New Reactors Programme

GDA close-out for the AP1000 reactor

GDA Issue GI-AP1000-SI-04 - Fracture Analysis of Containment Vessel

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EXECUTIVE SUMMARY

Westinghouse Electric Company 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 to which 51 GDA issues were attached. These issues require resolution prior to award of a Design Acceptance Confirmation 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 structural integrity. Specifically this report addresses GDA Issue GI-AP1000-SI-04 - Fracture Analysis of Containment Vessel (CV).
This GDA Issue arose in Step 4 due to the need for evidence that:

- the CV has adequate tolerance to the thermal shock due to the flow of Passive Cooling System (PCS) water onto the top head .
- the CV has adequate tolerance to small defects in the absence of post-weld heat treatment (PWHT).

The Westinghouse GDA Issue Resolution Plan stated that its approach to closing the issues was:

- Complete the fracture analysis to demonstrate that the CV can withstand the thermal shock due to the flow of PCS water.
- Provide additional information to demonstrate that the CV provides a sufficiently reliable barrier in the absence of PWHT of the welds.
- Provide adequate responses to any questions arising from assessment by ONR of documents submitted.

My assessment conclusions are:

- Westinghouse has demonstrated that the CV has adequate tolerance to the thermal shock due to the flow of PCS water onto the top head of the CV.
- Westinghouse has demonstrated that the CV has adequate defect tolerance in the absence of PWHT.

My judgement is based upon the following factors:

- Westinghouse has applied relevant good practice to demonstrate that the CV has adequate fracture tolerance without PWHT.
- The demonstration included a substantial safety margin and the underpinning analysis is conservative.
- The method of demonstration was suitably robust for the safety classification and functional requirements of the CV.
- Performance demonstration of ultrasonic inspection will adequately promote the avoidance of defects.
- There is adequate access for in-service inspection to support the through-life safety case for structural integrity of the CV.

My assessment has identified no matters that undermine the generic safety submission and require licensee input/decision.

In conclusion I am satisfied that GDA Issue GI-AP1000-SI-04 can be closed.

LIST OF ABBREVIATIONS

ALARP	As Low As Reasonably Practicable
ASME	American Society of Mechanical Engineers
BMS	Business Management System
CV	Containment Vessel
DAC	Design Acceptance Confirmation
DBA	Design Basis Accident
DCP	Design Change Proposals
GDA	Generic Design Assessment
IAEA	International Atomic Energy Agency
IDAC	Interim Design Acceptance Confirmation
ISI	In-Service Inspection
MSLB	Main Steam Line Break
MT	Magnetic Particle Testing
ONR	Office for Nuclear Regulation
PCCWST	Passive Containment Cooling Water Storage Tank
PCS	Passive Containment Cooling System
PCSR	Pre-Construction Safety Report
PTC	Pneumatic Test Condition
PWHT	Post Weld Heat Treatment
RCL	Reactor Coolant Loop
RGP	Relevant Good Practice
RT	Radiographic Testing
SAP	Safety Assessment Principles
TAG	Technical Assessment Guide
UK	United Kingdom
UT	Ultrasonic Testing

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1 INTRODUCTION

1.1 Background

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

2. This report is the Office for Nuclear Regulation's (ONR's) assessment of the Westinghouse **AP1000** reactor design in the area of structural integrity. Specifically this report addresses GDA Issue GI-AP1000-SI-04 - Fracture Analysis of Containment Vessel (CV).

3. The GDA Step 4 structural integrity assessment of the Westinghouse **AP1000** reactor (Ref. 1) is published on our website (Ref. 2) and describes the origin of the GDA Issue. General information on the GDA process is also available on our website (Ref. 3).

4. GDA Issue GI-AP1000-SI-04 was raised in Ref. 1 to address the following aspects of CV structural integrity:

- The CV will be subject to thermal loads when water flows over it from the Passive Containment Cooling System (PCS). Ref. 1 identifies that these stresses were not calculated during Step 4 of GDA.

- The majority of the CV is fabricated from plate sufficiently thin to avoid a requirement for post weld heat treatment (PWHT), as allowed under the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (the ASME Code). Ref. 1 identifies that further evidence was required to support the claim that PWHT is unnecessary.

5. This GDA Issue is captured in two actions in the resolution plan (Ref. 5) as follows:

- **GI-AP1000-SI.04.A1:** Provide sufficient evidence to show that the CV has adequate tolerance to the thermal shock due to the flow of PCS water onto the top head .

- **GI-AP1000-SI.04.A2:** Provide sufficient evidence to show that the CV has adequate tolerance to small defects in the absence of PWHT.

6. This report presents my assessment of the evidence that Westinghouse has provided to address these two actions.

1.2 Scope

7. The scope is described in my assessment plan (Ref. 4) and includes a review of Westinghouse submissions related to this issue. My assessment concentrated on evidence of tolerance of the CV to thermal shock, and on justification for the proposal by Westinghouse not to apply PWHT to the majority of CV welds.

8. The scope of assessment is appropriate for GDA because ONR expects requesting parties to demonstrate that vessels important to nuclear safety have adequate tolerance to credible thermal shock events. In this instance it also has to provide adequate justification, that PWHT of the majority of the CV welds is not warranted.

9. The scope of my assessment does not include matters ONR has already found to be satisfactory, as reported in Ref. 1

1.3 Method

10. This assessment complies with ONR guidance on the mechanics of assessment (Ref. 6) and with the requirements of the ONR Business Management System (BMS) document “Purpose and Scope of Permissioning” (Ref.7) that defines the process of assessment within the ONR.

1.3.1 Sampling Strategy

11. It is rarely possible or necessary to assess an entire safety submission, therefore ONR adopts an assessment strategy of sampling. Ref. 7 explains the process for sampling safety case documents.

12. The sampling strategy for this assessment focused on those aspects of CV design identified in the GDA Step 4 report (Ref. 1) as requiring further evidence to establish compliance with UK expectations of relevant good practice (RGP).

2 ASSESSMENT STRATEGY

2.1 Pre-Construction Safety Report

13. ONR's GDA Guidance to Requesting Parties (Ref. 9) states that the information required for GDA may be in the form of a Pre-Construction Safety Report (PCSR), Technical Assessment Guide (TAG) 051 (Ref. 10) sets out regulatory expectations for a PCSR.

14. At the end of Step 4, ONR and the Environment Agency raised GDA Issue GI-AP1000-CC-02 (Ref. 11) requiring that Westinghouse submit a consolidated PCSR and associated references to provide the claims, arguments and evidence to substantiate the adequacy of the **AP1000** plant design reference point.

15. A separate regulatory assessment report is provided to consider the adequacy of the PCSR and closure of GDA Issue GI-AP1000-CC-02, and therefore this report does not discuss the structural integrity aspects of the PCSR. This assessment focused on the supporting documents and evidence specific to GDA Issue GI-AP1000-SI-04.

2.2 Standards and Criteria

16. The standards and criteria adopted within this assessment are principally the Safety Assessment Principles (SAPs) (Ref. 12), internal TAGs, relevant standards and RGP informed by existing practices adopted on UK nuclear licensed sites.

2.2.1 Safety Assessment Principles

17. The SAPs that have informed this assessment are listed in Table 1.

2.2.2 Technical Assessment Guides

18. The TAGs that have informed this assessment are listed in Table 2.

2.2.3 National and International Standards and Guidance

19. Standards and guidance that have been used as part of this assessment are listed in Table 3.

2.3 Integration with Other Assessment Topics

20. 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. This assessment has considered information from **AP1000** plant fault studies to inform a review of load cases applied in fracture assessment of the CV.

2.4 Out of Scope Items

21. This report does not consider structural integrity aspects of the PCSR, which is covered by a separate ONR cross discipline assessment.

3 REQUESTING PARTY'S SAFETY CASE

22. Ref. 13 describes the CV and its safety functions. The CV is a large, vertical steel cylindrical vessel 39.6m in diameter with ellipsoidal steel closure heads; the total height is 65.6m. The lower dome is embedded in concrete and concrete is also poured into the lower dome to support structures within containment. It provides secondary containment for the reactor pressure vessel and its associated primary circuit.

23. The CV has been designed in accordance with ASME Section III, Article NE-2000 and is designated within the UK **AP1000** plant safety classification scheme as Class 1.

24. The CV will be constructed from ASME SA-738 Grade B plate. The first cylindrical course is 47.6 mm thick and the axial weld will be post weld heat treated. The rest of the cylindrical wall of the vessel is 44.4 mm thick and in accordance with ASME Section III 2001 edition with 2002 addenda it is not required to PWHT these welds. The heads are 41.3 mm thick and again will not be post weld heat treated.

25. The CV is housed in a shield building which protects against aircraft impact, gives some protection against the weather and also supports a Passive Containment Cooling Water Storage Tank (PCCWST). In certain accident conditions, cooling water from the PCCWST would be drained on to the outside of the CV top head.

26. The CV fulfils a number of safety functions the most significant of which are :

- To contain any airborne release of radioactive material following Design Basis Accidents (DBA).
- To provide a heat transfer surface to remove heat in normal operation and following DBA.
- To structurally support the polar crane.
- To structurally support the containment air baffle, which provides air cooling for the CV.

27. The CV is designed to withstand various DBA conditions. Ref. 19 identifies that the stress due to internal pressure and thermal stress associated with PCS actuation in response to a main steam line break (MSLB) or a large-break loss of coolant accident are the limiting faults.

28. In Ref. 14 Westinghouse consider the limiting stresses that occur when water from the PCCWST is poured on the CV top head following a MSLB with associated mass and energy release inside containment. Ref. 5 argued that this was an appropriate, conservative and bounding load case, since it was based on conservative assumptions regarding key factors including temperature, pressure and residual stress.

29. Ref. 14 postulates a range of weldment flaw sizes, and determines conditions where the applied stress intensity factor approximately equals the fracture toughness. Ref. 14 reports stress intensity factors that are less than calculated fracture toughness values, and evaluated critical flaw sizes larger than a postulated defect.

30. Based on the planned method of fracture analysis Westinghouse (Ref. 5) claimed that, in the absence of PWHT, the presence of relatively large weldment flaws will not result in failure of the CV in DBA conditions.

31. Also to support the decision by Westinghouse not to apply PWHT, Ref. 5 identifies that Subsection NE. Section NE-4622.7 of the ASME Code exempts vessels such as the **AP1000** plant CV from PWHT.

32. In response to GDA Issue GI-AP1000-SI-04, Westinghouse commit in Ref. 5 to provide the CV fracture analysis (Ref. 14) and respond to ONR Regulatory Queries.

33. Westinghouse propose that the CV will be subject to pre-service inspections in accordance with requirements of the ASME Code. Longitudinal and circumferential butt welded joints will be 100% radiographically tested (RT). Non butt-welded joints are examined by an ultrasonic method (UT), a magnetic particle method (MT), or a liquid penetrant method. Periodic visual inspections of the CV shell during its service life are required per ASME Section XI, IWE-2000.

4 ONR ASSESSMENT OF GDA ISSUE GI-AP1000-SI-04

34. This assessment has been carried out in accordance with the ONR BMS document “Purpose and Scope of Permissioning” (Ref.7).

4.1 Scope of Assessment Undertaken

35. Consistent with the two actions of GDA Issue GI-AP1000-SI.04, the scope of my assessment considered the following:

- Tolerance of the CV to thermal shock, due to flow of PCS water.
- The decision by Westinghouse not to apply PWHT to the majority of CV welds.

36. I initially assessed the Westinghouse CV fracture analysis submission (Ref. 14). To inform this, I raised a number of questions as regulatory queries. My subsequent assessment considered Westinghouse responses to my queries, given in Refs. 15 and 16.

37. I held a number of Level 4 technical engagements with Westinghouse where I discussed:

- my regulatory expectations, based on RGP, see Section 2; and
- the technical and safety aspects of each Westinghouse submission.

38. My interest was to establish whether Westinghouse’s safety case adequately considered UK RGP for CV design, and were supported by the necessary evidence to validate claimed CV performance.

39. Finally I considered whether risks associated with CV performance were reduced As Low As Reasonably Practicable (ALARP), such that GDA Issue GI-AP1000-SI-04 might be closed. Closure of this issue will support a broader conclusion that, from a structural integrity perspective, the **AP1000** design is suitable for construction in the UK.

40. In my assessment I did not address the subject of CV corrosion. At GDA Step 4 it was judged that the CV should not suffer significant corrosion during operation provided that the proposed coating is adequately applied and inspected. Assessment Findings were raised in Ref. 1 that address the application and inspection of the proposed coating as follows:

AF-AP1000-SI-26: *The Licensee shall include planned periodic visual inspection of the CV, its protective coatings and the moisture barrier in its arrangements for periodic inspections. Particular attention should be given to the concrete embedment transition.*

AF-AP1000-SI-27: *The licensee shall demonstrate the protective coating applied to the containment vessel is capable of protecting it against extended exposure to the potentially corrosive chemicals to which it may be exposed.*

AF-AP1000-SI-28: *The Licensee shall include the guidance on coating application, repair of coating defects and the qualification of staff for application and inspection of coatings in its procedures and arrangements.*

41. While I did not revisit the effectiveness of the coating in preventing CV corrosion, I did enquire as to its effect on inspection capability. As identified in Ref. 1, pre-service inspection and in-service inspection (ISI) are outside the scope of GDA, to be addressed by the licensee. Only accessibility issues for ISI are to be considered in GDA.

4.2 Assessment

42. This part of the report is divided into three sections and which describe in turn the following aspects of my assessment:

- CV fracture analysis;
- non-destructive inspection; and
- key assessment considerations and regulatory judgements.

4.2.1 CV Fracture Analysis

43. Following an accident, the CV will be subject to thermal and pressure loads when water is directed over it from the PCS. The resultant stresses were not calculated during the Step 4 assessment period and have been assessed under GDA Issue GI-AP1000-SI-04.A1. In this section, I describe my assessment of the method, application and outcome of the analysis undertaken by Westinghouse in response to GDA Issue GI-AP1000-SI-04.

44. During Step 4, ONR challenged Westinghouse to provide adequate evidence that the CV was defect tolerant under DBA conditions. To address this point, Westinghouse applied a method of fracture analysis given in Section XI, Division 1, Appendix A of the 2010 version of ASME Code (Ref. 14). The UK design reference point (Ref. 8) identifies the 2001 edition of the ASME Code, including the 2002 addenda for metal containment. In response to my query, Westinghouse confirmed that methods and materials property data pertinent to CV fracture analysis have not changed significantly between these editions.

45. The current version of the ASME Code is the 2015 edition. I questioned how Westinghouse will ensure the continued validity of the CV fracture analysis. Westinghouse responded that later editions of the ASME Code are not expected to significantly affect the results of the current CV fracture analysis.

46. Nevertheless, to promote the continued validity of the CV fracture analysis, in Ref. 15 Westinghouse committed that the edition of the ASME Code current at the time of site licensing will be evaluated against the standing analysis as necessary.

47. Following my query, Westinghouse confirmed that there are no Design Change Proposals (DCPs) to either CV design or inherent analytical assumptions that could invalidate the CV fracture analysis. Westinghouse also identified a procedure to manage any future DCPs.

48. The GDA Step 4 report (Ref. 1) identified that Westinghouse proposed a conservative approach for application of CV fracture analysis. This was judged to be an appropriate initial calculation. However, Ref. 1 also identified that Westinghouse recognised that the results of this evaluation might not be acceptable and so the analysis of more realistic bounding cases could be required.

49. Early in my assessment Westinghouse replaced the initial CV fracture analysis submission (Ref. 14) with a UK-specific document (Ref. 17) that applied less conservative input data, see paragraph 54ff. The original and UK-specific analyses apply the same method to calculate critical flaw size, based on that given in Section XI, Appendix A of the ASME Code. A range of flaw sizes are postulated and the conditions where applied stress intensity factor is approximately equal to fracture toughness are determined.

50. In Ref. 19 Westinghouse identified that Section III of the ASME Code does not require fracture analysis for the CV. Recognising that such analysis is required to

address GDA Issue GI-AP1000-SI-04, Westinghouse proposed the non-mandatory Appendix A of ASME Code Section XI as a suitable method for determination of critical flaw size. Whilst this method is normally applied to determine the acceptability of flaws detected in-service, Westinghouse contended that it is also suitable for CV fracture analysis. Based on the safety significance of the CV, a Class 1 component, and its required functions, I am content that Westinghouse has applied a suitable method, taken from a well-established nuclear design code, for fracture analysis of the CV.

51. I am satisfied that the commitment by Westinghouse, to evaluate the CV fracture analysis against the edition of ASME Code current at the time of site licensing, will sustain its validity. The requirement is effectively captured in the following Assessment Finding of Ref. 18:

> **AF-AP1000-ME-09:** *The licensee shall ensure that evidence is generated to ensure that the proposed codes and standards for the* ***AP1000*** *are adequate to support design, procurement, installation, operation, and subsequent examination, maintenance, inspection and testing activities. The licensee should also ensure that the* ***AP1000*** *codes and standards meet applicable UK Health and Safety legislation, including regulations and approved codes of practice (as appropriate).*

52. The limiting defect size reported in Ref. 14 was a surface breaking defect 4 x 41mm, approximately 10% of wall thickness. Extended part-wall defects were not considered. In response to my query Westinghouse explained that this omission was due to excessively conservative assumptions in the original analysis. Ref. 14 is now superseded by Ref. 17.

53. The GDA Step 4 report (Ref. 1) identifies an assessment conducted on behalf of ONR by a technical support contractor that did consider extended part-wall defects. For these, a limiting defect size of 3 x 100mm was estimated. Ref. 1 noted that a number of conservatisms had been identified in that assessment.

54. Ref. 17 reworked the original CV fracture analysis of Ref. 14 and considered an additional load case. Limiting conditions are met for a weldment surface-breaking defect size of 13.3 x 133mm, that is 32.5% of wall thickness. An extended part-wall defect is also considered, for which the limiting defect size is reported to be 7.4 mm x 743 mm, approximately 18% of wall thickness.

55. In response to my query of Ref. 15, Westinghouse explained that differences in estimated limiting defect sizes between Refs. 14 and 17 were due to more reasonable assumptions in the current analysis, which is judged to remain conservative. The degree of conservatism in the fracture analysis is considered further below.

56. Noting the observations raised by ONR at Step 4 of GDA (see paragraph 48) I examined the degree of conservatism in the initial CV fracture analysis (Ref. 14). The maximum design pressure, 406.8kPa and temperature, 148.9^{o}C, were applied coincidentally with minimum PCS water temperature. I considered this to be a significant and apparently unrealistic conservatism, as I believed it unlikely that the most adverse conditions of PCS water temperature, CV temperature and pressure would occur at the same instant. The analysis resulted in small limiting defect sizes that, in my opinion, would be difficult to reliably detect.

57. In Ref. 16 Westinghouse confirmed that the conditions of the initial analysis were unrealistic, particularly in terms of the sequence by which environmental conditions are assumed to progress following the initiating event. Westinghouse contend that CV metal temperature would only slightly exceed that of normal operation at the

moment of PCS actuation, whereas the analysis assumed that metal temperature is at its maximum design limit at that instant. Westinghouse acknowledged that this assumption resulted in significant conservatism, confirming my observation noted in the previous paragraph.

58. Westinghouse provided information to justify the assumptions of Ref. 17. My interest was twofold; to establish that the analysis was conservative and that levels of conservatism were not so excessive as to impose unreasonable demands on inspection objectives. I reviewed assumptions regarding the postulated defects, the loads, resultant stresses and material properties of the assessment. These aspects are considered below.

Postulated Defects

59. I questioned whether Westinghouse had postulated a conservative defect orientation at a bounding location (Ref. 16). Westinghouse identified that the upper region of the CV top head experiences the most severe thermal shock. The combined stress at that location envelops all CV locations and orientations, and is the most severe.

60. The maximum stress calculated for all directions in the CV shell was considered in Ref. 17. Westinghouse identified that the assumed orientation of the flaw aligned with this stress and so represented the least favourable orientation. I am satisfied that the assumed defect location and orientation were conservative and suitable for CV fracture analysis.

Loads and Stresses

61. Ref. 17 identified the conditions assumed for CV fracture analysis and considered the following load cases:

- MSLB combined with PCS actuation; and
- Pneumatic Test Condition (PTC).

62. MSLB with PCS actuation is identified as the limiting case, for which PCS water is conservatively set at its minimum design temperature of 4°C. Maximum CV metal temperature 103.3^{o}C and maximum CV internal pressure 351.6kPa are assumed. Applied CV metal temperature is the mean value of temperatures at the inner and outer surfaces.

63. These maxima of temperature and pressure are assumed to coincide when PCS water pours onto the CV. Westinghouse contended that more realistic estimates of CV metal temperature (81.7°C) and internal pressure (46 kPa) at the moment of PCS actuation were below those assumed in Ref. 17. Hence the pressurised thermal shock analysed in Ref. 17 was conservatively severe.

64. Maximum internal pressure of the PTC load case is 455.1 kPa, which exceeds that assumed for MSLB analysis. As a sensitivity study, to substantiate that MSLB with PCS actuation is the bounding fault, Ref. 17 also considered stresses due to internal pressure during PTC (which will occur at ambient temperature). For that load case Westinghouse reported an acceptable defect size of 20.6mm x 205mm.

65. In the GDA Step 4 report (Ref. 1), ONR judged that design conditions for the CV appeared reasonable but were unproven. The following Assessment Finding was raised:

> **AF-AP1000-SI-25**: *The Licensee shall confirm that the CV wall temperature does not rise above the design temperature in the event of a reactor coolant loop (RCL) or main steam line failure or if it does justify that this is acceptable.*

66. Noting the judgement of Ref. 1 in respect of CV corrosion (see paragraph 40) I questioned whether the CV was sufficiently resilient to through life degradation by fatigue. In Ref. 15 Westinghouse identified that the CV does not experience significant stress cycles during normal plant operation. CV stress cycles were primarily limited to daily temperature changes, which are mild, and periodic integrated leak rate testing, which are infrequent. The most limiting DBA condition is associated with a single stress cycle. Due to the low frequency of high stress events and low stress associated with high cycle events, Westinghouse argue that fatigue crack growth is not a concern for design against fracture. Based on this explanation I am satisfied that fatigue crack growth is not a significant damage mechanism for the CV.

67. Considering the evidence provided by Westinghouse to justify the assumed conditions of analysis (paragraphs 61 to 65) and noting the requirement of **AF-AP1000-SI-25**, I am satisfied that the temperatures and pressures assumed for CV fracture analysis are soundly based and adequately conservative.

68. Ref. 19 describes a sensitivity study, performed by Westinghouse to investigate the effect of considering a higher pressure stress of 169 MPa, which is the CV design pressure. The results show only a slight decrease in critical flaw depth to 31% of wall thickness for a 10:1 aspect ratio flaw. I am satisfied that this study shows that the Westinghouse analysis is not significantly sensitive to the assumption of pressure stress.

69. In response to my query (Ref. 16), Westinghouse asserted that conservative stresses are applied in the CV fracture analysis. A residual stress of 552 MPa is applied to account for welding and fabrication. This is 1.33 times the minimum yield stress specified in ASME Code. A thermal shock stress, 169 MPa, and pressure stress, 146 MPa, are applied. Westinghouse contend that the combined and concurrent stress is conservative as the thermal and pressure stresses will actually peak at different times in the transient. On this basis, I am satisfied that Westinghouse has applied a reasonable and conservative approach to establish stresses for CV fracture analysis.

Materials Properties

70. In response to my query (Ref. 16), Westinghouse provided information to justify its assumptions concerning CV fracture toughness. At the time of the original CV fracture analysis (Ref.14), actual CV material data were unavailable. The upper shelf fracture toughness was limited to 69.5MPa√m in Ref. 14, obtained from data given in Section II, Part D of the ASME Code.

71. In the reworked fracture analysis (Ref. 17) material properties are taken from actual measurements of CV material. The upper shelf fracture toughness is limited to 220MPa √m. Westinghouse identify that this value is significantly bounded by data given in the ASME Code. For this reason Westinghouse expressed confidence that significant margins exist in the results of Ref. 17.

72. Ref. 17 assumes a metal temperature of 79°C to establish fracture toughness. This is below the CV metal temperature of 103.3°C assumed for fracture analysis. The design temperature range for the CV is -28°C to 149°C. The fracture toughness of the CV material has a transition temperature of approximately -101°C. Hence Westinghouse contend that fracture toughness remains on the upper shelf and is unaffected by the temperature assumed for fracture analysis in Ref. 17. Based on the explanation provided by Westinghouse, summarised in the preceding paragraphs, I am satisfied the fracture toughness of CV material assumed for fracture analysis in GDA is adequately justified.

73. I noted that the GDA Step 4 report (Ref. 1) includes the following assessment finding:

AF-AP1000-SI-29: *The Licensee shall ensure that the safety case for the structural integrity components on the individual site reflects the actual build and operation on that site.*

74. In Ref. 16 Westinghouse identify that demonstration of minimum fracture toughness and transition temperature of all materials used in the construction of the CV will be required for UK construction. Westinghouse identified that this requirement, reiterated in Ref. 19, is intended to address Assessment Finding **AF-AP1000-SI-29** of Ref. 1. I am satisfied that this commitment by Westinghouse adequately provides for future validation of assumptions in the GDA fracture analysis of the CV during the licensing phase.

4.2.2 CV Inspection

75. ONR expects that components and structures important to safety are both free from significant defects and tolerant of defects. To examine evidence of defect avoidance and defect tolerance, I considered whether the CV can be inspected effectively and whether proposed inspection techniques, described in paragraph 33, will reliably detect significant defects.

76. I enquired whether the CV had been designed for effective examination. Westinghouse identified that, with the exception of the CV bottom head, access is generally good, and that CV weld geometries and surface condition are suitable for both surface and volumetric examination techniques.

77. There are few obstructions and where these occur there is generally sufficient access to conduct visual and volumetric inspection from at least one surface. There are CV pressure boundary welds that Westinghouse consider cannot be volumetrically inspected. An example, identified in Ref. 16, is a junction between the CV shell and a penetration. These welds are, however, subject to PWHT. Ref. 16 identifies that all pressure boundary welds subject to the conditions of thermal shock are plate-to-plate butt welds that will be volumetrically inspected.

78. The CV bottom head is embedded in concrete and so inaccessible for ISI. In Ref. 15 Westinghouse argue that failure of the CV bottom head welds is highly unlikely despite the absence of ISI, due to the planned post-welding inspections, low operational stress and non-corrosive environment.

79. In the GDA Step 4 report (Ref. 1) it was judged that the CV should not suffer significant corrosion during operation if the proposed coating, inorganic zinc, is adequately applied and inspected. Three associated Assessment Findings were raised, see Section 4.1. Assessment finding **AF-AP1000-SI-26** of Ref. 1 requires that particular attention is given to the periodic visual inspection of the CV concrete embedment transition.

80. Recognising that detailed consideration of ISI is outside the scope of GDA, but to establish confidence that the terms of **AF-AP1000-SI-26** can be satisfied, I requested that Westinghouse summarise the proposed scope and methods for ISI of the CV. My particular interest was for the top head of the CV, which is the location at which the conditions of pressurised thermal shock would be most severe.

81. Ref. 16 identifies the proposed scope for ISI of the CV, including interior and exterior surfaces not embedded in concrete, is to comply with the requirements of ASME Code Section XI, IWE-2000. This includes a general visual inspection of 100% of all accessible interior and exterior surfaces during a 10-year inspection period.

82. I am satisfied that the CV can be inspected effectively, where necessary, on the following basis:

- There is good access for visual and volumetric inspection from at least one surface of all pressure boundary welds subject to the conditions of thermal shock, including the CV top head.
- There is sufficient access to visually inspect the CV to satisfy the requirements of AF-AP1000-SI-26.
- Westinghouse has adequately justified the impracticability of ISI for the concrete-embedded CV bottom head.

83. Detailed specification of an ISI programme to establish the existence of defects of concern through the operating life of the facility remains to be addressed in future by the licensee.

84. Examining capability of manufacturing inspection, I enquired as to the proposed scope and type of examinations, and questioned what defect sizes and orientations may not reliably be detected. As noted earlier (paragraph 33), the ASME Code prescribes 100% RT inspection of CV butt welds.

85. In Ref. 15 Westinghouse identified that RT, required by ASME Code, is capable of detecting and length sizing structurally significant planar and volumetric flaws. However Westinghouse acknowledged that RT does not provide a through-wall size for a planar flaw.

86. Westinghouse identified that UT would provide this additional capacity and also could better detect smaller and tilted/skewed planar flaws. Westinghouse therefore committed that the requirement for RT will be augmented by, or replaced with, UT for the UK **AP1000** plant CV (Ref. 15). I consider that this commitment by Westinghouse enhances their inspection capability, particularly for detection and characterisation of planar defects.

87. UT examination will require performance demonstration, as prescribed by ASME Code. In Ref. 15 Westinghouse identify that this performance demonstration will consider the specific fracture assessments to determine the appropriate flaw matrix for the qualification block(s). I consider this to be a suitable general approach and requested more detail regarding the intended nature of the performance demonstration.

88. In Ref. 16 Westinghouse identify that the requirements of ASME Code will apply as a minimum, augmented for the UK **AP1000** plant CV as follows:

<u>Qualification Block</u>

- Additional planar flaws in weld oriented parallel to the fusion line.
- Volumetric flaws in weld oriented parallel to the fusion line to demonstrate flaw characterisation capability.

<u>Justification of Capability</u>

- Capability statement justifying the UT system (equipment, procedure and personnel).
- Performance demonstration administered by independent organisation.
- Blind test for inspection procedure and data interpretation personnel.

89. I requested that Westinghouse identify any influence the CV coating may have on the effectiveness of inspection. In Ref. 16 Westinghouse identify proof-of-principle tests

which concluded that the coating had no influence on magnetic particle testing (MT) but some influence on the sensitivity and acoustic velocity of UT.

90. Westinghouse assert that influence of the coating on UT inspection can be countered effectively by the use of suitable reference blocks for UT calibration. For effective performance demonstration, Westinghouse acknowledge the necessity that test specimens have a coating thickness equal to or greater than that of the CV (Ref. 16). I concur that representative test specimens promote effective inspection.

91. Satisfied that Westinghouse will apply methods to demonstrate inspection capability that are appropriate for the CV and its classification, I questioned the acceptance criterion for performance demonstration.

92. In Ref. 15 Westinghouse assert that UT inspection has reliable detection rates for defects 10% - 20% of wall thickness. Ref. 16 explains that the reliable detection claim of 10% wall thickness applies to surface flaws and the value of 20% relates to embedded flaws. In Ref. 16, Westinghouse identified that, for all cases evaluated, the critical defect is a surface flaw, hence the 10% wall thickness capability claim is judged applicable by Westinghouse.

93. In Ref. 16 Westinghouse identified that relevant ASME Code requirements are that the qualification block contains planar flaws (surface and sub-surface) having a through-wall extent of 3.1mm (~8% wall thickness) and a length of 1/3 weld thickness. ASME Code prescribes that the inspection system be demonstrated as capable of detecting such flaws.

94. As noted earlier (para. 54) the critical defect size established by fracture analysis is 13.3mm for a flaw of depth to length ratio 0.1. I consider the proposal to apply the identified acceptance criterion of ASME Code for performance demonstration of UT inspection to be adequate for confident detection of significant defects.

95. I examined how detection capability compares with the size of manufacturing defects typically encountered in practice. In Ref. 16 Westinghouse estimate that the weld bead in the through-thickness direction will range from 1.5mm to 3.5mm in height. Hence the required detection capability is broadly equivalent to the upper bound weld bead size. I am satisfied that this equivalence adequately supports the general avoidance of manufacturing defects in the CV.

4.2.3 Key Assessment Considerations and Regulatory Judgements

96. The CV is a Class 1 component required to contain any airborne release of radioactive material post DBA. In the course of my assessment Westinghouse has developed its safety case. The case is intended to demonstrate that the CV has the necessary level of integrity to withstand the pressurised thermal shock it would experience due to PCS actuation following MSLB. That event is identified by Westinghouse as the most limiting condition the CV is designed to withstand.

97. At my request, and late in my assessment, Westinghouse summarised the safety case for the CV (Ref. 19). In that submission, Westinghouse compiled evidence it had produced or updated over the course of my assessment.

98. The safety case combines evidence from fracture analysis and of inspection capability, intended to demonstrate that the CV is defect tolerant. I am content that this strategy is appropriate for the CV, given its functional requirements, and consider that the methods adopted by Westinghouse are appropriate for a Class 1 component. Whilst the demonstration is somewhat less demanding than Westinghouse apply for the highest reliability components of the UK **AP1000** plant, I consider the degree of rigour is commensurate with the safety significance of the CV.

99. Ref. 17 considers loads arising from thermal shock due to cooling of the CV top head by PCS water following MSLB. The results demonstrate an acceptable defect size of 32.5% wall thickness for a defect aspect ratio of 10. Stresses due to internal pressure during PTC, without thermal shock, result in an acceptable defect size 50% of wall thickness.

100. I have found that the method of fracture analysis applied by Westinghouse in Ref. 17 adopts RGP appropriate for the CV. The method is taken from a well- established nuclear code and applied in an appropriate and reasonably conservative manner. Westinghouse has provided sufficient evidence that critical assumptions underpinning the analysis are sound and also conservative. I am therefore content that Westinghouse has adequately validated the results of their CV fracture analysis.

101. Westinghouse will apply UT, subject to performance demonstration, for manufacturing inspection of CV welds. The claimed detection reliability for surface flaws, the limiting type, is given in Ref. 16 as 10% of wall thickness. Westinghouse has identified requirements for performance demonstration under ASME Code that can satisfy the claim of inspection capability. It has committed in Ref. 16 to apply those requirements as a minimum standard, augmented for inspection of the CV in the UK. I am content with the proposed method of manufacturing inspection, and satisfied it can be demonstrated as capable of detecting significant defects.

102. Ref. 19 combines the results of fracture analysis with evidence for demonstration of inspection capability. A critical flaw depth of 32.5% wall thickness is compared with a claimed detection capability for surface flaws of 10% wall thickness. As a result, a margin of 3.25 is established between these parameters, which exceeds the target value of 2.0 given in Ref. 19. Westinghouse contend that the margin established for the CV compares favourably with the objective applied for the highest reliability components of **AP1000** plant, which is a defect size margin of 2.0. I accept that Westinghouse has justified its claimed safety margin for the CV and judge that it establishes adequate tolerance of the CV to pressurised thermal shock.

103. Ref. 19 identifies the effect on critical flaw size of an extended surface defect that is ten times the length of the reference flaw. The critical depth for the extended defect is determined as 18% of wall thickness. In Ref. 16 Westinghouse identify that the extended flaw of 18% wall depth is more than 700 mm long and for that reason is not considered a credible manufacturing flaw, given the nature and extent of planned manufacturing inspections.

104. Westinghouse argue that the critical depth established for an extended defect demonstrates that the demonstration of defect tolerance safety is not critically sensitive to the adoption of an aspect ratio of 10 for the reference defect. Ref. 19 claims that performance demonstration will establish reliable detection of flaws of 10% wall thickness. From this I infer that an extended defect at the critical depth remains within limits of reliable detection identified by Westinghouse. I am satisfied the possibility that the CV could enter service containing an extended defect of significant depth is sufficiently remote. I am also content that Westinghouse has identified an appropriate aspect ratio for the reference defect applied in its defect tolerance safety case for the CV.

105. I note that the GDA Step 4 report (Ref. 1) identified an assessment by Westinghouse of the ultimate capacity of the CV, which is the pressure it could sustain following yield. Ref. 1 acknowledged that this indicated a significant further margin, beyond that which exists between maximum pressure and CV design pressure. Whilst not directly relevant to the failure mode I have considered in this assessment, this factor has influenced the nature of evidence I have sought to assess. For the Westinghouse case against CV fracture, I consider there is adequate defence in depth in the various margins that bolster the case for CV structural integrity.

106. My assessment considered whether Westinghouse had adopted all reasonably practicable measures to ensure that CV structural integrity will be maintained. I questioned whether CV design effectively minimised the number and length of welds. I also sought justification for the decision by Westinghouse not to apply PWHT.

107. Westinghouse provided information showing that minimisation of overall weld length is inherent to current manufacturability considerations. Plate size, and hence number of welds, is largely governed by press limitations, die size and handling capability. In Ref. 15 Westinghouse has committed that its design specification will be revised to indicate that choice of CV product form should have regard to enabling examination and minimising the number and length of welds.

108. For the purposes of GDA, I am satisfied that Westinghouse has specified measures to minimise the number and length of CV welds so far as is reasonably practicable. My judgement is based on evidence regarding the constraints of CV geometry and available manufacturing techniques, and also the commitment by Westinghouse noted in the previous paragraph.

109. Westinghouse acknowledged that PWHT could further enhance CV defect tolerance, but argued that it is also challenging, burdensome and could have significant adverse effects. In Ref. 15 Westinghouse summarise the basis of their decision not to undertake PWHT as follows:

- Fracture analysis, with a conservative allowance for weld residual stress, demonstrates significant tolerance to fracture.
- CV material has demonstrated excellent fracture toughness properties.
- UT is expected to reliably detect flaws 10% of CV thickness. (In Ref. 16, Westinghouse confirmed that all pressure boundary welds that are subject to the conditions of thermal shock are plate-to-plate butt welds that will be inspected using UT).
- PWHT is estimated to increase the tolerable flaw size from 33% to 60% of CV thickness.
- PWHT may reduce the physical strength and/or the fracture toughness of CV material.
- There is a risk that PWHT will result in reheat cracking.
- Local PWHT of plate welds could introduce unquantified residual stress into the structure. Prediction of these stresses is anticipated to be challenging
- Controlling local PWHT process on a large scale represents a significant challenge
- There is a risk of introducing local distortion that may reduce the buckling capacity of the CV shell.

110. Based on manufacturing constraints, the benefits and risks associated with PWHT, and the margin between the reliable detection of UT and the tolerable flaw size, Westinghouse conclude in Ref. 19 that PWHT is not warranted for the majority of CV shell welds.

111. CV material is generally within a thickness limit (44mm rising to 60mm providing that certain conditions are satisfied) given in ASME Code Case N-841, which permits exemption from PWHT for components below this threshold. I am therefore satisfied

that the proposal not to apply PWHT to the majority of CV welds complies with the requirements of ASME Code.

112. However, for the CV it has been identified that evidence of design code compliance alone is insufficient to satisfy UK regulatory expectations. The GDA Step 4 structural integrity assessment report (Ref. 1) identified a further need for a fracture mechanics assessment to better justify the absence of PWHT.

113. I am satisfied that the combination of fracture analysis and manufacturing inspection reported in Ref. 19 demonstrates that the CV has adequate fracture tolerance without PWHT. The demonstration includes a substantial safety margin and the underpinning analysis is conservative. Further, the performance demonstration of manufacturing inspection by UT significantly bolsters the case for defect avoidance. I therefore judge that Westinghouse has adequately justified the decision not to apply PWHT to the majority of CV welds.

114. In my judgement the decision by Westinghouse not to apply PWHT is further supported by information given in Ref. 19, summarised here in paragraph 109. Effective application of PWHT to the large welds of the CV, and to the complex arrangement of welds at its top head, would be difficult and has the potential to adversely affect the structural integrity of the CV, for example by reheat cracking or weakening of CV material. During my assessment, I inspected proprietary materials properties data held by Westinghouse, which I am satisfied adequately supports the judgements by Westinghouse of Ref. 19.

115. In Ref. 16 I finally questioned whether other design enhancements may reasonably be applied to further minimise risk. Westinghouse establish a safety margin associated with CV defect tolerance in Ref. 19 and consider the possible benefits and detriments to safety of increased CV thickness, alternative CV materials and welding methods.

116. Westinghouse argue in Ref. 19 that the potential risk enhancement in each case is not significant, and the sacrifice associated with each measure would be substantial. On that basis Westinghouse conclude that it is not reasonably practicable to implement each of the three design changes it has considered. Notable judgements and assertions by Westinghouse in Ref. 19 include the following:

- Any risk benefit of improved defect tolerance due to increased CV thickness is diminished by the adverse effect of the resultant increased thermal resistance of the thicker CV. Increased thermal resistance of the CV would result in a probable increase of peak containment pressure and temperature. This could impair performance of safety systems within the CV and also necessitate their widespread re-qualification.

- Alternative CV materials of higher strength may increase the margin of defect tolerance. Westinghouse judge this potential benefit is outweighed by the difficulties that may arise when welding such materials. From this I infer that Westinghouse consider that such a change may result in an increased propensity for manufacturing defects to occur. Westinghouse identify its experience in both China and the United States of America of constructing the CV from SA-738 Grade B, consider that this experience is of value for future construction in the UK and further consider its value would be lost or diminished by application of other materials for CV construction.

- Westinghouse argued that alternative welding techniques would be challenging to apply for construction of a vessel as large as the CV. Further, it is contended that little benefit would be realised by their application since a primary objective of alternative methods of welding is to reduce the potential for hydrogen cracking. Westinghouse identify that the CV will be subject to vacuum treatment in manufacture, a measure argued to effectively minimise hydrogen levels.

117. In Ref. 19 Westinghouse provide a qualitative appraisal of the benefits and detriments to risk, and consider the sacrifice associated with each of the three options considered for design change. Based on the arguments presented by Westinghouse, summarised in the previous paragraph, I judge that Westinghouse has adequately justified its decision to discount the options of increased CV thickness, alternative materials and welding methods. In coming to my judgement I have taken account of the margin of 3.25 between critical flaw depth and claimed detection capability, demonstrated by Westinghouse in its safety case for defect tolerance of the CV (Ref. 19). I am satisfied that the qualitative demonstration of ALARP presented by Westinghouse in Ref. 19 is well founded and sufficiently rigorous, in proportion to the level of risk and hazard.

118. Noting the requirement of AF-AP1000-SI-25(see paragraph 65), I consider there remains the remote potential for the Westinghouse ALARP assessment of the CV safety case to be infringed. If it is found in future that the CV temperature exceeds its design limit under failure of either the RCL or MSLB, it would be necessary for the licensee to justify an acceptable position. I consider that requirement is adequately captured by the current terms of AF-AP1000-SI-25.

4.3 Comparison with Standards, Guidance and Relevant Good Practice

119. Section 2.2 of this report identifies standards, guidance and RGP that has informed my assessment. In particular, my assessment has been guided by ONR’s SAPs (see Table 1) and TAGs (see Table 2).

120. A notable example of good practice adopted by Westinghouse is its commitment to apply UT with performance demonstration for manufacturing inspection of the CV. The performance demonstration will comply with requirements of ASME Code as a minimum, augmented by Westinghouse for UK application.

5 CONCLUSIONS

121. This report presents the findings of the assessment of GDA Issue GI-**AP1000**-SI-04 - Fracture Analysis of CV, relating to the **AP1000** plant GDA closure phase.

122. To conclude:

- Westinghouse has demonstrated that the CV has adequate tolerance to the thermal shock due to the flow of PCS water onto the top head.
- Westinghouse has demonstrated that the CV has adequate defect tolerance in the absence of PWHT.

123. My judgement is based upon the following factors:

- Westinghouse has applied RGP to demonstrate that the CV has adequate fracture tolerance without PWHT.
- The demonstration includes a substantial safety margin and the underpinning analysis is conservative.
- The method of demonstration is suitably robust for the safety classification and functional requirements of the CV.
- Performance demonstration of inspection by UT adequately promotes the avoidance of manufacturing defects.
- There is adequate access for ISI to support the through-life safety case for structural integrity of the CV.

124. I consider that, from a structural integrity perspective, the **AP1000** design is suitable for construction in the UK.

6 REFERENCES

1. ONR-GDA-AR-11-011, Step 4 Structural Integrity Assessment of the Westinghouse **AP1000** Reactor, Revision 0, 14th November 2011, TRIM Ref. 2010/581520.

2. http://www.onr.org.uk/new-reactors/ap1000/reports.htm

3. http://www.onr.org.uk/new-reactors/index.htm

4. UK **AP1000** Assessment Plan for Closure GDA Structural Integrity Issues 1 to 6, Revision 0, March 2015, TRIM Ref. 2015/149240

5. WEC-REG-0872N, Enclosure 4, Resolution Plan for GI-AP1000-SI-04: Containment Vessel, Revision 7, 13th April 2016, TRIM Ref. 2016/157087

6. Guidance on Mechanics of Assessment, TRIM Ref.:2013/204124.

7. Purpose and Scope of Permissioning, NS-PER-GD-014 Revision 5, TRIM Ref. 2015/304735

8. WEC-REG-1552N, Enclosure 2, UKP-GW-GL-060, **AP1000** Design Reference Point for UK GDA, Rev. 10, 31January 2017, TRIM Ref. 2017/18158.

9. GDA Guidance to Requesting Parties, www.onr.org.uk/new-reactors/ngn03.pdf

10. http://www.onr.org.uk/operational/tech_asst_guides/ns-tast-gd-051.pdf

11. http://www.onr.org.uk/new-reactors/reports/step-four/westinghouse-gda-issues/gi-ap1000-cc-02.pdf

12. Safety Assessment Principles for Nuclear Facilities. 2014 Edition Revision 0. ONR. November 2014. http://www.onr.org.uk/SAP/SAP2014.pdf

13. UK **AP1000** Containment Vessel Component Safety Report. UKP-GW-GLR-007 Revision A. Westinghouse Electric Company LLC. September 2010. TRIM Ref. 2011/82091.

14. APP-MV50-S2C-036, **AP1000** Containment Vessel Top Head Fracture Analysis due to PCS Flow Actuation, Revision 0, TRIM Ref. 2015/414472.

15. RQ-AP1000-1625, **AP1000** Containment Vessel Top Head Fracture Analysis, July 2016, TRIM Ref. 2016/265199.

16. RQ-AP1000-1781, **AP1000** Containment Vessel Top Head Fracture Analysis and Defect Tolerance, January 2017, TRIM Ref. 2017/18344.

17. UKP-MV50-S2C-036, **AP1000** Containment Vessel Flaw Tolerance Evaluation, Revision 0, TRIM Ref. 2016/422143.

18. ONR-GDA-AR-11-010, Step 4 Mechanical Engineering Assessment of the Westinghouse **AP1000** Reactor, Revision 0, 11th November 2011, TRIM Ref. 2010/581521.

19. UKP-MV50-GLR-001, Defect Tolerance Safety Case for the UK **AP1000** Containment Vessel, Rev. 0, February 2017, TRIM Ref. 2017/86917.

Table 1

Relevant Safety Assessment Principles considered in the assessment

SAP No	SAP Title	Description
SC.4	The regulatory assessment of safety cases - Safety case characteristics	A safety case should be accurate, objective and demonstrably complete for its intended purpose.
EMT.2	Engineering principles: maintenance, inspection and testing - Frequency	Structures, systems and components should receive regular and systematic examination, inspection, maintenance and testing as defined in the safety case.
EMT.5	Engineering principles: maintenance, inspection and testing - Procedures	Commissioning and in-service inspection and test procedures should be adopted that ensure initial and continuing quality and reliability.
ECS.2	Safety classification of structures, systems and components	Structures, systems and components that have to deliver safety functions should be identified and classified on the basis of those functions and their significance to safety.
ECS.3.	Engineering principles: safety classification and standards **-** Codes and standards	Structures, systems and components that are important to safety should be designed, manufactured, constructed, installed, commissioned, quality assured, maintained, tested and inspected to the appropriate codes and standards.
ECS.5	Engineering principles: safety classification and standards - Use of experience, tests or analysis	In the absence of applicable or relevant codes and standards, the results of experience, tests, analysis, or a combination thereof, should be applied to demonstrate that the structure, system or component will perform its safety function(s) to a level commensurate with its classification.
EMC.4	Engineering principles: integrity of metal components and structures: general - procedural control	Design, manufacture and installation activities should be subject to procedural control.
EMC.5	Engineering principles: integrity of metal components and structures: general - Defects	It should be demonstrated that components and structures important to safety are both free from significant defects and are tolerant of defects.
EMC.6	Engineering principles: integrity of metal components and structures: general - Defects	During manufacture and throughout the full lifetime of the facility, there should be means to establish the existence of defects of concern.
EMC.7	Engineering principles: integrity of metal components and structures: design - loadings	The schedule of design loadings (including combinations of loadings) for components and structures, together with conservative estimates of their frequency of occurrence should be used as the basis for design against normal operation, fault and accident conditions. This should include plant transients and tests together with internal and external hazards.
EMC.8	Engineering principles: integrity of metal components and structures: design - providing for examination	Geometry and access arrangements should have regard to the need for examination.
EMC.9	Engineering principles: integrity of metal components and structures: design - product form	The choice of product form of metal components or their constituent parts should have regard to enabling examination and to minimising the number and length of welds in the component.
EMC.10	Engineering principles: integrity of metal components	The positioning of welds should have regard to high-stress locations and adverse environments.

SAP No	SAP Title	Description
	and structures: design - weld positions	
EMC.11	Engineering principles: integrity of metal components and structures: design - failure modes	Failure modes should be gradual and predictable.
EMC.12	Engineering principles: integrity of metal components and structures: design - brittle behaviour	Designs in which components of a metal pressure boundary could exhibit brittle behaviour should be avoided.
EMC.13	Engineering principles: integrity of metal components and structures: manufacture and installation - materials	Materials employed in manufacture and installation should be shown to be suitable for the purpose of enabling an adequate design to be manufactured, operated, examined and maintained throughout the life of the facility.
EMC.14	Engineering principles: integrity of metal components and structures: manufacture and installation - techniques and procedures	Manufacture and installation should use proven techniques and approved procedures to minimise the occurrence of defects that might affect the integrity of components or structures.
EMC.15	Engineering principles: integrity of metal components and structures: manufacture and installation - control of materials	Materials identification, storage and issue should be closely controlled.
EMC.16	Engineering principles: integrity of metal components and structures: manufacture and installation - contamination	The potential for contamination of materials during manufacture and installation should be controlled to ensure the integrity of components and structures is not compromised.
EMC.18	Engineering principles: integrity of metal components and structures: manufacture and installation - third-party inspection	Manufacture and installation should be subject to appropriate third-party independent inspection to confirm that processes and procedures are being followed.
EMC.19	Engineering principles: integrity of metal components and structures: manufacture and installation - non-conformities	Where non-conformities with procedures are judged to have a detrimental effect on integrity or significant defects are found and remedial work is necessary, the remedial work should be carried out to an approved procedure and should apply the same standards as originally intended.
EMC.20	Engineering principles: integrity of metal components and structures: manufacture and installation - records	Detailed records of manufacturing, installation and testing activities should be made and be retained in such a way as to allow review at any time during subsequent operation.
EMC.21	Engineering principles: integrity of metal components and structures: operation - safe operating envelope	Throughout their operating life, components and structures should be operated and controlled within defined limits and conditions (operating rules) derived from the safety case.
EMC.22	Engineering principles: integrity of metal components and structures: operation - material compatibility	Materials compatibility for components should be considered for any operational or maintenance activity.
EMC.23	Engineering principles: integrity of metal components and structures: operation - ductile behaviour	For metal pressure vessels and circuits, particularly ferritic steel items, the operating regime should ensure that they display ductile behaviour when significantly stressed.
EMC.24	Engineering principles: integrity of metal components	Facility operations should be monitored and recorded to demonstrate compliance with, and to allow review against,

SAP No	SAP Title	Description
	and structures: monitoring - operation	the safe operating envelope defined in the safety case (operating rules).
EMC.25	Engineering principles: integrity of metal components and structures: monitoring - leakage	Means should be available to detect, locate, monitor and manage leakages that could indicate the potential for an unsafe condition to develop or give rise to significant radiological consequences.
EMC.26	Engineering principles: integrity of metal components and structures: monitoring -forewarning of failure	Detailed assessment should be carried out where monitoring is claimed to provide forewarning of significant failure.
EMC.27	Engineering principles: integrity of metal components and structures: pre- and in-service examination and testing - examination	Provision should be made for examination that is capable of demonstrating with suitable reliability that the component or structure has been manufactured to an appropriate standard and will be fit for purpose at all times during future operations.
EMC.28	Engineering principles: integrity of metal components and structures: pre- and in-service examination and testing - margins .	An adequate margin should exist between the nature of defects of concern and the capability of the examination to detect and characterise a defect.
EMC.29	Engineering principles: integrity of metal components and structures: pre- and in-service examination and testing - redundancy and diversity	Methods of examination of components and structures should be sufficiently redundant and diverse.
EMC.30	Engineering principles: integrity of metal components and structures: pre- and in-service examination and testing - qualification	Personnel, equipment and procedures should be qualified to an extent consistent with the overall safety case and the contribution of examination to structural integrity aspects of the safety case.
EMC.31	Engineering principles: integrity of metal components and structures: in-service repairs and modifications - repairs and modifications	In-service repairs and modifications should be carefully controlled through a formal procedure for change.
EMC.32	Engineering principles: integrity of metal components and structures: analysis - stress analysis	Stress analysis (including when displacements are the limiting parameter) should be carried out as necessary to support substantiation of the design and should demonstrate the component has an adequate life, taking into account time-dependent degradation processes.
EMC.33	Engineering principles: integrity of metal components and structures: analysis - use of data	The data used in analyses and acceptance criteria should be clearly conservative, taking account of uncertainties in the data and their contribution to the safety case.
EMC.34	Engineering principles: integrity of metal components and structures: analysis - defect sizes	Where high reliability is needed for components and structures and where otherwise appropriate, the sizes of crack-like defects of structural concern should be calculated using verified and validated fracture mechanics methods with verified application.
EAD.1	Engineering principles: ageing and degradation - safe working life	The safe working life of structures, systems and components that are important to safety should be evaluated and defined at the design stage.
EAD.2	Engineering principles: ageing and degradation - lifetime margins	Adequate margins should exist throughout the life of a facility to allow for the effects of materials ageing and degradation processes on structures, systems and components.

Table 2

Technical Assessment Guides considered in the assessment

Technical Assessment Guide No	Description
NS-TAST-GD-005	Guidance on the Demonstration of ALARP (As Low As Reasonably Practicable)
NS-TAST-GD-006	Deterministic Safety Analysis and The Use of Engineering Principles in Safety Assessment
NS-TAST-GD-009	Examination, Inspection, Maintenance and Testing of Items Important to Safety
NS-TAST-GD-016	Integrity of Metal Components and Structures
NS-TAST-GD-051	The Purpose, Scope, and Content of Safety Cases
NS-TAST-GD-094	Categorisation of Safety Functions and Classification of Structures, Systems And Components

Table 3

Standards and Guidance considered in the assessment

IAEA	Design of Reactor Containment Systems for Nuclear Power Plants	Safety Guide NS-G-1.10
ASME	Boiler and Pressure Vessel Code	1998 Edition, through 2000 Addenda
ASME	Boiler and Pressure Vessel Code	2001 Edition with 2002 addenda