Return to service safety case for Reactor 4 following core inspection results in 2018 - NP/SC 7785 - Seismic Assessment for Diverse Hold Down System

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EXECUTIVE SUMMARY

EDF Energy Nuclear Generation Limited (NGL) has submitted for Hunterston B power station a return to service safety case for Reactor 4 following core inspection results in 2018. The safety case seeks to justify the issue of a Licence Instrument to signify ONR's Agreement under arrangements made under Licence Condition 22 (1).

This assessment report presents the findings of an Office for Nuclear Regulation (ONR) assessment of the seismic safety case for the diverse hold down system at Hunterston B which provides support for the return to service safety case for Reactor 4. The assessment was undertaken to support a Project Assessment Report, which documents ONR's overall view on the adequacy of the licensee's submission. The ONR Safety Assessment Principles, together with supporting relevant Technical Assessment Guides, were used as the basis of this assessment.

The submission presents claims, arguments and evidence supporting the safety case. The scope of my assessment was limited to seismic hazards and the diverse hold down system. My sampling strategy focused on five shortfalls in NGL's earlier seismic assessment of the diverse hold down system at Hunterston B, which I had identified in a previous assessment, 'Review of ONR Seismic Assessment of Hunterston B Nitrogen Plant, 15.1.15 - 20.6.18'. These shortfalls were:

A) Provide a bottom line seismic design basis which corresponds to an event with a conservatively predicted probability of exceedance of 10^{-4} pa at HNB (ONR SAPs EHA.4 and FA.5).

B) Clarify the claims that are now being made for the DHD system (ONR SAPs FA.8, ERL.1). For example is it qualified against frequent or infrequent seismic events?

C) Substantiate the DHD system against the relevant seismic claims. Note that this has already been done for the civil engineering components (foundation slab, etc) (ONR SAP EQU.1).

D) Demonstrate that there are acceptable margins against beyond design basis (BDB) seismic events for the systems claimed for hold down (ONR SAPs ERC.2, EHA.7 and EHA.18).

E) Identify and assess adjacent plant with the potential to fail and cause damage to the DHD system in a seismic event. Demonstrate that credible failures do not undermine the seismic claims for the DHD system (ONR SAPs SC.4, ECE.1, EHA.1 and EHA.6).

My assessment has taken note of previous ONR and NGL assessments of the diverse hold down system at Hunterston B and I interacted with other ONR disciplines as necessary, for example to assess the adequacy of the Seismic Qualification Utility Group methodology and of its implementation by the licensee.

I am satisfied that the five shortfalls listed above, which I had identified in my previous assessment of the diverse hold down system, have now been adequately addressed. My assessment supports the adequacy of the licensee's bottom line seismic design basis for the Hunterston B site, the claims made on the diverse hold down system and its qualification against the claims. These conclusions also cover margins against beyond design basis seismic events and the assessment of interactions from plant adjacent to the diverse hold down system.

I am satisfied with the claims, arguments and evidence laid down within the licensee's safety case. On the basis of my assessment I have assigned a green rating to the seismic safety

case for the Hunterston B diverse hold down system in accordance with the ONR assessment rating guide.

Overall I judge this element of the submission adequate to justify the issue of a Licence Instrument to signify ONR's Agreement under arrangements made under Licence Condition 22 (1).

LIST OF ABBREVIATIONS

ALARP	As Low As Reasonably Practicable
AR	Assessment Report
BDB	Beyond Design Basis
BDBE	Beyond Design Basis Earthquake
C&I	Control and Instrumentation
DB	Design Basis
DHD	Diverse Hold Down system
GIP	Generic Implementation Procedure
HCLPF	High Confidence Low Probability of Failure
HNB	Hunterston B power station
HPB	Hinkley Point B power station
HPC	Hinkley Point C power station
INSA	Independent Nuclear Safety Assessment
LN	Liquid Nitrogen
N2	Nitrogen
NGL	(EDF) Nuclear Generation Limited
NIS	Nitrogen Injection System
NSVP	Nitrogen Storage and Vaporisation Plant
OA	Operational Allowance
pa	per annum
PAR	Project Assessment Report
phga	peak horizontal ground acceleration
PLS	Piecewise Linear Spectrum
PML	Principia Mechanica Limited
PSHA	Probabilistic Seismic Hazard Analysis
R4	Reactor 4
RGP	Relevant Good Practice
RTS	Return To Service

SACR	Super Articulated Control Rod
SAP	(ONR) Safety Assessment Principle
SQEPs	Suitably Qualified and Experienced Persons
SQUG	Seismic Qualification Utility Group
SS	Stage Submission, e.g. SS1 is Stage Submission 1
SSI	Soil Structure Interaction
TAG	Technical Assessment Guide
UHS	(Site Specific) Uniform Hazard Spectrum
ZPA	Zero Period Acceleration

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1 INTRODUCTION

1.1 Background

1. This report presents the findings of my seismic assessment for the Hunterston B (HNB) return to service safety case for Reactor 4 following core inspection results in 2018 (hereinafter the safety case), as presented in Ref. 1 and supporting documentation provided by EDF Energy Nuclear Generation Ltd (NGL). In particular this document assesses NGL's seismic assessment for the diverse hold down (DHD) system. The seismic assessment of other HNB plant is addressed elsewhere (e.g. Ref. 2).

2. NGL has requested (Ref. 3) that the Office for Nuclear Regulation (ONR) provide Agreement of the safety case in accordance with the licensee's arrangements made under Licence Condition 22 (1). ONR has decided to assess the case and, subject to a satisfactory assessment outcome, to issue an Agreement via a Licence Instrument. The updated safety case does not justify any physical modifications to the plant.

3. To ensure safe shutdown and sustained reactivity control (known as 'hold down') in a seismic event at HNB, super-articulated control rods (SACRs) may be inserted into the reactor cores, but only some of the control rods are SACRs. A new seismically qualified nitrogen storage, distribution, injection and blowdown system, also known as the DHD system, was installed in January 2015 and subsequently put into service. The new DHD system has been designed to have increased functionality and integrity relative to the previous system (Ref. 4).

4. Provision of a diverse system for reactor shutdown and hold down is required by established standards for nuclear safety, e.g. ONR Safety Assessment Principle (SAP) ERC.2 (Table 1, see also EDR.4, EKP.3). Ref. 1 states that the control rods can secure immediate shutdown and short term hold down. The DHD system is intended for long term hold down rather than shutdown; achieving hold down is ultimately the more onerous requirement. In practice HNB does not have a diverse system for shutdown, but there is substantial redundancy in the control rod system for shutdown. Only about 14% of the rods are required to fully insert to achieve shutdown in the worst case (new fuel with worst case geometry) and this is judged to be adequate (Ref. 1). Graphite cracking has the potential to undermine this argument and this is being assessed by other ONR specialisms (Structural Integrity, Fault Studies, etc) who are also reviewing the adequacy of the return to service safety case. This Assessment Report (AR) follows up the concern that the original claims by NGL on the DHD system were not entirely clear as to whether it is a diverse system for hold down in a design basis (DB) accident, a means of avoiding cliff edge effects in beyond design basis (BDB) accidents or a defence in depth ALARP measure.

5. About 92% of the control rods need to fully insert to achieve hold down in the worst case geometry with new fuel and without the DHD system. Hence, in the case of hold down the control rod redundancy is far less substantial than for shutdown. Moreover in a seismic event with a degraded core claims on the control rod redundancy are potentially undermined and the seismic qualification of the DHD system could be much more important in terms of nuclear safety.

6. Flow diagrams of the DHD and its tie-in to the reactor primary circuit are presented in Refs. 5, 6, 7 and 8. Following the most severe seismic event evaluated (Ref. 1), operators could partially depressurise the reactor cores ("blowdown") reducing the carbon dioxide concentration and then the DHD system could be used to inject nitrogen (N2) into them. The N2 injected into the cores will absorb neutrons, effectively reducing their ability to sustain the nuclear reaction. The new DHD systems at HNB

(and Hinkley Point B, HPB) are designed to provide sufficient N2 to achieve medium to long term hold down for both reactors at each site.

7. Cracks in the graphite cores of the reactors have the potential to result in misalignment of the control rod channels, especially in a seismic event, which might prevent one or more control rods from fully entering the core when required for shutdown/hold down. At present the safety case defines an Operational Allowance (OA), which specifies a number of cracked bricks of certain types with a specified crack opening. The safety case states that there is a safe margin beyond the OA but if the OA is exceeded operation will not continue under the current safety case. Additional cracks found recently in the HNB graphite cores mean that the OA has been exceeded and as a result HNB R3 and R4 are currently shut down and a new/revised safety case is required for generation to recommence.

8. EDF Nuclear Generation Limited (NGL) has presented a short term return to service (RTS) safety case for reactor 4 (R4) at Hunterston B (HNB) Power Station following core inspection results in 2018 (Ref. 1). This case rests mainly on claims against the control rods with a degraded graphite core during normal operation, plant faults and the seismic hazard. However compliance with the As Low As Reasonably Practicable (ALARP) principle is also supported in Ref. 1 by a defence in depth claim that the seismically qualified Diverse Hold Down (DHD) system is functionally capable of securing long term hold down on a shutdown reactor (Claim 2 in Ref. 9). This AR considers NGL's seismic assessment of the HNB DHD system.

9. The following terminology is used in various documents relating to the DHD system:

- Nitrogen (N2) plant
- Nitrogen Storage and Vaporisation Plant (NSVP)
- Nitrogen Injection System (NIS)

10. In this AR, apart from direct quotations from other documents, I have used "DHD system" throughout in preference to the above terms and, unless otherwise stated, this is intended to cover the entire nitrogen injection hold down system, i.e. all components of the system that are necessary to deliver the nuclear safety function, which are discussed in Ref. 12.

1.2 Scope

11. This assessment is one of several being undertaken by ONR specialist inspectors covering different aspects of the HNB return to service safety case for Reactor 4. The outcomes of the various assessments will be combined in a single PAR that will inform ONR's opinion on the submission and affect the content of the decision letter.

12. Whilst my assessment focuses on the risks arising from seismic hazard to the DHD system, there has been a key interface between the external hazards assessment and the civil engineering assessment and I have consulted the relevant civil engineering assessments/ONR civil engineering inspectors during its preparation.

1.3 Methodology

13. The methodology for the assessment follows HOW2 guidance on mechanics of assessment within ONR (Ref. 10).

14. This assessment has focused on the DHD system seismic aspects of the HNB return to service safety case for Reactor 4 to establish whether NGL's claims on the system are clear and adequately substantiated.

2 ASSESSMENT STRATEGY

15. I attended a Level 4 meeting with NGL in May 2018 to discuss the HNB DHD system (Ref. 11). There was some uncertainty about the precise claims that are currently made on the HNB DHD system, the level to which it has been substantiated and the scope of previous ONR assessments of it. In light of this, I wrote an assessment note titled ‘Review of ONR Seismic Assessment at Hunterston B Nitrogen Plant, 15.1.15-20.6.18’ (Ref. 12). In my assessment note (Ref. 12) I identified five shortfalls in relation to the previous NGL seismic assessment of the DHD system at HNB, as follows:

A) Provide a bottom line seismic design basis which corresponds to an event with a conservatively predicted probability of exceedance of 10^{-4} pa at HNB (ONR SAPs EHA.4 and FA.5).

B) Clarify the claims that are now being made for the DHD system (ONR SAPs FA.8, ERL.1). For example is it qualified against frequent or infrequent seismic events?

C) Substantiate the DHD system against the relevant seismic claims. Note that this has already been done for the civil engineering components (foundation slab, etc) (ONR SAP EQU.1).

D) Demonstrate that there are acceptable margins against beyond design basis (BDB) seismic events for the systems claimed for shutdown and hold down (ONR SAPs ERC.2, EHA.7 and EHA.18).

E) Identify and assess adjacent plant with the potential to fail and cause damage to the DHD system in a seismic event. Demonstrate that credible failures do not undermine the seismic claims for the DHD system (ONR SAPs SC.4, ECE.1, EHA.1 and EHA.6).

16. NGL has responded to these shortfalls (Ref. 13) and their responses are summarised and assessed in this AR.

2.1 Standards and Criteria

17. The relevant standards and criteria adopted within this assessment are principally the SAPs (Ref. 14) and I ONR Technical Assessment Guides (TAGs) (Ref. 15). The key SAPs are detailed in section 2.2 and, where applicable, they have been cited within the body of the assessment.

2.2 Safety Assessment Principles

18. The key SAPs applied and cited within the assessment are included within Table 1 of this report, which also identifies the paragraphs in which they are referenced.

2.2.1 Technical Assessment Guides

19. The following Technical Assessment Guides have been used as part of this assessment (Ref. 15):

- NS-TAST-GD-005 Revision 8: Guidance on the Demonstration of ALARP.
- NS-TAST-GD-013 Revision 7: External Hazards.
- NS-TAST-GD-051 Revision 4: The purpose, scope and content of safety cases.

2.2.2 National and International Standards and Guidance

20. Relevant national and international standards have been considered in the production of this assessment report. These standards and guidance were however used within ONR as part of the processes leading to the published ONR SAPs (Ref. 14) and TAGs (Ref. 15). The SAPs have been updated following the Fukushima accident and are considered to be consistent with developing IAEA and Western European Nuclear Regulators Association (WENRA) guidance on seismic hazards (Ref. 16, 17, 18, 19). Assessment methods used in the licensee's submission have been checked for compliance with modern assessment standards, e.g. seismic hazard characterisation (para 32) and the Seismic Qualification Utility Group (SQUG) methodology (para 42).

2.3 Use of Technical Support Contractors

21. Technical Support Contractors have not been used for this assessment.

2.4 Integration with Other Assessment Topics

22. Having characterised the seismic hazard for the site, its interaction with relevant structures on the site needs to be assessed, which involves other disciplines such as Civil Engineering. I therefore discussed these interactions with relevant ONR specialist inspectors and these discussions helped to:

- Confirm the adequacy of the SQUG methodology and of its implementation by the licensee in assessing seismic hazards to the DHD system (para 41), including the assessment of adjacent plant with the potential to damage the DHD system.
- Ensure a consistent approach by ONR to issues that relate to more than one technical discipline.

23. The outcomes of the various assessments will be combined in a single PAR that will inform ONR's opinion on the submission and affect the content of the decision letter.

2.5 Out of Scope Items

24. This assessment only covers seismic hazards to the DHD system; it does not cover other hazards or seismic hazards to other systems.

25. The licensee's submission addresses qualification of all aspects of the DHD system, including plant items, pipework, cabling (Ref. 20), electrical, control and instrumentation (Ref. 21) and mechanical engineering design (Ref. 22), not just the civil engineering design. However I have sampled documents relating to seismic qualification of the civil engineering design only, so the seismic qualification of other DHD system components has not been assessed by ONR in any detail (see section 4.2).

3 LICENSEE'S SAFETY ASSESSMENT

26. The document trail for the Licensee's safety case relies on a significant number of supporting references and revisions of documents. The key documents for my assessment are:

- NP/SC 7785 - Hunterston B - Return to service safety case for Reactor 4 following core inspection results in 2018, EC No: 364115, Revision 000 Proposal Version No: 08, EDF Energy, March 2019, CM 2019/76309 (Ref. 1).
- NP/SC 7557 Enhanced Long Term Shutdown Provisions Stage Submission 5: Safety Case for Putting the New Nitrogen Injection and Blowdown Plant Into Operational Service, date not stated but pre-2016, EC No: 351745, Proposal Version No: 05, CM 2015/53466 (Ref. 4).
- DA/FEGO/CIVIL/TO/18/06 – Technical Oversight Note: Beyond Design Basis Earthquake Capability of the HNB/HPB N_2 Injection System

The safety case for putting the new nitrogen injection and blowdown plant into service at HNB is presented in Ref. 4 (NP/SC 7557).

4 ONR ASSESSMENT

4.1 Scope of Assessment Undertaken

27. ONR has been engaging with the licensee in Level 4 meetings over the last year on the issues at HNB, including the seismic safety case for the DHD system. For example I attended a presentation on the seismic capability of the DHD system by NGL in July 2018 (Ref. 23) and characterisation of the seismic hazard for the HNB site was discussed further in September 2018 (Ref. 24).

28. Seismic qualification of the DHD system would be undermined if any of the five shortfalls I identified previously (para 15) had not been adequately resolved. Hence my assessment presented in Section 4.2 focused on whether or not the licensee has adequately addressed those five shortfalls.

4.2 Assessment

A) BOTTOM LINE SEISMIC DESIGN BASIS

29. The earlier AGRs, including HNB and Hinkley Point B (HPB) were retrospectively assessed for the seismic hazard as part of their initial Periodic Safety Review (PSR). The design basis spectra are discussed in Refs. 25 (for HPB) and 26 (for HNB).

30. The R4 RTS safety case (Ref. 1) is based on the legacy 0.14g Principia Mechanica Limited (PML) input motion. NGL has been investigating the HPB Uniform Hazard Spectrum (UHS) and it intends to use this input motion for the future long term safety case covering HPB and HNB (Ref. 27). The long-term case will use the HPB 84th percentile (conservative) UHS, although use of the HPB mean UHS could be justified for the BDB case (Ref. 28).

31. The 10^{-4} pa seismic hazard spectrum used for the original assessment of the 'bottom line' plant at HNB and HPB was the PML "hard site" piecewise linear spectrum (PLS) anchored at 0.14g. By comparison with more recent and hazard derivation (including recent Probabilistic Seismic Hazard Analysis, PSHA, work for Hinkley Point C, HPC) for acceleration, velocity and displacement, Ref. 25 argues that the PML spectrum is conservative or realistic at HPB for frequencies up to about 18 Hz. SSCs such as electrical relays which are vulnerable to the higher frequencies above 18Hz have been subject to specific assessments to provide a High Confidence Low Probability of Failure (HCLPF) position for the seismic safety case. However, I note that this assessment is specifically for HPB not HNB.

32. Also, Ref. 25 only devotes three paragraphs to the HPC PSHA results that clearly represent the most robust hazard characterisation for the site. For example the comparison presented in Fig. 5 of Ref. 25 does not clarify the compatibility of target horizons and the site response modelling. Most of Ref. 25 concerns demonstrating that the 0.14g PML design basis is conservative with respect to Seismic Hazard Working Party (SHWP) work. In principle, NGL should now take cognisance of the HPC work for this demonstration (modified somewhat in the site response for the HPB site). However there is a rather more detailed discussion of the HPC work in Ref. 26. Although the HPB (and HNB) reactor designs cannot realistically comply with modern standards in every respect, the design shortfalls against modern standards are an added reason for using modern assessment standards to provide a high level of confidence in the assessment. NGL's long term safety case for HPB and HNB should consider expanding this assessment to improve confidence in its rigour and its compliance with modern assessment standards. However, I judge that this does not undermine the conservatism of their assessment (Ref. **Error! Bookmark not defined.**) as explained in para 33.

33. Ref. 26 covers HNB and presents a similar argument to Ref. 25 (see previous para), except that there is nothing equivalent to the HPC work for the Hunterston site. However comparison between the various seismic assessments for Hinkley Point and Hunterston, along with a range of expert opinions, site specific factors and sensitivity studies, provides high confidence that the original PML spectra for HNB would bound a modern standard PSHA for the site for frequencies up to about 26 Hz. Ref. 26 states that the 2018 HPC[1] UHS curve provides a bounding hazard estimate for both Hinkley Point B and Hunterston B sites for the purposes of graphite core modelling. The focus in this AR is on seismic hazard to the HNB DHD system but the same argument is applicable, i.e. the 2018 HPC UHS curve provides a bounding hazard estimate. However the DHD system has been qualified for the infrequent (10^{-4} pa) bottom line event defined by the PML design response spectrum for a hard site, scaled to a Zero Period Acceleration (ZPA) of 0.14 g (Ref. 29), which is conservative at HNB for frequencies below 26 Hz (Ref. 26). I am content that this assessment of the seismic design basis is adequate for the RTS safety case.

Conclusion 1: NGL has made an adequate argument with regards to the characterisation and substantiation of the bottom line seismic design basis (ONR SAPs EHA.4 and FA.5) for the DHD system.

Finding 1: NGL should consider expanding the substantiation of the bottom line seismic design bases for the HNB and HPB sites in its long term safety cases to improve confidence in their rigour and compliance with modern assessment standards.

B) CLARIFY THE CLAIMS ON THE DHD SYSTEM

34. This shortfall essentially relates to my request that EDF clarify the level of seismic event that the DHD is claimed to withstand as this was not clear in previous submissions. EDF has now clarified these claims in Technical Oversight Note TO/18/06 (Ref. 29) . This document sets out the beyond design basis earthquake capability of the DHD system. The relevant claims can be summarised as follows:

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

35. The substantiation of these claims is assessed below against shortfall C. For the purposes of closing out shortfall B, it is sufficient to note that EDF has clarified in TO/18/06 (Ref. 29) that it claims the DHD system to have adequate capability to provide confidence in its performance in a beyond design basis seismic event.

36. I am content that this adequately clarifies the claims on the DHD system, although it would help if the claims were presented succinctly in a single document.

Conclusion 2: NGL has adequately clarified the claims on the DHD system (ONR SAPs FA.8, ERL.1).

Observation 1: NGL has not presented the claims succinctly in a single document, which would improve the clarity of the safety case.

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[1] *The reference states, "HPB UHS", which is a typographical error; "HPC UHS" is correct.*

C) SUBSTANTIATE THE DHD SYSTEM AGAINST THE RELEVANT SEISMIC CLAIMS

37. The full scope of ONR's assessment of the HNB return to service safety case for Reactor 4 is outlined in section 1.1 and will be covered by a Project Assessment Report (PAR). The seismic substantiation of the DHD system civil works has previously been assessed by an ONR Civil Engineering specialist inspector when it was first installed (Ref. 30). However at that time it was only substantiated against seismic events with a probability of exceedance of 10^{-2} pa (Ref. 29), apart from the foundations which were substantiated against 10^{-4} pa. Even so, much of the substantiation was already adequate because the demonstrated margins were sufficient for 10^{-4} pa events (see e.g. Ref. 32, Jan 2015) and the adequacy of the main component assessments has already been subject to review by ONR (e.g. Ref. 30).

38. Having requested clarification of the claims on the DHD system (see section B), my previous assessment (Ref. 12) then identified the need for the licensee to fully substantiate the DHD system against the relevant seismic claims.

39. NGL has done a significant amount of work over recent years to fully substantiate the current seismic claims on the DHD system and this work is summarised below (paras 40 - 47).

40. Ref. 29 assesses the BDB earthquake (BDBE) capability of the DHD system, and identifies the main components of the system as:

- Civil structures.
- Nitrogen Plant Items, including liquid nitrogen (LN) vessels.
- Inside Battery Limits (ISBL) Pipework - comprising all N2 plant associated with and founded on the new foundation slab external to the main buildings.
- Outside Battery Limits (OSBL) Pipework - comprising N2 plant located between the ISBL and the Reactor Building, i.e. primarily in piping trench.
- Injection and Blowdown Pipework - comprising N2 plant located inside the Reactor Building (entering at Ground Level) up to the PCPV injection points including all diverse branch and ring-main routes.
- Cabling Routes.
- C&I Components.

41. All of the above plant has now been qualified to withstand the 10^{-4} pa (bottom line or DB) seismic event (Ref. 31). Ref. 30 supported the issue of a Licence Instrument to put the DHD system into service. It confirmed that the HNB raft foundation has been designed to withstand the plant seismic loads that are due to the bottom line seismic event at the HPB site. The compatibility of the HPB seismic loads with the HNB site specific seismic response has been assured by modification of the HNB seismic response by replacing the ground between the underside of the raft foundation and the underlying bedrock with a mass concrete. This is shown to reduce the enhancement to the seismic loads due to the HNB soil structure interactions to provide a generally conservative design (Ref. 30).

42. The BDBE assessment of the DHD system has been based upon the following techniques (Ref. 29):

- Claims on inherent design margins for new plant designed to modern codes and standards.
- Electrical and C&I components qualified via shake table testing.

- Seismic ruggedness claims for existing plant assessed via SQUG walkdown techniques (Ref. 32). A high level review of this by ONR's Civil Engineering and External Hazards Professional Lead confirmed the adequacy of the approach and that those who prepared and approved the report were Suitably Qualified and Experienced Persons (SQEPs) (Ref. 33).
- Fragility Curves. Seismic fragility of a system or component is defined as the probability of failure of the item, for a given seismic input motion parameter, such as the Peak Ground Acceleration (PGA).

43. The methods and data used for each of the above techniques are explained and referenced in Ref. 29 **Error! Bookmark not defined.**and all of the above methods are consistent with RGP and are explicitly commended in ONR TAG13 (Ref. 34).

44. The overarching principles used to develop seismic claims on the DHD system are listed in Ref. **Error! Bookmark not defined.** and include:

- All new design work has been carried out in accordance with relevant modern design codes and standards.
- The structural detailing practices for reinforced concrete sections and steelwork elements provide inherent ductility under seismic loading.
- The deterministic design approach confers a reserve margin of strength such that the new structures and components will not exhibit a cliff edge effect in the event of a beyond Design Basis Hazard.
- The seismic design of the ISBL N2 plant included a highly conservative allowance for SSI effects to allow for softer ground conditions below the foundation slab (which can amplify high frequency input motions). The same SSI enhanced spectra was adopted for both sites. For the HNB site, the soil beneath the RC foundation slab was subsequently excavated and replaced with structural concrete, thus mitigating SSI effects.
- The actual SSI effects were later established to be minimal at both sites (i.e. negligible), however the conservative SSI enhanced spectrum was retained for design purposes and deliberate margin.
- All steelwork, reinforced concrete & anchorage design components were compliant to design code with appropriate material and load safety factors incorporated.

45. I judge that these principles include a mixture of realism and conservatism, giving overall conservative seismic claims and this collective approach supports a seismic qualification process that is consistent with the licensee's High Confidence Low Probability of Failure (HCLPF) claim.

46. There are 85 separate supporting references for the whole seismic qualification of the DHD system, noting that the qualification claims have progressively developed over the past 5 years due to the evolving graphite safety cases (Ref. 35). These include reports from a series of seismic walkdowns undertaken to progressively assess the DHD system. However, NGL has produced a head document in the form of an Engineering Advice Note (EAN, Ref. 31) that acts as a qualification route map and ABS Consulting (who undertook all the seismic walkdowns) has also produced an overarching reference (Ref. 32) that captured the seismic walkdown qualification of the final system.

47. Apart from the civil structures which are covered in Ref. 30 (para 41), Ref. 32 covers all of the DHD system components listed in para 40. It assesses them against the infrequent seismic hazard for the HNB site defined by the PML hard ground spectrum (5% damping) with a phga of 0.14g.

48. Detailed substantiation of the DHD system against the relevant seismic claims is outside the scope of this report but based on the sample I have reviewed I judge that:

- The scope of the substantiation adequate, i.e. it covers the whole of the DHD system for seismic events with a probability of exceedance of 10^{-4} pa (paras 40 - 41 and 47), ONR SAPs EQU.1 and EHA.4.
- Techniques that are recognised as RGP have been used for the substantiation (paras 42 - 43), ONR SAP SC.1, ONR TAG13.
- Conservative assumptions have been used where appropriate (paras 44 - 45), ONR SAPs EHA.4, EMC.33.
- SQEPs have performed the substantiation (para 42), ONR SAP EHF.8.
- The margins derived from the substantiation are adequate (paras 42 and 44, also see section D), ONR SAP EHA.18.

49. In summary, based on the sample I have assessed, all of the components of the DHD system (para 40) have been subject to assessment by SQEPs against the relevant seismic claims (section B) using conservative assumptions and techniques that are supported by RGP (para 43). I therefore judge that the HCLPF claim is adequately supported.

Conclusion 3: NGL has adequately substantiated the DHD system against the relevant seismic claims (ONR SAP EQU.1).

D) DEMONSTRATE ACCEPTABLE MARGINS AGAINST BDB SEISMIC EVENTS

50. Ref. 29**Error! Bookmark not defined.** discusses BDB margins for the DHD system. Design factors of safety for all the components of the DHD system against a DB seismic event have been calculated in Ref. 29**Error! Bookmark not defined.** along with consideration of whether failures in a BDBE would be “cliff edge” or ductile/partial, e.g. for multiple holding down bolts. Hence:

- A minimum overall BDBE margin of 2.1 was obtained for the LN vessels.

- A margin in excess of 2 was obtained for C&I equipment functionality associated with the DHD system by shake table testing.

- Based upon EPRI guidance for BDBE assessment, the seismic fragility assessment indicates a minimum combined seismic margin of 2.12 for seismic walkdown compliant bottom line plant items located in the main buildings.

    - Ref. 29**Error! Bookmark not defined.** judges that BDBE margins >2 are inherently available for the new N2 plant related civil structures using seismic walkdown qualification techniques. Similarly, it is claimed to be reasonable to confer an overall BDBE

- Other details are presented in section 4.0 of Ref. 29**Error! Bookmark not defined.**, which concludes that taking cognisance of the conservatism in the margins assessment, a best estimate of hazard level whereby the safety functions associated with a potential 10^{-4} pa bottom line claim of protection from the qualified sections of the N2 system could be challenged from a BDB event can be estimated. This is judged to be greater than twice the seismic hazard DB level.

51. The seismic walkdown qualification is based upon the use of earthquake experience data developed by the SQUG and presented in the Generic Implementation Procedure (GIP, Ref. 37). A Reference Spectrum was obtained by averaging and smoothing the average horizontal spectra from four recordings of data from earthquakes of magnitude 6.0 or greater and database facilities which have experienced a peak ground acceleration of 0.4g (compare with paras 30 and 33). The Reference Spectrum allowed comparison of the potential seismic exposure of equipment in a nuclear power plant with the estimated ground motion that similar equipment actually resisted in earthquakes described in the SQUG data base. Details of the seismic walkdown evaluation of the DHD system are presented in Ref. 32 and the adequacy of this has been reviewed by ONR's Civil Engineering and External Hazards Professional Lead (para 42). The GIP is also discussed further below (section E).

Conclusion 4: I judge that acceptable margins against BDB seismic events have been adequately demonstrated (ONR SAPs ERC.2, EHA.7, EHA.18).

E) IDENTIFY AND ASSESS ADJACENT PLANT WITH THE POTENTIAL TO DAMAGE THE DHD SYSTEM

52. The GIP earthquake experience data (see para 51 and Ref. 29**Error! Bookmark not defined.**) also defines the important characteristics and features which equipment should have (or not have) in order to have seismic capacities equal to or greater than the Reference Spectrum. These characteristics and features are addressed by both inclusion rules (range of general parameters of the equipment included within each class of equipment) and exclusion rules or caveats (specific equipment design and installation features which should be avoided as being seismically vulnerable).

53. The inclusion rules were based upon the characteristics of the equipment at the Reference Spectrum database sites using experience and judgement. Similarly, the exclusion rules were based upon lessons learned from equipment performance and expert judgement as to what features and characteristics should be avoided. Secondary interactions, e.g. masonry walls and other adjacent non-qualified plant or structures are identified in the walkdown process as outliers for specific assessment. This is a key part of the walkdown qualification process as it addressed local and site specific interaction threats.

54. In developing the GIP, SQUG performed walkdowns and collected earthquake experience data at various sites that had experienced large earthquakes. A key attribute of the earthquake experience data collected by SQUG is that nearly all the equipment subjected to strong motion earthquakes performed satisfactorily during and/or following the earthquake. The relatively few instances of damage in the database would have been prevented if the equipment had been screened by the GIP screening criteria.

55. Thus the actual onset of failure or malfunction occurs at higher seismic loadings than those defined in the reference spectrum e.g. an envelope of all the spectral ordinates at each frequency from the earthquakes represents a lower bound estimate of the capacity at that frequency.

56. Noting Refs. 32**Error! Bookmark not defined.** and 33, I judge that the above process as described in Ref. 29**Error! Bookmark not defined.** is adequate in principle to identify and assess adjacent plant with the potential to damage the DHD system.

57. The adequacy of the SQUG walkdown method, scope and implementation have been discussed previously (paras 42 and 47). Seismic interactions from plant near to the DHD system have been assessed as part of the SQUG GIP walkdown process (Refs. 32**Error! Bookmark not defined.** and 33). Interactions of note or concern are identified within each walkdown as outliers and then subsequently assessed or modified as appropriate. The main interactions arose from non-seismically qualified H&V plant, masonry walls, drain lines and cabling trays. In addition, the main buildings that support / protect the internal DHD system, e.g. Reactor Building, Fuel Handling Building, Gas Circulator Halls were already qualified under PSR. All the external DHD system was upgraded by new design and installation of a dedicated N2 plant including seismically qualified reactor coolant trench ducts up to the point where the system enters the Reactor Building (Ref. 35).

58. The head documents (Refs. 31 and 32) collect together the key qualification aspects and seismic walkdown issues and provide confirmation that the DHD system, including allowance for interactions from nearby plant (also note para 50, 4th bullet point on BDBE margins), is seismically adequate with outliers and recommendations from the earlier walkdowns completed.

Conclusion 5: I judge that the SQUG GIP walkdown process is adequate in line with RGP and has been adequately implemented with respect to assessing interactions from plant adjacent to the DHD system and resolving the identified outliers (ONR SAPs SC.4, ECE.1, EHA.1 and EHA.6).

4.3 Comparison with Standards, Guidance and Relevant Good Practice

59. As stated in section 2.1, the relevant standards, guidance and RGP adopted within this assessment are principally the SAPs (Ref. 14) and TAGs (Ref. 15). The relevant SAPs are cited in the assessment text and listed within Table 1. My findings (para 66) indicate that the licensee's submission complies with all of the relevant SAPs.

4.4 ONR Assessment Rating

60. My assessment of the licensee's submission with respect to the seismic safety case for the DHD system has not identified any non-compliances with the relevant standards. On this basis I judge that a rating of 'green' is appropriate in accordance with the ONR assessment rating guide (Ref. 38).

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

61. This report presents the findings of the ONR assessment of the seismic safety case for the DHD system at Hunterston B power station, which supports the Hunterston B return to service safety case for Reactor 4 following core inspection results in 2018 (Ref. 1).

62. Based on the foregoing assessment I am satisfied that NGL has adequately addressed the five shortfalls which I identified in Ref. 12.

63. As noted in conclusion 2 (para 35), the clarity of the seismic safety case for the HNB DHD system could be improved, but despite this I am satisfied with the claims, arguments and evidence laid down within the licensee's safety case. Overall I judge this element of the submission adequate to justify the issue of a Licence Instrument to signify ONR's Agreement under arrangements made under Licence Condition 22 (1).

64. Findings:

- **Finding 1:** (Para 33) NGL should consider expanding the substantiation of the bottom line seismic design bases for the HNB and HPB sites in its long term safety cases to improve confidence in their rigour and compliance with modern assessment standards.

65. Observations:

- **Observation 1:** NGL has not presented the claims succinctly in a single document, which would improve the clarity of the safety case.

66. My assessment has reached the following conclusions:

- **Conclusion 1:** NGL has made an adequate argument with regards to the characterisation and substantiation of the bottom line seismic design basis (ONR SAPs EHA.4 and FA.5) for the DHD system.
- **Conclusion 2:** NGL has adequately clarified the claims on the DHD system (ONR SAPs FA.8, ERL.1).
- **Conclusion 3:** NGL has adequately substantiated the DHD system against the relevant seismic claims (ONR SAP EQU.1).
- **Conclusion 4:** I judge that acceptable margins against BDB seismic events have been adequately demonstrated (ONR SAPs ERC.2, EHA.7, EHA.18).
- **Conclusion 5:** I judge that the SQUG GIP walkdown process is adequate in line with RGP and has been adequately implemented with respect to assessing interactions from plant adjacent to the DHD system and resolving the identified outliers (ONR SAPs SC.4, ECE.1, EHA.1 and EHA.6).

5.2 Recommendations

67. I have not raised any recommendations based on this assessment.

6 REFERENCES

1 NP/SC 7785 - Hunterston B - Return to service safety case for Reactor 4 following core inspection results in 2018, EC 364115, Revision 000 Proposal Version 8, EDF Energy, March 2019, CM 2019/76309.

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

3 EDF Energy letter to ONR – Hunterston B Nuclear Site Licence No. Sc.13 - Request for Approval under Licence Condition 22 (2), EC 364115 - Return to service safety case for Reactor 4 following core inspection results in 2018, 6 November 2018, CM 2018/365949.

4 NP/SC 7557, EC 351745 Version 5, HNB Enhanced Long Term Shutdown Provisions Stage Submission 5: Safety Case for Putting the New Nitrogen Injection and Blowdown Plant Into Operational Service, CM 2015/53466.

5 HNB N2 Plant Flow Diagram - C24_41418_EDF_336340 Sht 1 Rev 021 - 2018_280158, CM 2018/280158.

6 HNB N2 Plant Flow Diagram - C24_41418_EDF_336340 Sht 2 Rev 007 - 2018_280181, CM 2018/280181.

7 HNB N2 Plant Flow Diagram - C24_41418_SNL_320794 Sht 1 Rev 006 - 2018_280187, CM 2018/280187.

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21 NP/SC 7557 Stage Submission 3C EC 348654 000, Hunterston B Power Station. New Blowdown and Nitrogen Injection Provisions – Overall Design Substantiation, Encompassing Civil, Mechanical, Electrical and Control System Elements.

22 NP/SC 7557 Stage Submission 3B EC 346159 000, Hunterston B Power Station. New Nitrogen Storage and Distribution Plant – Mechanical Engineering Design.

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34 Technical Assessment Guide, External Hazards. NS-TAST-GD-013, Revision 7. October 2018. http://www.onr.org.uk/operational/tech_asst_guides/index.htm (2018/315641).

35 Email, References supporting HNB DHD system seismic assessment, CM 2019/78680 (especially note email at 14:58 on 11/3/19).

36 Email on 29/4/19, Review required by Civils SQEP - CM 2019/124065.

37 Seismic Qualification Utility Group (SQUG) Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Power Plant Equipment.

38 ONR Assessment Rating Guide Table (2016/118638).

Table 1

Relevant Safety Assessment Principles Considered During the Assessment (listed in alphabetical order)

SAP No	SAP Title	Description	Paras in main text
ECE.1	Engineering principles: civil engineering: Functional performance	The required safety functions and structural performance of the civil engineering structures under normal operating, fault and accident conditions should be specified.	15, 58
EDR.4	Engineering principles: design for reliability: Single failure criterion	During any normally permissible state of plant availability, no single random failure, assumed to occur anywhere within the systems provided to secure a safety function, should prevent the performance of that safety function.	4
EHA.1	Engineering principles: external and internal hazards: Identification and characterisation	An effective process should be applied to identify and characterise all external and internal hazards that could affect the safety of the facility.	15, 58
EHA.4	Engineering principles: External and internal hazards: Frequency of initiating event	For natural external hazards, characterised by frequency of exceedance hazard curves and internal hazards, the design basis event for an internal or external hazard should be derived to have a predicted frequency of exceedance that accords with Fault Analysis Principle FA.5. The thresholds set in Principle FA.5 for design basis events are 1 in 10 000 years for external hazards and 1 in 100 000 years for man-made external hazards and all internal hazards (see also para 629). Para. 239: For external hazards, the design basis event should be derived conservatively to take account of data and model uncertainties.	15, 33
EHA.6	Engineering principles: external and internal hazards: Analysis	The effects of internal and external hazards that could affect the safety of the facility should be analysed. The analyses should take into account hazard combinations, simultaneous effects, common cause failures, defence in depth and consequential effects.	15, 58
EHA.7	Engineering principles: external and internal hazards: ‘Cliff-edge’ effects	A small change in DBA parameters should not lead to a disproportionate increase in radiological consequences.	15, 51
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.	15, 51

		Para. 246. Analysis of beyond design basis events should; a) confirm the absence of 'cliff edge' effects just beyond the design basis (Principle EHA.7); b) identify the hazard level at which safety functions could be lost (i.e. determine the beyond design basis margin) (non-discrete hazards only); c) provide an input to probabilistic safety analysis of whether risk targets are met (see para 713 ff.); d) ensure that safety is balanced so that no single type of hazard makes a disproportionate contribution to overall risk (see para 749); and e) provide an input to severe accident analysis (non-discrete hazards only) (see paras 663 ff.).	
EHF.8	Engineering principles: human factors Personnel competence	A systematic approach to the identification and delivery of personnel competence should be applied.	48
EKP.3	Engineering principles: key principles: Defence in depth	Nuclear facilities should be so designed and operated so that defence in depth against potentially significant faults or failures is achieved by the provision of multiple independent barriers to fault progression.	4
EMC.33	Engineering principles: integrity of metal components and structures: analysis: Use of data	The data used in analyses and acceptance criteria should be clearly conservative, taking account of uncertainties in the data and their contribution to the safety case.	48
EQU.1	Engineering principles: equipment qualification: Qualification procedures	Qualification procedures should be applied to confirm that structures, systems and components will perform their allocated safety function(s) in all normal operational, fault and accident conditions identified in the safety case and for the duration of their operational lives.	15, 46
ERC.2	Engineering principles: reactor core: Shutdown systems	At least two diverse systems should be provided for shutting down a civil reactor.	4, 15, 51
ERL.1	Engineering principles: reliability claims: Form of claims	The reliability claimed for any structure, system or component should take into account its novelty, experience relevant to its proposed environment, and uncertainties in operating and fault conditions, physical data and design methods.	15, 35
FA.5	Fault analysis: design basis analysis: Initiating faults	The safety case should list all initiating faults that are included within the design basis analysis of the facility.	15, 33
FA.8	Fault analysis: design basis analysis: Linking of initiating faults, fault sequences and safety measures.	DBA should provide a clear and auditable linking of initiating faults, fault sequences and safety measures.	15, 35

SC.1	The regulatory assessment of safety cases Safety case production process	The process for producing safety cases should be designed and operated commensurate with the hazard, using concepts applied to high reliability engineered systems.	48
SC.4	The regulatory assessment of safety cases: Safety case characteristics	A safety case should be accurate, objective and demonstrably complete for its intended purpose.	15, 58