



New Reactors Programme

GDA close-out for the AP1000 reactor

**GDA Issue GI-AP1000-ME-02 – Metrication of Mechanical Equipment and Civil
Structural Steelwork Connections**

Assessment Report: ONR-NR-AR-16-015
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EXECUTIVE SUMMARY

Westinghouse is the reactor design company for the **AP1000**[®] reactor. Westinghouse completed Generic Design Assessment (GDA) Step 4 in 2011 and paused the regulatory process. It achieved an Interim Design Acceptance Confirmation which had 51 issues attached to it. 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 outstanding issues.

This report is the Office for Nuclear Regulation's (ONR's) assessment of the Westinghouse **AP1000** reactor design in the areas of mechanical and civil engineering. This work was supported by human factors and control and instrumentation inspectors. Specifically this report addresses the GDA Issue concerning metrication of mechanical equipment and civil structural steelwork connections.

This GDA Issue arose in Step 4 due to:

- ONR's requirement in its GDA guidance that plants should be designed, built and operated using Système Internationale (SI) metric units and that documents are written in English;
- an expectation that the design submitted by the requesting party is essentially metric, using metric structures, systems and components;
- further ONR advice provided to clarify the detail of its expectations, and to allow variation from this for a limited, controlled and justified set of equipment; and
- ONR judging that Westinghouse had not satisfactorily met its expectations for mechanical engineering equipment, associated systems or civil engineering structures and components during Step 4.

Westinghouse developed adequate arguments to explain why its strategy for metrication reduces risks so far as is reasonably practicable. Westinghouse clarified its position on the key expectations that ONR provided in Step 4. Westinghouse also improved the adequacy of its arguments for the proposed exceptions.

To assess Westinghouse's approach to metrication, I inspected its:

- main submission, the metrication report;
- document management procedures;
- design and safety case input and output documents; and
- reference documents concerning its 'as low as reasonably practicable' assessment of exceptions to its metrication strategy.

My conclusion is that Westinghouse's submission:

- adequately justifies its position for not meeting ONR's expectations that design, construction and operation of the **AP1000** reactor is in metric units;
- adequately justifies that its quasi-metric approach provides suitable confidence that the **AP1000** reactor design should be largely metric, with limited non-metric structures, systems and components, in line with regulatory expectations; and
- the proposed metrication strategy adequately demonstrates that reasonably foreseeable risks have either been reduced so far as is reasonably practicable, or that a licensee may implement adequate arrangements to further reduce risks.

My judgement is based on the following factors:

- it may be considered disproportionate to require entirely metric designs where the design has originated from a country employing non-metric units, codes and standards. Risks imposed by the introduction of non-metric structures, systems and components in the design must be understood and controlled.
- Westinghouse has demonstrated that so far as is reasonably practicable, metric structures, systems or components are either already proposed for the **AP1000** design or processes are in place to allow this in site licensing and construction.
- Westinghouse has demonstrated that there are adequate arrangements in place to enable a future licensee to make a risk informed judgement about whether the use of metric or non-metric designed structures, systems or components is acceptable.
- Westinghouse has demonstrated that those exceptions identified in the metrication report are reasonable and that risks are reduced so far as is reasonably practicable.
- Westinghouse's procedures are compliant with regulatory expectation for design and safety case documentation.
- Westinghouse's claim that information on-site will be in metric units complies with regulatory expectations.

Assessment Findings

The following mechanical engineering matters remain, which are for a future licensee to consider and take forward in their site-specific safety submissions. While these matters do not undermine the generic safety submission, they require licensee input and decision.

- Assessment Finding CP-AF-AP1000-ME-07 concerning the assessment and demonstration of equivalence between metric and non-metric codes, standards and relevant good practice; and
- Assessment Finding CP-AF-AP1000-ME-08 concerning configuration control and management of risks regarding metrication within the **AP1000** design.

In summary I am satisfied that the GDA issue regarding the metrication of mechanical equipment and civil structural steelwork connections can be closed.

LIST OF ABBREVIATIONS

AF	Assessment Finding
ALARP	As Low As Reasonably Practicable
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
BEIS	Department for Business, Energy & Industrial Strategy
BS	British Standard
C&I	control and instrumentation
CE	Conformité Européenne
DCP	Design Change Proposal
DIN	Deutsches Institut für Normung (German Institute for Standardisation)
DN	Diamètre Nominale (Nominal Diameter)
E&DCR	Engineering and Design Coordination Report
EN	European Norme (European Standard)
EIMT	Examination, Inspection, Maintenance and Testing*
FEM	Fédération Européenne de la Manutention
GDA	Generic Design Assessment
HSE	Health and Safety Executive
IAEA	The International Atomic Energy Agency
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
LC	Licence Condition
NSSS	nuclear steam supply system
NPS	Nominal Pipe Size
ONR	Office for Nuclear Regulation
PCSR	Pre-construction Safety Report
PSA	probabilistic safety assessment
RGP	relevant good practice
RP	Requesting Party
RQ	Regulatory Query
SAPs	Safety Assessment Principles
SI	Système Internationale (International System of Units)
SSC	structure, system (or) component
TAG	Technical Assessment Guide
WENRA	The Western European Nuclear Regulators' Association

* EIMT is an abbreviation used within the ONR SAPs and TAGs. It is also referred to as EMIT within industry. Both terms are equivalent.

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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 which had 51 GDA issues attached to it. 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.
2. This report is the Office for Nuclear Regulation's (ONR's) assessment of the Westinghouse **AP1000** reactor design in the areas of mechanical engineering and civil engineering, supported by human factors and control and instrumentation (C&I). Specifically this report addresses GDA Issue GI-AP1000-ME-02 – Metrication of Mechanical Equipment and Civil Structural Steelwork Connections. Although led by the mechanical engineering specialism, my assessment is supported by other specialisms due to the cross-discipline nature of metrication.
3. The related GDA Step 4 report is published on our website (www.onr.org.uk/new-reactors/ap1000/reports.htm), and this provides the assessment underpinning the GDA issue. Further information on the GDA process in general is also available on our website (www.onr.org.uk/new-reactors/index.htm).

1.2 Definitions

Metrication

4. Metrication (also called “metrification”) is the process of converting imperial measurements to metric units.
5. I use the term ‘US units’ in place of ‘imperial units’.
6. For this **AP1000** GDA issue, metrication is also used by ONR to describe the conversion of design and safety case information from US (imperial) codes, standards and units to the international system / système internationale (SI) codes, standards and units (referred to in my report as “metric”).
7. Information on ONR's expectations for metrication of reactor designs is included in Section 2.2 of this assessment report.

Dual units

8. Where a unit of measure is provided in both metric and non-metric units, this is termed ‘dual units’. In general the common unit of use is presented first, with the secondary units within parenthesis. In the US, dual units are normally presented in non-metric first with metric units in parenthesis eg 1.0 inch (25.4 mm). In the UK, it is common to place metric units first and other units in parenthesis eg 25.4 mm (1.0 inch).

Quasi-metric

9. Quasi-metric is a term identified by ONR at Step 4 of GDA. It is defined as the conversion of structures, systems or components initially conceived as non-metric, or imperial, but now designated and designed as metric using metric codes and

standards, and fully dimensioned in metric. This process is also known as 'hard metrication'.[†]

Substitution

10. Westinghouse identifies processes in its strategy that allow for a manufacturer / supplier, constructor or site licensee to request changes of structures, systems or components (SSCs) from non-metric to metric. These changes are formally assessed and where considered acceptable, implemented through existing procedures.

Form, Fit and Function

11. Westinghouse defines this as a concept that allows the 'standardisation' design principle to be aligned with a desire for 'localisation' that is, construction of an **AP1000** plant in a particular country rather than globally. It claims that this concept does not require equipment suppliers and specific dimensions to be specified.
12. Rather, requirements (as identified in a design specification) to define the form (design requirements), fit (interface requirements) and function (such as safety requirements) of the equipment are specified for the standard design. This allows different suppliers from around the world to make their own specific products comply either to metric or non-metric codes and standards.

Bulk Commodities

13. Westinghouse's specification of bulk commodities defines these as SSCs that have a widespread use throughout the plant design not specifically designed and analysed to the form, fit and function process. The form, fit and function process is used for these commodities, but on a more wide-ranging scale to allow for the large implementation of these SSCs across the plant design. Examples include piping, flanges, valves, cable trays and ducting.

1.3 Scope

14. The scope of my assessment is detailed in assessment plan ONR-GDA-AP-14-010 (Ref. 1)
15. It focuses on the two actions detailed in the GDA issue (Ref. 2). The issue was raised at the end of the GDA Step 4 mechanical engineering assessment and identified actions for Westinghouse to:

*"Provide an updated response to document titled '**AP1000** Standard Plant Metrication, APP-GW-G1-011', to reflect the guidance provided by ONR. Westinghouse should commit to re-designing equipment in line with the guidance, or provide a more rigorous justification (which aligns with the guidance provided) as to why it considers equipment should be an exception to metrication.*

*"Provide an updated response to document titled '**AP1000** Standard Plant Metrication, APP-GW-G1-011 Rev 3' to explicitly list the exclusions from metrication for Civil Steelwork SSCs. This should include Westinghouse's intention for all the component parts. It is accepted that the generic design for permanent civil steel structures is based on imperial sections (and materials). However, the exceptions listed in Table A-1 of APP-GW-G1-011*

[†] 'Soft metrication' is simply converting values from imperial to metric units rather than redefining the codes and standards of design, manufacture and operation. Soft metrication is often performed at the end of the design and manufacture process.

Rev 3 do not clearly define what approach will be used for the design of the detailed connections which will be carried out by local suppliers.

“The wide scale use of imperial bolting / fastenings is not acceptable. Although strict quality control during construction can be adopted, there is an increased risk of last minute substitutions with locally supplied, metric bolts. APP-GW-G1-011 Rev 3 does not confirm whether the supplier’s design will be quasi metric and or in imperial. The update of this document should clarify Westinghouse’s intentions on this, and discuss the effects if the other approach is used.”

16. The GDA issue identifies mechanical equipment and also civil structural aspects for consideration. As a result, during my assessment I have sought professional civil engineering advice and my assessment includes my judgements and those of a civil engineering specialist inspector.
17. The implications of metrication to Westinghouse and the consequences of mixing metric and non-metric unit SSCs for a licensee within a construction site and an operational reactor site, will be affected by human performance. My assessment includes both my judgements and those of a human factors specialist inspector.
18. Finally, during my initial review of the GDA issue I noted that exceptions proposed for C&I had not been fully accepted by ONR. Therefore, my assessment includes my judgements and those of a C&I specialist inspector.
19. Westinghouse has submitted a single document (Ref. 3) providing its strategy for metrication of the **AP1000** design for construction within the UK. It presents Westinghouse’s justification that it has met regulatory expectations so far as is reasonably practicable. This document, discussed in Section 3, forms the scope of my assessment.
20. The scope of my assessment is appropriate for GDA because it focuses on the risk of metrication and the consequences of inappropriate or unauthorised substitution for a generic **AP1000** design.

1.4 Method

21. This assessment complies with ONR’s internal guidance on the mechanics of assessment (Ref. 4).
22. During my assessment, I held a series of Level 4 technical engagements with Westinghouse. These engagements aimed to provide advice and guidance to Westinghouse, where necessary, on its submission and allowed Westinghouse to seek clarification.
23. The Level 4 engagements involved detailed discussions concerning the metrication strategy to ensure that the overall approach and its individual aspects were understood.
24. I assessed a number of iterations of Westinghouse’s main submission and, where shortfalls have been identified, these have been communicated to Westinghouse in Regulatory Queries (RQs) and records of meetings.

1.4.1 Sampling Strategy

25. It is rarely possible or necessary to assess a safety submission in its entirety, and therefore ONR adopts an assessment strategy of sampling.
26. The sampling strategy for this assessment was to firstly assess whether the **AP1000** design meets the regulatory requirements for a metric or quasi-metric design.
27. I sampled Westinghouse processes, which claimed to ensure that the use of metric and US units is controlled during the design process. These processes were:
 - a Westinghouse quality procedure for document control;
 - an equivalency study of US and UK codes and standards; and
 - an expert panel review of risk borne as a result of metrication.
28. I assessed Westinghouse's submission, as identified in Section 3 of this assessment report. This enabled me to judge the adequacy of the strategy to meet ONR expectations.
29. During my assessment of Westinghouse's submission, I sampled documents that it claims should include dual units or metric units only. I did this to assess the adequacy of its implementation of arrangements.
30. With the support of a C&I inspector, I sampled the C&I exceptions and how Westinghouse intends to present data in the control room. This responded to concerns noted at the end of Step 4.
31. Finally, I sampled Westinghouse's justification of exceptions for the SSCs that I judge most onerous in terms of hazard and consequences. Specifically, I have targeted those that I deem not to have met the regulatory expectation for justified exceptions at Step 4. These were:
 - nuclear steam supply system (NSSS) engineered fasteners and lift attachments;
 - load-handling systems associated with nuclear lifts, structures and fastenings;
 - ASME[‡] piping, flanges, valves and flange bolting throughout the plant;
 - explosively actuated (squib) valves; and
 - structural shapes and engineered connections for seismic structures.
32. The above exceptions consist of the civil and mechanical engineering aspects relevant to this GDA issue.
33. Many aspects of this GDA issue involve human factors in Westinghouse's strategy and consequently human performance related risks.

[‡] ASME is the American Society of Mechanical Engineers which is an organisation that produces standards.

2 ASSESSMENT STRATEGY

2.1 Pre-Construction Safety Report (PCSR)

34. ONR's GDA Guidance to Requesting Parties (RPs) (www.onr.org.uk/new-reactors/ngn03.pdf) states that the information required for GDA may be in the form of a PCSR, and Technical Assessment Guide (TAG) NS-TAST-GD-051 sets out regulatory expectations for a PCSR (www.onr.org.uk/operational/tech_asst_guides/ns-tast-gd-051.pdf).
35. At the end of Step 4, ONR and the Environment Agency raised GDA Issue GI-AP1000-CC-02 (www.onr.org.uk/new-reactors/reports/step-four/westinghouse-gda-issues/gi-ap1000-cc-02.pdf) requiring that Westinghouse submit a consolidated PCSR and associated references to provide the claims, arguments and evidence to substantiate the adequacy of the **AP1000** design reference point.
36. A separate regulatory assessment report considers the adequacy of the PCSR and closure of GDA Issue GI-AP1000-CC-02, and therefore this report does not discuss the mechanical engineering aspects of the PCSR. This assessment focuses on the supporting documents and evidence specific to GDA Issue GI-AP1000-ME-02.

2.2 Standards and Criteria

37. The standards and criteria adopted in this assessment are principally the Safety Assessment Principles (SAPs) (Ref. 5), internal ONR TAGs (Ref. 6), relevant national and international standards and relevant good practice (RGP) informed by existing practices adopted on GB nuclear licensed sites.
38. ONR publishes guidance to requesting parties (Ref. 7) that identifies the following requirement:
- “ONR recognises that the RP [requesting party] may choose to make use of existing design and safety documents that were written to address the regulatory requirements of countries other than Great Britain. However, because the regulatory basis in Great Britain is goal-setting, rather than prescriptive, and is based on the ALARP principle, it is unlikely that such documents will be sufficient, on their own, for the purposes of GDA. ONR needs to receive additional and specific submissions that demonstrate how the regulatory requirements of Great Britain have been, or will be, met.*
39. In particular the guidance states that:
- “ONR requires that plants are designed and will be built and operated using SI (Système Internationale) Units and that documents submitted are written in English.”*
40. In March 2010, during ONR's Step 4 assessment of the **AP1000** design, additional guidance was provided to Westinghouse stating ONR's position and expectations for the use of metric codes, standards and units (Ref. 8).
41. Considered by ONR to be relevant good practice, this guidance provides the following expectation:[§]

[§] This advice is not specific to the GDA phase only and is considered relevant good practice during Phase 2 (site licensing and construction) and during operation of new nuclear facilities.

- (1) For construction of the **AP1000** in Great Britain, the regulatory expectation is that the design and associated equipment should be fully metric (i.e. conceived, designed, and manufactured as metric); or
 - (2) As an alternative, 'quasi metric' (i.e. initially conceived as US units, but now designated and designed as metric using metric codes / standards, and fully dimensioned as metric). All fastenings shall be metric.
 - (3) However, exceptionally, the regulator may accept non-metric products (including fastenings) for one-off fabrications of a specialist nature associated with the NSSS, or other specialist NSSS equipment, but these will need to be justified to the regulator on a case by case basis.
 - (4) Notwithstanding the above, all design and safety case documentation shall be fully metric from conception, through intermediate results, to final presentation.
 - (5) All information displayed within the constructed facility will need to be fully metric.
42. These five principles are the basis of my assessment of the **AP1000** design regarding GDA Issue GI-AP1000-ME-02.
43. In addition to these five principles, I examined Westinghouse's process of 'substitution'. This is the replacement of non-metric (or metric) SSCs with metric (or non-metric) SSCs during detailed design, construction or during the **AP1000** plant operation phase. I have assessed evidence that Westinghouse claims to demonstrate the adequacy of arrangements to assess the feasibility of substitutions. These arrangements are used in its ongoing construction projects in the US and China.
44. At this closure stage of the **AP1000** reactor GDA, it has been necessary to evaluate the reasonableness of ONR's expectations. The **AP1000** design is one intended for international deployment. Ordinarily, such products originating from the US may expect to be designed using metric units to enable this.
45. However, the **AP1000** design evolved from an earlier design intended for national deployment in the US. It was designed primarily using US codes, standards and units. The **AP1000** design's evolution was not in line with the expectation on products intended for international supply or use. This influences the requirement to retain elements of the design to non-metric (US) codes and standards.
46. A new design, originating from the US and / or any country utilising SI units, may reasonably be expected to be designed, built and operated using metric units.
47. Westinghouse's submission aims to address the specific regulatory expectations identified in Step 4 of GDA, and also to provide a strategy for reducing the overall risk imposed by the use of a non-metric design, codes, standards, units and SSCs in Great Britain (GB).
48. Therefore I have also assessed the overall strategy to determine whether Westinghouse provides information for a licensee to take all reasonable measures to reduce risk so far as is reasonably practicable (SFAIRP).

2.2.1 Safety Assessment Principles

49. There are no specific SAPs that apply to the use of metric units. However, there are principles that I judge to influence the metrication of designs.
50. The key SAPs used in my assessment are included within Table 1.

Table 1: Key SAPs used in my assessment of GI-AP1000-ME-02

SAP reference	Title
MS.4	Leadership and management for safety: Learning
ECS.3	Safety classification and standards: Codes and standards
EMT.5	Maintenance, inspection and testing: Procedures
EAD.5	Ageing and degradation: Obsolescence
ECE.18	Civil engineering: Inspection during construction
ECE.19	Civil engineering: Non-conformities
EHF.1	Human factors: Integration within design, assessment and management
EHF.3	Human factors: Identification of actions impacting safety
EHF.4	Human factors: Identification of administrative controls
EHF.5	Human factors: Task analysis
EHF.9	Human factors: Procedures
RP.7	Radiation protection: Hierarchy of control measures

2.2.2 Technical Assessment Guides

51. The TAGs I used in my assessment are set out in Table 2.

Table 2: Key TAGs used in my assessment of GI-AP1000-ME-02

TAG number and revision	Title
NS-TAST-GD-005 Rev 7	Guidance on the demonstration of ALARP (As Low As Reasonably Practicable)
NS-TAST-GD-009 Rev 3	Examination, Inspection, Maintenance and Testing of Items Important to Safety
NS-TAST-GD-057 Rev 3	Design Safety Assurance

2.2.3 National and International Standards and Guidance

52. The national and international standards and guidance used in my assessment are set out in Table 3.

Table 3: National and international standards and guidance used in my assessment of GI-AP1000-ME-02

Standard Reference	Title
Council Directive 80/181/EEC	Council Directive of 20 December 1979 on the Approximation of the Laws of the Member States relating to Units of Measurement and on the Repeal of Directive 71/354/EEC
SI 1995 No. 1804	Weights and Measures The Units of Measurement Regulations 1995
Department for Trade and Industry (now the Department for Business, Energy & Industrial Strategy (BEIS)) Guidance issued in 1995	Guidance Note on the use of Metric Units of Measurement by the Public Sector

53. Table 3 shows legislation, guidance and RGP requirements for the use and notation of metric units in Europe. While the Units of Measurement Regulations 1995 (Ref. 9) primarily concerns produce, liquids and measurement instruments sold in the EU, it is a useful basis for consistent use of measurement units.

54. The 1995 Guidance Note on the use of Metric Units of Measurement by the Public Sector (Ref. 10) provides guidance on the consistent use of units, primarily for public bodies. The guidance states that the preferred notation for mixed (US and metric) units is for the metric unit to be noted first and the US unit to be placed in parentheses.

55. I assessed the submission and sampled supporting references with this guidance in mind, together with the RGP produced by ONR in Step 4 of GDA (Ref. 8).

2.3 Use of Technical Support Contractors

56. I have not used Technical Support Contractors in my assessment of this GDA issue.

2.4 Integration with Other Assessment Topics

57. The resolution of this GDA issue itself has no direct link to the resolution of other GDA issues.

58. There were, however, a number of interfaces with other specialisms that have been included in engagements and assessment of the Westinghouse submissions.

- 59. Assessments by other topic areas are recorded in either Assessment Notes or Assessment Reports. My assessment report presents the relevant judgements along with any clarifying text needed.
- 60. These are referenced later in my assessment report.

2.5 Out-of-scope Items

- 61. Table 4 sets out the items outside the scope of my GDA assessment.

Table 4: Out-of-scope items for GDA Issue GI-AP1000-ME-02

Item	Comments
Assessment Findings	Assessment findings from ONR's assessment of the AP1000 design are not addressed through this assessment report. Any reference to existing findings is only to link those with licensee -specific requirements to be undertaken during site licensing and construction.
Licensee specific activities or input	Activities or input required by a future licensee are not assessed in the closure of this GDA issue as they are not deemed 'generic' to the AP1000 design.

3 REQUESTING PARTY'S SAFETY CASE

62. The strategy for metrication of the **AP1000** design for construction and operation is detailed in the following submission:
- APP-GW-G1-011: **AP1000** Plant Metrication Strategy and ALARP Assessment for the United Kingdom
63. Westinghouse's submission (Ref. 3) details its position on how the strategy is ALARP concerning the five principles identified by ONR at Step 4 (Ref. 8).
64. It also provides information on a process allowing the substitution of SSCs from US codes, standards and units to metric (or vice versa). This process for substitution involves procedures such as the Engineering and Design Coordination Report (E&DCR) and Design Change Proposal (DCP). The latter has already been assessed during Step 4 (Ref. 11).
65. Westinghouse identifies a number of processes undertaken during design and manufacture of components. It claims that these ensure that the risks of generating errors are identified and mitigated.
66. A number of expectations are placed on future licensees to adopt adequate control measures. These are claimed to ensure that risks imposed by the metrication strategy are further reduced during construction and operational activities.
67. Westinghouse also claims that its processes are implemented on its US and China projects, which involve the use of metric and non-metric SSCs.
68. Westinghouse provides the results of ALARP assessments for each of the proposed exceptions to the metrication strategy in Appendix A to its submission.
69. These exceptions cover, but are not limited to:
- buildings and interfaces;
 - bulk commodities and connections;
 - engineered components and connections; and
 - load-handling and fuel-handling systems.

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

70. My assessment is carried out in accordance with ONR guide NS-PER-GD-014, Purpose and Scope of Permissioning (Ref. 12).

4.1 Scope of Assessment Undertaken

71. ONR's expectation concerning metrication is identified in the correspondence issued to Westinghouse (Refs 7 and 8).

72. My assessment of GI-AP1000-ME-02 is based on Westinghouse's main submission, APP-GW-G1-011 (Ref. 3), which aims to justify that it meets ONR's expectation for metrication and show that risks are reduced SFAIRP.

73. During my assessment, I sampled the following process-related documents that I considered key to the assumptions made in the main submission.

74. These were:

- APP-GW-GAP-061: Westinghouse Level 3 Procedure, **AP1000** Plant Documentation Control

This is key to the assumption that units of measurement are consistently presented. Consequently, I have also sampled design and safety case documentation to determine if procedures are adequately implemented.

- UKP-GW-GL-045: **AP1000** Plant Equivalency/Maturity Study of US Codes and Standards

This is key to the assumption that codes and standards are adequately assessed for equivalency and compatibility, allowing changes from non-metric US standards to metric standards to be made.

- DCP_DCP_008333: Expert Panel Risk Review of UK **AP1000** Plant Metrication Strategy

This is key to the assumption that all reasonably foreseeable risks have been identified and assessed.

75. These documents are Refs 13, 14 and 15 respectively.

4.2 Assessment

76. I assessed a number of iterations of Westinghouse's metrication report. Each version was a formal submission (APP-GW-G1-011 Revision 5 and Revision 6) with guidance and advice provided to Westinghouse in RQ and verbal format in Level 4 meetings. Westinghouse submitted APP-GW-G1-011 Revision 7 (Ref. 3) in November 2016. My assessment is based on this revised report.

77. Sections 4.2.1 to 4.2.8 describe my assessment and judgement of Westinghouse's submission and a sample of evidential documents. My assessment covers the following areas:

- i. whether the overall metrication strategy presents an ALARP position concerning metrication risk (Section 4.2.1)

- ii. compliance with ONR's metric expectations (Section 4.2.2)
 - iii. compliance with quasi-metric expectations (Section 4.2.3)
 - iv. appropriate and adequately justified exceptions (Section 4.2.4)
 - v. compliance with expectations concerning design and safety case documentation (Section 4.2.5)
 - vi. compliance with expectations concerning information displayed on the site (Section 4.2.6)
78. In Section 4.2.7, I also assessed:
- vii. whether the human factors risks have been adequately assessed and whether there are mitigating measures to remove or reduce these risks SFAIRP.
79. Each of the sections describe my key mechanical engineering assessment considerations and judgement, which includes:
- the judgement of a civil engineering, C&I, or human factors specialist inspector on the adequacy of Westinghouse's response to close the expectation related to the GDA issue, where relevant; and
 - any minor shortfalls and Assessment Findings resulting from my engagement, if applicable.
80. My judgement regarding Westinghouse's resolution of GDA Issue GI-AP1000-ME-02 is presented in Section 4.2.8.

4.2.1 The Overall AP1000 Metrication Strategy

81. ONR's advice and guidance to Westinghouse on the overall strategy was:
- "...it is the expectation that the design submitted by the Requesting Party is essentially metric, using metric Structures, Systems and Components. ONR has provided advice to clarify the detail of its expectations, and to allow variation from this expectation for a limited, controlled, and justified sub-set of equipment..."*
- "Provide an updated response to document titled 'AP1000 Standard Plant Metrication, APP-GW-G1-011', to reflect the guidance provided by ONR."*
82. Since the end of GDA Step 4, Westinghouse has further developed its design and maintained its own project strategy for metrication, which includes the use of US codes and standards and the use of dual units. Westinghouse has also since claimed (Ref. 3) that it uses metric SSCs in US **AP1000** projects. As such, a number of the concerns originally raised by ONR during GDA are realised in Westinghouse's US projects and so they are not specific to the UK **AP1000** project.
83. Westinghouse claims that it has a number of procedures in place that adequately deal with the risks of mixing metric and non-metric SSCs.
84. Westinghouse's metrication report (Ref. 3) presents its approach to using non-metric and metric SSCs. A number of internal processes aim to ensure that changes requested by a licensee or a supplier / manufacturer of SSCs can be assessed to see whether the proposed codes or standards are equivalent to the original design codes and/or standards. This ensures that the design intent is maintained.

85. Westinghouse's report intends to address ONR's expectations. It identifies gaps in meeting the expectations, and provides mitigating factors for why this presents an ALARP approach. I have assessed compliance with each of ONR's expectation in Sections 4.2.2 to 4.2.6.
86. Westinghouse's report also assesses risks imposed by metrication of SSCs throughout the plant lifecycle and identifies mitigating procedures that are currently in place at Westinghouse that a licensee may wish to adopt to reduce risk. It is my expectation that licensees would adopt or develop similar processes considering any lessons learnt. However, how to manage risks remains the licensee's choice.
87. Without identifying risk reduction methods and knowing where risks remain in the generic Westinghouse strategy, a future licensee cannot make informed decisions about the detailed design and selection of structures, systems and components.
88. I judge that the metrication report provides evidence of the impact of metrication on processes in place for other **AP1000** projects. I also judge that an adequate assessment of metrication risks has been undertaken, providing a basis for mitigating metrication risk during the lifetime of the **AP1000** plant. Westinghouse also provides information on risks in future phases of the **AP1000** plant lifecycle, which will allow a licensee to consider these in its detailed design and future arrangements.

Scope of Metrication in the AP1000 design

89. Westinghouse claimed that the scope of non-metric components might be somewhat limited but that this will depend on a licensee's choices concerning quasi-metric SSCs (see Section 4.2.3 for my assessment). This was not clear in a previously assessed version of the metrication report.
90. Section 2.9 of Westinghouse's revised metrication report (Ref. 3) presents the scope of metric and non-metric SSCs within the GDA **AP1000** design.
91. This presents a design where:
 - a. the seismically qualified nuclear island SSCs identified as either quasi-metric (which ONR expect to be supplied to metric codes and standards so far as is reasonably practicable) or an exception to metrication;
 - b. the non-seismically qualified SSCs identified as metric or quasi-metric, with the same expectation as above; and
 - c. a small number of exceptions located outside the seismically qualified structures (which Westinghouse has defined as the NSSS).
92. It is not possible to determine an accurate proportion of metric to non-metric SSCs, as Westinghouse has claimed that this will depend on detailed design and a licensee's arrangements for the SSCs specified using its form, fit and function process.
93. I judge that it is reasonable to assume that a greater proportion of these will be metric given the largely metric industry and markets available to a licensee.
94. The full extent of metric versus non-metric SSCs is unknown at this stage of the design, as a licensee's choices will have a significant impact on this.
95. Based on the information provided in the metrication report, I judge that there are limited exceptions to metrication outside of the NSSS and a strategy providing future licensees with options for its choice of SSCs and processes.

Use of expert panel to inform risk assessment

96. Following a series of Level 4 engagements involving mechanical, civil, probabilistic safety assessment (PSA) and human factors inspectors, Westinghouse undertook a risk assessment focussing on reasonably foreseeable risks associated with implementing its metrication strategy (Ref. 15). This was then used to inform the mitigation strategies proposed in the metrication report.
97. With the aim of adequately conducting this assessment, Westinghouse put together an “expert panel” to assess the relevant metrication risks. I discuss the expert panel itself further within Ref. 16.
98. I judge that the process undertaken by the expert panel is in line with my expectations for assessing risk and identifying mitigation measures or providing adequate information for future designers to control and manage those risks SFAIRP.
99. An ONR PSA specialist inspector assessed the PSA elements of the metrication report (Ref. 3 Section 3.2.1). The result of this assessment is presented in Ref. 17.
100. The conclusion of the assessment is that:
- the list of equipment is not unreasonable for a mechanical equipment sensitivity study;
 - the range of numerical values chosen for the sensitivity study is reasonably broad and will give a good indication of overall sensitivity;
 - the sensitivity study assumes that all equipment is subject to metrication uncertainty or error at the same time, which is judged to be a conservative assumption; and
 - the sensitivity study undertaken by Westinghouse is considered to provide an indicative assessment of human error probabilities that may be introduced by metrication.
101. The PSA assessment thus concludes that Westinghouse’s study is adequate and presents a reasonable set of assumptions used to inform the risk assessment.
102. Westinghouse’s risk assessment concludes that the metrication approach does not significantly increase the risk of core damage.

Mitigation strategies to reduce risk

103. Westinghouse’s submission (Ref. 3) also presents a number of mitigation strategies to manage and control risk during the post-GDA phases. These were also discussed during the expert panel review identified above. Details of my assessment of these are presented within Ref. 16.
104. I judge this to be sufficient for GDA as it identifies reasonably foreseeable risks, the processes that Westinghouse currently uses to manage risks, and the further controls that a licensee may wish to consider in its management and control of metrication risk.
105. Westinghouse also details incidences where its current procedures have identified errors related to metrication during phases of the **AP1000** plant lifecycle.
106. Due to legislation mandating the need for continuous risk assessment as projects and risks evolve (see Ref. 16), it is my expectation that a licensee should review Westinghouse’s arrangements and proposed mitigation strategies to inform and develop its own processes to mitigate metrication risks.

107. I expect this to be undertaken throughout the plant lifecycle in a licensee's arrangements, in accordance with risk management and relevant legislation. Although I consider this to be normal business in the implementation of a licensee's arrangements, the risks resulting in implementation of a metrication strategy are not necessarily commonplace. I capture this in **Assessment Finding CP-AF-AP1000-ME-08** concerning management and control of metrication risk (see Section 4.2.8).
108. Westinghouse's justification provides confidence that:
- a. arrangements are in place for US and China projects which may be replicated for **AP1000** projects in GB;
 - b. evidence exists that these arrangements can successfully identify and resolve metrication issues; and
 - c. continued learning from experience from Westinghouse's other projects (for example, in US and China construction) might be used to improve the **AP1000** project in GB.
109. 'Substitution' is an important concept in Westinghouse's metrication report. A future licensee may use this to develop a largely metric design using SSCs specified to the form, fit and function concept. My assessment of the arguments and evidence provided by Westinghouse to demonstrate the adequacy of its substitution process is reported in Section 4.2.3.
110. In relation to the overall strategy for metrication, I judge that the ability for a licensee to make an informed assessment of design changes, including substitution, is in accordance with my expectations related to guidance in NS-TAST-GD-057. It is appropriate in that it provides a suitable means to:
- recognise a change;
 - understand the safety impact of the change;
 - provide agreement of the change at the correct authority level;
 - control the implementation and communication of the change; and
 - update documentation where necessary.

4.2.2 Metric Expectation

111. ONR guidance to Westinghouse (Refs 7 and 8) identifies that the regulatory expectation for metrication is:

"ONR requires that plants are designed and will be built and operated using SI (International System) Units and that documents submitted are written in English."

*"For construction of the **AP1000** in the UK, the regulatory expectation is that the design and associated equipment should be fully metric (i.e. conceived, designed, and manufactured as metric)."*

112. Westinghouse claims that it is not reasonably practicable to meet ONR's expectations concerning an all-metric design. It does so on the grounds of gross disproportion when considering the cost of re-design, re-analysis and re-specification of all SSCs in the **AP1000** design from US units to metric units. This statement is based on the design originating in the US and has used US codes, standards and units in its development.

113. Many designers will ordinarily use metric codes, standards and units in design due to SI unit use across the world. This is not always the case in the US¹¹. My assessment therefore recognises that there may be instances where it would be disproportionate to insist that designs and associated equipment are metric.
114. There may, however, be reasonable steps that a requesting party may take to reduce the scope of non-metric SSCs in a design and/or the risks resulting from the use of non-metric units, codes and standards.
115. Taking these factors into consideration along with the arguments Westinghouse presents within its submission, I judge that it may be considered disproportionate to require entirely metric designs where the design has originated from a country employing non-metric units, codes and standards.
116. I consider that there are reasonably foreseeable risks that may be introduced when using unfamiliar units in the design, construction, operation and decommissioning of a facility in GB. Risks must be adequately assessed and removed or reduced and controlled. This is discussed further in Section 4.2.3.
117. Westinghouse splits the design units, codes and standards (metric / non-metric) into two areas:
- nuclear seismic structures: these structures shall be designed in US units, codes and standards; and
 - non-seismic structures: these structures shall be designed in metric units, codes and standards.
118. This approach clarifies the structural elements of the design that are to be metric.
119. Westinghouse claims that its structures will include a mixture of metric, quasi-metric (see Section 4.2.3) and non-metric unit SSCs, or exceptions (see Section 4.2.4).
120. Westinghouse's arrangements enable a future licensee to ensure that SSCs it designates as quasi-metric are manufactured in metric units, codes and standards (see Section 4.2.3). This allows for a significant proportion of SSCs in the **AP1000** plant, excluding exceptions, to be designed and built to metric codes and standards.
121. Westinghouse has also provided evidence that it has a process to allow suppliers and constructors to propose substitutions during design and construction (see Section 4.2.3).
122. Consequently, I judge that, although Westinghouse does not meet the regulatory expectation for a metric design, it has demonstrated that there are adequate arrangements in the requesting party's organisation to enable a future licensee to make a risk-informed judgement upon whether the use of metric or non-metric designed SSCs reduces risk so far as is reasonably practicable (SFAIRP).
123. This judgement is influenced by my assessment of Westinghouse's approach to quasi-metric and the use of substitutions discussed further in Section 4.2.3.

¹¹ *The United States' Omnibus Trade and Competitiveness Act of 1988 made the metric system the "preferred system of weights and measures for United States trade and commerce" however, conversion in the private sector is on a voluntary basis only.*

4.2.3 Quasi-metric Expectation

124. ONR guidance to Westinghouse (Ref. 8) identifies the regulatory expectation for quasi-metric as:

“...an alternative [to metric], ‘quasi metric’ (i.e. initially conceived as imperial, but now designated and designed as metric using metric codes / standards, and fully dimensioned as metric). All fastenings shall be metric.”

125. For those SSCs that are not justified as exceptions, I consider that, where the original **AP1000** design used non-metric codes and standards, an assessment to demonstrate equivalency and/or compatibility is a reasonable requirement to ensure that no detriment to safety occurs as a result of the quasi-metric approach.
126. The availability of International Organization for Standardization (ISO) standards throughout the world and their aim to improve the flow of goods internationally is an enabler for providing compatibility. However, there are still historical differences between some codes and standards that may need additional work by a licensee to overcome, such as additional quality assurance requirements.
127. RGP from other new-build projects implies that this is a reasonably practicable approach and one that is in line with ONR SAP ECS.3.
128. I also consider that it may not be reasonably practicable that all fastenings are metric. Non-metric piping and associated commodities such as flanges, supports and valves, may not be adequately designed to accommodate metric fastenings. However, these should be exceptions to metrication (see Section 4.2.4).
129. I have assessed Westinghouse’s arguments concerning compliance with the quasi-metric expectation in Ref. 3. Westinghouse states that it does not meet the regulatory expectation on grounds of reasonable practicability.
130. While its submission does not meet ONR’s expectation concerning quasi-metric (that is, SSCs originally designed to non-metric codes and standards are now designated and designed to metric codes and standards), Westinghouse states that it has developed a strategy that will allow this to happen, based on design choices in site licensing and construction. My assessment focusses on this argument.
131. Westinghouse’s metrication report provides examples of this strategy and I have also discussed this with Westinghouse at our Level 4 engagements.
132. Using its ‘form, fit and function’ method in design specifications, a licensee may obtain metric components for the **AP1000** design. Equally, an SSC that is originally designed to US codes and standards, can be substituted for one designed to metric codes and standards, provided there is a thorough assessment of the impact of this on the **AP1000** design.
133. To provide a reasonable basis for assessment, Westinghouse studied US and UK codes and standards to determine whether there is equivalency between the two systems. This was assessed at Step 4 (Ref. 18) and resulted in Assessment Finding AF-AP1000-ME-09.
134. I judge that this is a reasonable step to take in assessing the adequacy of substituting an SSC originally designed to US codes and standards, with one designed to metric codes and standards.

Substitution of Structures, Systems and Components

135. In its metrication report (Ref. 3), Westinghouse points out that it allows for the substitution of items such as materials and components in its current projects, using a process of review and assessment of proposals from designers, constructors, manufacturers and operators (licensees).
136. It indicates that this may also be done where a licensee, manufacturer or constructor wishes to substitute a non-metric SSC with a metric SSC.
137. Westinghouse presented these processes to ONR, during Level 4 (technical) engagements.
138. In many cases this followed the Westinghouse DCP process, assessed as adequate by ONR at Step 4 in Ref. 11. One other example is an E&DCR.
139. Once received, a request is reviewed, categorised and undergoes a detailed technical and safety case assessment to fully understand the impact on the **AP1000** design, the nuclear safety implications and commercial implications. I understand that this assessment also considers any changes to design codes or standards and their impact, equivalency and compatibility.
140. Westinghouse claims that these requests and approved changes are tracked to determine if they are applicable to future plants. The process provides me with confidence that learning and applicability to future projects is recorded and acted on where relevant (ONR SAP MS.4).
141. Based on the Level 4 engagements held with Westinghouse and the substitution examples provided to me, my judgement of the substitution process is that it allows an informed decision in areas of nuclear and conventional safety, and the consequent impacts on design, human performance and environmental considerations amongst others.
142. Substitution is likely to occur during manufacture, construction and possibly operation. It may also happen during design at the request of a licensee.
143. This is not an activity that I would expect to occur during GDA and so an assessment of a licensee's arrangements is outside the scope of GDA.
144. However, Westinghouse has provided evidence that it has procedures in place that have been used on US and China projects. I expect these to be used in a similar manner by a licensee on **AP1000** projects in GB.
145. I judge that Westinghouse applies appropriate assessment of proposed substitutions during design, construction and operation of the **AP1000** plant and that it is a reasonable assumption that a future licensee may adopt and develop these for a project in GB.

Equivalency Study for US and UK Codes and Standards

146. The equivalency study (Ref. 14) was undertaken in 2011 during Step 4. The ONR Step 4 report (Ref. 18) raised an AF stating:

*"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 EIMT [Examination, Inspection, Maintenance and Testing] activities. The licensee should also ensure that*

the AP1000 codes and standards meet applicable UK Health and Safety legislation, including regulations and ACOPs (as appropriate)."

147. This finding was raised in 2011 prior to the break in the **AP1000** reactor GDA. As codes, standards and other RGP adapts, I expect the equivalency study to evolve.
148. My expectations for codes and standards are primarily driven by ONR SAP ECS.3 but also informed by NS-TAST-GD-057 (see Ref. 6). Namely:
- "A range of standards exists for nuclear design application, including IAEA [International Atomic Energy Agency] standards, International, European and British standards as well as in house developed standards, (some with accepted general application with the UK nuclear industry). It is important that the design organisations have an up to date knowledge of the range of available standards, and are able to demonstrate a mature selection process for the specific design application. Selected standards must be effectively communicated within the design organisation, with training requirements identified and implemented as necessary. Changes to standards must also be effectively assessed, communicated and implemented, (although a design standards freeze may also be put in place).*
- "The SAPs ECS series (Safety classification and standards) and WENRA [Western European Nuclear Regulators' Association] reference level C (Quality Management) are applicable to Design Standards."*
149. In my assessment of its strategy, I sampled a small number of mechanical codes and standards that appeared in Westinghouse's equivalency study (Ref. 14). The details of this assessment are presented within Ref. 16.
150. I advised Westinghouse during our Level 4 engagements that I do not believe that the equivalency study considers sufficient detail on relevant design standards and good practice within GB. I have concluded that industry standards exist, but do not appear to have been compared in Westinghouse's study.
151. Considering the apparent gaps in its assessment found in the small sample of materials I assessed, I judge that Westinghouse's equivalency study does not yet present an adequately detailed assessment of equivalence between non-metric and metric – including European Norme (EN), ISO and International Electrotechnical Commission (IEC) standards. I also expect Westinghouse to consider further assessment of RGP within the GB nuclear industry, in accordance with the RGP found in NS-TAST-GD-057 as indicated above.
152. I would expect an assessment of compliance with European standards concerning European Conformity (CE) marking. These standards are directly linked to European Union Directive and Regulatory requirements. I understand that this will be dealt with in the scope of Assessment Finding AF-AP1000-ME-09 raised during Step 4.
153. I also judge that where the GB nuclear industry collectively develops good practice guidance and standards – especially where licensees adopting these have demonstrated improvements in safety – these may be considered to be RGP.
154. Based on the guidance in ONR SAP ECS.3 concerning compatibility of standards, the current study performed by Westinghouse does not meet my regulatory expectation in this area. Considering the guidance in NS-TAST-GD-057 concerning the evolution of standards throughout the design process and assessment of impact, I also judge that the Westinghouse study is not adequate for detailed design and site licencing.
155. A licensee cannot adequately use the study to determine the validity of a proposed metric, equivalent standard, if the study does not compare all relevant metric standards

with the non-metric standards. A licensee with an adequate Intelligent Customer capability, discussed within NS-TAST-GD-049 (see Ref. 6), and experience of the GB nuclear industry may be better placed to undertake this additional work. I therefore judge that, to some extent, the resolution of this matter requires licensee choices on organisational matters in particular a competent design authority, which is outside the scope of GDA.

156. While the Step 4 Assessment Finding covers the adequacy of the results of the review of codes and standards equivalency, it does not appear to cover the adequacy of the study itself – that is, the level to which standards are compared and which standards have been reviewed.
157. Consequently I raised an additional **Assessment Finding** related to AF-AP1000-ME-09.

Assessment Finding CP-AF-AP1000-ME-07

The licensee shall demonstrate that the codes, standards and relevant good practice are equivalent and compatible where metric and non-metric codes, standards and relevant good practice exist.

158. The licensee should ensure that the equivalency study is sufficient to provide an adequate basis for demonstrating equivalency and compatibility of SSCs and compliance with legal requirements, where relevant. I do not believe that the Step 4 Assessment Finding covers this. Therefore, I expect CP-AF-AP1000-ME-07 to be combined with AF-AP1000-ME-09 for resolution.
159. Westinghouse stated that, for GDA, the SSCs in the nuclear seismic structures are quasi-metric, apart from the justified exceptions (see Section 4.2.4). Westinghouse's processes allow these SSCs to be designated and designed to metric codes and standards using metric units. Alternatively, specifying form, fit and function, SSCs can be procured to metric codes and standards. I judge that this is reasonable from a mechanical engineering perspective.
160. Westinghouse identifies that, for the non-seismically qualified structures, the majority of SSCs are identified as, or are expected to be, metric (currently identified as metric or quasi-metric within Ref. 3). The main exception to this is a proportion of bulk commodities eg piping, valves, flanges and flange fasteners, which Westinghouse identifies as an exception. This is discussed further in Section 4.2.4. From a mechanical engineering perspective, I judge this to be a reasonable approach.
161. There are a number of human factors involved when a mixture of SSCs is designed to metric and non-metric codes and standards. ONR's civil engineering, human factors specialists and I judged that this presents a reasonably foreseeable risk with respect to design, construction and operation.
162. Westinghouse says it has processes in place for China and US **AP1000** projects. It provided evidence in the metrication report that these processes have identified matters concerning the management and control of risk regarding use of metric / non-metric units.
163. Westinghouse makes a commitment to develop similar procedures with a future licensee, taking learning from its existing projects and improving the adequacy of the procedures as necessary. This is in line with regulatory guidance concerning the use of operating experience and learning (ONR SAP MS.4).

164. While the development of such arrangements is normal business for a licensee, specific metrication risks are less usual and I expect these to be specifically addressed.
165. To ensure that this is taken forward during site licensing and construction, I identify this in **Assessment Finding CP-AF-AP1000-ME-08** concerning **AP1000** design configuration management and control of risk associated with metrication for facilities in GB (see Section 4.2.8).
166. Where Westinghouse states that SSCs are to be quasi-metric, the regulatory expectation is that these are, as a minimum, procured to metric codes and standards using the equivalency study as a basis for this.
167. SSCs that are not metric (or cannot be procured to metric codes and standards) will require appropriate justification by the licensee. The regulator will only accept further exceptions where non-metric SSCs are justified to reduce risk so far as is reasonably practicable. For example, through demonstrating that there is no equivalent and compatible alternative to a non-metric SSC, a justification may be made.
168. I judge this to be an acceptable position for a design that was originally to US (non-metric) codes and standards.

4.2.4 Appropriateness and Justification of Exceptions

169. The GDA Issue GI-AP1000-ME-02 presents ONR's judgement on Westinghouse's metrication report (Ref. 3) in the areas of civil engineering and mechanical engineering SSCs and identifies what is needed to resolve the issues. My assessment is focussed on the adequacy of exceptions in these two areas.
170. ONR guidance to Westinghouse (Ref. 8) identifies the regulatory expectation as:
"However, exceptionally, the regulator may accept non-metric products (including fastenings) for one-off fabrications of a specialist nature associated with the NSSS, or other specialist NSSS equipment, but these will need to be justified to the regulator on a case by case basis."
171. I accept that it may not be reasonably practicable to restrict exceptions to the NSSS alone. There are a number of SSCs that extend beyond the NSSS and, as such, the scope of exceptions may need to 'expand'. However, these should be equally justified to the regulator.
172. It is prudent for a licensee to manage the extent of these types of exceptions.

MECHANICAL ENGINEERING

173. The GDA Issue Action 1 required Westinghouse to:
"...reflect the guidance provided by ONR. Westinghouse should commit to re-designing equipment in line with the guidance, or provide a more rigorous justification (which aligns with the guidance provided) as to why they consider equipment should be an exception to metrication."
174. The guidance provided by ONR during Step 4 consisted of the clarification provided in Ref. 8 and discussions held on NS-TAST-GD-005 Guidance on the Demonstration of ALARP.

175. In my engagements with Westinghouse during GDA closure I reiterated the guidance in NS-TAST-GD-005, in particular its Annex 2 where Westinghouse undertook ALARP assessments for proposed exceptions.
176. From a mechanical engineering perspective, I sampled the following exceptions identified in Appendix A of the Westinghouse submission (Ref. 3):
- NSSS engineered fasteners and lift attachments;
 - load-handling systems associated with nuclear lifts – structures and fasteners; and
 - ASME piping, flanges, valves, associated fasteners and supports.
177. I selected these exceptions as they represent some deviation from ONR’s definition of an ‘exception’ provided to Westinghouse (Ref. 8) and because they were identified by ONR in the Step 4 assessment report (Ref.18) as not meeting regulatory expectations.
178. The items I selected all include the use of non-metric fasteners. The advice provided by ONR at Step 4 identified that there is a requirement that all fasteners shall be metric.
179. Of note is the use of piping and flanges designed and manufactured to US codes and standards – for example American National Standards Institute (ANSI) and ASME. These standards specify the use of non-metric (US) fasteners to ensure correct mating, sealing and integrity of the joint.
180. British standard BS EN 1759-1 (2004) identifies metric equivalents to non-metric flanges and joints (Ref. 19). This provides flange and fastening details for class-designated flanges with piping sizes in nominal pipe size (NPS) and nominal diameter / diamètre nominale (DN) designations.
181. In its Annex C (metric bolting in lieu of imperial bolting) the following statement is made:
- “Whilst not recommended, if users prefer or require to use metric bolting in lieu of the imperial bolting given in Tables 9 to 14, [section] C.3 gives the comparable metric bolt sizes that have been agreed in the preparation of ISO 7005.*
- “Users should note that the centring of an inside bolt circle gasket in an assembled flange joint will be affected when using metric bolting. In bolt sizes up to and including 1½, the metric comparable sizes tend to be larger in diameter, whilst above this size they tend to be smaller. It is essential therefore that great care be taken to ensure that gaskets are centred properly.*
- “However, dependant on the tolerances, which have been used it should be possible to fit the normal imperial dimensioned gasket when using metric bolting in existing imperial holes.”*
182. This indicates difficulties in the use of metric fasteners with non-metric flanges and gaskets.
183. From a nuclear safety perspective, it may be disproportionate to impose such use. Instead, I assessed Westinghouse’s demonstration that an adequate solution may be adopted for the **AP1000** design in GB.
184. In each exception case, my expectation was that the ALARP assessment considers the key points raised in ONR TAG NS-TAST-GD-005:
- relevant good practice

- options
- risk assessment
- conclusion that no further reasonably practicable improvements can be implemented and thus the exception is ALARP

Exception 6: NSSS engineered fasteners and lift attachments

185. Westinghouse's exception is for:
- engineered fasteners using US sizes for eight NSSS components; and
 - construction and installation lifting attachments along with the shipping skids for the eight identified NSSS components using a US design.
186. The eight NSSS components were accepted by ONR as appropriate exceptions to metrication during Step 4.
187. During Step 4, ONR indicated to Westinghouse that where fasteners are expected to be removed during operation, including EIMT, these shall be metric unless justified as an exception (see Exception 9 below).
188. Westinghouse's arguments considered two key risks:
- standardisation of the **AP1000** design; and
 - cost.
189. Westinghouse argues that the loss of standardisation throughout the **AP1000** fleet will be a detriment to its approach to lessons learnt. I recognise the importance of standardisation in this respect.
190. Westinghouse also argues that the cost of redesign (estimated to be £80 million or \$100 million) would be grossly disproportionate to any perceived safety benefit. Although Westinghouse does not quantify a safety benefit in monetary terms, its argument concentrates on standardisation and redesign.
191. It is reasonable to suggest that the engineered fasteners for the eight identified SSCs are not removed and replaced at a high frequency. I also judge it reasonable to suggest that specialist tooling will be used for a number of those fasteners, common to **AP1000** plants.
192. I therefore judge that the engineered fasteners for the eight listed NSSS components are a reasonable exception to metrication.
193. The lifting attachments used for delivery to site and installation during construction are, in my view, appropriately considered as one-off use components. While their use is limited, the future licensee will need to ensure that they are easily identifiable and that the interface with lifting equipment on the **AP1000** plant is appropriately managed.
194. I judge that construction and installation lifting attachments, along with the shipping skids for the NSSS components listed above, is a reasonable exception to metrication.
195. I also consider it prudent to include lifting interfaces in **Assessment Finding CP-AF-AP1000-ME-08** concerning **AP1000** design configuration management and control of risk associated with metrication for facilities in GB (see Section 4.2.8).

Exception 8: Load handling systems associated with nuclear lifts – structures and fasteners

196. Westinghouse proposes exceptions to metrication for:
- structural elements and non-typically used fasteners for heavy and light load-handling systems associated with nuclear lifts.
197. Exceptions are identified in Tables 4-4 and 4-5 in Section 4.1.3.1 of Westinghouse's metrication report (Ref. 3). The non-metric elements are those related to structural steelwork and their associated engineered fasteners to the civil structure.
198. This was assessed as acceptable by a civil engineering specialist inspector and is discussed further below in Exception 1: Structural shapes and engineered connections for seismic structures.
199. Providing that a licensee puts equivalent arrangements in place to manage these interfaces during the lifetime of the **AP1000** plant, I judge that the structural elements interfacing with the civil structures and their associated fasteners are a reasonable exception to metrication.
200. It is important that licensees identify all non-metric items in order to address the risk of misidentification or misuse of such items. This is discussed further in the assessment of human factors in Section 4.2.7 and Ref. 16.

Exception 9: ASME piping, flanges, valves, associated fasteners and supports

201. The proposed exception to metrication across the **AP1000** plant is for all piping, flanges, valves and pipe flange fastenings. In addition, supports and associated fastenings within the seismic structures will be an exception to metrication.
202. Details of my assessment are in Ref. 16. The main conclusions are identified below.
203. There are many instances in the UK construction industry where metric codes and standards are used. Also current new-build reactor facilities in the UK are using metric codes and standards. However, Westinghouse presents what I judge to be a reasonable argument for the use of non-metric codes and standards across the **AP1000** plant for this exception. This is based upon:
- Westinghouse's argument that risk is reduced by the use of a single code or standard for the piping, flanges, valves and associated fasteners and supports;
 - Westinghouse's argument that the cost of re-design of all piping, flanges, valves and associated fasteners and supports may be grossly disproportionate;
 - relevant good practice in the UK is not conclusive about the preference to use metric standards only for piping, flanges, valves and associated fasteners and supports; and
 - the use of multiple codes and standards for single systems does not align with guidance in ONR SAP ECS.3.
204. I therefore judge that ASME piping, flanges, valves, associated fasteners and supports are a reasonable exception to metrication.

Exception 3: Explosively actuated (squib) valves

205. In the Step 4 assessment report (Ref. 18), ONR judged that the flange fastenings should be metric, in line with ONR's opinion that the piping in the **AP1000** plant should be metric.
206. In light of Westinghouse's arguments for maintaining the piping, flanges, valves, associated fasteners and supports to non-metric codes and standards, I judge that it is adequately justified to also maintain the fasteners for these valves to non-metric codes and standards.

CIVIL ENGINEERING

207. The GDA Issue Action 2 requested Westinghouse:

"...to explicitly list the exclusions from metrication for Civil Steelwork SSCs. This should include Westinghouse's intention for all the component parts of structural steelwork connections.

"It is accepted that the generic design for permanent civil steel structures is based on imperial sections (and materials). However, the exceptions listed in Table A-1 of APP-GW-G1-011 Rev 3 do not clearly define what approach will be used for the design of the detailed connections which will be carried out by local suppliers.

"The widescale use of imperial bolting / fastenings is not acceptable. Although strict quality control during construction can be adopted, there is an increased risk of last minute substitutions with locally supplied, metric bolts.

"APP-GW-G1-011 Rev 3 does not confirm whether the supplier's design will be quasi metric and or in imperial. The update of this document should clarify Westinghouse's intentions on this, and discuss the effects if the other approach is used."

208. Westinghouse provides arguments and evidence for an ALARP assessment of the use of non-metric structural steelwork and associated connections in Appendix A to the metrication report (Ref. 3).
209. A civil engineering specialist inspector's assessment of Westinghouse's resolution is summarised below.

Exception 1: Structural shapes and engineered connections for seismic structures

210. The civil engineering assessment of Westinghouse's ALARP justification for this exception is provided in Ref. 20.
211. The civil engineering judgement made for this exception is that Westinghouse has constructed a reasonable ALARP assessment in its submission (Ref. 3) which results in an acceptable argument for not using metric codes and standards for the seismic civil engineering structures. **AP1000** plant constructors should be able to take reasonable steps to manage and mitigate the risk of incorrect material substitution during the construction phase.
212. In conclusion, I judge that Westinghouse has provided adequate ALARP assessment and justification of the proposed exceptions to metrication.

4.2.5 Design and Safety Case Documentation

213. ONR guidance to Westinghouse (Ref. 8) identifies that the regulatory expectation in this regard is:

“...all design and safety case documentation shall be fully metric from conception, through intermediate results, to final presentation.”

214. The consistent use of dual units is also appropriate for design documentation, given that, historically, analyses and calculations may have been undertaken in non-metric units. I consider that it is reasonable to require this.

215. Westinghouse’s submission claims that it does not comply with the regulatory expectation that all design and safety case documentation shall be fully metric from conception, through intermediate results, to final presentation.

216. A clear identification of an exception for design and safety analyses is provided in Exception 12 of the submission. This is in line with previous discussions held during GDA Step 4.

217. Westinghouse justifies the use of dual units in design documentation, primarily in the results section. While the inner workings of the design and relevant documentation may be presented in non-metric units, I judge that it would be disproportionate to require all of these numbers to be presented in metric or dual units.

218. Westinghouse’s submission states that:

- design analyses use non-metric units (with metric units in parenthesis) for results – or shall use metric units for new site specific design;
- design drawings use non-metric units (with metric units in parenthesis) – or shall use metric units for new site-specific design;
- fabrication and construction drawings shall use metric units;
- as-built drawings to be used by a licensee shall use metric units;
- UK safety case documentation shall use metric units; and
- documentation supporting the UK safety case shall use metric or dual units.

219. I judge that it is adequate for documentation to provide results in dual units or solely in metric units.

Westinghouse documentation procedures

220. Westinghouse identifies that its arrangements are used for its current projects in the US and China.

221. I sampled Westinghouse’s internal procedure for documentation control APP-GW-GAP-061 (Ref. 13), which is pertinent to this GDA issue as it aims to ensure consistency of units in Westinghouse documents. Reading this in conjunction with the metrication submission (Ref. 3) I have determined that there is potential to devise two different numbering systems in the same project, based on the units used in the originating country. In my opinion, this introduces a reasonably foreseeable risk.

222. Further details of my assessment of this are contained in Ref. 16. The key findings and judgements are presented below.

223. For the **AP1000** design, Westinghouse's procedures and strategy do not use a single method to identify dual units. Therefore I judge that risk is not reduced SFAIRP. A licensee should also consider this when developing its arrangements for site licensing, construction and operation.
224. I judge that it is reasonably practicable to consider a single method of stating dual units, in line with the intent of Westinghouse's procedure (Ref. 13).
225. In the sampled documents, I found that Westinghouse presents information in a mixture of metric and non-metric units. Consequently, Westinghouse has not implemented its own strategy or arrangements concerning metrication consistently, as referenced from its safety case submissions.
226. Since I pointed out the above shortfalls to Westinghouse, it has informed me that it has raised an internal corrective action (Ref. 21). Westinghouse has required its technical teams to determine the extent to which this non-compliance exists; rectify any issues identified; and ensure that this is corrected for future documentation. I believe this is an appropriate and proportionate measure to take.
227. While further work will not be concluded in GDA, I do not judge it sufficient to prevent closure of this GDA issue.
228. The licensee's arrangements will need to consider the risk of mixing metric and non-metric units. While Westinghouse has taken reasonable steps to reduce the potential for error in its GDA design and safety case documentation, there is still a risk of this happening. Although this does not impair ONR's ability to understand the risks associated with the generic design, it requires further consideration during site licensing and construction.
229. Therefore, I incorporated this into **Assessment Finding CP-AF-AP1000-ME-08** concerning the configuration of metric / dual units and risk associated with metrication for facilities in GB (see Section 4.2.8).

4.2.6 Information Displayed on the Site

230. ONR's guidance to Westinghouse (Ref. 8) identifies that the regulatory expectation is:
"All information displayed within the constructed facility will need to be fully metric."
231. I consider this a fundamental requirement considering the historical use of metric units in GB in education and industry. It is therefore reasonable to require this.
232. Westinghouse's submission claims that all on-site information is in metric (SI) units. This includes:
- main control room and information displays;
 - **AP1000** plant C&I channels, for example, plant control system and protection and safety monitoring system; and
 - plant operating procedures.
233. An ONR C&I specialist inspector assessed Westinghouse's claim concerning the control room, information displays and the **AP1000** plant C&I channels. This assessment is presented in Ref. 22.

234. The concluding judgement is that Westinghouse's protection and monitoring system Basis of Safety Case document (Ref. 23) identifies that software modules convert units from non-metric to metric units. ONR would expect to see particular emphasis placed on these functions in their development, verification and validation during licensing. This is the basis of an Assessment Finding in the C&I Assessment Report for closure of GDA Issue GI-AP1000-CI-08 (Ref. 24).
235. At this GDA stage, it is not possible to confirm or sample this claim. However, despite the above C&I Assessment Finding, I judge that Westinghouse has met the regulatory expectation in this instance and I expect that this will be progressed as normal regulatory business during site licensing.

4.2.7 Human Factors

236. In addition to the mechanical and civil engineering issues raised at Step 4, a dominating factor in risks resulting from metrication issues are those of human performance. Throughout my engagements with Westinghouse during GDA closure, the influence of human interactions with the plant was discussed and feature in a number of arguments made in the metrication report.
237. I asked a human factors specialist inspector to assess Westinghouse's metrication report. The findings from this assessment are presented in Ref. 25. The concluding judgements are presented below.
238. The human factors specialist judged that metrication does pose an increased risk of human error; however, this risk can be managed.
239. While a number of areas concerning human performance have been identified, where a licensee may make improvements, the specialist inspector judged that the proposed strategy adequately addresses the GDA issue from a human factors perspective.
240. The human factors assessment (Ref. 25) proposes three Assessment Findings. These findings all relate to recommendations for configuration management and control of risk associated with metrication. Therefore, I have combined these into one **Assessment Finding CP-AF-AP1000-ME-08** (see Section 4.2.8).

4.2.8 Judgement

241. I have identified areas where I judge that Westinghouse's arrangements do not fully meet regulatory expectations for metrication with respect to configuration control of metric and/or dual units and the risks associated with metrication. I therefore raise the following **Assessment Finding**:

Assessment Finding CP-AF-AP1000-ME-08

The licensee shall ensure that adequate arrangements are in place to control the configuration of the **AP1000** design and manage risks associated with metrication, throughout the lifetime of the **AP1000** plant.

242. These arrangements should include, but are not limited to:
- consistent application of dual units;

- verifying dual or metric units in design inputs and outputs and safety case reference documentation;
- ensuring that the risk of inadvertent use or mixing of metric units with non-metric units, is reduced so far as is reasonably practicable;
- managing all interfaces between SSCs throughout the lifetime of the **AP1000** plant;
- continually reviewing the operating experience and incorporating relevant lessons learnt;
- a targeted human factors ALARP assessment of safety critical components to identify whether further mitigation measures can be introduced; and
- identifying all non-metric SSCs, and measures on site to allow these to be identified and tracked to reduce the risk of inadvertent substitution during construction, commissioning, operations and decommissioning.

243. Despite the two Assessment Findings (CP-AF-AP1000-ME-07 and CP-AF-AP1000-ME-08) raised in my report, I judge that Westinghouse's metrication strategy provides:

- a. adequate arguments and evidence to demonstrate that it is not reasonably practicable to provide an **AP1000** design entirely to metric codes, standards and units;
- b. adequate arguments and evidence to demonstrate that a quasi-metric approach to design, manufacture and construction of an **AP1000** plant is reasonably practicable and that the extent of metric SSCs will require technical and organisational choices to be made by a licensee;
- c. adequate justification for proposed exceptions to metrication, including where these extend beyond the NSSS;
- d. adequate arguments and evidence to demonstrate that information displayed on site shall be in metric units only;
- e. evidence that Westinghouse's processes have been implemented in other **AP1000** projects;
- f. adequate assessment of the risks that metrication is foreseen to impose on the **AP1000** design;
- g. adequate assessment of further mitigation measures that a licensee may develop during site licensing and construction to reduce risk so far as is reasonably practicable (SFAIRP); and
- h. adequate assurance that risks introduced by metrication during design, construction and operation of the **AP1000** plant may be adequately controlled by a licensee.

4.3 Assessment Findings

244. During my assessment I identified two key items for a future licensee to take forward in their site-specific safety submissions. These are:
- a. **CP-AF-AP1000-ME-07**: the licensee shall demonstrate that the codes, standards and relevant good practice are equivalent and compatible where metric and non-metric codes, standards and relevant good practice exist; and
 - b. **CP-AF-AP1000-ME-08**: the licensee shall ensure that adequate arrangements are in place to control the configuration of the **AP1000** design and manage risks associated with metrication, throughout the lifetime of the **AP1000** plant.
245. These matters do not undermine the generic safety submission and are primarily concerned with the provision of site-specific safety case evidence, which will usually become available as the project progresses through the detailed design, construction and commissioning stages. These items are recorded as Assessment Findings.
246. Residual matters are recorded as Assessment Findings if one or more of the following apply:
- site specific information is required to resolve this matter;
 - the way to resolve this matter depends on licensee design choices;
 - the matter raised is related to operator specific features / aspects / choices;
 - the resolution of this matter requires licensee choices on organisational matters;
 - to resolve this matter the plant needs to be at some stage of construction / commissioning.
247. See Annex 1 for Assessment Findings.

4.4 Minor Shortfalls

248. I have not identified any minor shortfalls during my assessment of GDA Issue GI-AP1000-ME-02.

4.5 ONR Assessment Rating

249. My assessment has rated Westinghouse's submission as adequate. This rating was awarded because Westinghouse's submission demonstrates that:
- relevant good practice is met; and
 - there are some opportunities for a licensee to make further improvements during site licensing, construction and operation (identified in the Assessment Findings).

5 CONCLUSIONS

250. This report presents the findings of the mechanical engineering assessment of GDA Issue GI-AP1000-ME-02 relating to the **AP1000** reactor GDA closure phase.
251. To conclude, I judge that Westinghouse's strategy for metrication of the **AP1000** design for construction in the UK:
- adequately justifies its position regarding ONR's expectations for design, construction and operation of the **AP1000** reactor in metric units;
 - adequately justifies that a quasi-metric approach provides suitable confidence that the **AP1000** reactor should be largely metric with limited non-metric SSCs, in line with regulatory expectation;
 - adequately demonstrates that reasonably foreseeable risks have been reduced SFAIRP; and.
 - identifies mitigation measures that a licensee may adopt during site licensing, construction and operation to ensure risks are reduced SFAIRP.
252. In summary, I am content that GDA Issue GI-AP1000-ME-02: Metrication of Mechanical Equipment and Civil Structural Steelwork Connections can be closed.

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Annex 1
Assessment Findings to be Addressed During the Forward Programme – Metrication

Assessment Finding number	Assessment Finding	Report section reference
CP-AF-AP1000-ME-07	The licensee shall demonstrate that the codes, standards and relevant good practice are equivalent and compatible where metric and non-metric codes, standards and relevant good practice exist.	Section 4.2.3 para 157
CP-AF-AP1000-ME-08	The licensee shall ensure that adequate arrangements are in place to control the configuration of the AP1000 design and manage risks associated with metrication, throughout the lifetime of the AP1000 plant.	Section 2.2.1 para 107 Section 4.2.3 para 165 Section 4.2.4 para 195 Section 4.2.5 para 229 Section 4.2.7 para 240