New Reactors Programme

GDA close-out for the AP1000 reactor

GDA Issue GI-AP1000-CE-03: Justification that materials adopted on the AP1000 design are compatible for what would normally be expected for European construction

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EXECUTIVE SUMMARY

Westinghouse Electric Company LLC is the reactor design company for the **AP1000®** reactor. Westinghouse completed Generic Design Assessment (GDA) Step 4 in 2011 and paused the regulatory process. It achieved an Interim Design Acceptance Confirmation (IDAC) which had 51 GDA issues attached to it. These issues require resolution prior to the award of a Design Acceptance Confirmation (DAC) and before any nuclear safety-related construction can begin on site. Westinghouse re-entered GDA in 2014 to close the 51 issues.

This report is the Office for Nuclear Regulation's (ONR's) assessment of the Westinghouse **AP1000** reactor design in the area of civil engineering. Specifically, this report addresses GDA Issue GI-AP1000-CE-03: Justification that materials adopted on the **AP1000** reactor design are compatible for what would normally be expected for European construction. It includes a clear statement on procedures for accepting suppliers' proposals for material substitution of European materials for the US materials specified in the **AP1000** reactor design.

During Step 4, it was identified that the Westinghouse **AP1000** design submission and the civil engineering standards that it references typically refer to construction materials conforming to US standards and requirements. Construction materials in the UK are predominately in accordance with European specifications. This GDA issue therefore arose in Step 4 due to concerns about the following:

- Procedures will need to be robust for accepting suppliers' material substitutions without endangering the design principles.
- The US standards must be at least equivalent to European standards or normal European industry good practice. Additional specification clauses may therefore need to be added.
- Certain materials will almost certainly be sourced locally, eg concrete and other bulk materials. The current strategy to use US specifications throughout does not make any allowance for this.

As a result of the above concerns, GDA Issue GI-AP1000-CE-03 was raised.

The Westinghouse GDA issue resolution plan stated that its approach to closing the issues was:

- Westinghouse will review its standard design specifications for structural steel in light of European standards and as appropriate develop requirements for maximum yield stress and Charpy V notch tests.
- Westinghouse will submit the **AP1000** reactor safety-related concrete specification and provide a concrete justification report to justify the claims within the specification.

My assessment conclusion is:

- The steel materials specified have been adequately justified to achieve the designed intent and to comply with known design and specification codes.
- Testing of steel materials complies with US standards but does not comply fully with established European codes of practice. An Assessment Finding has been raised on this.
- The concrete mix has been adequately justified for use of UK materials, use of self-consolidating concrete and to incorporate UK-specific requirements on concrete design.
- Testing of construction concrete has been specified to the applied design code. As some of these are not common practice in the UK, a Minor Shortfall has been raised.

My judgement is based on the following factors:

- Safety Assessment Principles

- Technical Assessment Guides
- Standards and Guidance providing relevant good practice
- technical findings of the Technical Support Contractor (TSC)
- regular interactions with the requesting party

The following matters remain, which are for a future licensee to consider and take forward in its site-specific safety submissions. These matters do not undermine the generic safety submission.

There are two Assessment Findings, both from Action 1:

- The Licensee shall discount brittle failure mechanisms within the beyond design basis justification using the site specific seismic conditions and construction materials for all SC structures.
- The licensee shall demonstrate that its testing regime for Charpy V notch testing is compliant with BS EN 1993-1-10 or provide and justify an equivalent level of assurance.

There is one Minor Shortfall, from Action 2:

- The UK uses cube specimens for compressive strength determination as the basis of concrete design, supply and verification. Structural design to Eurocodes is based on cylinder strength and the use of cube testing in support of this has proved satisfactory. The licensee should consider the current practices in the UK and the use of established conversion techniques from cube testing to cylinder testing for future concrete supply.

In summary, I am satisfied that GDA Issue GI-AP1000-CE-03 can be closed.

LIST OF ABBREVIATIONS

ACI	American Concrete Institute
AISC	American Institute of Steel Construction
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials (American section of the International Association for Testing Materials)
BDBE	Beyond Design Basis Earthquake
BS	British Standard
CA	CA (Naming convention) modules are the prefabricated structural modules used for the in containment structures and within the auxiliary building. These comprise steel / concrete composite or steel only modules used for walls and floors.
DAC	Design Acceptance Confirmation
DBE	Design Basis Earthquake
GDA	Generic Design Assessment
IDAC	Interim Design Acceptance Confirmation
ONR	Office for Nuclear Regulation
PCSR	Pre-Construction Safety Report
RQ	Regulatory Query
SAPs	Safety Assessment Principles
SC	Steel-Concrete (Naming convention) modules are the prefabricated structural modules made of steel plate materials.
SSE	Safe Shutdown Earthquake
TAG	Technical Assessment Guide
TSC	Technical Support Contractor

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1 INTRODUCTION

1.1 Background

1. Westinghouse completed Generic Design Assessment (GDA) Step 4 in 2011 and paused the regulatory process. It achieved an Interim Design Acceptance Confirmation (IDAC) which had 51 GDA issues attached to it. These issues require resolution prior to the award of a Design Acceptance Confirmation (DAC) and before any nuclear safety-related construction can begin on site. Westinghouse re-entered GDA in 2014 to close the 51 issues.

2. This report is the Office for Nuclear Regulation's (ONR's) assessment of the Westinghouse **AP1000**® reactor design in the area of civil engineering. Specifically, this report addresses GDA Issue GI-AP1000-CE-03: Justification that materials adopted on the **AP1000** reactor design are compatible for what would normally be expected for European construction. It includes a clear statement on procedures for accepting suppliers' proposals for material substitution of European materials for the US materials specified in the **AP1000** reactor design.

3. The related GDA Step 4 report (Ref. 1) is published on our website (**www.onr.org.uk/new-reactors/ap1000/reports.htm**), and this provides the assessment underpinning the GDA issue. Further information on the GDA process in general is also available on our website (**www.onr.org.uk/new-reactors/index.htm**).

1.2 Scope

4. The scope of this assessment is detailed in the assessment plan (Ref. 2). As detailed within the plan, the assessment is restricted to considering whether the Westinghouse submissions stated in the resolution plan (Ref. 3) for resolving Issue GI-AP1000-CE-03 (and its two actions) provide an adequate response to justify closure of the issue. As a result, this report only presents the assessment undertaken as part of the resolution of this GDA issue and you should read this report in conjunction with "Step 4 Civil Engineering and External Hazards Assessment of the Westinghouse AP1000® Reactor" (Ref. 1) and assessment reports for Issues GI-AP1000-CE-01, GI-AP1000-CE-02 and GI-AP1000-CE-04 in order to appreciate the totality of the assessment undertaken for civil engineering as part of the GDA process.

5. The scope of assessment focused on the two main actions set out by this issue which are stated in paragraphs 6 and 7 below.

6. GDA Issue **GI-AP1000-CE-03 Action A1** comprises four detailed actions with specific reference to steel plate materials. Although the observations are specifically for the CA modules, the issue is raised for the whole generic site to ensure that such oversights are not made elsewhere. Correct material specification is fundamental to the safety of the design – for example, specifying a maximum strength for steel ensures ductility, so this needs to be properly documented in the safety case. The four detailed items within this action are as below:

Item 1. ASTM (American section of the International Association for Testing Materials) A572, "Standard Specification for High-Strength Low-Alloy Columbian-Vanadium Structural Steel" (Ref. 4), only covers grade 60 up to 1.25 inches thick. Therefore, the 1.5 inch-thick plates to be used on the CA modules (Ref. 5) are not covered by the claimed standard A572.

Item 2. ASTM A572 specifies minimum values of yield and tensile strengths. It does not specify maximum values of these strengths or the ratio of yield to tensile strength, ie ductility. Maximum values are specified for European materials to ensure that an element is not significantly stronger than assumed in the design, such that the failure mechanism of the whole system occurs in a different location to that intended by the designer. Similarly, if the ductility of a material is low, this will tend towards brittle failure. Good practice, particularly for seismic structures, is to have ductile failure mechanisms.

Item 3. ASTM A588, "Specification for High-Strength Low-Alloy Structural Steel, up to 50ksi [345MPa] Minimum Yield Point, with Atmospheric Corrosion Resistance" (Ref. 6), is for steel with atmospheric corrosion resistance and is usually used on external structures, particularly bridges. Weathering steels such as these are similar to ordinary structural steels but with additions of small amounts of alloying elements, typically copper. Under the appropriate environmental conditions, these alloy additions allow the steel to form a stable patina on the surface that greatly slows down corrosion rates compared with other steels and it is therefore possible to use weathering steels in fully exposed conditions without additional corrosion protection. The UK Highways Agency guidance BD7/01 on the use of this steelwork for bridges (Ref. 7) gives a list of situations where it is not to be used, which includes "where the steel would be continuously wet or damp". If the conditions are such that the steel is permanently damp, the patina may not form and the steel may continue to corrode. Justification is required that this steel is being used in the appropriate environments.

Item 4. The specification of Charpy V notch impact tests is a normal requirement for structural steelwork in the UK. BS EN 1993 (Eurocode 3, Ref. 8) Part 1-1 requires that brittle fracture is considered for all structures and refers to Part 1-10 for conditions that satisfy that requirement. Part 1-10 gives rules for the selection of the subgrade of steel, ie the Charpy V-notch value. **AP1000** design specifications should therefore ensure that the steel complies with BS EN 1993-1-10, including the UK national annex, since this is a supplementary requirement for the claimed standard ASTM A572.

7. GDA Issue **GI-AP1000-CE-03 Action A2** comprises a single action for Westinghouse to support a review of its concrete construction specification in order to confirm whether it satisfies expectations for the generic design. The main concerns were raised because detailed design for UK concrete will adopt local constituent materials and therefore the mix designs for all concrete will need to be re-specified. The items most affected by a change from US to UK standards are as follows:

Item 1. Types of aggregate can affect the coefficient of thermal expansion of the concrete. Limestone is the most commonly used aggregate in the UK.

Item 2. The mix used for self-compacting concrete is of particular concern for steel-concrete composite construction where the size of aggregate and matrix design can affect the shear stud interaction.

Item 3. European specifications for concrete now take due account of concrete ageing or deterioration effects such as alkali-silica reaction. The US standards proposed need to include the same improvements.

Item 4. UK concrete strength testing is usually based on cube strengths rather than cylinder strengths.

Item 5. On-site testing of concrete mixes will be different in the UK to that used in the US, and so exact testing procedures need to be confirmed.

8. The scope of assessment is appropriate in order to complete the Step 4 assessment of the civil engineering designs that remained incomplete when the previous Step 4 stage was paused. The previous GDA assessment scope was necessary to complete sufficient detailed assessment of the civil engineering designs to allow ONR to come to a judgement whether a DAC can be issued.

1.3 Method

9. This assessment complies with internal guidance on the mechanics of assessment within ONR (Ref. 9).

1.3.1 Sampling strategy

10. It was not practicable or necessary to assess all components of the work scope to the same degree. The ONR approach used a combination of two different assessment methods: 1) broad review and 2) deep-dive assessment. A broad review is used to provide an overview of a submission or a significant part of a submission. A deep-dive assessment is undertaken (if required) on one (or more if appropriate) element of a submission to examine the detail from the response, through the detail design development to the final output for construction.

2 ASSESSMENT STRATEGY

2.1 Pre-Construction Safety Report

11. ONR's "Generic Design Assessment Guidance to Requesting Parties" (www.onr.org.uk/new-reactors/ngn03.pdf) states that the information required for GDA may be in the form of a Pre-Construction Safety Report (PCSR). Technical Assessment Guide (TAG) 051 sets out regulatory expectations for a PCSR (www.onr.org.uk/operational/tech_asst_guides/ns-tast-gd-051.pdf).

12. At the end of Step 4, ONR and the Environment Agency raised GDA Issue CC-02 (www.onr.org.uk/new-reactors/reports/step-four/westinghouse-gda-issues/gi-ap1000-cc-02.pdf) requiring that Westinghouse submit a consolidated PCSR and associated references to provide the claims, arguments and evidence to substantiate the adequacy of the **AP1000** reactor design reference point.

13. A separate regulatory assessment report is provided to consider the adequacy of the PCSR and closure of GDA Issue CC-02, and therefore this report does not discuss the civil engineering aspects of the PCSR. This assessment focused on the supporting documents and evidence specific to GDA Issue GI-AP1000-CE-03.

2.2 Standards and Criteria

14. The standards and criteria adopted within this assessment are principally the Safety Assessment Principles (SAPs) (Ref. 10), internal TAGs (Ref. 11), relevant national and international standards, and relevant good practice informed from existing practices adopted on UK nuclear-licensed sites.

2.2.1 Safety Assessment Principles

15. The key SAPs applied within the assessment are included within Table 1.

Table 1: ONR Safety Assessment Principles used in this assessment

Description
Civil Engineering SAPs within the Engineering Principles ECE.1 Engineering principles: civil engineering. The required safety functions and structural performance of the civil engineering structures under normal operating, fault and accident conditions should be specified. ECE.2 Engineering principles: civil engineering. Independent arguments ECE.16 Engineering principles: civil engineering: construction. Materials ECE.17 Engineering principles: civil engineering: construction. Prevention of defects ECE.18 Engineering principles: civil engineering: construction. Inspection during construction

2.2.2 Technical Assessment Guides

16. The TAGs that have been used as part of this assessment are set out in Table 2.

Table 2: ONR Technical Assessment Guides used in this assessment

NS-TAST-GD-017 Civil Engineering Revision 3 T/AST/076 Construction Assurance Issue 1

2.2.3 National and International Standards and Guidance

17. The international standards and guidance that have been used as part of this assessment are set out in Table 3.

Table 3: National and International Standards and Guidance used in this assessment

Standard Title
BS EN 1993-1-10: 2005. Eurocode 3: Design of steel structures. Part 1-10: Material toughness and through-thickness properties.
NA to BS EN 1993-1-10: 2005. National Annex (informative) to Eurocode 3: Design of steel structures. Part 1-10: Material toughness and through-thickness properties.
PD 6695-1-10: 2009. Published document. Recommendations for the design of structures to BS EN 1993-1-10.
BS EN 10025-1: 2004. Hot rolled products of structural steels. Part 1: General technical delivery conditions.
BS EN 10025-3: Hot rolled products of structural steels. Part 3: technical delivery conditions for normalized/normalized rolled weldable fine grain structural steels.
BS EN 10025-5: 2004. Hot rolled products of structural steels. Part 5: Technical delivery conditions for structural steels with improved atmospheric corrosion resistance.
British Geological Society, Construction Aggregates, Mineral Planning Factsheet, June 2013.
BS EN 206: 2013, Concrete – Specification, performance, production and conformity.
BS 8500: 2015 Concrete – Complementary British Standard to BS EN 206.
APP-0000-C9-001, “AP1000 Concrete General Notes” Revision 7.

2.3 Use of Technical Support Contractors

18. It is usual in GDA for ONR to use Technical Support Contractors (TSC) – for example, to provide additional capacity to optimise the assessment process, to enable access to independent advice and experience, analysis techniques and models, and to enable ONR‘s inspectors to focus on regulatory decision-making, etc.

19. A TSC was used across all areas of this assessment scope to provide resource and expertise not available within ONR.

20. While the TSCs undertook the detailed technical reviews, this was done under supervision from ONR. ONR made the regulatory judgement on the adequacy of the civil engineering arguments for the **AP1000** reactor.

2.4 Integration with Other Assessment Topics

21. GDA requires the submission of an adequate, coherent and holistic generic safety case. Regulatory assessment cannot therefore be carried out in isolation as there are often safety issues of a multi-topic or cross-cutting nature.

22. However, **no cross-cutting issues** are considered as part of this assessment.

2.5 Out of Scope Items

23. The ONR issues and the Westinghouse resolution plans clearly defined the scope of the assessment. Table 4 sets out the items that are agreed with Westinghouse as being outside the scope of GDA.

Table 4: Out of Scope Items

Post-Fukushima considerations
Malicious aircraft impact assessment
Site-specific considerations

3 REQUESTING PARTY'S RESPONSE TO GDA ISSUE GI-AP1000-CE-03

24. The Westinghouse safety case for GDA Issue GI-AP1000-CE-03, "Justification that materials adopted on the **AP1000** design are compatible for what would normally be expected for European construction", is documented in Westinghouse's UK **AP1000** reactor GDA Resolution Plan (Ref. 3).

25. The Westinghouse response is structured against the GDA issue, where the scope of the GDA issue is further described by reference to a number of actions. The Westinghouse response is summarised as follows.

26. **Westinghouse Response to Action GI-AP1000-CE-03.A1**

A summary document (Ref. 12) outlined the key conclusions and justifications of the Westinghouse response and referenced a number of documents that supported these conclusions. Westinghouse supplied the referenced documentation (full response to RQ-AP1000-1508 (Ref. 13)) with further information supplied as full responses to Regulatory Queries (RQs) RQ-AP1000-1572 (Ref. 14) and RQ-AP1000-1661 (Ref. 15). This information encompasses the response for Action 1. The submitted documents covered the following:

- Item 1: Steel plate US standards ASTM A572 and A588 cover certain steel grades and thicknesses. Westinghouse identified which standards will be used and explained their applicability and suitability in situations where steel plate is to be used outside the range covered by the proposed standards.
- Item 2: Westinghouse stated the use of the ACI (American Concrete Institute) 349 approach and claimed that the structure remains elastic under design basis loading. A pushover analysis of the Sheild Building at 2.4 times the Design Basis Earthquake (DBE) is used to demonstrate this elasticity for conditions up to and beyond the DBE.
- Item 3: Westinghouse gave a justification for the use of steel grade ASTM A588 within the design and the environment in which it will be used. This included the statement that the corrosion-resistant properties were not being claimed; rather, a protective coating would be applied.
- Item 4: Westinghouse specified that all steels conform to AISC (American Institute of Steel Construction) N690, which has specific requirements for the Charpy V notch impact tests.

27. **Westinghouse Response to Action GI-AP1000-CE-03.A2**

A summary document (Ref. 16) outlined the key conclusions and justifications of the Westinghouse safety case and referenced a number of documents that supported these conclusions. Westinghouse supplied the referenced documentation (full response to RQ-AP1000-1509 (Ref. 17)) with the further information as a full response to query RQ-AP1000-1573 (Ref. 18). This information encompasses the safety case for Action 2. The submitted documents covered the following:

- Item 1: Westinghouse supplied a justification for the type of aggregate and the coefficient of thermal expansion. The justification indicates that limestone aggregate is within the normal range of thermal expansion. Westinghouse also supplied a compliance matrix of UK standards that could be substituted in place of the US standards.
- Item 2: Westinghouse gave a justification for the use of self-consolidating concrete and its interaction with shear studs. This included references to tests undertaken by Westinghouse that reported its suitability. Westinghouse also supplied

photographs of a mock-up prototype CA20 module showing the flow of self-consolidating concrete between the shear studs.

- Item 3: Westinghouse provided a justification for concrete durability to achieve its service life. This included a submission from Westinghouse stating that BS 8500 should be applied to accommodate sulphate attack.
- Item 4: Westinghouse stated that cylinder tests would be undertaken in compliance with the design code used: ACI 349-01.
- Item 5: Westinghouse explained concrete mix testing. It stated that these procedures would be to US standards in compliance with ACI 349-01 (the primary design code used).

4 ONR ASSESSMENT OF GDA ISSUE GI-AP1000-CE-03

28. My assessment of Westinghouse's submissions for GDA Issue GI-AP1000-CE-03 is set out below.

29. I have carried out this assessment in accordance with the HOW2 guide NS-PER-GD-014, "Purpose and Scope of Permissioning" (Ref. 19).

4.1 Scope of Assessment Undertaken

30. The scope of this assessment was limited to the scope of GDA Issue GI-AP1000-CE-03, as presented by Westinghouse in the related resolution plan (Ref. 3). For this issue, I considered that a deep-dive assessment was not required and I judged a broad review to be sufficient. I assessed only the topics included in the actions listed in this GDA issue and I investigated no other topics.

4.2 Assessment

31. Westinghouse prepared the submissions in accordance with the resolution plan (Ref. 3) and submitted them for ONR assessment in accordance with the integrated schedule (Ref. 20). ONR, the TSC and Westinghouse held weekly teleconferences to progress and resolve technical questions. The ONR TSC technically reviewed all received information and compiled a report of its findings (Ref. 21).

4.2.1 Westinghouse Response to GI-AP1000-CE-03.A1

Overview

32. Westinghouse submitted letter WEC-REG-0197N (Ref. 21) with two enclosures. Enclosure 1 was another letter explaining the submission (Ref. 22) and Enclosure 2 was a summary document (Ref. 12) of the response to GDA Issue GI-AP1000-CE-03 Action 1 (all items). The summary document outlined the conclusions reached by Westinghouse regarding the actions and identified the key documents where these conclusions were defined. ONR raised RQ-AP1000-1508 (Ref. 13), RQ-AP1000-1572 (Ref. 14) and RQ-AP1000-1661 (Ref. 15). Westinghouse supplied further information to accommodate a comprehensive assessment.

Assessment of Item 1

33. Item 1 is as follows: "ASTM A572, 'Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel' (Ref. 4), only covers grade 60 up to 1.25 inches thick. Therefore, the 1.5 inch-thick plates to be used on the CA modules (Ref. 5) are not covered by the claimed standard A572."

34. To elaborate, the steel grades and associated mechanical properties are restricted to thickness limits which are stipulated in the respective ASTM product standards. The objective of Action 1 item 1 was, therefore, to understand the extent to which each steel product standard and grade would be used with reference to the stated thickness limits.

35. Westinghouse has clarified that it proposes to use ASTM A572 / A572M grade 60 for materials up to and including 1.25 in (31.8 mm). This is consistent with and corresponds to the maximum thickness limit for the grade of structural steel given in ASTM A572 / A572M. Beyond this thickness limit Westinghouse proposes to use either ASTM A572 / A572M grade 50 or ASTM A588 / A588M.

36. Westinghouse stated in the summary document (Ref. 12) that these material product standards, steel grades and plate sizes shall be chosen based on structural demand to meet the appropriate design code of practice.

37. Westinghouse reported that typical plate thicknesses are 0.5 in (12.7 mm) and in limited locations the plate thickness can be 1.5 in (38.1 mm). Within the response to RQ-AP1000-1572 (Ref. 14, Comment 1), Westinghouse reported that it has reviewed the CA module and shield building design and has determined that the structural materials used are within applicability as defined by the design bases and material standard requirements.

38. Westinghouse stated in the summary document (Ref. 12) that these steels are being used in an environment where the materials are not intended to be wet in normal service operation. The materials will, however, be provided with a corrosion protection system, although corrosion is not a design-limiting factor.

39. Westinghouse has confirmed in the summary document (Ref. 12) that duplex stainless steel for the wetted surfaces of CA modules (eg spent fuel pool, in-containment refuelling water storage tank, refuelling canal) will use ASTM A240 UNS designation S32101. It further reported that the plate thickness range is less than 1 in (25.4 mm). The mechanical properties quoted by Westinghouse are consistent with thicknesses >0.187 in (5 mm) as quoted in ASTM A240. As such, the plates are being used within the proposed range of the product standard.

40. Following the above assessment, I judge the responses to Action 1 item 1 to satisfy SAP ECE. 16 as the structural materials used are within applicability as defined by the design bases and material standard requirements.

Assessment of Item 2

41. Item 2 is as follows: “It is usual practice in Europe to specify maximum values of yield and tensile strengths and the ratio of yield to tensile. This is to ensure appropriate ductile behaviour. As ASTM A572 does not specify maximum strengths, define the maximum strengths to be specified as additional clauses to US steel standards ASTM A572, Duplex 2101, etc. This may be done on a structure-by-structure basis depending on the ductile performance required.”

42. In its response, Westinghouse has stated that its design approach simply follows the limit state approach set out in ACI 349 and / or the working stress approach of ANSI (American National Standards Institute) / AISC N690 as appropriate; that is, the design follows the recognised codes of practice. In effect, Westinghouse asserted that the design is such that under the maximum demand the structures remain elastic and therefore remain ductile.

43. Westinghouse stated in the summary document (Ref. 12) that this same design philosophy is applied to non-safety-related buildings.

44. While this action item undoubtedly relates to materials and specifically material property limits, more fundamentally the issue applies to that of seismic design and the perceived adequacy or otherwise of the design approach being adopted. As noted above, it is usual practice in Europe to specify maximum values of yield strength. This in turn relates to the Beyond Design Basis Earthquake (BDBE) structural response, whereby excessive material over-strength could lead to non-ductile failure mechanisms governing the response, and therefore the formation of a brittle collapse mechanism under a beyond design basis event.

45. In response to queries, Westinghouse provided further commentary in response to RQ-AP1000-1572 (Ref. 14, Comment 2) regarding the maximum yield strength of ASTM A572 material. The pushover analysis referred to by Westinghouse (which has not been reviewed) is stated to demonstrate that the shield building remains elastic up to 2.4 x Safe Shutdown Earthquake (SSE). This would be considered acceptable for demonstrating the BDBE margin, provided that shear response and other brittle failure

mechanisms are included in the pushover analysis (or that they are checked separately after the analysis at 2.4 x SSE). The engineering principles for required safety functions and structural performance in SAPs 2014 (Ref. 10) states that:

> *Margins should be such that civil engineering structures will continue to provide their residual safety function(s) following the application of beyond design basis loads by either having sufficient design margins, or by failing in a manner that suitably limits the radiological consequences* (ECE.1 334)

46. A similar criterion would apply to elements that use duplex stainless steel. If brittle mechanisms do not develop with sufficient margin, then this is an adequate demonstration of BDBE response, and higher material over-strength would not compromise this.

47. I judge the Westinghouse response to resolution plan Action 1 item 2 – ASTM A572 Maximum Yield Strength – to satisfy SAPs ECE.1 and ECE.2 by demonstrating that BDBE response has sufficiently high margin, subject to the licensee demonstrating that brittle mechanisms do not develop in other areas of the structure due to material over-strength. I have raised an Assessment Finding to capture this within the site-specific stage as AF-AP1000-CE-03-01:

Assessment Finding CP-AF-AP1000-CE-01: The Licensee shall discount brittle failure mechanisms within the beyond design basis justification using the site specific seismic conditions and construction materials for all SC structures.

<u>Assessment of Item 3</u>

48. Item 3 is as follows: “Justify that the environment is appropriate for the performance of ASTM A588 in all locations where it will be used.”

49. The product standard ASTM A588 / A588M relates to steels with improved atmospheric corrosion resistance, which might otherwise be more typically termed weathering steels in UK terminology. The degree to which this resistance was being claimed as part of the long term integrity of the steel was unclear.

50. In its response, Westinghouse simply confirmed that the additional corrosion resistance is not a design factor and that the steel will be provided with a corrosion protection system, which will be maintained. In this respect, the steel will be treated no differently to ASTM A572 / A572M steels; that is, Westinghouse proposes not to use the possible additional atmospheric corrosion resistance, only the mechanical properties, which are comparable to ASTM A572 / A572M grade 50 that would be used as an alternative.

51. I judge the Westinghouse response to resolution plan Action1 item 3 – ASTM A588 Corrosion Resistant Properties – to satisfy SAPs ECE.16 and ECE.17 as Westinghouse proposes not to use the possible additional atmospheric corrosion resistance, only the mechanical properties, which are comparable to ASTM A572 / A572M grade 50 that would be used as an alternative.

<u>Assessment of Item 4</u>

52. Item 4 is as follows: “The specification of Charpy V notch impact tests is a normal requirement for structural steelwork in the UK. BS EN 1993 (Eurocode 3,Ref. 8) Part 1-1 requires that brittle fracture is considered for all structures and refers to Part 1-10 for conditions that satisfy that requirement. Part 1-10 gives rules for the selection of the

subgrade of steel, ie the Charpy V-notch value. **AP1000** design specifications should therefore ensure that the steel complies with BS EN 1993-1-10, including the UK national annex, since this is a supplementary requirement for the claimed standard ASTM A572."

53. With respect to V-notch Charpy impact properties, Westinghouse reported that the testing of steels shall satisfy the requirements of ANSI / AISI (The American Iron and Steel Institute) N690-1994:

- *The Charpy V-notch impact test shall be conducted at a temperature not less than 30°F (16.7°C) below the lowest service temperature of the structural component.*
- *The lowest service temperature for the AP1000 reactor low extreme outside temperature is assumed to be -40°F (-40°C).*
- *The acceptance criteria shall be that the material withstand not less than ft-lb energy indicated in Table Q1.4.1.1* (of ANSI/AISI N690-1994) *and with any individual specimen withstanding not less than ft-lb energy indicated in the table.*

54. ONR raised two RQs against this item: RQ-AP1000-1572 (Ref. 14, Comment 3) and RQ-AP1000-1661 (Ref. 15). These responses re-iterated the above statements. This does not therefore accommodate the use of BS EN 1993-1-10. ONR has satisfied itself that a procedure could be developed to ensure that these materials conform with BS EN 1993-1-10.

55. I judge that the Westinghouse response to resolution plan Action 1 item 4 – Charpy V-Notch Impact Tests has satisfied the concept of Charpy V notch testing by use of ANSI/AISI N690-1994 and the ONR has satisfied itself that a procedure could be developed to conform to BS EN 1993-1-10. This response therefore satisfies SAP ECE.17, this being said, all clauses from BS EN 1993-1-10 have not been addressed. . I have raised an Assessment Finding to capture this within the site-specific stage as the licensee is best placed to undertake this during material sourcing. The assessment finding is below:

Assessment Finding CP-AF-AP1000-CE-02: The licensee shall demonstrate that its testing regime for Charpy V notch testing is compliant with BS EN 1993-1-10 or provide and justify an equivalent level of assurance.

4.2.2 Westinghouse Response to Action GI-AP1000-CE-03.A2

Overview

56. Westinghouse initially submitted letter WEC-REG-0324R (Ref. 23) with one enclosure. The summary document outlined the conclusions reached by Westinghouse regarding the actions and identified the key documents where these conclusions were defined. During the technical assessment, RQ-AP1000-1509 (Ref. 17) and RQ-AP1000-1573 (Ref. 18) were raised by ONR and responded to by Westinghouse.

Assessment of Item 1

57. Item 1 is as follows: "Types of aggregate can affect the coefficient of thermal expansion of the concrete. Limestone is the most commonly used aggregate in the UK."

58. The Westinghouse response acknowledged the effect of aggregate type and pointed out that the thermal coefficient of limestone is within the normal range for aggregates.

The common use of limestone aggregate in the UK is noted, but the response points out that final selection will be decided on the basis of the UK supply chain, ie local availability.

59. Additionally, the Westinghouse response (Ref. 18) contains a compliance matrix of UK standards that could be substituted in place of the US standards. The matrix is very thorough in its coverage and provides an adequate response to the comment raised.

60. I judge that the Westinghouse response to resolution plan Action 2 item 1 satisfies SAPs ECE.16 and ECE.17 as the appropriate material is being specified to comply with the design methodologies employed through the use of a compliance matrix.

Assessment of Item 2

61. Item 2 is as follows: "The mix used for self-compacting concrete is of particular concern for steel-concrete composite construction where the size of aggregate and matrix design can affect the shear stud interaction."

62. Westinghouse referred to testing undertaken that is reported to demonstrate that the use of self-consolidating concrete is acceptable in steel-concrete composite construction because ductile behaviour and sufficient interfacial shear are ensured. References included shear stud spacing and flowability tests for filling and passing ability. Westinghouse also included photographs of a mock-up prototype of a CA20 module illustrating the effective flow of self-consolidating concrete between the shear studs.

63. I judge that this response satisfies SAPs ECE.16 and ECE.17 as the construction materials comply with the design methodologies employed while the construction of such modules uses appropriate materials and proven techniques to minimise defects.

Assessment of Item 3

64. Item 3 is as follows: "European specifications for concrete now take due account of concrete ageing or deterioration effects such as alkali-silica reaction. The US standards proposed need to include the same improvements."

65. Westinghouse stated that it would use ACI 349-01 and the ASTM for specifying concrete. Following technical review, it was apparent that UK-specific durability requirements would be required, eg BS 8500-1, in particular for concrete in contact with the ground. Sulphate attack is one example of such requirements where the UK has very detailed guidance (BRE Special Digest 1 and BS 8500-1) whereas the requirements of ACI 349 do not cover this situation. BS 8500-1 and BS 8500-2 also include provisions on alkali-silica reaction, another aspect not contained within ACI 349.

66. Westinghouse stated that BS 8500 (parts 1 and 2) should be used to supplement ACI 349-01 and the ASTM to specify concrete within the UK. Westinghouse also stated that the specifier also has the freedom to refer to relevant BRE publications if required and permitted by BS 8500 and BS EN 206. On the basis that the future licensee undertakes the above action, I judge that this satisfies the issue and SAP ECE.2, as consideration of potential in-service degradation mechanisms and proven materials will be used by encompassing UK relevant good practice through use of an established design code.

Assessment of Item 4

67. Item 4 is as follows: "UK concrete strength testing is usually based on cube strengths rather than cylinder strengths."

68. The Westinghouse response noted the use of cube testing in the UK but states that cylinders will be tested for compliance with ACI 349-01. I judge that this response satisfies SAP ECE.17, as proven techniques are being used to minimise defects that might affect the required integrity of structures through an established test method. This being said, the following Minor Shortfall, MS-AP1000-CE-03-01, should be considered:

Minor Shortfall CP-MS-AP1000-CE-03-01: The UK uses cube specimens for compressive strength determination as the basis of concrete design, supply and verification. Structural design to Eurocodes is based on cylinder strength and the use of cube testing in support of this has proved satisfactory. The licensee should consider the current practices in the UK and the use of established conversion techniques from cube testing to cylinder testing for future concrete supply.

<u>Assessment of Item 5</u>

69. Item 5 is as follows: “On-site testing of concrete mixes will be different in the UK to that used in the US, and so exact testing procedures need to be confirmed.”

70. The Westinghouse response was brief, but direct, saying that testing will be to US standards in compliance with ACI 349-01. I judge that this response satisfies SAP ECE.16, as the construction material testing complies with the design methodologies employed.

4.3 Assessment Findings

71. During my assessment I identified two items for a future licensee to take forward in its site-specific safety submissions. Details of these are contained in Annex 1 and are further described within this report and the technical assessment report (Ref. 21) produced by the ONR TSC.

72. These matters do not significantly undermine the generic safety submission and are primarily concerned with the provision of additional and site-specific safety case evidence, which can be made available as the project progresses through the detailed design, construction and commissioning stages. These items are captured as Assessment Findings.

73. Residual matters are recorded as Assessment Findings if one or more of the following apply:

- Site-specific information is required to resolve this matter.
- The way to resolve this matter depends on licensee design choices.
- The matter raised is related to operator-specific features / aspects / choices.
- The resolution of this matter requires licensee choices on organisational matters.
- To resolve this matter the plant needs to be at some stage of construction / commissioning.

4.4 Minor Shortfalls

74. During my assessment I identified one item as a Minor Shortfall in the safety case, but did not consider it serious enough to require specific action to be taken by the future licensee. Details of this are contained in Annex 2 and further described within this report and the technical assessment report (Ref. 21) produced by the ONR TSC.

75. Residual matters are recorded as a Minor Shortfall they do not:

- undermine ONR's confidence in the safety of the generic design;
- impair ONR's ability to understand the risks associated with the generic design;
- require design modifications; or
- require further substantiation to be undertaken.

5. CONCLUSIONS

76. This report presents the findings of the assessment of GDA Issue GI-AP1000-CE-03 relating to the **AP1000** reactor GDA closure phase.

77. To conclude, I am content overall with the response provided by Westinghouse to Issue GI-AP1000-CE-03, with only two Assessment Findings requiring work to be progressed in the next step.

78. I judge that Westinghouse has addressed Action 1 through the use of the correct specifications relevant to the design intent for steel. Westinghouse has shown that the materials will be used in the correct conditions with sufficient margin, subject to justification of brittle fracture. The Charpy V notch testing has been specified to US standards but does not meet the full requirements of BS EN 1993-1-10, which is normal practice in the UK. I have raised two Assessment Findings to be taken into account in the future design: 1) justification of brittle fracture mechanisms in the pushover analysis showing sufficient margin, and 2) the inclusion of BS EN 1993-1-10 requirements.

79. I judge that Westinghouse has addressed Action 2 through the use of a compliance matrix, use of established concrete material testing methods and the use of results from testing of material properties and constructability. I have specified a Minor Shortfall as to the use of cylinder testing in comparison with the common use of cube testing in the UK.

80. I consider that from a civil engineering viewpoint, subject to the provisions of the Assessment Findings, the **AP1000** reactor design is suitable for construction in the UK regarding GDA Issue GI-AP1000-CE-03.

6. REFERENCES

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Ref. 2. UK AP1000 Assessment Plan for Closure of GDA Civil Engineering Issues 1 to 4, ONR-GDA-AP-14-008 Revision 2, Office for Nuclear Regulation, 2 April 2015, TRIM Ref. 2015/58360

Ref. 3. Resolution Plan for GI-AP1000-CE-03, Materials – AP1000 Material Standards and Material Specifications Revision 3, Westinghouse Electric Company, TRIM Ref. 2015/89848

Ref. 4. ASTM A572 Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel, American Society for Testing and Materials (ASTM), 2007

Ref. 5. Design Methodology for Structural Modules, APP-GW-SUP-001 Revision 2, Westinghouse Electric Company LLC, October 2010, TRIM Ref. 2011/81430

Ref. 6. ASTM A588 Specification for High-Strength Low-Alloy Structural Steel, up to 50ksi [345MPa] Minimum Yield Point, with Atmospheric Corrosion Resistance, American Society for Testing and Materials (ASTM)

Ref. 7. Weathering Steel for Highway Structures, BD7/01, UK Highways Agency, November 2011

Ref. 8. Eurocode 3: Design of Steel Structures – General Rules and Rules for Buildings, BS EN 1993-1-1:2004, British Standards Institute (BSI), 2004

Ref. 9. ONR Guidance on Mechanics of Assessment, Steve McCabe, 31 May 2013, TRIM Ref. 2013/204124

Ref. 10. Safety Assessment Principles for Nuclear Facilities, 2014 Edition Revision 0, ONR, November 2014, www.onr.org.uk/saps/saps2014.pdf

Ref. 11. Technical Assessment Guides – Civil Engineering, NS-TAST-GD-017 Revision 3, www.onr.org.uk/operational/tech_asst_guides/ns-tast-gd-017.pdf

Ref. 12. WEC-REG-0197N – Enclosure 2 – UK GDA Resolution Plans CE-03 Action 1 Justification of Steel Materials Summary, 29 July 2015, TRIM Ref. 2015/283332

Ref. 13. RQ-AP1000-1508 – Civil Engineering, Graham Butler, 26 February 2016, TRIM Ref. 2016/120290

Ref. 14. RQ-AP1000-1572 – GDA Issues CE-03 A1 Questions Relating to the Assessment of the Steel Material Standards, Graham Butler, 9 May 2016, TRIM Ref. 2016/303695

Ref. 15. RQ-AP1000-1661– Further Clarification to Response to RQ-AP1000-1572 Item 3 Charpy Impact Testing, Graham Butler, 8 August 2016, TRIM Ref. 2016/343147

Ref. 16. WEC-REG-0324R – Enclosure 1 – UK GDA Resolution Plans CE 03 Action 2 Justification of Concrete Materials Summary,17 September 2015, TRIM Ref. 2015/349415

Ref. 17. RQ-AP1000-1509 – Information Requested to Facilitate the Assessment of the WEC Responses to GDA Issues CE-03 A2, Graham Butler, 26 February 2016, TRIM Ref.

2016/117427

Ref. 18. RQ-AP1000-1573 – GDA Issues CE-03 A2 Questions Relating to the Assessment of the Concrete Material Standards, Graham Butler, 9 May 2016, TRIM Ref. 2016/303742

Ref. 19. Purpose and Scope of Permissioning, G. Grint, August 2015, TRIM Ref. 2015/304735

Ref. 20. Westinghouse Integrated Schedule, 27 January 2015, TRIM Ref. 2015/32915

Ref. 21. 247462-CE-03-A1-A2 – Steel and Concrete Material Report Issue 1,18 November 2016, TRIM Ref. 2016/451005

Ref. 22. WEC-REG-0197N – Letter from Westinghouse – UK GDA Resolution Plans CE.03 Action 1 Justification of Steel Materials Summary, 29 July 2015, TRIM Ref. 2015/283313

Ref. 23. WEC-REG-0324R – Letter from Westinghouse – UK GDA Resolution Plans CE.03 Action 2 Justification of Concrete Materials Summary, 17 September 2015, TRIM Ref. 2015/349409.

Annex 1

Assessment Findings to be addressed during the Forward Programme – GI-AP1000-CE-03

Assessment Finding Number	Assessment Finding	Report Section Reference
CP-AF-AP1000-CE-01	The Licensee shall discount brittle failure mechanisms within the beyond design basis justification using the site specific seismic conditions and construction materials for all SC structures.	4.2 – Action 1, Assessment of item 2
CP-AF-AP1000-CE-02	The licensee shall demonstrate that its testing regime for Charpy V notch testing is compliant with BS EN 1993-1-10 or provide and justify an equivalent level of assurance.	4.2 – Action 1, Assessment of item 4

Annex 2

Minor Shortfalls – GI-AP1000-CE-03

Minor Shortfall Number	Minor Shortfall	Report Section Reference
CP-MS-AP1000-CE-01	The UK uses cube specimens for compressive strength determination as the basis of concrete design, supply and verification. Structural design to Eurocodes is based on cylinder strength and the use of cube testing in support of this has proved satisfactory. The licensee should consider the current practices in the UK and the use of established conversion techniques from cube testing to cylinder testing for future concrete supply.	4.2 – Action 2, Assessment of item 4