New Reactors Programme

GDA close-out for the AP1000® reactor

GDA Issues

GI-AP1000®-CE-01 Rev 0 – Justification of Novel Forms of Structure for the Steel/Concrete Composite Wall and Floor Panels Known as CA Modules

GI-AP1000®-CE-02 Rev 1 – Further Justification of Novel Form of Structure for the Steel/Concrete Composite Wall to the Enhanced Shield Building

Assessment Report: ONR-NR-AR-16-040
Revision 0
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EXECUTIVE SUMMARY

Westinghouse Electric Company (Westinghouse) 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 required resolution prior to 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 two GDA issues: GI-AP1000®-CE-01 Rev 0 – Justification of Novel Forms of Structure for the Steel/Concrete Composite Wall and Floor Panels Known as CA Modules; and GI-AP1000®-CE-02 Rev 1 – Further Justification of Novel Form of Structure for the Steel/Concrete Composite Wall to the Enhanced Shield Building. These two GDA issues include some topics common to both issues and the included actions have therefore been dealt with on a common basis.

These GDA issues arose in Step 4 due to the requirement to justify novel forms of structure for the steel/concrete modules and floors known as CA modules and for the steel/concrete composite (SC) walls to the Enhanced Shield Building. ONR required the following:

- a consolidated set of design documents;
- additional acceptance criteria for out-of-plane shear capacity;
- additional acceptance criteria for in-plane shear capacity when considered with other loads;
- additional substantiation of shear connections and tie bars;
- justification of connections for CA modules;
- justification of ability of SC to withstand thermal load case;
- justification of ability of SC to withstand fire;
- justification of long-term reliability.

The Westinghouse GDA Issue Resolution Plan presented a detailed technical appraisal of each of the actions presented in the GDA issues and stated Westinghouse's intention to submit further design to justify the novel forms of structure for use on the **AP1000®** civil structures in the UK.

My assessment conclusion is:

- Westinghouse has presented an adequate response to the actions raised in the GDA issues, albeit with a number of assessment findings and minor shortfalls being recorded;
- it is demonstrated that the use of steel/concrete modules, including CA modules, as proposed for the construction of the **AP1000®** civil structures will not lead to a significant reduction in nuclear safety, subject to cognisance being taken of the assessment findings, during further detailed designs.

My judgement is based on the following factors:

- a wide sample of Westinghouse's responses to the actions raised in the GDA issues has been subjected to challenge and detailed technical assessment by specialist Technical Service Contractors, on behalf of ONR;
- my review of the outcome of the challenge and detailed technical assessments allows me to conclude that relevant good practice has generally been met, there are relatively minor deficiencies in the technical quality of the safety case and opportunities for improvement to reduce risks have been identified.

Each section of this report includes a table of assessment findings, minor shortfalls and closed comments, 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 and require licensee input/decision. The assessment findings are further summarised in Annex 1.

In summary, I am satisfied that GDA issues GI-AP1000®-CE-01 Rev 0 and GI-AP1000®-CE-02 Rev 1 can be closed.

LIST OF ABBREVIATIONS

AF	assessment finding
ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineers
CIS	Containment Internal Structures
DAC	Design Acceptance Confirmation
DCR	Demand Capacity Ratio
ESB	Enhanced Shield Building
fc'	Specified compressive strength of concrete
FE	Finite Element
GDA	Generic Design Assessment
HCLPF	High Confidence of Low Probability of Failure
H/T	Height to thickness ratio
in	An imperial unit of length
IRWST	In Reactor Water Storage Tank
kip	An imperial unit of force (1000 ponds force)
LOCA	Loss Of Coolant Accident
MS	minor shortfall
ONR	Office for Nuclear Regulation
P- Δ	P-Delta effect that causes a destabilising moment
PCSR	Pre-Construction Safety Report
RGP	relevant good practice
RP	Requesting Party
RQ	Regulatory Query
SAPs	Safety Assessment Principles
SC	Steel/Concrete
TAG	Technical Assessment Guide
TSC	Technical Support Contractor
Vc	Nominal shear strength provided by concrete
Westinghouse	Westinghouse Electric Company

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Annex 1: Assessment Findings to be Addressed During the Forward Programme – Civil Engineering

1. INTRODUCTION

1.1 Background

1. Westinghouse Electric Company (Westinghouse) completed GDA Step 4 in 2011 and paused the regulatory process. It achieved an IDAC which had 51 GDA issues attached to it. These issues require resolution prior to award of a 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 ONR's assessment of the Westinghouse **AP1000®** reactor design in the area of civil engineering. Specifically, this report addresses two GDA issues: GI-AP1000®-CE-01 Rev 0 – Justification of Novel Forms of Structure for the Steel/Concrete Composite Wall and Floor Panels Known as CA Modules (Ref. 1); and GI-AP1000®-CE-02 Rev 1 – Further Justification of Novel Form of Structure for the Steel/Concrete Composite Wall to the Enhanced Shield Building (Ref. 2). The related GDA Step 4 report 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

3. The scope of this assessment is detailed in ONR Assessment Plan ONR-GDA-14-008 Revision 2 (Ref. 3).

4. The assessment focused on the definition and justification of the novel design used for the steel/concrete composite system proposed for the CA modules within the nuclear island, and the further justification of the novel design used for the Enhanced Shield Building. 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.

5. The two GDA issues include some topics that are common to both issues and the included actions have therefore been dealt with on a common basis by both Westinghouse and ONR.

6. This assessment complies with internal guidance on the mechanics of assessment within ONR Ref. 4.

1.3 Sampling strategy

7. It was not practicable or necessary to assess all components of the work scope to the same degree. All parties decided that a combination of two different assessment methods would be used, 1) broad review and 2) deep-dive assessment. A broad review was used to provide an overview of a submission or a significant part of a submission. A deep-dive assessment was undertaken on one (or more if appropriate) element of a submission to examine the detail from the safety case, through the detailed design development to the final output.

2 ASSESSMENT STRATEGY

2.1 Pre-Construction Safety Report (PCSR)

8. ONR's GDA 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 PCSR, and 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).

9. 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®** design reference point.

10. 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 issues GI-AP1000®-CE-01 (Ref. 1) and GI-AP1000®-CE-02 (Ref. 2).

2.2 Standards and criteria

11. The standards and criteria adopted within this assessment are principally the Safety Assessment Principles (SAPs) (Table 1) (Ref. 18), internal TAGs (Table 2), relevant national and international standards and relevant good practice (Table 3) informed from existing practices adopted on UK nuclear licensed sites.

2.3 Safety Assessment Principles

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

Table 1 – SAPs Applied in this Assessment

ONR Safety Assessment Principles	EHA.1 Identification and characterisation EHA.6 Analysis EHA.14 Fire, explosion, missiles, toxic gases etc. ECE.1 Functional performance ECE.2 Engineering principles: civil engineering. Independent arguments ECS.3 Engineering principles: safety classification and standards ECE.6 Engineering principles: civil engineering: design. Loadings ECE.12 Engineering principles: civil engineering: design. Structural analysis and model testing ECE.13 Engineering principles: civil engineering: structural analysis and model testing. Use of data ECE.14 Engineering principles: civil engineering: structural analysis and model testing. Sensitivity studies

	ECE.15 Engineering principles: civil engineering: structural analysis and model testing. Validation of methods ECE.16 Engineering principles: civil engineering: construction. Materials

2.4 Technical Assessment Guides

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

Table 2 – TAGs Used in this Assessment

ONR Technical Assessment Guides	NS-TAST-GD-017 Civil Engineering Revision 3 NS-TAST-GD-051 The Purpose, Scope and Content of Safety Cases Revision 3

2.5 National and international standards and guidance

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

Table 3 – Standards and Guidance Used in this Assessment

Relevant Codes	American Concrete Institute ACI 349-01: Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary ANSI / AISC N690-12: Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities Japan Electric Association, Technical Guidelines for Seismic Design of Steel Plate Reinforced Concrete Structures – Buildings and Structures – JEAG 4618-2005 AISC N690-94: Specification for Safety-related Structures for Nuclear Facilities BS EN 1993-1-9:2005: Eurocode 3. Design of steel structures. Fatigue. BS 476-10:2009: Fire tests on building materials and structures. Guide to the principles, selection, role and application of fire testing and their outputs. AISC Steel Construction Manual 2011 ASTM, Standard Test methods for Fire Tests of Building Construction Materials, ASTM E119-14, 2014 ISO 834-11:2014: Fire resistance tests – Elements of building construction – Part 11: Specific requirements for the assessment of fire protection to structural steel elements BS EN 1991-1-2:2002 Eurocode 1. Actions on structures. Actions on structures exposed to fire Korea Electric Power Industry Code, SNG Steel-Plate Concrete Structures Rev.1 ANSI / AISC 360-10 Specification for Structural Steel Buildings

2.6 Use of Technical Support Contractors (TSCs)

15. It is usual in GDA for ONR to use technical support; for example, to provide additional capacity to optimise the assessment process, enable access to independent advice and experience, analysis techniques and models, and to enable ONR's inspectors to focus on regulatory decision-making etc.

16. ONR used technical support across all areas of this assessment scope to provide resource and expertise not available within ONR.

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

2.7 Integration with other assessment topics

18. 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.

19. ONR considered the following Internal Hazards issue:
GI-AP1000®-IH-01 GDA Issue – Internal Fire Safety Case Substantiation (Ref. 5).

2.8 Out of scope items

20. The scope of the assessment was clearly defined by the ONR GDA issues and the Westinghouse Resolution Plans. Table 4 sets out the items agreed with Westinghouse as being outside the scope of GI-AP1000-CE-01 and GI-AP1000-CE-02.

Table 4 – Out of Scope Items

Post-Fukushima considerations
Malicious Aircraft Impact Assessment
Site-specific considerations

3 REQUESTING PARTY'S SAFETY CASE

21. The Westinghouse safety case for resolution of GDA Issue GI-AP1000®-CE-01 Rev 0 – Justification of Novel Forms of Structure for the Steel/Concrete Composite Wall and Floor Panels Known as CA Modules, is documented in Westinghouse's UK **AP1000®** GENERIC DESIGN ASSESSMENT Resolution Plan GI-AP1000®-CE-01 – Justification of Novel Forms of Structure for the Steel/Concrete Composite Wall and Floors Known as CA Modules (Ref. 6).

22. The Westinghouse safety case for resolution of GDA Issue GI-AP1000®-CE-02 Rev 1 – Further Justification of Novel Form of Structure for the Steel/Concrete Composite Wall to the Enhanced Shield Building, is documented in Westinghouse's UK **AP1000®** GENERIC DESIGN ASSESSMENT Resolution Plan GI-AP1000®-CE-01 – Further Justification of Novel Form of Structure for the Steel/Concrete Composite Wall to the Enhanced Shield Building (Ref.7).

23. These two GDA issues and resolution plans include some topics common to both issues and the included actions have therefore been dealt with on a common basis by both Westinghouse and ONR.

24. The Westinghouse safety case incorporates the responses to the two GDA issues, where the scope of the GDA issue is further described by a number of actions. The Westinghouse safety case, as included in the resolution plans, is summarised as follows.

3.1 GI-AP1000®-CE-01 REV 0 – JUSTIFICATION OF NOVEL FORMS OF STRUCTURE FOR THE STEEL/CONCRETE COMPOSITE WALL AND FLOOR PANELS KNOWN AS CA MODULES.

25. Definition and justification of the novel design used for the steel/concrete composite system proposed for the CA modules within the nuclear island.

Action GI-AP1000®-CE-01.A1 – Consolidated set of design documents

26. Westinghouse has provided a consolidated set of formal documents that define the design submission.

- A single overarching document summarises the structure submitted and design methodology used for the UK GDA submission.
- The submittal draws together all the various submissions on the design methodology for the CA modules that have been submitted under GDA Step 4, and highlights UK regulator requirements.
- The submittal includes a document map and lists the set of formal documents that define the structural layout, materials, form, design methodology and substantiation for the CA modules.

27. The Westinghouse primary submission is included in the document, AP1000® Plant Structural Module, Behaviour and Design Summary Report, APP-GW-SUP-003 Revision 0, 25 April 2016 (Ref. 8).

Action GI-AP1000®-CE-01.A2 – Additional criteria for out-of-plane shear capacity

28. Westinghouse has provided additional acceptance criteria for the proposed design methodology to ACI 349-01 for out-of-plane shear. The acceptance criteria includes: a reduction in the limit of Vc value for the concrete contribution to shear strength, justification for using the chosen limit of Vc, confirmation of the limit on Vc above which

shear reinforcement will be added, substantiation for the type of reinforcement provided as described in the response to Action GI-AP1000®-CE-01.A4.

29. The Westinghouse primary submission is included in the document, UK GDA Resolution Plans CE-01 Action 2 and CE-02 Action 3 Out of Plane Shear Acceptance Criteria, 22 July 2015 (Ref. 9).

Action GI-AP1000®-CE-01.A3 – Additional acceptance criteria for in-plane shear capacity when considered with other loads

30. Westinghouse has provided additional justification for the proposed design methodology for in-plane shear when combined with other loads. As part of the justification, Westinghouse has provided further calculations for in-plane shear to alternative codes. The calculations consider coincident loads present for critical load cases. These calculations include the symmetric sharing of in-plane shear stress used by these codes, and the deliverable defines the limitations for which the Westinghouse methodology of asymmetric sharing of in-plane shear stress is applicable.

31. The Westinghouse primary submission is included in the document, UK GDA Resolution Plans CE.01 Action 3 and CE.02 Action 4 In-Plane Shear Capacity (Ref.10).

Action GI-AP1000®-CE-01.A4 – Additional substantiation of shear connection

32. Westinghouse has provided further substantiation with respect to the shear connectors. The substantiation includes the following:

- justification that the strength reduction factor of 0.75 for shear studs taken from ACI 349-01 B.4.4 is appropriate;
- justification of the capacity for the channel acting as a shear lug, and justification of the length of the channel used in calculating the bearing onto the concrete;
- justification for omission of any tension force in the shear studs (resulting from restraining the plate), and, if a tension force is required, the effect on the stud shear capacity has been considered;
- calculations of the development length to justify the shear for the full range of wall thicknesses incorporating the outcomes of the first two points above.

33. The Westinghouse primary submission is included in the document, UK GDA Resolution Plans CE-01 Action 4 and CE-02 Action 5 Justification of Shear Connections (Ref. 11).

Action GI-AP1000®-CE-01.A5 – Justification of connections for CA modules

34. Westinghouse has submitted the final concept details for a sample of generic connections for the CA modules. These include detailed drawings and calculations. The calculations state the failure mechanisms of the connections considered and the effects on the ductile behaviour of the whole structure.

35. The Westinghouse primary submission is included in the document, UK GDA Resolution Plans CE-01 Action 5 and CE-02 Action 6 Justification of Shear Connections Summary (Ref. 12).

Action GI-AP1000®-CE-01.A6 – Justification of the ability of SC to withstand thermal load case

36. Westinghouse has justified how the thermal analysis models transient thermal effects, such as environmentally-induced transients. Westinghouse has provided further justification that vapour pressure within the CA modules is not a concern.

37. The Westinghouse primary submission is included in the document, UK GDA Resolution Plans CE.01 Action 6 and CE.02 Action 7 Justification of the Ability of SC to Withstand Thermal Load Case (Ref. 13).

Action GI-AP1000®-CE-01.A7 – Justification of the ability of SC to withstand fire

38. Westinghouse has provided evidence on the effect of fire on the CA modules. The Westinghouse primary submission is included in the document, Confirmation of the Required Scope of Response to GI-AP1000®-CE-01.A7 and AP1000®-CE-02.A8 (Ref. 14).

Action GI-AP1000®-CE-01.A8 – Long-term reliability

39. Westinghouse has provided further substantiation on the long-term reliability.

- Westinghouse has assessed the effects on the calculation of HCLPF for the CA modules, based on the completion of actions 02 to 04 of this issue.
- Westinghouse has provided relevant reliability calculations similar to Eurocodes.

40. The Westinghouse primary submission is included in the document, Generic Design Assessment (GDA) AP1000® Plant CE.01 Action 8 and CE.02 Action 9 Long Term Reliability of SC Structures (Ref. 15).

3.2 GI-AP1000®-CE-02 REV 1 – FURTHER JUSTIFICATION OF NOVEL FORM OF STRUCTURE FOR THE STEEL/CONCRETE COMPOSITE WALL TO THE ENHANCED SHIELD BUILDING

41. Further justification of the novel design used for the steel/concrete composite wall is proposed for the Enhanced Shield Building (ESB) within the nuclear island.

Action GI-AP1000®-CE-02.A1 – Provide further justification of the steel material used for the tie bars in the SC wall of the ESB

42. Westinghouse has provided further justification on the steel material used for the tie bars in the SC wall of the ESB to demonstrate why A496 is appropriate to use as shear reinforcement in a seismic design.

43. The Westinghouse primary submission is included in the document, UK GDA Resolution Plan CE.02 Action 1 Tie Bar Material and CE.02 Action 2 Tie Bar Demand (Ref.16).

Action GI-AP1000®-CE-02.A2 – Provide further substantiation of the demand calculations for the tie bars

44. Westinghouse has provided further justification of the design tensile load present in the tie bars due to combined loading effect.

45. The Westinghouse primary submission is included in the document, UK GDA Resolution Plan CE.02 Action 1 Tie Bar Material and CE.02 Action 2 Tie Bar Demand (Ref. 16).

Action GI-AP1000®-CE-02.A3 – Provide a clear statement in the methodology that the out-of-plane shear is taken on the reinforcement alone

46. Westinghouse has further justified the ties as shear reinforcement in the shield building cylindrical wall. The justification has included the following:

- a clear statement in the methodology that the out-of-plane shear is taken on the reinforcement alone;
- a comparison of the proposed ACI 349-01 design methodology for out-of-plane shear and provision of shear reinforcement with alternative codes including JEAG 4618 and Draft AISC N690 App. 9.

47. The Westinghouse primary submission is included in the document, UK GDA Resolution Plans CE-01 Action 2 and CE-02 Action 3 Out of Plane Shear Acceptance Criteria, 22 July 2015 (Ref.9).

Action GI-AP1000®-CE-02.A4 – Provide additional justification for the proposed design methodology for in-plane shear when combined with other loads

48. Westinghouse has provided additional justification for the proposed design methodology for in-plane shear when combined with other loads by performing the following:

- further calculations for in-plane shear to alternative codes including JEAG 4618 and Draft AISC N690 App. 9;
- in conjunction with item 1, Westinghouse, defining the limitation on combined loading (e.g. moment and axial load) for which the defined methodology of asymmetric sharing of the in-plane shear stress is applicable.

49. The Westinghouse primary submission is included in the document, UK GDA Resolution Plans CE.01 Action 3 and CE.02 Action 4 In-Plane Shear Capacity (Ref. 10).

Action GI-AP1000®-CE-02.A5 – The adequacy of the shear connection between the faceplates and the concrete needs to be verified for the general areas and the connection zones

50. Westinghouse has demonstrated the adequacy of the shear connection between the faceplates and the concrete in general areas and in the connection zones by providing the following:

- justification along with a supporting sensitivity assessment that the strength reduction factor of 0.75 for shear studs taken from ACI 349-01 B.4.4 is appropriate;
- justification of the nominal and design shear capacity for the tie bars;
- justification for omission of any tension force in the shear studs (resulting from restraining the plate in compression), and, if a tension force is required, the effect on the stud shear capacity has been considered;
- calculations to justify that the development length will be satisfied for the recalculated shear resistance of the ties and studs.

51. The Westinghouse primary submission is included in the document, UK GDA Resolution Plans CE-01 Action 4 and CE-02 Action 5 Justification of Shear Connections (Ref. 11).

Action GI-AP1000®-CE-02.A6 – Westinghouse shall provide further justification for ’the connections’

52. Westinghouse has provided further justification for the following:

- the base connection of the ESB to the RC wall below;
- the connection between the Auxiliary Building roof and the ESB;

- the calculation of stresses at the transition from the typical 3 ft wall to the 4.5 ft wall at the air inlet region, and the justification that the tie bar arrangement is sufficient to provide a competent transition.

53. The Westinghouse primary submission is included in the document, UK GDA Resolution Plans CE-01 Action 5 and CE-02 Action 6 Justification of Shear Connections Summary (Ref. 12).

Action GI-AP1000®-CE-02.A7 – Westinghouse is required to justify how the thermal analysis models transient thermal effects, such as environmentally induced transients

54. Westinghouse has provided further justification how the thermal analysis models transient thermal effects.

55. The Westinghouse primary submission is included in the document, UK GDA Resolution Plans CE.01 Action 6 and CE.02 Action 7 – Justification of the Ability of SC to Withstand Thermal Load Case (Ref. 21).

Action GI-AP1000®-CE-02.A8 – Westinghouse is required to provide evidence on the effect of fire on the ESB SC wall, also if vapour pressure is a concern

56. In conjunction with the information provided in response to GI-AP1000®-CE-01 Action 7, Westinghouse has provided the following:

- evidence on the effect of a fire on the ESB steel concrete composite wall;
- evidence to demonstrate that vapour pressure within the ESB steel concrete composite wall is not a concern.

57. Westinghouse has provided evidence on the effect of fire on the CA modules. The Westinghouse primary submission is included in the document, Confirmation of the Required Scope of Response to GI-AP1000®-CE-01.A7 and AP1000®-CE-02.A8 (Ref. 14).

Action GI-AP1000®-CE-02.A9 – Westinghouse is required to provide further substantiation on the reliability of the Enhanced Shield Building

58. Westinghouse has provided further substantiation on the long-term reliability of the shield building as follows:

- relevant reliability calculations for the shield building based on a Eurocode-based approach and justified that the calculated reliability is sufficient;
- assessed any potential impacts on the shield building HCLPF calculations based on the responses to Actions 1-8.

59. The Westinghouse primary submission is included in the document, Generic Design Assessment (GDA) AP1000® Plant CE.01 Action 8 and CE.02 Action 9 Long Term Reliability of SC Structures (Ref. 15).

4 ONR ASSESSMENT

4.1 Scope of Assessment Undertaken

60. It was not practicable or necessary to assess all components of the work scope to the same degree. ONR decided that a combination of two different assessment methods would be used, 1) broad review and 2) deep-dive assessment. A broad review was generally used to provide an overview of a submission or a significant part of a submission. A deep-dive assessment was undertaken on one (or more if appropriate)

element of a submission to examine the detail from the safety case, through the detail design development to the final output. Some elements of the assessment did not require all of this process to be undertaken.

61. The assessment focused on the definition and justification of the novel design used for the steel/concrete composite system proposed for the CA modules within the nuclear island, and the further justification of the novel design used for the Enhanced Shield Building. The scope of this closure phase 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 on whether a Design Acceptance Confirmation can be issued.

62. The scope of this assessment was limited to the scope of the two GDA issues, GI-AP1000®-CE-01 Rev 0 and GI-AP1000®-CE-02 Rev 1, as presented by Westinghouse in the two related resolution plans. Only the topics included in the actions listed in each GDA issue were assessed and no other topics have been considered.

4.2 Assessment Process

63. The Westinghouse submissions were prepared by Westinghouse in accordance with the resolution plans and submitted for ONR assessment, and in accordance with Westinghouse Integrated Schedule, 27 January 2015 (Ref. 24). The exception was the Westinghouse submission in response to GDA actions that relate to the structural capacity of the modules to withstand a fire, Action GI-AP1000®-CE-01.A7 and Action GI-AP1000®-CE-02.A8. These were delayed, as the original Westinghouse Resolution Plan did not accurately respond to all the requirements of the GDA issue. Receipt of RQ-AP1000®-1584 (Ref. 53) confirmed the agreed requirements on 25 July 2016.

64. The initial submitted documents were generally high level 'signpost' documents that prompted requests for numbers of supporting documents and references. The requests for supporting documents and references were recorded on Regulatory Queries (RQ) and issued to Westinghouse. The relevant RQs are listed in each of the following sections of this document.

65. On receipt of the supporting documents and references from Westinghouse by the ONR, they were passed to the TSC and detailed assessment commenced, including challenge. The number and size of documents to be assessed exceeded the predictions and this influenced the scope of the assessments.

66. Following the broad review by the ONR TSC, further documents and references were requested to facilitate the deep-dive reviews using RQs. Preliminary assessment comments were also issued at this time.

67. On receipt of the further supporting documents and references from Westinghouse by the ONR TSC, the deep-dive assessments were progressed to produce further RQs that requested further work and submissions by Westinghouse.

68. Weekly teleconferences were held between ONR, the TSC and Westinghouse to progress and resolve technical questions.

69. Design standards, guidance and relevant good practice were referenced during the course of the assessments as appropriate and these are listed in Tables 2 and 3.

4.3 Assessment of GI-AP1000®-CE-01.A1 – Consolidated set of design documents

70. The Westinghouse primary response to Action GI-AP1000®-CE-01.A1 is included in the document, AP1000® Plant Structural Module, Behaviour and Design Summary Report, APP-GW-SUP-003 Revision 0, 25 April 2016 (Ref. 8). The ONR assessment of this submission is recorded in the document, CE-01-A1 Consolidated Set of Design Documents (Ref. 25).

71. The Westinghouse response includes a single overarching document that summarises the structure submitted and the design methodology. The ONR assessment recorded some minor editorial and technical comments that have been resolved.

72. The Westinghouse response includes a document map and list of formal documents that describes the design of the modules. Following a broad review a deep-dive assessment was undertaken on a sample of documents. Although the deep-dive assessment has not included all documents, it was possible to judge from the sample that the list of documents is comprehensive and that this part of the action is satisfied.

73. The Westinghouse response includes descriptions and diagrams that explain the structural layout and form of the CA modules. Therefore, ONR judges that this part of the action is satisfied.

74. ONR considers that the Westinghouse response to this action with respect to SAP ECS.3 (Codes and Standards) and, based on the evidence presented above, satisfies the relevant parts of ECS.3 by demonstrating that these SSCs have been designed to appropriate codes and standards, and recording them.

4.4 Assessment of GI-AP1000®-CE-01.A2 to A5 and GI-AP1000®-CE-02.A1 to A6 – Additional acceptance criteria and justification of shear capacities and connections

75. As these GDA actions had a common theme, they were assessed holistically and the Westinghouse responses to assessment comments were reported in a single detailed technical assessment. The ONR assessment of the responses to these actions is compiled into a single report, CE-01.A2 to A5 & CE-02.A1 to A6: Shear, tie bar and connections (Ref. 26).

76. The Westinghouse primary responses to actions GI-AP1000®-CE-01.A2 to A5 and GI-AP1000®-CE-02.A1 to A6 are included in documents:

- UK GDA Resolution Plan CE-02 Action 1 Tie Bar Material and CE.02 Action 2 Tie Bar Demand (Ref. 16);
- UK GDA Resolution Plan CE-01 Action 2 and CE -02 Action 3 Out of Plane Shear Acceptance Criteria, 22 July 2015 (Ref. 9);
- UK GDA Resolution Plan CE.01 Action 3 and CE.02 Action 4 in-plane shear capacity (Ref. 10);
- UK GDA Resolution Plan CE-01 Action 4 and CE-02 Action 5 Justification of Shear Connections (Ref. 11);
- UK GDA Resolution Plan CE-01 Action 5 and CE-02 Action 6 Justification of Shear Connections Summary (Ref. 12).

77. The first stage of the assessment comprised a broad review of the work undertaken by Westinghouse to resolve each action item, for which a broad review was prepared and recorded in the document, Connections Broad Review (Ref. 32). The broad review record documented the assessment of whether, on the basis of the broad review, each action item has been resolved, or if further information was required for the TSC to assess whether or not the action had been resolved. This record also identified three critical elements from the actions which required a deep-dive assessment. For the deep-dive assessments, the TSC conducted a detailed investigation into

Westinghouse's response to assess whether or not the action had been adequately resolved. Areas selected for a deep-dive assessment were as follows:

- deep-dive 1. CE-01.A2 – Justification of the use of the limit of $Vc=2\sqrt{fc'}$;
- deep-dive 2. CE-01.A5 – Review of the module wall to base-mat connection;
- deep-dive 3. CE-02.A6 – Review of the connection between the cylindrical wall and air inlets.

78. In parallel to producing the broad review record and undertaking the deep-dive assessment on the three critical elements above, a preliminary comments list derived from the TSC's broad review assessment was prepared as two drafts. It was initially submitted as Draft 0 on 28 April 2016 and it consisted of comments 1 to 10 relating to the TSC's broad review for actions CE-01.A2 to CE-01.A5 and CE-02.A3 to CE-02.A6. It was subsequently revised on 15 June 2016 to Draft 1 to incorporate additional comments 11 to 14, which related to the TSC's broad review of actions CE-02.A1 to CE-02.A2 and initial comments from the TSCs deep dive assessments. A summary of the final update to the Comments Register was included in a report compiled by the ONR TSC (Ref. 26).

79. The ONR broad review and deep dive assessment comments, with the Westinghouse responses, are included in the following RQs:

- RQ-AP1000®-1474 – Information requested to facilitate the assessment of Document NPP_JNE_000185 Enclosure 1. (Ref. 33)
- RQ-AP1000®-1476 – Information requested to facilitate the assessment of the WEC responses to GDA Issue CE-01 & CE-02 (Ref. 34)
- RQ-AP1000®-1541 – Information requested to facilitate the WEC responses to GDA Issues CE-01 & CE-02 (Ref. 35)
- RQ-AP1000®-1570 – GDA issues CE-01 &CE-02. Questions relating to the assessment of the steel/concrete modules (1 of 2) (Ref. 36)
- RQ-AP1000®-1571 – GDA issues CE-01 &CE-02. Questions relating to the assessment of the steel/concrete modules (2 of 2) (Ref. 37)
- RQ-AP1000®-1586 – Information requested to facilitate the assessment of the WEC responses to GDA issues CE-01 & CE-02 (Ref. 38)
- RQ-AP1000®-1601 – Auxiliary Building Roof to Enhanced Shield Building Wall Connection (Ref. 39)
- RQ-AP1000®-1603 – Information requested to facilitate the assessment of the WEC responses to GDA issues CE-01 & CE-02 (Ref. 40)
- RQ-AP1000®-1605 – Information requested to facilitate the assessment of the WEC responses to GDA issues CE-01 & CE-02 (Ref. 41)
- RQ-AP1000®-1615 – GDA issues CE-01 & CE-02 Questions relating to the assessment of the steel concrete modules. Additional to RQ-AP1000®-1571 (Part 3 of comments) – (Ref. 42)
- RQ-AP1000®-1630 – CE-01A.5 Module wall to base-mat connection (Ref. 43).

80. The outcome of the ONR assessment is recorded in detail in a report compiled by the ONR TSC, CE-01.A2 to A5 & CE-02.A1 to A6: Shear, tie bar and connections (Ref. 26).

81. The final comments and the conclusion of the ONR assessment are summarised in Table 5 below. The assessment conclusions are categorised into assessment findings (AF), minor shortfalls (MS) and closed comments (CC). Assessment findings should be dealt with in the next phase of the design, minor shortfalls are advisory and closed comments are for record purposes. The assessment findings are further summarised in Annex 1.

Table 5 – Summary and Conclusion of the Assessment of GI-AP1000®-CE-01.A2

to A5 and GI-AP1000®-CE-02.A1 to A6 (Ref. 26)

ID	Assessment Comment Summary	Assessment Conclusion	Cat.
5-1	CE-01.A2 Item 2: Westinghouse has implemented the special provisions for deep flexural members for the design of Wall 2 between walls L-2 and N of the CA modules. The provisions for deep flexural members specified in ACI 349-01 Section 11.8 would be applicable if out-of-plane shear forces from hydrostatic loads dominated the structural design of the wall. In the deep beam evaluation reported in APP-CA20-S3C-016 (Ref. 29) Page 55, the applied shear force acting on this wall is stated as 102.7 kips. However, in the Response to the Questions Related to RQ-AP1000®-1570 Item 3, Westinghouse's calculation of the hydrostatic pressures based on a 37 ft flood results in a maximum shear force of approximately 21 kips acting at the base of this wall. The hydrostatic contribution to out-of-plane shear is therefore small compared to the total applied shear, which is likely to be due to seismic loading. Without the additional provision of deep beam theory, the nominal shear strength of the 2.5 ft wall is 45.5 ksi, considerably below the applied shear force of 102.7 kips. The C6 x 13 trusses in the wall are at 30 in x 48 in spacing, above the d/2 limit specified in ACI 349-01 for them to be credited as out-of-plane shear reinforcement. ONR notes that the out-of-plane shear force on this section of wall will be dependent on how the stiffness of the section has been modelled in the FE analysis; however, it is unclear whether this would increase or decrease the predicted load.	Based on this reasoning, the section of Wall 2 between walls L-2 and N of the CA modules does not comply with the geometric and loading requirements for deep flexural members stated in ACI 349-01 Section 11.8 and may be over-used. This should be addressed during the next phase of the work.	AF
5-2	CE-01.A4 Item 2: For the channel acting as a shear lug, Westinghouse does not appear to have considered the flexural and shear capacity of the channel itself. The ONR TSC has calculated the flexural and shear capacity of the channel under against a base load of 125 kips, and the calculated stresses in the section meet the requirements of AISC Steel Construction Manual 2011. The capacity of the channel should also be considered by Westinghouse for any future calculations. For the push-out test conducted by Westinghouse, the channel ends 2 inches short of the edge of the liner plate. This would result in a lower bearing length than the 8 in assumed by Westinghouse in its calculations.	The capacity of the channel itself needs to be considered for future bearing capacity calculations. In addition, the use of a single physical test is not a statistical robust approach to validate the design.	MS
5-3	CE-01.A5 Deep-dive 2: The module wall to base-mat connection has been designed to an SSE load factor of 1.30, lower than the 1.67 factor recommended in the Design Methodology for Structural Modules.	During the next phase of the work, the designers should ensure that the load combinations adopted for design are consistent with their design and methodology documents, to ensure that there is no misunderstanding in the future on the load factor that the	MS

		connection has been designed for.	
5-4	CE-01.A5 Deep-dive 2: For numerous calculations, Westinghouse has demonstrated the performance of individual components within the module wall to base-mat connections, but is inconsistent regarding the loads considered to act on each component.	During the next phase of the work, the designers should consider the overall load path and additional local forces generated when demonstrating performance of the individual components that make up the module wall to base-mat connection.	AF
5-5	CE-01.A5 Deep-dive 2: There is a manufacturing tolerance of ±1 in on the embed plate bolt holes as these are drilled on site. Westinghouse's current calculations for bending of the embed plate do not consider this eccentricity. The revised utilisation for the tension anchors is therefore 0.84, 25% higher than the maximum utilisation of 0.67 stated in APP-CA20-S3C-017 (Ref. 28) Table B5-14.	Although there is still sufficient margin for the current tension anchors provisioned, Westinghouse's calculation is unconservative and any future calculations for the tension anchors should account for any possible eccentricities in the vertical load applied to the embed plate.	MS
5-6	CE-01.A5 Deep-dive 2: The embed plate has been designed for out-of-plane bending, which arises due to transferring the tension load from the bolt into the dowels. To calculate the bending stresses in the embed plate, Westinghouse has assumed that this connection can be treated as a simply supported beam. This approach is acceptable; however, the maximum bending stress will occur at mid-span, where three 2 in diameter bolt holes are present. The elastic section modulus has not been reduced to account for the presence of these bolt holes. The ONR TSC has recalculated the bending stresses based on a reduced section modulus, and accounting for the fact that the load is transmitted into the embed plate around the perimeter of the bolt holes. The ONR TSC found that the maximum bending stress is 42.0 ksi (compared to 28.6 ksi calculated by Westinghouse in APP-CA20-S3C-017 (Ref. 28)), based on these assumptions, within the allowable stress limit of 43.2 ksi for A36 steel.	During the next phase of the work, the designers should use the net section modulus when calculating the bending capacity of the embed plate in future calculations.	MS
5-7	CE-01.A5 Deep-dive 2: For the moment acting on the bracket from in-plane shear and out-of-plane shear, Westinghouse has assumed an eccentricity of 2.5 inch for in-plane shear and 6 in for out-of-plane shear. It is unclear from Westinghouse's calculation how these eccentricities have been derived.	For in-plane shear an assumed eccentricity of 2.5 inch may be under-predicting the applied moment on the bracket, and may mean the brackets are being over-used. This should be addressed during the next phase of the work.	AF
5-8	CE-01.A5 Deep-dive 2: Westinghouse has checked the shear resistance of the bracket for lateral and vertical loading. The shear area assumed when calculating the design resistance does not appear to be correct. The ONR TSC has checked the shear capacity of the bracket based on the correct shear area and found that the stresses meet the requirements of AISC N690-94.	The correct shear area of the bracket should be used for future calculations.	MS
5-9	CE-01.A5 Deep-dive 2: On page 145 of APP-CA20-S3C-017 (Ref. 28), it states that the directionality of	These forces described above should also be accounted for in	AF

	the weld group is not taken into consideration. This approach is reasonable for the welds of the bracket; however, using this assumption for the welds of the liner plate local reinforcement implies transverse shear/bending and torsion in the plates that make up this reinforcement.	future calculations.	
5-10	CE-02.A1: Westinghouse reports that cyclic stresses for the tie bar connection to the liner plate are predominantly induced by thermal stress cycles. Westinghouse has conducted three fatigue tests on this connection, and the test results suggest at double the stress range, the number of cycles at failure is at least 8 times the predicted number of cycles. From guidance on the fatigue design of steel structures in BS EN 1993-1-9, the number of cycles to failure is Nf ∝ $\Delta\sigma_c^m$, where m = 3 for less than 5 million cycles. Therefore, based on these results, the connection has sufficient capacity for fatigue.	Westinghouse's conclusion on the fatigue capacity of the connection is based on the results of three tests, which is not considered statistically robust.	MS
5-11	CE-02.A1: Westinghouse has reported in its response to RQ-AP1000®-1615 that from data it has received from the manufacturers of the D2L bars, the elongation at maximum load is 8%, and is therefore compliant with the requirements of Eurocode 2.	Future designers should provide the reference to the manufacturer data for elongation of the D2L bars, in order for ONR to independently verify that this is the case.	MS
5-12	CE-02.A2 Item 4: ONR agrees with Westinghouse not including concrete placement stresses in its calculations, and a spot check in TQ-AP1000®-1085 (Ref. 23) has shown DCR values are acceptable for combined tension and shear.	ONR would expect more of a systematic check to demonstrate performance in combined tension and shear, similar to the DCR values provided for tie bar tension. DCR values for combined tension and shear forces should be provided for the critical areas of the ESB to demonstrate adequate capacity in the tie bars.	MS
5-13	CE-02.A5 Item 2: To verify the tie bar shear capacity of 24.6 kips/bar (as calculated according to ACI 349-01), Westinghouse has carried out three push-out tests as documented in Section 8 of APP-1208-T2R-001 (Ref. 27). However, the results for Specimens 1 and 2 are both based on concrete and reinforcement properties considerably higher than assumed in calculating the nominal shear strength, and result is approximately the same nominal shear strength as predicted by ACI 349-01. For Specimen 3, the concrete compressive strength is lower than for Specimens 1 and 2, and more similar (6.3 ksi versus 6 ksi) to the concrete strength assumed for calculating the nominal shear strength to ACI 349-01. The push-out test for Specimen 3 found a lower force at yield of 17.5 kips/bars. In RQ-AP1000®-1571 Item 10, Westinghouse argues that out-of-plane shear tests on beams of varying shear span/depth documented in the **AP1000®** Shield Building Test Report demonstrate the shear capacity of the tie bars. However, the data recorded by Westinghouse in these tests only records the axial strain in the bars, and does not	Based on this, ONR does not accept Westinghouse's justification on the nominal shear strength of the tie bars that they have assumed. A verifiable design strength for the tie bars should be established and this should be addressed during the next phase of the work.	AF

	demonstrate the shear capacity of the bars. In addition, the tests presented in the **AP1000®** Shield Building Test Report are for tie bars at 17 in spacing, which will be influenced significantly by the shear capacity of the shear studs at 6 in spacing. There are regions of the ESB design around discontinuities where tie bars are required at 6 in spacing. In these regions, the tie bars are critical to the out-of-plane shear capacity of the section and for transferring interfacial shear forces from the liner plate to the concrete. In TQ-AP1000®-1085 (Ref. 23) Westinghouse has calculated an interaction value for combined tension and shear of 0.47 for the 6 in tie bar spacing, and 0.53 for the 17 in tie bar spacing region. For tension due to out-of-plane shear forces, in APP-1208-S3C-022 (Ref. 22) the maximum DCR value is calculated as 0.606 in the 6 in tie bar spacing zone and 0.573 in the 17 in tie bar spacing zone. These DCR values are also based on a yield strength of 60 ksi for the bars, a limit specified by ACI 349-01, rather than the actual yield strength of the bars at 70 ksi. While the utilisation values presented by Westinghouse are low, low DCR values do not validate what is potentially an unconservative value for the nominal shear capacity that has been adopted by Westinghouse in its calculations.		

82. The Westinghouse response to these actions has been considered with respect to the SAPs and used for guidance in the assessment as follows:

- SAP ECE.2 (Independent Arguments) by demonstrating the use of sound design concepts;
- SAP ECE.6 (Loadings) by demonstrating that appropriate load combinations have been considered in the structural design;
- SAP ECE.12 (Structural analysis and model testing) by demonstrating that structural analysis has been carried out to demonstrate that the structure can fulfil its safety function requirements;
- SAP ECE.13 (Use of data) by demonstrating that the data used in the structural analysis is conservative;
- SAP ECE.14 (Sensitivity studies) by demonstrating that the outcome of the analysis is not unduly sensitive to the methods of calculation.

4.5 Assessment of GI-AP1000®-CE-01.A6 – Justification of the ability of SC to withstand thermal load case and GI-AP1000®-CE-02.A7 – Justify how the thermal analysis models transient thermal effects

83. As these GDA actions had a common theme, they were assessed holistically and the Westinghouse responses to assessment comments were reported in a single detailed technical assessment. The ONR assessment of these actions is compiled into a single report, CE-01.A6 & CE-02.A7: Thermal loading (Ref. 44).

84. The Westinghouse primary responses to actions GI-AP1000®-CE-01.A6 and GI-AP1000®-CE-02.A7 are included in document: UK GDA Resolution Plans CE-01 Action 6 and CE.02 Action 7 Justification of the Ability of SC to Withstand Thermal Load Case (Ref. 13).

85. The first stage of the assessment comprised a broad review of the work undertaken by Westinghouse to resolve each action item, for which a broad review record was prepared (Ref. 46). The broad review record documented the assessment of whether, on the basis of the broad review, each action item has been resolved, or if further information was required for the TSC to assess whether or not the action had been resolved. It also identified the requirement for a deep-dive.

86. The deep-dive assessment related to the requirement to satisfy Resolution Plan GI-AP1000®-CE-01.A6 (Ref. 13) as follows. Westinghouse had provided an updated thermal analysis for the containment internal structures (CIS) in response to TQ 1079 (Ref. 47). Their response included a new non-linear thermal analysis of the CIS, considering a combination of thermal loads with mechanical loads resulting from earthquakes, documented in APP-1100-S3C-017 (Ref. 48). A final issue of the static thermal analysis report APP-1100-S2C-005 (Ref. 49) was also submitted as part of Westinghouse's response. A detailed review of these documents was undertaken by the ONR TSC.

87. The ONR broad review and deep-dive assessment comments, with the Westinghouse responses, are included in the following RQs:

- RQ-AP1000®-1617, GDA issues CE-01.A6 and CE-02.A7 – Questions relating to the assessment of thermal stress analysis and design of SC modules (Ref. 50);
- RQ-AP1000®-1629, CE-01.A6 and CE-02.A7 – Thermal analysis of modules (Ref. 51);
- RQ-AP1000®-1636, GDA issues CE-01.A6 and CE-02.A7 – Questions relating to the assessment of thermal stress analysis and design of SC modules (Part 2) (Ref. 52);
- RQ-AP1000®-1643 GDA issues CE-01.A6 and CE-02.A7 – Questions relating to the assessment of thermal stress analysis and design of SC modules (Part 3) (Ref. 76).

88. The outcome of the ONR assessment is recorded in detail in a report compiled by the ONR TSC, CE-01.A6 & CE-02.A7: Thermal loading (Ref. 44).

89. The final comments and the conclusion of the ONR assessment are summarised in Table 6 below. The assessment conclusions are categorised into minor shortfalls (MS) and closed comments (CC). Minor shortfalls are advisory and closed comments are for record purposes.

Table 6 – Summary and Conclusion of the Assessment of GI-AP1000®-CE-01.A6 and GI-AP1000®-CE-02.A7 (Ref. 44)

ID	Assessment Comment Summary	Assessment Conclusion	Cat.
6-1	Westinghouse has supplied the requested documents, which relate to non-linear thermal analyses of the CIS and corresponding static linear analyses. These documents were previously received too late to be reviewed as part of Step 4 GDA and the intention of GI-AP1000®-CE-01 was partly to allow for these documents to be formally issued in response to TQ-AP1000®-1079 (Ref. 47).	These documents were reviewed in the deep-dive resulting in the comments with their corresponding assessment conclusions.	CC
6-2	With reference to the response to the resolution plan, the ONR TSC concluded that the rapid rise in	Westinghouse's response that the maximum force and displacement	CC

	temperature of the steel face plates following a LOCA event would not compromise the integrity of the shear studs and truss elements in the SC modules during the initial stages of the transient. Documentation has been supplied to support this statement.	at any shear stud location is sufficiently low as to not cause a structural integrity issue is considered adequate. This conclusion justifies the assumption that the rapid rise in temperature of the steel face plates following a LOCA event would not compromise the integrity of the shear studs and truss elements in the SC modules during the initial stages of the transient.	
6-3	With reference to the response to the resolution plan, longer-term transient events have been designed for on the basis that steady state temperature profiles will give rise to the most onerous design loads, as they induce less cracking within the concrete sections. This is a general statement that requires closer inspection of the supplied documentation before we can conclude on the acceptability of the response.	Westinghouse's response that the transient phase takes place over a period that is sufficiently long to consider the structural response to the thermal loading as steady state is considered adequate, as the corresponding temperature profile generates the peak loads and there will be no significant dynamic augmentation of the thermally-induced loads earlier in the event. This justifies the use of the steady state thermal condition as the basis of the most onerous design load.	CC
6-4	Arguments are presented in Section 4.5 of Ref. 21 (the response to the resolution plan) regarding the impact of vapour pressure inside the SC modules during periods of high thermal loading. It is claimed that "various research" studies involving "analytical studies and tests" have been reviewed but no citations are supplied to back this up.	Westinghouse has supplied the requested references, which have been reviewed by the ONR TSC who find these references adequate to demonstrate the validity of the assumptions used to estimate the maximum back pressure applied to the inside surface of the liner plate.	CC
6-5	A claim is made in Section 4.5 of Ref. 21 (the response to the resolution plan) that local structural failures, such as "concrete cracking, stud break out and liner plate yielding" will not result in a global structural failure due to the design of the module walls. This appears to be a general statement. Westinghouse should provide justification that the structural failures such as "concrete cracking, stud break out and liner plate yielding" are local and, also, that they do not result in a global failure.	Westinghouse has responded to the general statement regarding concrete cracking and liner plate yielding, but stud break-out has not been addressed. However, it is noted that the quoted vapour pressure of 0.4 MPa (58.2 psi) provided in Section 4.5 of the response to the resolution plan is less than the tensile strength of the concrete (1.72 MPa (250 psi)), suggesting it would not lead to problems with the closely-spaced stud design. Furthermore, although the maximum force in the out-of-plane shear test with thermal loading exceeds the design resistance, this conclusion is based on only a single test result, rather than multiple tests. Following advice from the TSC, ONR considers the above conclusions stated by	CC

		Westinghouse to be adequate.	
6-6	Concerns were raised during Step 4 that thermal loads from the environment have a potentially significant impact on the ESB SC wall and the adequacy of their assessment requires further justification. Specifically, it was an intention of GI-AP1000®-CE-02 that Westinghouse should supply documentation which shows they have conducted their own assessment of solar gains on the steel faceplates, which should be used to justify the thermal performance criteria for the cladding. The outcome of an assessment of the structural response to environmental transients is discussed in Section 4.1 of the response to the resolution plan. However, the basis for this assessment (i.e. the thermal response analysis) is not presented and requires further clarification. Westinghouse should provide further documentation to allow the basis for the thermal cycle shown in Figure 1 of the response to the resolution plan to be reviewed. Westinghouse should also provide further documentation to allow the calculation of the structural response to the calculated thermal loads to be reviewed.	Based on Westinghouse's response and supporting documentation, ONR is satisfied that the assessment of environmental transients is adequate. Providing that Westinghouse can justify that the long-term performance of the light-coloured external coating of the shield building is sufficient to at least match the tabulated sol-air values from ASHRAE, then this coating method is considered adequate. The calculation of the structural response to the calculated thermal loads has been reviewed by the ONR TSC in the Shear, Tie-Bar and Connections assessment report 247462-CE-01.A2-A5-CE-02.A1-A6 (Ref. 26).	MS
6-7	It is stated in Section 4.1 of Ref. 21 that a light-coloured coating will be applied the exterior of the SB to control solar gains. However, no supporting analysis is provided.	Westinghouse's response to this comment has been reviewed by the TSC and found adequate but it is noted that the analysis conclusions are predicated upon provision of a 'light'-coloured coating for the building. This is a qualitative term but the implication is that whatever coating is applied to the external surfaces of the SB, it should achieve a long-term thermal performance (including the impact of dirt and material degradation) no worse than that assumed by the analysis. This performance should be stated in the design documentation.	MS
6-8	Section 4.5.3.1 of the Non-linear Thermal Analysis of **AP1000®** CIS (Ref. 21) states that the concrete-filled steel walls were modelled using composite shell elements. This element type does not allow for the potential effects of de-bonding between the concrete and steel. Effects that could be significant in terms of the interface between the two materials are concrete drying shrinkage and the difference in thermal expansion coefficient between the steel ($7.32x10^{-6}$/°F) and concrete ($5.5x10^{-6}$/°F). Westinghouse should provide justification for their assumptions in the use of composite shell elements for modelling the concrete-filled composite walls.	Based on the good correlation between experimental test and finite element results, the referenced paper is taken as adequate justification for the assumptions in the use of composite shell elements for modelling the concrete-filled composite walls.	CC
6-9	In Section 4.5.3.3.1 of Structural Module Integrity – Initial Thermal Transient Gradient (Ref. 20) Westinghouse states: "Note that the 24 hours static state analysis is more conservative than the transient analysis". It is not clear what the time	Westinghouse's response that the transient phase takes place over a period that is sufficiently long to consider the structural response to the peak thermal loading as	CC

	scales are for which the transient thermal effects occur, i.e. over what period is the temperature (260 °F) of the IRWST water applied to the steel plate. It is also unclear if the initial temperature of 70 °F has been taken as the stress-free temperature for all elements. Westinghouse should provide clarification concerning the assumptions used to justify the steady state thermal condition as the basis of the analysis.	steady state as the basis of the analysis is considered adequate, as the natural periods associated with the structural response will be orders of magnitude shorter; hence, there will be no significant dynamic augmentation of loads.	
6-10	In Section 4.5.3.3.2.c of Non-linear Thermal Analysis of **AP1000®** CIS (Ref. 21) the magnitude, location and method of application of the thermal reactions has not been provided. For example, it is not clear if they were applied to the inner or outer face of the composite wall sections. Westinghouse should provide clarification for the method used for applying the thermal reactions to the analysis model.	Westinghouse's response that the thermal reactions are applied to the model in the form of forces and moments is considered adequate to justify the method used for applying the thermal reactions to the analysis model.	CC
6-11	It is stated in Section 4.5.1 of Non-linear Thermal Analysis of **AP1000®** CIS (Ref. 21) that: "the top of the IRWST wall and the corresponding edge of the operating deck have three degrees of freedom coupled". However, the document also states that only one degree of freedom between the walls and tank roof were coupled in the original ANSYS model. Westinghouse should provide the reasons for this difference, and provide clarification of the actual connectivity between the IRWST wall and roof.	Westinghouse's response that the original ANSYS model had an error that was subsequently updated is considered adequate to justify the statement used in reference to the coupling method used in the models.	CC
6-12	It is stated in Section 4.5.1 of Non-linear Thermal Analysis of AP1000® CIS (Ref. 21) that: "Because ABAQUS coupling interaction is based on rigid body degrees of freedom, the employed coupling scheme is reasonable and most representative of the described connection between the IRWST steel walls and the roof". This statement does not describe the connectivity in sufficient detail for us to make a judgement on the adequacy of the simulation. Westinghouse should provide clarification of the actual connectivity between the steel walls of the IRWST and the operating deck.	The Westinghouse response is considered adequate to describe the actual connectivity between the steel walls of the IRWST and the operating deck.	CC
6-13	It is not clear that the significance of the effect of thermal bridging along the truss elements connecting the inner and outer steel liner plates has been considered.	ONR agrees with the description provided by Westinghouse concerning the thermal bridging of the truss elements and finds the response adequate.	CC
6-14	Section 4.5.3.3.2 of Non-linear Thermal Analysis of **AP1000®** CIS (Ref. 21) describes the loads that have been applied to the model, but does not include the effects of self-weight of the structure. Have the effects of self-weight been considered in the analysis?	The response from Westinghouse that the effects of self-weight have been considered in the analysis is considered adequate.	CC
6-15	Section 4.5.3.3.2.d of Non-linear Thermal Analysis of **AP1000®** CIS (Ref. 21) describes how the seismic loading was applied to the model. How have the effects of the water contained in the IRWST been considered, both in terms of hydrostatic and hydrodynamic pressures?	The ONR TSC advised that the approach for applying hydrostatic and inertial fluid loads to the IRWST, by using the total mass of the water acting on the walls, is adequate. This is assuming that	MS

		Westinghouse has verified that the resulting inertial load is at least equal to the sum of the true inertial and hydrostatic loads.	

90. The Westinghouse response to these actions has been considered with respect to the SAPs and used for guidance in the assessment as follows:

- SAP ECE.2 (Independent Arguments) by demonstrating the use of sound design concepts and by consideration of potential in-service degradation mechanisms;
- SAP ECE.13 (Use of data) by using data in the analysis that is demonstrably conservative;
- SAP ECE.15 (Validation of methods) by demonstrating that the controlling physical equations have been correctly implemented.

4.6 Assessment of GI-AP1000®-CE-01.A7 – Justification of the ability of SC to withstand fire and GI-AP1000®-CE-02.A8 – Provide evidence on the effect of fire on the ESB SC wall

91. As these GDA actions had a common theme, they were assessed holistically and the Westinghouse responses to assessment comments were reported in a single detailed technical assessment. The assessment of these actions is compiled into a single report CE-01.A7 & CE-02.A8: Fire Barrier and Effect of Fire on ESB SC Wall (Ref. 53).

92. The Westinghouse primary responses to actions GI-AP1000®-CE-01.A7 and GI-AP1000®-CE-02.A8 was compiled into a single document:

- RQ-AP1000®-1584 Confirmation of the Required Scope of Response to GI-AP1000®-CE-01.A7 and AP1000®-CE-02.A8 (Ref. 54).

93. The RQ was used by Westinghouse to transmit the document in addition to two RQs that had been issued during the process of confirming the scope of this work; these are noted below:

- Request for Confirmation of Scope of Response to GI-AP1000®-CE-01.A7 and AP1000®-CE-02.A8 RQ-AP1000®-1484 (Ref. 55);
- Request for Confirmation of Scope of Response to GI-AP1000®-CE-01.A7 and AP1000®-CE-02.A8 RQ-AO1000-1546 (Ref. 56).

94. The assessment was initially undertaken in a single stage to accelerate the programme, and this comprised a detailed review of the work undertaken by Westinghouse to resolve each action item, from which a list of assessment comments was prepared in document, Task 5 Fire Performance of CA and SC Modules (Ref. 57).

95. The ONR assessment comments, with the Westinghouse responses, are included in the following RQs:

- RQ-AP1000®-1653 Questions Relating to the Assessment of Fire Resistance of SC Modules (Ref. 58);
- RQ-AP1000®-1691 Questions Relating to the Assessment of the Fire Barrier – Steel/Concrete Failure Mechanism (Part 1) (Ref. 59);
- RQ-AP1000®-1692 Questions Relating to the Assessment of the Fire Barrier – Steel/Concrete Failure Mechanism (Part 2) (Ref. 60);
- RQ-AP1000®-1693 Questions Relating to the Assessment of the Fire Barrier – Heat Transfer Analysis (Part 1) (Ref. 61);

- RQ-AP1000®-1694 Questions Relating to the Assessment of the Fire Barrier – Heat Transfer Analysis (Part 2) (Ref. 62);
- RQ-AP1000®-1695 Questions Relating to the Assessment of the Fire Barrier – Module Capacity Analysis (Part 1) (Ref. 63);
- RQ-AP1000®-1696 Questions Relating to the Assessment of the Fire Barrier – Module Capacity Analysis (Part 2) (Ref. 64);
- RQ-AP1000®-1697 Questions Relating to the Assessment of the Fire Barrier – Conclusions (Ref. 65).

96. Following a review of Westinghouse's responses to the RQs, further comments and requests for information were issued. The ONR assessment comments, with the Westinghouse responses, are included in the following RQs:

- RQ-AP1000®-1766 Further Clarifications Required for the Responses to RQ-AP1000®-1691, RQ-AP1000®-1693, RQ-AP1000®-1694, and RQ-AP1000®-1696 (Ref. 66);
- RQ-AP1000®-1767 Further Clarifications Required for the Responses to RQ-AP1000®-1692 (Ref. 67).

97. Further technical questions were addressed verbally at the Level 4 meetings and these questions, along with the Westinghouse responses, are recorded in Ref. 53.

98. The final comments and the conclusion of the ONR assessment are summarised in Table 7 below. The assessment conclusions are categorised into assessment findings (AF), minor shortfalls (MS) and closed comments (CC). Assessment findings should be dealt with in the next phase of the design, minor shortfalls are advisory and closed comments are for record purposes. The assessment findings are further summarised in Annex 1.

99. The outcome of the assessment of these actions is compiled into a single report CE-01.A7 & CE-02.A8: Fire Barrier and Effect of Fire on ESB SC Wall (Ref. 53).

Table 7 – Summary and Conclusion of Assessment of GI-AP1000®-CE-01.A7 and GI-AP1000®-CE-02.A8 (Ref. 53)

ID	Assessment Comment Summary	Assessment Conclusion	Cat.
7-1	No evidence was provided to demonstrate the applicability of the reference fire resistance tests to the proposed **AP1000®** design. Evidence of the applicability, specifically of the heating exposure, the structural design, the structural materials used and the restraint conditions for the proposed design was requested. Where the fire resistance tests cannot be shown to be applicable, the conclusions drawn on failure mechanisms and the justification for a simplified assessment of capacity are not adequate. Alternatively, specific fire resistance testing of the proposed construction should be undertaken.	Westinghouse is relying on evidence from the referenced fire tests to identify the relevant potential failure modes and general response of the unit. Westinghouse has demonstrated that the proposed CA units for the **AP1000®** design are similarly detailed, are of similar slenderness, with similar materials of construction and therefore the use of the referenced tests to understand the failure modes for the proposed wall units is judged to be adequate.	CC
7-2	The fire resistance tests in the response to RQ-AP1000®-1697 (Ref. 65) were conducted on walls with a height to thickness ratio (H/T) of 10. An H/T ratio of 13 is assumed for the ESB and CA wall modules in Appendix A of the Westinghouse	In the response to RQ-AP1000®-1691 (Ref. 59) Westinghouse states that the maximum H/T of the CA wall modules is 13, which is within the range reported in	CC

	response to RQ-AP1000®-1584 (Ref. 54). Justification as to why a simplified design method supported by Ref.65 is appropriate for a more slender wall construction being proposed was requested.	Moon et al (Ref. 45) and is accepted.	
7-3	The H/T value assumed in 7-2 above shall act as a design limit. It is necessary to confirm if any proposed wall in the **AP1000®** design has an H/T value in excess of 13. Where this value is exceeded the Westinghouse assessment of fire performance is not applicable.	Westinghouse confirms that the maximum H/T ratio in the design is 13.	CC
7-4	In RQ-AP1000®-1697 (Ref. 65) the fire resistance tests were conducted on a 1.65 m width of wall panel and no information is provided in the referenced paper about the edge restraint conditions. The fire performance of walls is sensitive to the width of the wall and the edge support conditions. BS476 recommends that walls are tested with representative edge restraint conditions. ONR requested evidence of the edge support conditions undertaken in the test and their applicability to the wall edge restraint conditions in **AP1000®** design to demonstrate they are applicable.	The global FE analysis conducted in response to the ONR assessment comments does include the specific edge restraint to the walls of interest.	CC
7-5	The fire resistance tests in RQ-AP1000®-1697 (Ref. 65) were conducted on a straight wall element only. The ESB walls appear to be curved in Appendix A in the Westinghouse response to RQ-AP1000®-1584. No evidence was provided that the fire resistance tests can be considered suitable for curved sections. As the surface of the SC structure heats it expands faster than the cool interior; in a straight section this behaviour causes the wall to bow towards the fire. The curvature of the wall section may restrain this action, inducing additional forces in the surface sections of the SC structure. ONR requested evidence that the fire resistance tests can be extrapolated to the curvature and dimensions of the proposed ESB wall.	The study presented in the Westinghouse report does not address a fire in an area with curved structural members. Therefore, the performance of the curved elements has not been quantified. However, in their responses in RQ-AP1000®-1691 (Ref. 59), Westinghouse notes that due to the deflections of the model being relatively small, the effect of a small curvature is not significant. This is accepted as an adequate demonstration that the curvature of the ESB wall will not significantly affect its response to a fire compared to a fully straight section of wall.	CC
7-6	Reference is made to Ref. 45 to justify consideration of flexure and shear capacity only for the assessment of half-steel concrete composite floor elements: a) ONR requested evidence that ignoring the internal compression resulting from restrained thermal expansion is conservative. b) ONR requested evidence that the **AP1000®** CA floor design is sufficiently ductile to produce a plastic hinge at the centre and ends. Where this evidence is not supplied, the simplified assessment undertaken is not appropriate to demonstrate the fire performance of the CA floor module.	Westinghouse has undertaken a non-linear finite element analysis of the structure. The material models explicitly permit the assessment to address thermally-induced compression forces and plastic behaviour in the structural elements. Westinghouse has therefore adequately addressed this comment.	CC

7-7	Ref. 65 and 45 have been used to justify the use of simplified analytical calculations to determine the performance of the ESB wall and CA wall and floor SC modules. Action GI-AP1000®-CE-01.A7 "Justification of the ability of SC to withstand fire" requires that the "overall response of the whole structure to the temperatures in the fire, i.e. combination of induced thermal moment with other loads and deflections" is specifically considered. The performance of individual elements has been considered only by this calculation. ONR requested a calculation of the overall response of the whole structure including quantification where necessary.	ONR has reviewed this analysis report in detail. In conclusion, the overall response of the structure is analysed in the non-linear finite element analysis. The model explicitly includes the effect of thermal expansion and the restraint created around the heated room by modelling the complete structure. However, Westinghouse has not provided sufficient information to permit ONR to determine if the finite element model is sufficiently accurate, and further work is required. See Table 8 below.	AF
7-8	Ref. 65 and 45 have used the ASTM E119 and ISO 834 fire curve respectively. The Westinghouse response to RQ-AP1000®-1584 has used the EN 1991-1-2:2002 hydrocarbon shape curve, which has a much faster heating rate and peak temperature. The study has not provided evidence of why the assessment can be extrapolated to a different heating regime. The calculation method has not been demonstrated to be valid for the hydrocarbon heating regime and therefore without the requested evidence is not considered adequate.	Westinghouse acknowledges that the tests are relied on for the outline failure modes only. The test results are not relied on for any other purpose in the calculation of the fire resistance of the CA wall modules. Westinghouse has addressed the difference in fire curve by undertaking a specific heat transfer analysis using a hydrocarbon-type fire. The Westinghouse assessment is adequate, provided that the global model adequately addresses the transient thermal gradients developed in the model during the course of a hydrocarbon-type fire.	AF
7-9	The codes (JEAG, SNG) and research papers Ref. 45 and 65 state that the fire performance of the test SC walls and floors are subject to specific detailing provisions such as top reinforcement ratio in floor structures, and steam vapour holes in wall structures, in addition to the quoted H/T ratio and axial load ratio limitations. These specific detailing requirements should be incorporated into the design, otherwise the guidance and applicability of the reported tests are not valid. To assess applicability and therefore validity of the approach, please provide the specific detailing requirements and provide evidence of their incorporation into the design.	The issue of vapour holes has been dealt with by removal of the steel faceplate from the strength hand calculations. Westinghouse has stated that the design of the CA wall and floor units is within the tested H/T ratio and axial load ratio. The units also address the requirements of ambient gravity and seismic design for ductility. Therefore Westinghouse has adequately addressed the specific comment on detailing of the CA units.	CC
7-10	The basis for the 3-hour maximum duration of exposure was agreed between ONR and Westinghouse in RQ-AP1000®-1584. However, no specific fire model, for example the parametric fire model or temperature-time curve (for example ISO 834, ASTM E119) is specified, nor type of fire hazard, are defined in this agreement. The assessment has identified a hydrocarbon-type temperature-time curve as a more severe fire curve	Westinghouse has defined an exposure curve which addresses the characteristics of the worst case fuel load. This exposure is considered the most onerous for the structural elements and therefore Westinghouse's approach is judged to be adequate.	CC

	than the standard fire and therefore used this. Westinghouse should provide evidence that this heating regime is the worst case in terms of structural response, in order to answer the GDA issue.		
7-11	In quantifying the structural capacity of the ESB wall and CA wall and floor SC modules, two hydrocarbon temperature-time curves have been used, the 'Eurocode Hydrocarbon' temperature-time curve and the 'max hydrocarbon' temperature-time curve. No reference is provided for the 'max hydrocarbon' temperature-time curve.	The Westinghouse response provides clarification on the basis for the maximum temperature and this is accepted.	CC
7-12	In Ref. 74, all heat transfer analyses conducted are 1D (post comment correction, 2D analysis of 1-sided heating). Confirmation of the presence of any penetrations or openings through the SC modules was requested. If these are present, the 1D [sic] heat transfer results are not conservative as heating of the SC modules may occur on more than 1 face. In this case, the predictions of structural capacity would be considered as not adequate; the effect of these openings on the SC module thermal profile and structural capacity would need to be demonstrated.	Modules credited as fire barriers will only be exposed on one side. The effect on the loadbearing capacity of the CA modules of a fire passing through an unstopped penetration and affecting both sides of the unit simultaneously has not been addressed by Westinghouse and this should be considered further.	AF
7-13	In defining the radiation heat transfer thermal boundary, it is noted that the boundary definition has been linearised by use of a radiation heat transfer coefficient (Ref. 74). It is common structural fire engineering practice to explicitly define the radiation thermal boundary and this is feasible in the used software ANSYS. Evidence that the adopted approach is conservative in predicting the structural temperatures, was requested.	Westinghouse's adoption of the very large convective coefficient means that the surface temperature of the modelled CA wall section will inherently be very close to the gas phase temperature of the proposed fire, which is the worst case. The Westinghouse approach is therefore judged to be adequate.	CC
7-14	A convective heat transfer coefficient of 40 kW/m^2 has been used in Ref. 74. It should be noted that EN 1992-1-2:2002 recommends a convective heat transfer coefficient of 50 kW/m^2 for hydrocarbon-type exposure.	In their response in RQ-AP1000®-1693, Westinghouse presented a graph comparing the results of the heat transfer analysis using a value of 40 W/m^2.K with the results of the assessment using 50 W/m^2.K. The difference is demonstrated as negligible and therefore Westinghouse's approach is demonstrated as adequate.	CC
7-15	The material thermal properties were not provided in Ref. 74. The density, thermal conductivity and specific heat thermal properties for the steel and concrete materials used in the analysis were requested. For concrete, the moisture content and aggregate type are two parameters known to significantly affect the rate of heat transfer and therefore temperature predictions. The assumptions regarding the moisture content of the concrete and the aggregate type and then how this has been included in the heat transfer analysis were requested. Evidence is also required of the	The material properties implemented by Westinghouse are close to those reported in industry standards. Therefore, the Westinghouse approach is judged to be acceptable.	CC

	applicability of all steel and concrete material assumptions to the **AP1000®** design.		
7-16	Evidence that the accuracy of the heat transfer finite element analysis documented in Ref. 74 is not affected by the selected mesh size, i.e. that the mesh size is appropriate for the modelled materials and thermal exposure, was requested.	Westinghouse presented results of a sensitivity study that demonstrate that the mesh size used in their models will produce accurate results. Therefore, Westinghouse's assessment is judged to be adequate.	CC
7-17	Ref. 31 contains heat transfer analyses of the SC modules under exposure to the ISO 834 standard temperature-time curve. No reference is made to these analyses in Westinghouse's response to RQ-AP1000®-1584: confirmation was requested of the relevance of these assessments to the prediction of SC module fire performance. No comment was provided on these analyses at this time.	Westinghouse confirmed that the ISO 834 analysis is not relevant to this Action.	CC
7-18	To determine the structural demand under fire, the load combinations have been determined in accordance with AISC 360-10. The load combination should contain load 'T' which is 'load effects due to fire'. These effects are incorrectly stated to relate to material degradation effects only. Load effects due to fire should include such effects as forces and moments arising from thermal expansion and its restraint where significant. No consideration of thermal expansion effects has been included in the calculation. These effects, where significant, are required to be evaluated in order to make a prediction of structural performance, as they can govern over loss of material strength. For example, in large concrete structures subject to very long exposure, large thermal expansions by floors and beams can create overturning forces at the head of column walls. To quantify the whole structural response this effect must be accounted for or be demonstrated to be negligible. This is considered necessary to address Action GI-AP1000®-CE-01.A7 which requires consideration of "overall response of the whole structure to the temperatures in the fire, i.e. combination of induced thermal moment with other loads and deflections".	It has not been possible to determine the reliability of the Westinghouse finite element model from the information provided.	AF
7-19	In Table 3 of Ref. 15, the minimum section sizes required to support the applied load under the fire limit state is calculated. The purpose of this information is not clarified, nor how the Westinghouse assessment relies on this information. Confirmation of the purpose of this information was requested.	Westinghouse confirmed in the response to RQ-AP1000®-1695 that Table 3 is the minimum CA section required to resist the applied loads.	CC
7-20	The ESB and CA wall modules provide lateral stiffness to the structure. Confirmation that lateral loading with the appropriate load safety factors have been included in the analysis, was requested.	Westinghouse has confirmed that lateral loads are addressed in its global model. However, the global model does not demonstrate the stability of the ESB structure when it is exposed to fire. This was not	MS

		requested by ONR.	
7-21	The ESB and CA wall modules are assessed under 1-sided heating. As the material strength on the exposed face decreases, an eccentricity in the applied load develops. No load eccentricity has been considered in the calculation. Clarification as to how potential load eccentricity effects were accounted for in determining the performance of wall systems, was requested.	Westinghouse stated that the fully non-linear finite element model of the CA wall adequately addresses the issue of load eccentricity. The ESB modules were not addressed, however this was not requested by ONR.	MS
7-22	In Ref. 65, the tested SC wall system is shown to deflect initially towards the fire and then away. This outward deflection (Δ) of the wall and the applied compressive load (P) will induce a moment (P-Δ). No moment effects have been considered in this calculation. Evidence that this effect will not exceed the load carrying capacity prediction in a fire, was requested. The P-δ effects are accounted for in the global non-linear analysis due to the inclusion of thermal expansion through the use of a recognised reference model and material degradation of concrete and steel with the temperature rise using appropriate data from credible references.	To demonstrate that the results of the model are reasonably capturing the real response of this type of structure, a review of the time-dependant output is required.	AF
7-23	A calculation of residual CA and ESB wall capacity is undertaken using guidance from AISC 360-10 (Appendix A). The check for buckling capacity uses the AISC 360-10 guidance for encased composite members. Encased composite members are defined in AISC 360-10 as “a composite member consisting of a structural concrete member and one or more embedded steel shapes”. Neither the CA nor the ESB wall modules are encased composite members. Therefore, the adopted buckling calculations are considered not applicable and the resultant prediction of structural capacity not appropriate.	Westinghouse has confirmed that the method presented in AISC 360-10 for encased composite sections is relevant to filled composite sections (similar to the CA modules) provided that specific modifications are made to the nominal axial strength and the effective rigidity. Westinghouse further demonstrated that its assumptions for these two factors are conservative. Therefore, it is judged that Westinghouse have adequately addressed this comment in their approach.	CC
7-24	Action GI-AP1000®-CE-01.A7 and Action GI-AP1000®-CE02.A8 requested consideration of the risk of vapour pressure in the event of fire for the SC wall modules. No explicit assessment of the risk of vapour pressure for the **AP1000®** SC modules has been included. The assessment references SNG and JEAG code guidance and fire testing in Ref. 65 on provision of vapour holes for SC modules and includes a ‘spalling factor’ from Ref. 30 in the compressive capacity calculations. These references are not considered to address the GDA query as no evidence is provided on: (a) the specific vapour pressure risk for the **AP1000®** SC wall modules and its consequence for structural fire performance;	Westinghouse has adequately accounted for the effects of vapour build up in their calculations by neglecting the contribution of the steel faceplate and allowance for reduced cross section. This was judged to be an acceptable approach.	CC

	(b) whether the vapour holes will be incorporated into the **AP1000®** SC wall module design; and (c) the relevance of reducing compressive capacity by a 'spalling factor' to the risk and effect of vapour pressure for structural fire performance in an SC member. Evidence of the above must be provided.		
7-25	It was noted that the referenced spalling factor in Ref. 30 has been extrapolated from experimental testing of reinforcement concrete columns. It is not therefore applicable to filled composite steel-concrete sections. The assessment is not therefore considered to account for the risk of spalling or pressure vapour within the steel and therefore does not answer the specific query raised in the GDA.	Westinghouse has yet to demonstrate that assumptions made in determining spalling in their calculations are reasonable, and this should be considered in further work.	AF
7-26	The calculated ESB wall and CA wall module capacities are compared with the peak compressive force demand in an ANSYS analysis. As the ASNYS model has been used to define the force demand only for the SC sections, the following information must be provided to demonstrate that the load demands have been calculated appropriately: the applied loading in accordance with the stated load combinations, the relative stiffness of individual elements and the applied boundary conditions and what supports they represent, so that it can be verified that the load paths and therefore force demand are representative of the proposed structure.	It is judged that Westinghouse has adequately demonstrated that the ANSYS model provides representative force demands for the assessment.	CC
7-27	Westinghouse has through their literature review identified shear capacity as a critical mechanism for the CA floor modules. Westinghouse has undertaken a shear calculation in accordance with ACI 349-01 Clause 11.7 which relates specifically to shear friction and is quoted in 11.7.1 as being applicable to considering shear transfer across "an existing or potential crack, an interface between dissimilar materials, an interface between two concretes cast at different times". No evidence is provided for the applicability of this calculation to the shear capacity of the SC CA floor modules in the fire condition. Evidence of this was requested.	Westinghouse has demonstrated that it is appropriate for the top slab reinforcement to resist the out-of-plane shear demand and this is judged to be an acceptable approach.	CC

100. In support of the assessment of GI-AP1000®-CE-01.A7 and GI-AP1000®-CE-02.A8, the supporting finite element modelling report was assessed in detail. The outcome of that assessment is summarised in Table 1 of the document, CE-01.A7 & CE-02.A8: Fire Barrier and Effect of Fire on ESB SC Wall (Ref. 53). The outcome of this detailed assessment is summarised in Table 8 below. The assessment conclusions are categorised into assessment findings (AF), minor shortfalls (MS) and Closed Comments (CC). Assessment findings should be dealt with in the next phase of the design, minor shortfalls are advisory. The assessment findings are further summarised in Annex 1.

<u>Table 8 – Summary and Conclusion of the Assessment of the Finite Element</u>

Analysis Produced for GI-AP1000®-CE-01.A7 and GI-AP1000®-CE-02.A8 (See Ref. 53)

ID	Assessment Comment Summary	Assessment Conclusion	Cat.
8-1	Clarification of the sequence in which the gravity loads and the thermal loads were applied in the mechanical analysis was requested.	Westinghouse stated that gravity load is applied as an instantaneous load at the start of the analysis and has undertaken checks to confirm that this sudden application of load will not introduce unrealistic dynamic effects. Westinghouse stated that the end state of the heat transfer model is implemented into the structural model as temperature input. The structure starts at ambient and all elemental section points heat up to the maximum temperature linearly over a 1 second analysis time. ONR has the opinion that the application of thermal load will underestimate the thermal gradient in the concrete structures in the early stages of the fire. The effects of this have been qualitatively determined by Westinghouse to be negligible, but not demonstrated and further work is required.	AF
8-2	ONR questioned whether the thermal loading input applied to the mechanical analysis? Was it applied over time and if so was time scaling used?	Westinghouse stated that the thermal load is applied over a 1 second analysis time. This implements a time scaling factor of 10,800, i.e. the analysis time is 1:10,800th of the actual proposed fire exposure. High time scaling factors are known to potentially affect the accuracy of results in structural fire models and this should be considered in future work.	AF
8-3	It was noted that ABAQUS explicit was used for the analysis and it was questioned if a static or a dynamic analysis was performed. Also, if a dynamic analysis was performed, was damping/mass scaling considered?	Westinghouse stated that the ABAQUS Explicit / Dynamic solver was used. The default viscous damping parameters were implemented and mass scaling was applied. The mass scaling did not significantly affect the mass of the model, and hence is unlikely to affect the results of the model.	CC
8-4	ONR questioned how the loads have been applied to the structure, i.e. elemental body force or individual nodal forces?	Westinghouse stated that the heat transfer analysis applied temperatures to nodes, and that the mechanical analysis applied gravity and lateral loads as body forces to each element.	CC
8-5	ONR questioned how, for the concrete material, tension strength was considered in the damaged plasticity model?	Westinghouse stated that the same tension material model was used as implemented in APP-1100-S3C-017 (Ref. 21). ONR has the opinion that this material model is not temperature dependent. This effectively increases the energy that the concrete can absorb in tension at higher temperatures. This is likely to reduce the deflections observed in the floors and walls in the model, and further work is required.	AF
8-6	Section 4.5.1 of Ref. 19 states that the mesh size is sufficient, but no proof is provided.	Westinghouse has not provided evidence that the element size will provide accurate results. ONR has the opinion that mesh size is an important aspect of computational modelling. Without demonstration that the element size is adequate, the model cannot be demonstrated as accurate and further work is	AF

		required.	
8-7	ONR requested a sample of time-dependent results for a few representative nodes, i.e. mid-span deflection for the floors and walls and time-dependent stresses and strains.	Westinghouse provided a justification that time-dependant results would not affect the fire assessment conclusions ONR paused the assessment and further work is required to close this.	AF

101. The Westinghouse response to these actions has been considered with respect to the SAPs and used for guidance in the assessment as follows:

- SAP EHA.1 (Identification and characterisation) by identifying and characterising an appropriate fire hazard;
- SAP EHA.6 (Analysis) by analysing the effects of the fire on the surrounding structure;
- SAP EHA.14 (Fire, explosion, missiles, toxic gases etc. – sources of harm) by identifying and quantifying the fire that may lead to collapse of the surrounding structure;
- SAP ECE.1 (Functional performance) by specifying that the surrounding structure should not collapse during a fire;
- SAP ECE.6 (Loadings) by using appropriate load combinations in conjunction with the fire load;
- SAP ECE.12 (Structural analysis and model testing) by using fire test data in conjunction with finite element analysis to demonstrate the performance of the SC structure in a fire;
- SAP ECE.13 (Use of data) by using suitably conservative data.

4.7 Assessment of GI-AP1000®-CE-01.A8 – Long term reliability and GI-AP1000®-CE-02.A9 – Provide further substantiation on the reliability of the Enhanced Shield Building

102. As these GDA actions had a common theme, they were assessed holistically and the Westinghouse responses to assessment comments were reported in a single detailed technical assessment. The ONR assessment of the responses to these actions is compiled into a single report, CE-01.A8 & CE-02.A9: Long Term Reliability of SC Structures (Ref. 68).

103. The Westinghouse primary responses to actions GI-AP1000®-CE-01.A8 and GI-AP1000®-CE-02.A9 are included in documents:

- UK GDA Resolution Plans CE-01 Action 8 and CE.02 Action 9 Long Term Reliability of SC Structures (Ref. 15).

104. A single combined broad review and deep-dive assessment was carried out; a report was not issued.

105. The ONR preliminary assessment comments, with the Westinghouse responses, are included in the following RQs:

- RQ-AP1000®-1575, GDA Issues CE-01.A8 & CE-02.A9 Questions Relating to the Assessment of the Long Term Reliability (1 of 4) (Ref. 70);
- RQ-AP1000®-1576, GDA Issues CE-01.A8 & CE-02.A9 Questions Relating to the Assessment of the Long Term Reliability (2 of 4) (Ref. 71);
- RQ-AP1000®-1577, GDA Issues CE-01.A8 & CE-02.A9 Questions Relating to the Assessment of the Long Term Reliability (3 of 4) (Ref .72);

- RQ-AP1000®-1578, GDA Issues CE-01.A8 & CE-02.A9 Questions Relating to the Assessment of the Long Term Reliability (4 of 4) (Ref. 73).

106. The outcome of the ONR assessment is recorded in detail in a report compiled by the ONR TSC, CE-01.A8 and CE-02.A9: Long Term Reliability of SC Structures (Ref. 68).

107. The final comments and the conclusion of the ONR assessment are summarised in Table 9 below. The assessment conclusions are categorised as assessment findings (AF), minor shortfalls (MS) and closed comments (CC). Assessment findings should be dealt with in the next phase of the work, minor shortfalls are advisory. The assessment findings are further summarised in Annex 1.

108. ONR reviewed the summary and conclusions in Table 9 (Ref.78) against the requirements of the SAPs and outcome is also summarised in the table.

Table 9 – Summary and Conclusion of the Assessment of GI-AP1000®-CE-01.A8 and-CE-02.A9 (See Ref. 68)

ID	Assessment Comment Summary	Assessment Conclusion	Outcome of Further ONR Review	Cat.
9-1	Westinghouse has not demonstrated that they have considered the need for the structure to remain functional beyond the 60-year planned operational life of the reactor.	The functional design life of the structures, which should extend beyond their operational life to allow for safe decommissioning, should be confirmed. The outcome should be considered in the designs.	While the evidence provided to demonstrate the reliability of SC units may be inconsistent with Eurocode requirements, the large margin to failure (probably 2) inherent in elastic code designs is judged to ensure that the reliability provided by the ACI-349 design is adequate.	MS
9-2	Westinghouse has not been explicit in defining the target reliability for Class 1 structures. The detailed assessment has found inconsistencies between the claims being made and the supporting evidence provided.	In conjunction with the response to Comment 9-1, the inconsistencies should be resolved and taken into account in the designs.	As above in 9-1, the conservatisms inherent in designing the SC structures to codes based on elastic limits is judged to provide adequate margins against failure and thereby demonstrate that there are measures to provide an adequate degree of reliability.	CC
9-3	Westinghouse has not demonstrated that the SC structures achieve the flexural reliability assumed by the Eurocodes, contravening the claims made. Westinghouse claims that SC structures conform with the reliability of RC structures in accordance with ACI 349, and that this reliability is comparable to that of similar class RC structures designed to the Eurocodes. However, the evidence put forward does not support these claims.	In conjunction with the response to Comments 9-1 and 9-2, the evidence-based justification (i.e. test data etc.) should be revisited to ensure consistency between this evidence and the design basis, and take account of the outcome in the designs.	The ONR TSC has advised that a more exact calculation method is appropriate and has re-calculated the strength reduction factors to demonstrate that the strength reduction factor for flexure is not met They have however demonstrated that the default strength reduction factor for in-plane shear, the dominant resistance, is met.	MS
9-4	Westinghouse has not demonstrated the significance of the reduced in-plane shear resistances presented in the report, In-Plane Shear Calculations to Support RQ-AP1000®-1575 Item 2b, NPP_JNE_001203 Enclosure 08 (Ref. 77).	Confirmation is required that the design basis, reports and working calculations are thoroughly consistent.	It has not been made clear that an erroneous statement in the calculation of in-plane shear capacity of the SC units has been corrected in the design. This is not a reliability issue.	MS
9-5	Westinghouse claims that designing out-of-plane shear using ACI 349-01 provisions can achieve a target reliability index of 4. The evidence shows this is not correct.	In conjunction with the response to Comments 9-1 and 9-2, the evidence-based justification (i.e. test data, etc.) should be revisited to ensure consistency between this evidence and design basis, and the outcome	The ONR TSC has advised that a more exact calculation method is appropriate and has re-calculated the strength reduction factors using the exact method and demonstrated that the strength reduction factors	AF

		accounted for in the designs.	for out-of-plane shear and flexure are not met. Also, the WEC calculated values do not demonstrate that the ACI-349 requirements are met for out-of-plane shear (0.74 cf. 0.85 is a 15% difference). It is not clear to me that this reduction in the margin is acceptable, and a further response is appropriate	
9-6	Informal ’conservative sizing‘ of structural members is outside of the codified rules and is not accepted as a reliable design procedure.	General references to conservatism in the design will not be accepted in this assessment unless a quantitative quality control procedure is provided to ensure such conservatisms are consistently achieved across all elements. Any such use of conservatisms must be clearly recorded as design limits in the basis of design documentation.	The comment is valid and is acknowledge in Westinghouse’s response to the comment. Westinghouse do not intend to include “over-sizing” in their design process and state that they will use the usual load and resistance factors to ensure reliability.	MS
9-7	The allowable dimensions of SC components go beyond the bounds of the specimens tested that have been used to demonstrate reliability. The design therefore assumes extrapolation of this data.	It should be demonstrated that the test data, upon which the reliability claims are based, is representative of the planned structure.	The ONR TSC has reviewed the range of minor inconsistencies between the test and the construction details. From my examination of the review I can judge that the inconsistencies are relatively minor and unlikely to reduce the design margins.	MS

109. The Westinghouse response to these actions has been considered with respect to the SAPs and used for guidance in the assessment as follows:

- SAP ECE.2 (Independent Arguments) by demonstrating the use of specific appropriate design standards have been considered;
- SAP ECE.6 (Loadings) by demonstrating the load combinations and their frequencies have used as the basis for the structural design;
- SAP ECE.12 (Structural analysis and model testing).by demonstrating the structure can fulfil its safety function requirements over the full range of loading for the lifetime of the structure;
- SAP ECE. 13 (Use of data) by demonstrating that the data used in the analysis is demonstrably conservative;
- SAP ECE.14 (Sensitivity studies) by demonstrating the sensitivity of the results to the assumptions made;
- SAP ECE.16 (Materials) by demonstrating the construction materials used comply with the design methodologies used.

5 ASSESSMENT FINDINGS

110. During my assessment, a number of items were identified for a future licensee to take forward in their site-specific safety submissions. Details of these are contained in the technical assessment reports produced for ONR. They are summarised in Tables 5 to 9 of this report and are further summarised in Annex 1.

111. 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 stages. These items are captured as assessment findings.

112. Residual matters are recorded as assessment findings if one or more of the following apply:

- site-specific information is required to resolve this matter;
- relatively minor deficiencies in the technical quality of the safety case do not result in a significant reduction in nuclear safety, and opportunities for improvement to reduce risks have been identified;
- 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.

6 MINOR SHORTFALLS

113. During my assessment, a number of items were identified as minor shortfalls in the safety case, which are not considered to require specific action to be taken by the future licensee. Details of these are contained in the detailed technical assessment reports produced for ONR, and they are summarised in Tables 5 to 9 of this report.

114. Residual matters are recorded as minor shortfalls if 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;
- require further substantiation to be undertaken.

7 CLOSED COMMENTS

115. During my assessment, it was appropriate to close out many of the assessment comments and this is recorded in Tables 5 to 9.

8 CONCLUSIONS

116. This report presents the findings of the ONR assessment of the responses to two GDA issues, GI-AP1000®-CE-01 Rev 0 – Justification of Novel Forms of Structure for the Steel/Concrete Composite Wall and Floor Panels Known as CA Modules, and GI-AP1000®-CE-02 Rev 1 – Further Justification of Novel Form of Structure for the Steel/Concrete Composite Wall to the Enhanced Shield Building relating to the **AP1000®** closure phase.

117. To conclude, I judge that from a civil engineering viewpoint, and subject to taking cognisance of the assessment findings, the **AP1000®** design is suitable for construction in the UK.

2. REFERENCES

1 GI-AP1000®-CE-01 Rev 0 – Justification of Novel Forms of Structure for the Steel/Concrete Composite Wall and Floor Panels Known as CA Modules, TRIM Ref. 2011/369280.

2 GI-AP1000®-CE-02 Rev 1 – Further Justification of Novel Form of Structure for the Steel/Concrete Composite Wall to the Enhanced Shield Building, TRIM Ref. 2011/369282.

3 ONR assessment plan ONR-GDA-14-008 Revision 2 TRIM Ref. 2016/58360.

4 Office for Nuclear Regulation (ONR), Guidance on Mechanics of assessment, TRIM Ref. 2013/204124.

5 GI-AP1000®-IH-01 GDA Issue – Internal Fire Safety Case Substantiation, TRIM Ref. 2011/369342.

6 Westinghouse UK **AP1000®®** GENERIC DESIGN ASSESSMENT Resolution Plan for GI-AP1000®-CE-01. Justification of Novel Forms of Structure for the Steel/Concrete Composite Wall and Floors Known as CA Modules 3, TRIM Ref. 2015/89841.

7 Westinghouse UK **AP1000®®** GENERIC DESIGN ASSESSMENT Resolution Plan for GI-AP1000®-CE-01. Further Justification of Novel Form of Structure for the Steel/Concrete Composite Wall to the Enhanced Shield Building, TRIM Ref. 2015/89846.

8 **AP1000®** Plant Structural Module, Behaviour and Design Summary Report, APP-GW-SUP-003 Revision 0, 25 April 2016, TRIM Ref. 2016/173009.

9 UK GDA Resolution Plans CE-01 Action 2 and CE-02 Action 3 Out of Plane Shear Acceptance Criteria, DCP_DCP_007351, 22 July 2015, TRIM Ref. 2015/276147.

10 UK GDA Resolution Plans CE.01 Action 3 and CE.02 Action 4 In-Plane Shear Capacity Combined with Other Loads, DCP_DCP_007421, TRIM Ref. 2015/305351.

11 UK GDA Resolution Plans CE-01 Action 4 and CE-02 Action 5 Justification of Shear Connections, DCP_DCP_007441, TRIM Ref. 2015/313503.

12 UK GDA Resolution Plans CE-01 Action 5 and CE-02 Action 6 Justification of Shear Connections Summary, DCP_DCD_007329, TRIM Ref. 2015/267900.

13 UK GDA Resolution Plans CE.01 Action 6 and CE.02 Action 7 Justification of the Ability of SC to Withstand Thermal Load Case, DCP_DCP_007969, TRIM Ref. 2016/150285.

14 Confirmation of the Required Scope of Response to GI-AP1000®-CE-01.A7 and AP1000®-CE-02.A8, DCP_DCP_007938, TRIM Ref. 2016/296826.

15 Generic Design Assessment (GDA) **AP1000®®** Plant CE.01 Action 8 and CE.02 Action 9 Long Term Reliability of SC Structures, DCP_DCP_007792, TRIM Ref. 2016/30179.

16 UK GDA Resolution Plan CE.02 Action 1 Tie Bar Material and CE.02 Action 2 Tie Bar Demand, DCP_DCP_008029, TRIM Ref. 2016/192715.

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18 ONR Safety Assessment Principals for Nuclear facilities 2014 Edition Revision 0, TRIM Ref. 2014/443919.

19 WEC-REG-1493N – UKP-GW-GL-131 – Revision 0 – AP1000® Global Analysis for Postulated Fire Loading, TRIM Ref. 2016/495703

20 APP-GW-SUP-008 Rev 0 – Structural Module Integrity - Initial Thermal Transient Gradient (Response to RQ-AP1000®-1564) – 16 May 2016, TRIM Ref. 2016/201622.

21 APP-1100-S3C-017 Rev 0 – Non-linear Thermal Analysis of **AP1000®** CIS (Response to RQ-AP1000®-1564) – 16 May 2016, TRIM Ref. 2016/201768.

22 NOT USED.

23 TQ-AP1000®-1085, TRIM Ref. 2011/126942.

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

25 Consolidated Set of Design Documents, TRIM Ref. 2016/451004.

26 CE-01.A2 to A5 & CE-02.A1 to A6: Shear, tie bar and connections, TRIM Ref. 2016/452742.
27 APP-1208-T2R-001 – **AP1000®** Rev.0 Shield Building Structural Test Report – RQ-AP1000®-1341, TRIM Ref. 2016/188223.
28 APP-CA20-GEF-1392 – Revision 0 – APP-CA20-S3C-017 Calculation Revision (Response to RQ-AP1000®-1630) – 30 September 2016, TRIM Ref. 2016/382823.
29 APP-CA20-S3C-016 – Revision 2 – **AP1000®** CA20 Structural Module Design Evaluation (Response to RQ-AP1000®-1476) – 4 March 2016, TRIM Ref. 2016/99885.
30 Japan Electric Association, Technical Guidelines for Seismic Design of Steel Plate Reinforced Concrete Structures – Buildings and Structures – JEAG 4618-2005.
31 Westinghouse Electric Company, Heat Transfer Analysis of SC Walls and Floors in a Three-Hour Standard Fire, UKP-GW-GL-123, Revision 0, 31 March 2016.
32 Connections Broad Review, ONR275-T2-BR Draft 1 28 April 2016, TRIM Ref. 2016/488265.
33 RQ-AP1000®-1474 Information requested to facilitate the assessment of Document NPP_JNE_000185 Enclosure 1, TRIM Ref. 2016/68432.
34 RQ-AP1000®-1476 Information requested to facilitate the assessment of the WEC responses to GDA Issue CE-01 & CE-02, TRIM Ref. 2016/99608.
35 RQ-AP1000®-1541 Information requested to facilitate the WEC responses to GDA Issues CE-01 & CE-02, TRIM Ref. 2016/150219.
36 RQ-AP1000®-1570 GDA Issues CE-01 &CE-02. Questions relating to the assessment of the steel/concrete modules (1 of 2), TRIM Ref. 2016/279217.
37 RQ-AP1000®-1571 GDA Issues CE-01 &CE-02. Questions relating to the assessment of the steel/concrete modules (2 of 2), TRIM Ref. 2016/285369.
38 RQ-AP1000®-1586 Information requested to facilitate the assessment of the WEC responses to GDA issues CE-01 & CE-02, TRIM Ref. 2016/239212.
39 RQ-AP1000®-1601 Auxiliary Building Roof to Enhanced Shield Building Wall Connection, TRIM Ref. 2016/265544.
40 RQ-AP1000®-1603 Information requested to facilitate the assessment of the WEC responses to GDA issues CE-01 & CE-02, TRIM Ref. 2016/265671.
41 RQ-AP1000®-1605 Information requested to facilitate the assessment of the WEC responses to GDA issues CE-01 & CE-02, TRIM Ref. 2016/278884.
42 RQ-AP1000®-1615 GDA Issues CE-01 & CE-02 Questions relating to the assessment of the steel concrete modules. Additional to RQ-AP1000®-1571 (Part 3 of comments), TRIM Ref. 2016/378117.
43 RQ-AP1000®-1630 CE-01A.5 Module wall to base-mat connection, TRIM Ref. 2016/382818.
44 CE-01.A6 & CE-02.A7: Thermal loading, TRIM Ref. 2016/455401.
45 Kim, W., Jee, N.Y., Lee, C.S., and Mun, T.Y, Performance-based Fire Design of Half SC Slabs in Nuclear Power Plants, 20th International Conference on Structural Mechanics in Reactor Technology (SMiRT 20), Espoo, Finland, August 9-14, 2009, Paper 1698.
46 Task 4. Thermal Load Broad Review. ONR275-T4-BR Draft 1, TRIM Ref. 2016/491650.
47 TQ-AP1000®-1079. Thermal Stress Analysis and Design of SC Modules. TRIM Ref. 2010493268.
48 APP-1100-S3C-017. Rev.0 Non-linear thermal analysis of AP1000® CIS, TRIM Ref. 2016/2017.
49 APP-1100-S2C-005. Rev. 6 Static Analysis of Containment Internal Structures – Thermal Analysis, TRIM Ref. 2016/201803.
50 RQ-AP1000®-1617, GDA Issues CE-01.A6 and CE-02.A7 Questions relating to the assessment of thermal stress analysis and design of SC modules, TRIM Ref. 2016/378117.
51 RQ-AP1000®-1629, CE-01.A6 and CE-02.A7 Thermal analysis of modules, TRIM Ref. 2016/304693.

52 RQ-AP1000®-1636, GDA Issues CE-01.A6 and CE-02.A7 Questions relating to the assessment of thermal stress analysis and design of SC modules (Part 2), TRIM Ref. 2016/344031.
53 CE-01.A7 & CE-02.A8: Fire Barrier and Effect of Fire on ESB SC Wall, TRIM Ref. 2017/52036.
54 RQ-AP1000®-1584 Confirmation of the Required Scope of Response to GI-AP1000®-CE-01.A7 and AP1000®-CE-02.A8, TRIM Ref. 2016/296826.
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56 Request for Confirmation of Scope of Response to GI-AP1000®-CE-01.A7 and AP1000®-CE-02.A8 RQ-AO1000-1546, TRIM Ref. 2016/165915.
57 Task 5 Fire performance of CA and SC Modules, TRIM Ref. 2016/488264.
58 RQ-AP1000®-1653 Questions Relating to the Assessment of Fire Resistance of SC Modules, TRIM Ref. 2016/332009.
59 RQ-AP1000®-1691 Questions Relating to the Assessment of the Fire Barrier – Steel/Concrete Failure Mechanism (Part 1), TRIM Ref. 2016/446394.
60 RQ-AP1000®-1692 Questions Relating to the Assessment of the Fire Barrier – Steel/Concrete Failure Mechanism (Part 2), TRIM Ref. 2016/446414.
61 RQ-AP1000®-1693 Questions Relating to the Assessment of the Fire Barrier – Heat Transfer Analysis (Part 1), TRIM Ref. 2016/414554.
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63 RQ-AP1000®-1695 Questions Relating to the Assessment of the Fire Barrier – Module Capacity Analysis (Part 1), TRIM Ref. 2016/446424.
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68 CE-01.A8 & CE-02.A9: Long Term Reliability of SC Structures, TRIM Ref. 2016/455405.
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70 RQ-AP1000®-1575, GDA Issues CE-01.A8 & CE-02.A9 Questions Relating to the Assessment of the Long Term Reliability (1 of 4), TRIM Ref. 2016/332186.
71 RQ-AP1000®-1576, GDA Issues CE-01.A8 & CE-02.A9 Questions Relating to the Assessment of the Long Term Reliability (2 of 4), TRIM Ref. 2016/332254.
72 RQ-AP1000®-1577, GDA Issues CE-01.A8 & CE-02.A9 Questions Relating to the Assessment of the Long Term Reliability (3 of 4), TRIM Ref. 2016/332526.
73 RQ-AP1000®-1578, GDA Issues CE-01.A8 & CE-02.A9 Questions Relating to the Assessment of the Long Term Reliability (4 of 4), TRIM Ref. 2016/332533.
74 Westinghouse Electric Company, ANSYS Transient Thermal Analysis of Fire Loading for Generic SC Walls and Floors, APP-CA00-SUC-005, Revision 0, 25 July 2016.
75 ONR Assessment Rating Guide, TRIM Ref. 2016/118638.
76 RQ-AP1000®-1643 GDA Issues CE-01.A6 and CE-02.A7 Questions relating to the assessment of thermal stress analysis and design of SC modules (Part 3), TRIM Ref. 2016/344053.
77 In-Plane Shear Calculations to Support RQ-1575 Item 2b, NPP_JNE_001203 Enclosure 08, TRIM Ref. 2016/332248.
78 ONR Review of the TSC Assessment of WEC's Response to Reliability Actions Ref. GI-AP1000®-CE-01.A8 and GI-AP1000®-CE-02.A9, Trim Ref. 2017/92162.

Annex 1

Assessment Findings to be addressed during the Forward Programme – Civil Engineering

Assessment Finding Number	Assessment Finding	Report Section Reference
<u>Assessment Findings for GI-AP1000®-CE-01.A2 to A5 and GI-AP1000®-CE-02.A1 to A6</u>		
CP-AF-AP1000®-CE-08	The licensee shall demonstrate that, where the provisions of deep beam theory have been used to justify the section of wall between Walls L-2 and N of the CA Modules and other similar sections of walls, the walls comply with the geometric and loading requirements for deep flexural members as required by ACI349-01.	Table 5, Item 5-1
CP-AF-AP1000®-CE-09	The licensee shall demonstrate the performance of the components that make up the module to base mat connections by completing the analysis of the load path through the connection. The licensee shall confirm that the assumed (2.5in) eccentricity of the in-plane shear force is not under-predicting the applied moment on the bracket at the module wall to base-mat connection, such that the brackets are over-utilised. The licensee shall consider the directionality of the weld group and the implied transverse shear/bending and torsion on the liner plate local reinforcement.	Table 5, Item 5-4, Item 5-7 & Item 5-9
CP-AF-AP1000®-CE-10	The licensee use site specific materials to verify the design strength of the tie bars.	Table 5, Item 5-13
<u>Assessment Findings for GI-AP1000®-CE-01.A7 and GI-AP1000®-CE-02.A8</u>		
CP-AF-AP1000®-CE-11	The licensee shall demonstrate that the FE model used for the fire analysis, provides sufficiently accurate results. This shall include specific demonstrations that the difference in fire curves addresses the transient thermal gradients, that the modelling reflects the P- Δ effects predicted by tests, the sequence of application of gravity and thermal loads does not introduce unrealistic dynamic effects and that the use of time scaling factors is justifiable.	Table 7, Items 7-7, 7-8, 7-18, 7-22 & Table 8, Items 8-1, 8-2 & 8-6.
CP-AF-AP1000®-CE-12	The licensee shall demonstrate the load bearing capacity of the SC modules when subjected to a fire passing through an unprotected opening.	Table 7, Item 7-12
CP-AF-AP1000®-	The licensee shall demonstrate that the spalling behaviour under fire reflects the site specific materials for the SC units.	Table 7, Item 7-25

CE-13		
Assessment Findings for the Finite Element Analysis Produced for GI-AP1000®-CE-01.A7 and GI-AP1000®-CE-02.A8		
CP-AF-AP1000®-CE-14	The licensee shall demonstrate that using the same tension material model as implemented in AP-1100-S3C-017 does not incorrectly underestimate the deflections observed in the floors and walls in the model at higher temperatures.	Table 8, Item 8-5
CP-AF-AP1000®-CE-15	The licensee shall provide time-dependent FE analysis results for a sample of representative nodes of the model, to demonstrate that the mid-span deflection for the floors and walls and time-dependent stress and strains are acceptable.	Table 8, Item 8-7
Assessment Findings for GI-AP1000®-CE-01.A8 and-CE-02.A9		
CP-AF-AP1000®-CE-16	The licensee shall demonstrate that the test data used to inform the design of the SC units and CA modules, and upon which the reliability claims are based, is fully representative of the planned structure, and that strength reduction factors used in the designs are substantiated.	Table 9, Item 9-5