response spectra comparison at core boundary for PML synthetic input motion for legacy and final PCPV models (After Ref. 11, Figure 54)

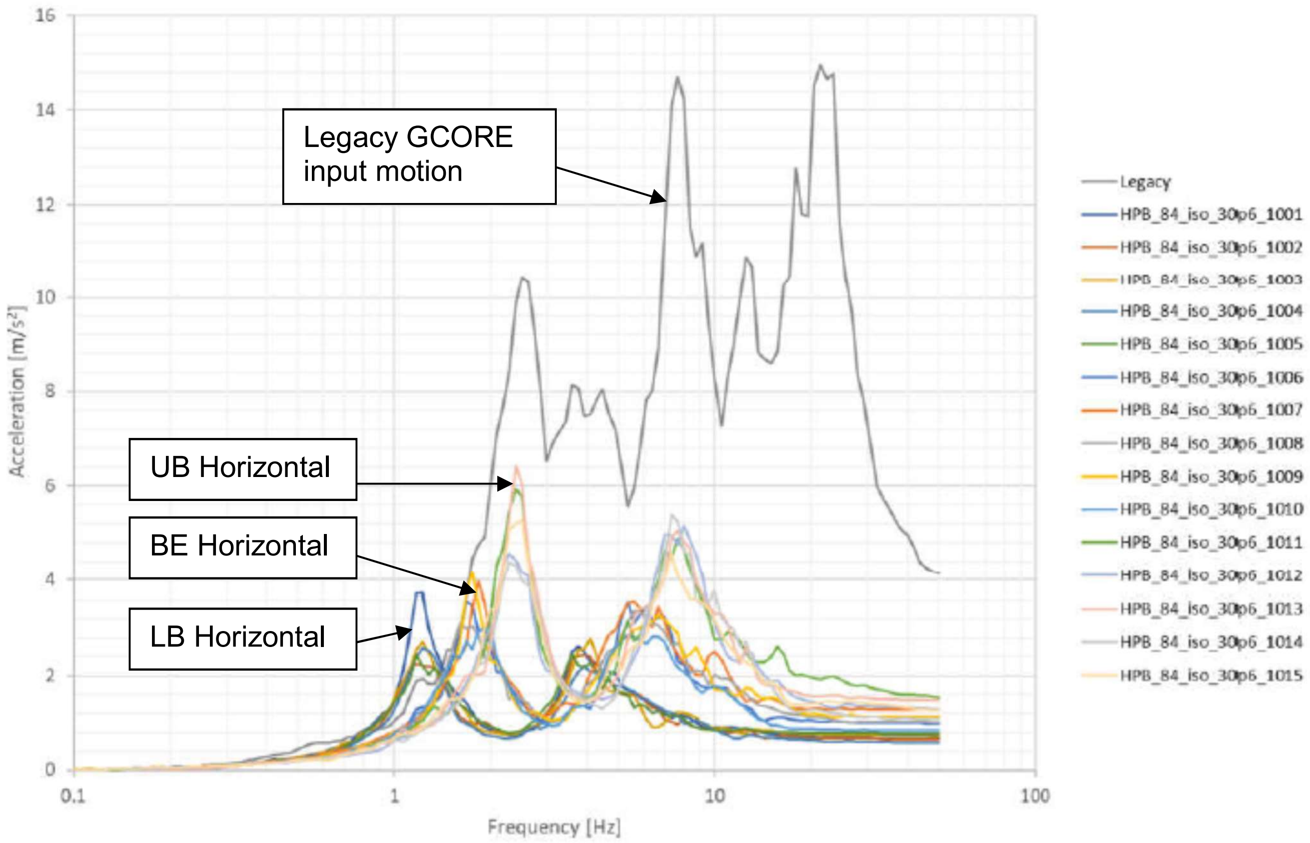


Figure 2 – HPB 84th percentile target response spectra – North-South core boundary secondary response spectra for the LB, BE and UB Final model (After Ref. 11, Figure 44)

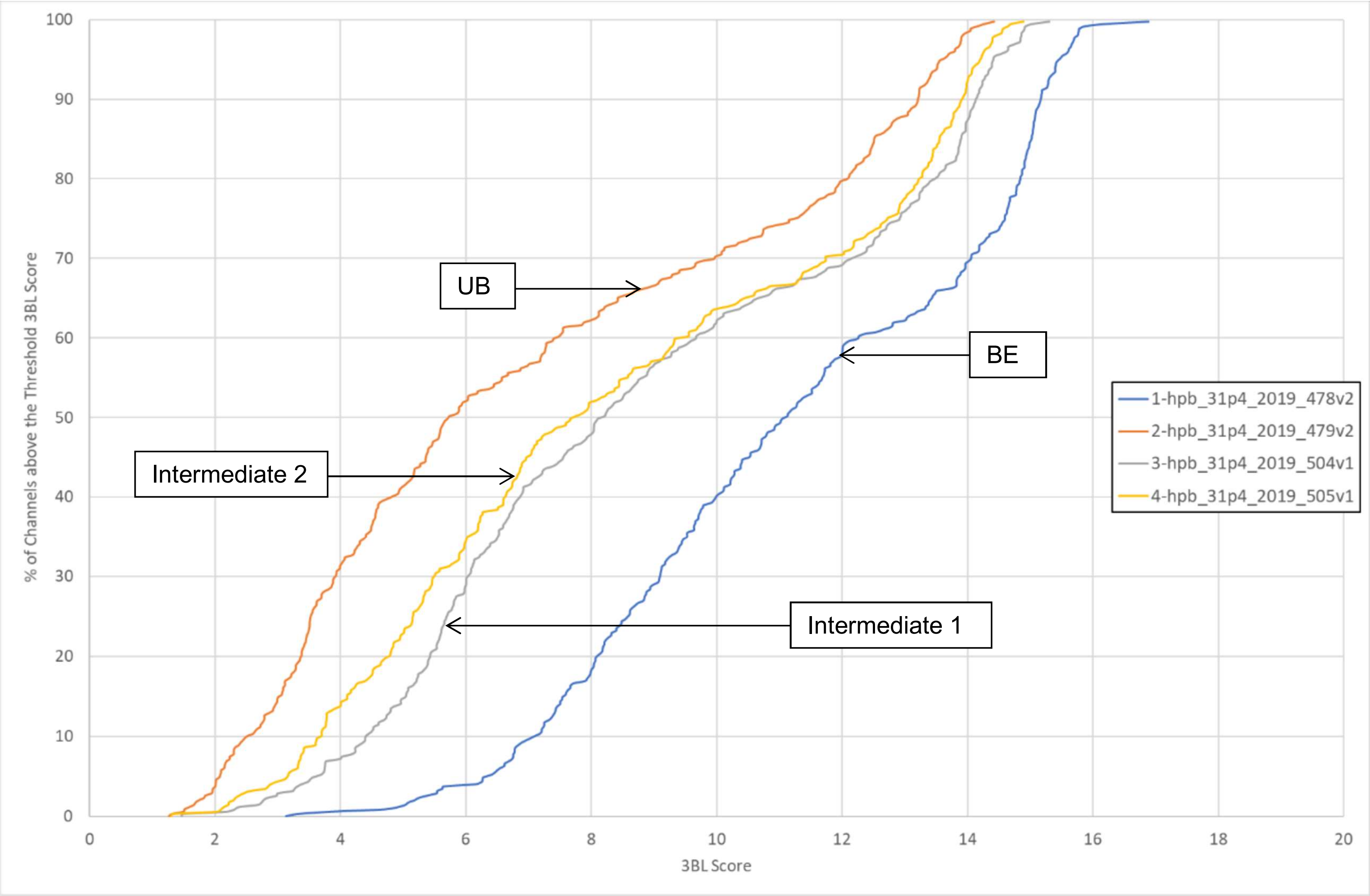


Figure 3 - Core distortion as measured by cumulative interstitial channel score 3BL – CEDTL core - PML synthetic input motion - Comparison of four different PCPV property sets (after Ref. 26, Figure 8-3 and based on HPB)

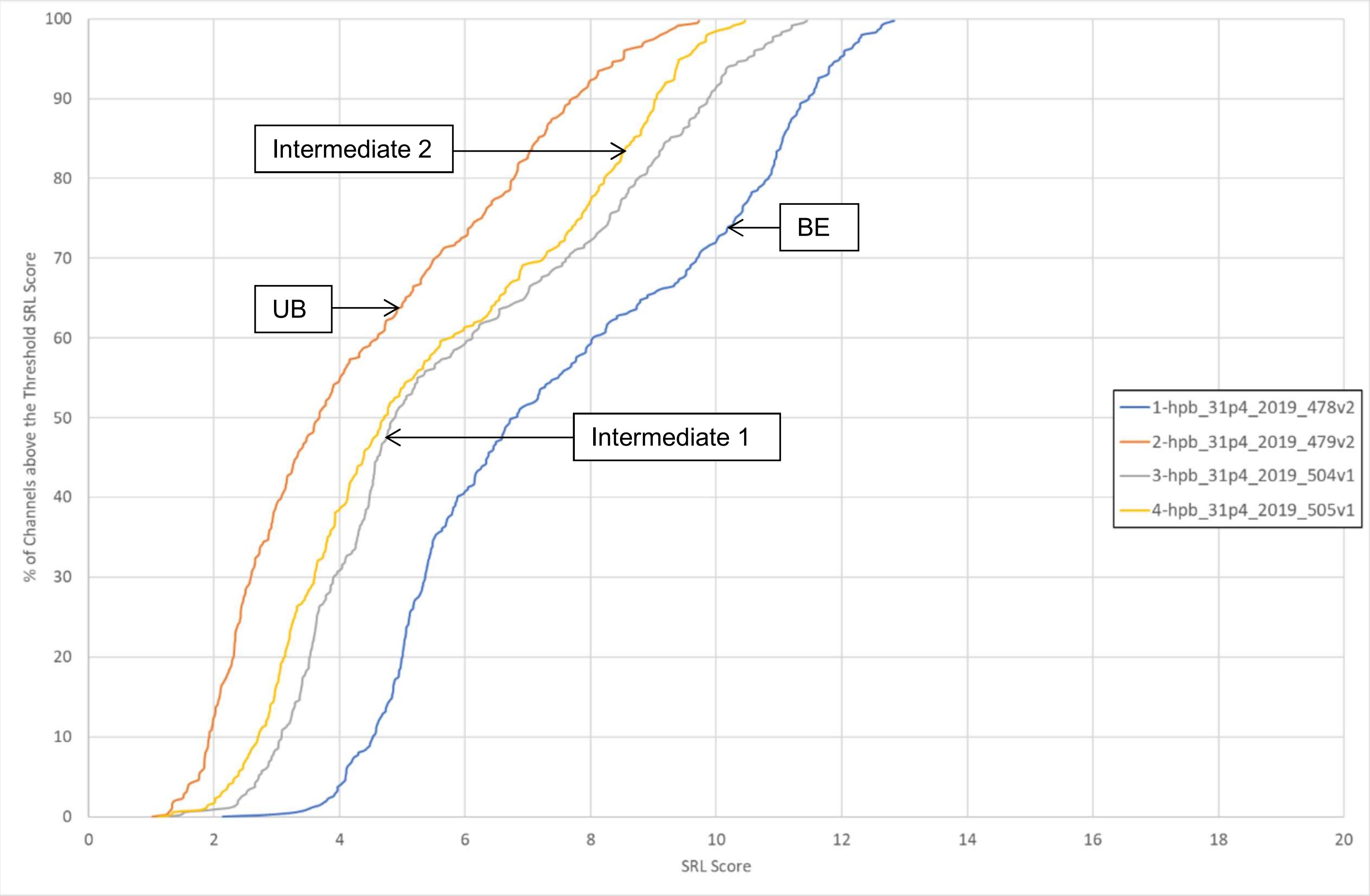


Figure 4 - Core distortion as measured by cumulative interstitial channel score SRL – CEDTL core - PML synthetic input motion - Comparison of four different PCPV property sets (after Ref. 26, Figure 8-3 and based on HPB)