New Reactors Programme

GDA close-out for the AP1000 reactor

GDA Issue GI-AP1000-SI-02 - Fatigue Analysis of ASME III Class 1 Piping

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EXECUTIVE SUMMARY

Westinghouse is the design company for the **AP1000**® reactor. Westinghouse completed Generic Design Assessment (GDA) Step 4 in 2011 and paused the regulatory process. It achieved 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 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-02 - Fatigue Analysis of ASME III Class 1 Piping. This GDA issue arose in Step 4 of GDA because:

- At the time Westinghouse had yet to demonstrate that the pressuriser surge line design satisfied the fatigue limits prescribed in the American Society of Mechanical Engineers' Boiler and Pressure Vessel Code (ASME Code).
- Westinghouse expressed confidence that such demonstration would be achieved in the design finalisation process. This assurance was accepted by ONR at Step 4 of GDA for award of an IDAC. GDA Issue GI-AP1000-SI-02 was raised so that compliance with fatigue limits could be established to support award of a DAC.

The Westinghouse GDA Issue Resolution Plan identified that its approach to close the issue was to provide:

- sufficient evidence to show that ASME Code Section III Class 1 pipework has adequate fatigue life for the 60-year design life of the reactor.
- adequate responses to any questions arising from assessment by ONR.

My assessment conclusion is:

- Westinghouse has demonstrated that ASME Code Section III Class 1 pipework of **AP1000** plant has adequate fatigue life for the 60 year design life of the reactor.
- I consider that, from a structural integrity perspective, the **AP1000** design is suitable for construction in the UK.

My judgement is based upon the following factors:

- Fatigue analysis of Class 1 piping has been properly conducted in accordance with relevant good practice (RGP).
- Limiting operating transients and locations have been correctly identified.
- The analysis is conservative.
- The results of fatigue analysis establishes compliance with fatigue usage limits to justify a 60-year design life.

In summary I am satisfied that GDA Issue GI-AP1000-SI-02 can be closed.

LIST OF ABBREVIATIONS

ALARP	As Low As Reasonably Practicable
ASME	American Society of Mechanical Engineers
BMS	Business Management System
CUF	Cumulative Usage Factor
DAC	Design Acceptance Confirmation
DCD	Design Certification Document
DVI	Direct Vessel Injection
EAF	Environmentally Assisted Fatigue
GDA	Generic Design Assessment
IAEA	International Atomic Energy Agency
IDAC	Interim Design Acceptance Confirmation
ISI	In Service Inspection
LBB	Leak Before Break
ONR	Office for Nuclear Regulation
PCSR	Pre-Construction Safety Report
PSA	Probabilistic Safety Analysis
PWR	Pressurised Water Reactor
RCS	Reactor Coolant System
RGP	Relevant Good Practise
SAPs	Safety Assessment Principles
TAG	Technical Assessment Guide
TSC	Technical Support Contractor

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1 INTRODUCTION

1.1 Background

1. Westinghouse, the design company for the AP1000® reactor, 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 before a Design Acceptance Confirmation (DAC) can be awarded, and before any nuclear safety-related construction can begin on site. Westinghouse resumed GDA in 2014 to close the 51 GDA 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-02 - Fatigue Analysis of ASME III Class 1 Piping.

3. The GDA Step 4 structural integrity assessment of the **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. At Step 4 of GDA Westinghouse had yet to demonstrate that the pressuriser surge line design meets fatigue limits given in Section III of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (ASME Code).

5. Westinghouse expressed confidence that this would be achieved as part of the design finalisation process. This assurance was accepted in Ref. 1 for award of an IDAC. ONR raised GDA Issue GI-AP1000-SI-02 to confirm that sufficient evidence of fatigue life is established to support award of a DAC.

6. Ref. 1 also questioned the extent to which the plant as a whole had been shown to comply with the fatigue limits of the ASME Code. The scope of GI-AP1000-SI-02 was therefore issued to cover all ASME Class 1 piping as follows:

GI-AP1000-SI-02: *Westinghouse shall provide sufficient evidence to show that ASME III Class 1 pipework has an adequate fatigue life for the 60 year design life of the reactor.*

1.2 Scope

7. The scope is described in my assessment plan (Ref. 4) and includes a review of submissions by Westinghouse. The purpose is to confirm that sufficient evidence of adequate fatigue life is established for ASME III Class 1 piping.

8. The resolution plan (Ref. 5) identifies actions planned by Westinghouse to promote closure of GDA Issue GI-AP1000-SI-02 as follows. Westinghouse committed to provide:

- sufficient evidence to show that ASME III Class 1 pipework has an adequate fatigue life for the 60 year design life of the reactor.

- adequate responses to any questions arising from assessment by ONR of documents submitted.

9. The scope of my assessment is appropriate for GDA because, in the UK, there is an expectation that the design should take due account of degradation processes, including fatigue. At Step 4 of GDA the demonstration of adequate fatigue life was incomplete for ASME III Class 1 piping. The subject of this assessment is work undertaken by Westinghouse to address that shortcoming.

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

1.3 Method

11. 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) which defines the process of assessment within the ONR.

1.4 Sampling Strategy

12. 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.

13. The sampling strategy for this assessment focused on fatigue analysis of ASME III Class 1 pipework, identified in Ref. 1 as requiring further evidence to establish compliance with UK expectations of relevant good practice (RGP).

14. I was aware that ONR had identified uncertainties relating to the Westinghouse demonstration of ASME III design compliance under GI-AP1000-SI-05. Noting that ASME III fatigue analyses involve more complex methods than the stress analyses considered under GI-AP1000-SI-05 I sought to gain further confidence in the veracity of the Westinghouse design compliance approach in its ASME III Class 1 piping fatigue analyses.

2 ASSESSMENT STRATEGY

2.1 Pre-Construction Safety Report (PCSR)

15. ONR's GDA Guidance to Requesting Parties (Ref. 8) states that the information required for GDA may be in the form of a PCSR, Technical Assessment Guide (TAG) 051 (Ref. 9) sets out regulatory expectations for a PCSR.

16. At the end of Step 4, ONR and the Environment Agency raised GDA Issue GI-AP1000-CC-02 (Ref. 10) 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.

17. A separate regulatory assessment report is provided to consider the adequacy of the PCSR and closure of GDA Issue CC-02, 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-02.

2.2 Standards and Criteria

18. The standards and criteria adopted within this assessment are principally the Safety Assessment Principles (SAPs) (Ref. 11), internal TAGs, relevant standards and RGP informed by existing practices adopted on UK nuclear licensed sites.

2.2.1 Safety Assessment Principles

19. The key SAPs that have informed my assessment are listed in Table 1.

2.2.2 Technical Assessment Guides

20. The key TAGs that have informed my assessment are listed in Table 2.

2.2.3 National and International Standards and Guidance

21. The standards and guidance that I have used as part of my assessment are listed in Table 3. Note that the edition of the ASME Code accords with that identified in the design reference point (Ref. 12).

2.3 Use of Technical Support Contractors (TSCs)

22. We engaged a Technical Support Contractor (TSC) to support closure of GDA Issue GI-AP1000-SI-02. The TSC, Frazer-Nash Consultancy Limited (Frazer-Nash), provided independent expert advice on methodology and reviewed a sample of the Westinghouse fatigue analyses of ASME Section III Class 1 pipework.

2.4 Integration with Other Assessment Topics

23. 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. I have consulted with ONR specialists in fault studies, mechanical engineering and Probabilistic Safety Analysis (PSA) to inform my assessment.

2.5 Out of Scope Items

24. This report does not consider structural integrity aspects of the PCSR, which is addressed by a separate ONR cross-disciplinary assessment.

3 REQUESTING PARTY'S SAFETY CASE

25. At the outset of my assessment, Westinghouse's response to GI-AP1000-SI-02 for fatigue life of ASME III Class 1 piping was as follows.

26. Westinghouse applied the ASME Code for fatigue analysis of Class 1 piping. The purpose was to demonstrate compliance with limits prescribed in the ASME Code with the objective of justifying a 60-year design life. The general requirement of the ASME Code is to demonstrate, by analysis, a fatigue cumulative usage factor (CUF) less than 1.

27. Following GDA Step 4, Westinghouse revised its fatigue analyses for the ASME III Class 1 piping. The revision took account of design change proposals and Ref. 13 gives controlling CUFs for ASME Class 1 pipe lines in UK **AP1000** plant. All results satisfy ASME Code requirements. The maximum value of 0.99 is reported for the pressuriser surge line.

28. Ref. 14 describes Westinghouse's general method of fatigue analysis, which is based on the ASME Code Section III, 1998 Edition through 2000 Addenda.

29. Westinghouse has adapted the general method for analysis of certain components. For example, the pressuriser surge line analysis applies a refined technique to address thermal stratification.

4 ONR ASSESSMENT OF GDA ISSUE GI-AP1000-SI-02

30. This assessment has been conducted according to ONR BMS document "Purpose and Scope of Permissioning" (Ref.7).

4.1 Scope of Assessment Undertaken

31. My assessment reviewed Westinghouse's method for fatigue analysis of ASME III Class 1 piping, its application and outcome.

32. At my request, Westinghouse submitted the following documents for my review:

- Piping Fatigue Analysis General Methods and Inputs (Ref.14).
- Pressuriser Surge Line Transients (Ref. 15).
- Pressuriser Surge Line Piping Component Fatigue Analysis (Ref. 16).
- Reactor Coolant System (RCS) Transients Input for ASME Class 1 Piping Fatigue Evaluations (Ref. 17)
- Reactor Coolant Loop Piping Component Fatigue Evaluation (Ref. 18).
- Reactor Coolant Loop Branch Nozzle Component Fatigue Analysis (Ref. 19).
- Direct Vessel Injection (DVI) Transient Input for ASME Class 1 Piping Fatigue Evaluation (Ref. 20).
- DVI Piping Component Fatigue Analysis (Ref. 21).

33. The reasons for my interest in these submissions are as follows:

- I sought to establish the level of conservatism in the analyses, particularly where Westinghouse reports high CUF values.
- Ref. 1 identified the pressuriser surge line as a significant area where Westinghouse had yet to show compliance with the ASME fatigue limits. Analysis of the surge line was necessarily complex and challenging. In addition, there is operating experience of high fatigue life consumption in such lines due to thermal stratification.
- The RCS loop piping and branches are amongst the most safety-significant examples of Class 1 piping in the **AP1000** plant.
- The DVI piping is a distinctive feature of **AP1000** plant design and was reviewed to provide a broad sample of evidence to reliably demonstrate ASME Code compliance.

34. I raised a series of questions in the course of my assessment, issued as Regulatory Queries. I have subsequently assessed responses by Westinghouse to my queries of Refs. 22 to 26.

35. I held a number of level 4 technical engagements with Westinghouse where we discussed:

- my regulatory expectations, based on RGP, see Section 2.2.
- the technical and safety aspects of each Westinghouse submission.

36. My assessment was conducted with TSC support; Frazer-Nash undertook a detailed review of both the Westinghouse fatigue analysis methods and their application, reported in Ref. 27.

37. My interest in this assessment was first to establish whether Westinghouse applied RGP for its fatigue analysis, whether the outcome of analysis was acceptable and substantiated by the necessary evidence.

38. I also considered whether, within the scope of my assessment, risks associated with fatigue of ASME III Class 1 piping are reduced As Low As Reasonably Practicable (ALARP), such that GDA Issue GI-AP1000-SI-02 may be closed. Closure of this issue will support a broader conclusion that, from a structural integrity perspective, the **AP1000** plant design is suitable for construction in the UK.

39. At Step 4 of GDA, Westinghouse had not adequately addressed the effect of environment in its fatigue analysis. In Ref. 1 ONR accepted that environmental influence on fatigue life would not be addressed in GDA, but found that the matter should be resolved before operation. ONR raised the following assessment finding:

__AF-AP1000-SI-39__: The licensee shall undertake a fatigue design evaluation for locations in stainless steel and ferritic components that are in contact with the wetted environment to ensure that the effects of environment have been properly accounted for in the fatigue design analysis.

40. The scope of my assessment did not therefore consider the matter of Environmentally Assisted Fatigue (EAF) in detail. I did however seek assurance that current estimates of fatigue life were conservative such that, where necessary, an environmental penalty can be accommodated in future (Ref. 23).

4.2 Assessment

41. This part of the report is divided into three sections and each describes in turn my assessment of the following aspects:

- Method of fatigue analysis
- Application of the method.
- Key assessment considerations and regulatory judgements.

4.2.1 Method of Fatigue Analysis

42. The Westinghouse general fatigue analysis method (Ref.14) includes generic assumptions applicable to all the fatigue analyses, whereas the individual analysis provides details of the methods, assumptions and results of specific ASME III Class 1 piping. Ref. 14 is based on the ASME Code Section III, 1998 Edition through 2000 Addenda. The ASME Code is now at the 2015 Edition. Whilst I acknowledge that the AP1000 standard plant design uses a code year consistent with its certified design in the USA, in Ref. 23 I questioned the acceptability of using an edition of the ASME Code that has been superseded by later editions.

43. Westinghouse identified reviews it had conducted of the ASME Code from the 1998 to 2015 editions. This work considered reports by Hartford Steam and Boiler Inspection and Insurance Company which summarise changes for each edition and subsequent addenda. In general, Westinghouse concluded that there is no expected threat to qualification against fatigue limits due to changes in ASME Code.

44. I noted that more recent editions of the ASME Code include somewhat more conservative fatigue curves for austenitic stainless steels and nickel-based alloys than

those given in the edition applied by Westinghouse. In response to my query of Ref. 23, Westinghouse identified how such differences will be addressed and provided comparative examples to confidently establish that the design can accommodate such changes.

45. Assessment Finding AF-AP1000-SI-40 of Ref. 1 requires a review, by any future licensee, of changes to the design that would be required if the current version of ASME Code Section III were used. Where changes are indicated the licensee would be required either to make those changes or justify why they are not required. Given this existing finding, I am content that the edition of ASME Code applied by Westinghouse for fatigue assessment of Class 1 piping is adequate for the purposes of GDA. The basis for my judgement is as follows:

- Westinghouse have provided evidence that there is sufficient conservatism in their current fatigue analyses to accommodate changes in more recent editions of the ASME Code without infringement of allowable limits of fatigue usage.

- According to the terms of AF-AP1000-SI-40, any future licensee is required to justify the continued validity of the fatigue analyses of Class 1 piping despite changes to the ASME Code.

46. Ref. 27 identifies an important point of detail concerning the method for fatigue analysis of butt-welded pipe elbows. I questioned how these elbows and their welds are treated for fatigue analysis; in particular are these features assessed separately or are bounding arguments applied to limit the scope of analysis? Westinghouse identified that such features are evaluated for fatigue as separate components, i.e. the elbow body and the welds to attached piping. Westinghouse has demonstrated that this approach accords with the requirements of the ASME Code, and I therefore consider it acceptable for analysis of Class 1 piping.

47. In reviewing the method of fatigue analysis, I noted that the treatment of EAF is not yet formally incorporated into the ASME Code. Whilst the matter was outside the scope of my assessment, see Section 4.1, when assessing the Westinghouse safety case I sought assurance that any environmental penalty could be accommodated in future, see Section 4.2.3.

4.2.2 Application of the Method

48. In Ref. 23 I questioned the general method for selection of locations for fatigue assessment. This was by reason of my regulatory expectation for a non-mechanistic approach to structural integrity classification. In the UK it is expected that components are classified based on the direct and indirect consequences of their postulated gross failure. As such, evidence of Leak Before Break (LBB) behaviour, a mechanistic approach adopted in the USA and other countries, is not accepted as sufficient reason to disregard gross failure of piping.

49. Westinghouse confirmed that it has evaluated all Class 1 piping components for fatigue, either explicitly or by identification of bounding cases, irrespective of LBB considerations. Fatigue assessment locations are based on a review by Westinghouse of plant drawings that define ASME Class 1 pipe boundaries. I am content that Westinghouse has identified appropriate locations for fatigue analysis, in accordance with UK good practice. The basis for my judgement is as follows:

- Westinghouse has not applied the concept of LBB to limit the scope of their fatigue analyses of Class 1 piping.

- Westinghouse has provided evidence that the scope of their fatigue analysis is sufficiently comprehensive. Where bounding locations have been identified to limit the scope of analysis, this has been adequately justified.

50. In Ref. 23 Westinghouse identified that it has used a nominally conservative methodology for the fatigue evaluations of most piping components to demonstrate acceptability. In some cases with more severe or complex design transient loadings, more detailed evaluations are performed using finite element analyses to reduce conservatism and demonstrate acceptability.

51. In my assessment of the pressuriser surge line piping fatigue analysis (Ref. 16) I questioned whether an appropriate aspect ratio of elements had been applied in the finite element analysis (Ref. 25). Westinghouse identified the results of a study conducted to examine this question, showing that the analysis is not significantly sensitive to element aspect ratio. I am therefore content that the finite element model developed by Westinghouse provides a sufficiently accurate estimation of stresses.

52. Also in my assessment of Ref. 16, I questioned whether an uplift factor to expansion stresses resulting from pipework flexibility analysis, required by Section III NB-3672.5 of the ASME Code, had been properly applied. Frazer-Nash, on ONR's behalf, submitted a code inquiry on this matter to the ASME committee. This resulted in the issue of code interpretations, identified in Ref. 27 as ASME Code interpretations III-1-86-105 and III-1-16-1891, the conclusions of which confirm the validity of the Westinghouse method.

53. With TSC support, I assessed the degree of conservatism for various assessment locations in each Westinghouse submission and I am content that its approach leads in all cases to a conservative result. We have not identified any significant non-conservatisms and I consider that an appropriate range of sensitivity studies have been carried out, for example to identify the most adverse transients from a postulated listing.

54. I have discovered that the degree of conservatism is often significant (for example in terms of assumptions relating to fatigue cycles). One significant conservatism I have identified is the manner of stress range calculation. The largest moment stress range developed between all thermal conditions is applied for every fatigue pair in the evaluation. This assumption is conservatively maintained regardless of the actual transient conditions represented in the pair.

55. Westinghouse terminate the analysis where it provides acceptable results, even where fatigue usage approaches the prescribed limit. Otherwise, where the CUF is initially predicted to be greater than 1, conservatisms are systematically removed from the Westinghouse analysis until the limit is satisfied. In my assessment of the Reactor Coolant Loop Piping Component Fatigue Evaluation (Ref. 13) I identified that refinement of analysis resulted in reduction of the initial CUF by a factor of at least 16 at one location. Westinghouse confirmed that such levels of conservatism also applied to other locations in its analysis.

4.2.3 Key Assessment Considerations and Regulatory Judgements

56. Westinghouse has applied the ASME Code for fatigue analyses of Class 1 piping. While the edition of the ASME Code applied for fatigue analysis has been superseded, Westinghouse has provided evidence that the results of its analyses remain valid despite changes to more recent editions of the ASME Code. An Assessment Finding, raised in Ref. 1 at Step 4 of GDA, requires any future licensee to conduct a review against the edition of ASME Code current at the time of licensing (see Section 4.2.1). I am satisfied that the method applied by Westinghouse for fatigue analysis of Class 1 piping is satisfactory for the purposes of GDA.

57. The results of fatigue analyses of Class 1 piping establish compliance with fatigue usage limits to justify a 60-year design life. My assessment of the application of fatigue analysis has found no shortcomings that could significantly infringe the justification of a 60-year fatigue life for ASME III Class 1 Piping, for which Westinghouse is to be commended.

58. I raised a small number of questions where it was unclear whether the method and application of fatigue analysis complied with RGP. I have discussed these matters in Sections 4.2.1 and 4.2.2; all have been resolved to my satisfaction. I raised a larger number of less significant comments or requests for clarification in the course of my assessment. These are recorded in Ref. 27, all have been resolved to my satisfaction and noteworthy cases are described in this report.

59. My assessment has established that fatigue analyses of Class 1 piping have been properly conducted in accordance with RGP. Limiting operating transients and locations have been correctly identified and the analyses are conservative. Inherent conservatisms of the ASME Code are compounded by conservative assumptions by Westinghouse in its analyses. I am therefore satisfied that Westinghouse has demonstrated adequate fatigue life of ASME III Class 1 piping for the 60-year design life of the reactor.

60. In the course of my assessment I observed that fatigue usage factors of Class 1 piping are applied to determine some failure frequencies in the PSA. These data are derived from Pressurised Water Reactors (PWRs) with active safety systems. I questioned whether fatigue usage of **AP1000** Class 1 piping was typical of PWR plant in general, rather than a feature of the **AP1000** plant passive design.

61. I requested a comparison of fatigue usage between active and passive Westinghouse PWR plant. Westinghouse provided information for the Spray, Auxiliary Spray, DVI, and Surge lines. Westinghouse selected these for comparison because they are similar in both passive and active PWR plants with respect to fatigue usages due to basic function and operation, and are subject to significant transient loading so have relatively high fatigue usage. Westinghouse noted that design basis fatigue analyses for PWRs with active safety systems were based on a 40-year operating life, whereas **AP1000** plant fatigue analyses consider a 60-year life. For each line considered, Westinghouse identified that usage factors for both designs are of similar order, typically maximum reported values are above 0.9. Also, locations of higher fatigue usage are similar in both the passive **AP1000 plant** and active PWR designs.

62. I am satisfied that maximum levels of fatigue usage and locations of higher fatigue usage result from generic PWR design features and the inherent conservatism in the Westinghouse fatigue analyses, rather than particular aspects of the **AP1000** plant design.

63. In the course of my assessment I observed that a number of analyses resulted in fatigue CUFs approaching the allowable limit of 1. Aware that Westinghouse has provided evidence that these analyses are significantly conservative, I nonetheless questioned whether such locations could accommodate a future penalty to account for the effects of environment. My aim was to establish confidence that Westinghouse had a way forward, particularly for cases where CUF is relatively high (i.e. >0.75).

64. Westinghouse expressed its judgement that accounting for EAF would result only in a reduction of margins, and not infringement of the fatigue usage limit. This view was supported by a number of examples, identified by Westinghouse, where initially high values of CUF had been reduced significantly by applying a refined approach with more realistic assumptions. In particular, Westinghouse has refined their methods by accounting for realistic plant transients, rather than those derived from bounding assumptions. I am satisfied that Westinghouse have demonstrated good reason for its

confident expectation that environmental effects can be accommodated in future, as required by AF-AP1000-SI-39 of Ref. 1.

65. In my assessment I finally examined evidence of defence-in-depth against fatigue damage. I questioned whether there is good access to effectively inspect ASME III pipework so that the absence of fatigue cracking can be confirmed, particularly at locations where the predicted fatigue CUF is high.

66. Westinghouse confirmed that there is general good access to ASME III Class 1 piping for inspection, including the reactor coolant loops and pressuriser surge line which are some of the highest fatigue usage locations in the plant. Westinghouse identified that insulation can easily be removed to afford access, and that weld finish, surface extent and surface smoothness requirements for ASME III Class 1 piping promote effective inspection.

67. Access for In-Service Inspection (ISI) was considered in Step 4 of GDA. Ref. 1 identifies a "Design for Inspectability" review produced by Westinghouse for ISI of Class 1 components (Ref.28) which describes the concepts, design philosophy and goals for ensuring that **AP1000 plant** design takes due account of the need for inspectability. These aspects were judged to appear reasonable in Ref. 1, however it was identified that a key outcome of the review are actions identified in a series of ISI Inspectability Reports. Accordingly, the following assessment findings were raised in Ref. 1:

AF-AP1000-SI-31. *The Licensee shall ensure that all the Design/Fabrication Actions in the ISI Inspectability Reports are either completed, or the issue addressed in an alternative way.*

AF-AP1000-SI-32*. The Licensee shall ensure that all the Pre PSI/ISI Actions in the ISI Inspectability Reports are either completed, or the issue addressed in an alternative way.*

68. I am satisfied that these assessment findings of Step 4 will effectively promote good access for effective ISI during the licensing phase. I also note that the broader subject of access for inspection, including but not solely confined to Class 1 Piping, is considered in the assessment of GDA Issue GI-AP1000-SI-01 and will be discussed in the separate assessment report for that GDA issue. I questioned whether, in contingency against fatigue damage, vulnerable locations could, if necessary, be repaired or replaced in future. Westinghouse confirmed that such reparatory work is possible in theory and that there is operating experience of the replacement of Class 1 components in similar plant.

69. Provided that the proposed arrangements for effective inspection are adequately implemented in site licensing, I am satisfied that the capacity for repair or replacement, if required in future operation, adequately controls any residual risk of fatigue damage.

4.3 Comparison with Standards, Guidance and Relevant Good Practice

70. Section 2.2 of this report identifies standards, guidance and RGP that have informed my assessment, which is described in Section 4.2. In particular, my assessment has been guided by ONR's SAPs (see Table 1) and TAGs (see Table 2). A notable example of RGP adopted by Westinghouse is their application of the ASME Code for fatigue analysis.

4.4 Overseas regulatory interface

71. ONR has formal information exchange agreements with a number of international nuclear safety regulators, and collaborates through the work of the International Atomic Energy Agency (IAEA) and the Organisation for Economic Co-operation and Development Nuclear Energy Agency. This enables us to utilise overseas regulatory assessments of reactor technologies, where they are relevant to the UK. It also enables the sharing of regulatory Assessment Findings, which can expedite assessment and helps promote consistency.

72. ONR also represents the UK on the Multinational Design Evaluation Programme, which is a group of nuclear safety regulators engaged in the technical review of reactor technologies. This helps to promote consistent assessment standards, and enables the sharing of information.

73. In this assessment, I contacted the United States Nuclear Regulatory Commission to identify how the matter of EAF was addressed for design licensing in the USA. My understanding is that the AP1000 plant Design Certification Document (DCD) does not explicitly address EAF, but identifies that a “Component Cyclic or Transient Limit Program” shall be established, implemented, and maintained by the licensee. This provides controls to track the cyclic and transient occurrences to ensure that components are maintained within design limits.

74. In addition, Section III, NCA-1130 and NB-3121 of the ASME Code provides general statements about accounting for environmental effects in the design, even though EAF is not explicitly addressed. As is the case for the UK, the AP1000 plant DCD commits to the 1998 Edition with 2000 Addenda.

75. Noting that Assessment Finding AF-AP1000-SI-39 requires that the licensee shall, in future, undertake a fatigue design evaluation to account for EAF, I am satisfied that consideration of EAF within GDA is broadly consistent with the approach taken in the USA, where detailed treatment of EAF is also deferred to the licensing phase.

4.5 Assessment Findings

76. In GDA residual matters are recorded as Assessment Findings if any of the following apply:

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

77. My assessment has not resulted in any assessment findings.

4.6 Minor Shortfalls

78. Residual matters are recorded as a minor shortfall if it does 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

79. My assessment identified no minor shortfalls in the safety case.

5 CONCLUSIONS

80. This report presents the findings of the assessment of GDA Issue GI-AP1000-SI-02 - Fatigue Analysis of ASME III Class 1 Piping, relating to the **AP1000 plant** GDA closure phase.

81. To conclude:

- Westinghouse has demonstrated that ASME III Class 1 pipework has an adequate fatigue life for the 60 year design life of the reactor.

82. My judgement is based upon the following factors:

- Fatigue analysis of Class 1 piping has been properly conducted in accordance with RGP.
- Limiting operating transients and locations have been correctly identified.
- The analysis is conservative.
- The results of fatigue analysis establish compliance with fatigue usage limits to justify a 60-year design life.

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

6 REFERENCES

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5. Westinghouse-REG-0872N, Enclosure 2, Resolution Plan for GI-AP1000-SI-02: Fatigue Analysis of ASME III Class 1 Piping, Revision 3, 13 April 2016, TRIM Ref. 2016/157050.

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16. APP-RCS-PLC-003, Revision 0, **AP1000** Pressuriser Surge Line Piping Component Fatigue Analysis, TRIM Ref. 2015/400951.

17. APP-RCS-PLC-001, Revision 0, **AP1000** RCS Transients Input for ASME Class 1 Piping Fatigue Evaluations. TRIM Ref. 2016/46841.

18. APP-RCS-PLC-061, Revision 1, **AP1000** Reactor Coolant Loop Piping Component Fatigue Evaluation. TRIM Ref. 2016/46798.

19. APP-RCS-PLC-101, Revision 0, **AP1000** Reactor Coolant Loop Branch Nozzle Component Fatigue Analysis. TRIM Ref. 2016/47004.

20. APP-PXS-PLC-001, Revision 0, **AP1000** DVI Transient Input for ASME Class 1 Piping Fatigue Evaluation. TRIM Ref. 2016/46883.

21. APP-PXS-PLC-002, Revision 0, **AP1000** DVI Piping Component Fatigue Analysis. TRIM Ref. 2016/46850.

22. GDA Regulatory Query RQ-AP1000-1425, GI-AP1000-SI-02 ASME III Class 1 Piping Fatigue Analyses, 23 October 2015, TRIM Ref. 2015/396582

23. GDA Regulatory Query RQ-AP1000-1449, GI-AP1000-SI-02 ASME III Class 1 Pipework - General Methods & Criteria, 4 December 2015, TRIM Ref. 2015/460512

24. GDA Regulatory Query RQ-AP1000-1468, GI-AP1000-SI-02 ASME III Class 1 Piping Fatigue Analyses, 12 January 2016, TRIM Ref. 2016/15519.

25. GDA Regulatory Query RQ-AP1000-1495, UK AP1000-SI-02 – Pressuriser Surge Line Fatigue Analyses, 19 February 2016, TRIM Ref. 2016/74441.

26. GDA Regulatory Query RQ-AP1000-1496, UK AP1000 SI-02 – ASME III Class 1 Piping Fatigue Analyses Methods, 19 February 2016, TRIM Ref. 2016/74470.

27. FNC 48995/43677R, Generic Design Acceptance Assessment Review of ASME III, Class 1 Piping Fatigue Analyses, Issue 1, February 2017, TRIM Ref. 2017/52843.

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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.

SAP No	SAP Title	Description
EMC.10	Engineering principles: integrity of metal components and structures: design - weld positions	The positioning of welds should have regard to high-stress locations and adverse environments.
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.

SAP No	SAP Title	Description
EMC.24	Engineering principles: integrity of metal components and structures: monitoring - operation	Facility operations should be monitored and recorded to demonstrate compliance with, and to allow review against, 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
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 & guidance considered in the assessment

ASME	Boiler and Pressure Vessel Code	1998 Edition, through 2000 Addenda
IAEA	Assessment and management of ageing of major nuclear power plant components important to safety - primary piping in PWRs.	IAEA-TECDOC-1361, July 2003