New Reactors Programme

GDA close-out for the AP1000 reactor

GDA Issue GI-AP1000-FS-02 “Design Reference Point and Adequacy of Design Basis Analysis”

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EXECUTIVE SUMMARY

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

This report is the Office for Nuclear Regulation's (ONR's) assessment of the Westinghouse **AP1000** reactor design in the area of fault studies. Specifically, this report addresses GDA Issue GI-AP1000-FS-2 "Design Reference Point and Adequacy of Design Basis Analysis".

This GDA Issue arose for three main reasons established during GDA Step 4:

- Westinghouse's proposed reference design for the UK **AP1000** plant only started to emerge towards the end of the Step 4, while the bulk of its design basis analysis was much older, predating interactions with the UK regulators by several years. The appropriateness of this old analysis to the emerging reference design was never established.
- Construction of **AP1000** plants in China at the same time as GDA Step 4 accelerated the pace of design changes and updates to analysis methods. New work done by Westinghouse to extend the scope of the UK **AP1000** design basis safety case to be consistent with ONR's expectations used the latest models and design assumptions extant during GDA Step 4, which meant it differed from the bulk of the older design basis analysis.
- With the uncertainty over the design, the use of several generations of analyses, and UK-specific fault sequences being considered for the first time, it was not clear what limits and conditions were being established by the design basis analysis that would inform and / or constrain future reactor core loading patterns.

The GDA Issue has two actions. To address the first action, Westinghouse has:

- clarified the design reference point for the UK **AP1000** plant**,** updating it to include design changes generated up to 2016;
- submitted a report to ONR which proposes two generations of analyses for the UK **AP1000** plant: a 2015 suite of calculations performed for the "standard" list of design basis faults considered internationally, supplemented by a smaller group of 2010 calculations for fault sequences only considered in the UK safety case. The report justifies why these two generations of analyses, when taken together, are appropriate for the declared design reference point; and
- updated the Pre-Construction Safety Report (PCSR) to formally include the two generations of analyses, replacing the majority of the analysis cases considered in GDA Step 4 with new results.

For the second action, Westinghouse has generated a Safety Analysis Checklist (SAC), which captures the key limits and conditions assumed for the reactor core design in the updated PCSR design basis analysis. This checklist is based on the latest "standard" analysis undertaken for overseas **AP1000** projects but it also has UK-specific limits included which reflect the broadened safety case in the PCSR.

My assessment conclusion is that Westinghouse's approach and submissions adequately address the two actions of GI-AP1000-FS-02. This judgement is based on:

- discussions with Westinghouse over many months on its strategy for defining a new design reference point and its internal process for managing changes to the design;

- a review, informed by consultations with specialist fuel design colleagues and a detailed report commissioned from a technical support contractor, of the impact of physical design changes and alterations in analysis methodologies on the design basis analysis results and ONR's GDA Step 4 conclusions;
- a review of the updated fault studies chapters of the PCSR, looking for evidence that Westinghouse's new design basis analysis is adequately captured and that the key features established in ONR guidance for safety cases are provided; and
- a review of the submitted SAC against the requirements established in Action 2 of the GDA Issue.

One Assessment Finding has been raised, which is for a future licensee to consider and take forward in its site-specific safety submissions. This matter does not undermine the generic safety submission and requires licensee input / decision.

- CP-AF-AP1000-FS-02: The licensee shall demonstrate in its design basis safety case that it has analysed all the implications of the design change to increase the feedwater system capacity (EPS-GW-GEE-003) on the UK **AP1000** plant, including, but not necessarily limited to, loss of feedwater faults and increase in feedwater faults.

A notable conclusion of this assessment is that the consistency of Westinghouse's design basis analysis with the declared UK **AP1000** design reference point has significantly improved from the position at the end of GDA Step 4. The general quality of its fault studies submissions against ONR's expectations for a traceable safety case has also improved. I have made an observation for Westinghouse and future licensees to improve the links between the supporting calculations and what will be an evolving UK design reference point during site licensing and construction. Westinghouse has identified a need to revisit its design basis analysis during site licensing to demonstrate that it matches the as-built design. There is also an Assessment Finding from GDA Step 4 which could result in the 2010 UK-specific analysis being repeated. These re-evaluations will provide an opportunity for further strengthening of the consistency between of the design basis safety analysis and the applicable design reference point. ONR will be able to review a hopefully strengthened position as part of routine regulatory interactions at the appropriate time. However, the extant levels of consistency and traceability are adequate for GDA.

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

LIST OF ABBREVIATIONS

ADS	Automatic Depressurisation System
AFC	Advanced First Core
ATWS	Anticipated Transient Without Scram
CCS	Component Cooling Water System
CMT	Core Makeup Tanks
DAC	Design Acceptance Confirmation
DAS	Diverse Actuation System
DCD	Design Control Document
DCP	Design Change Proposal
EDCD	European Design Control Document
$F^N_{\Delta H}$	Nuclear Enthalpy Rise Hot Channel Factor Limit
FWS	Main Feedwater System
GDA	Generic Design Assessment
GRS	Gesellschaft für Anlagen und Reaktorsicherheit
IAEA	International Atomic Energy Agency
IDAC	Interim Design Acceptance Confirmation
LOCA	Loss of Coolant Accident
ONR	Office for Nuclear Regulation
PCSR	Pre-Construction Safety Report
PRHR	Passive Residual Heat Removal
PSA	Probabilistic Safety Analysis
PWR	Pressurised Water Reactor
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RNS	Normal Residual Heat Removal System
RQ	Regulatory Query
SAA	Severe Accident Analysis
SAC	Safety Analysis Checklist
SFS	Spent Fuel Pool Cooling System
SGTR	Steam Generator Tube Rupture
SWS	Service Water System
TSC	Technical Support Contractor

WEC	Westinghouse Electric Company LLC
WENRA	Western European Nuclear Regulators Association

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1 INTRODUCTION

1.1 Background

1. Westinghouse Electric Company LLC (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 IDAC which had 51 GDA Issues attached to it. 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 GDA Issues.

2. This report is the ONR's assessment of the Westinghouse **AP1000** reactor design in the area of fault studies. Specifically, this report addresses GDA Issue:

   - GI-AP1000-FS-02 – Design Reference Point and Adequacy of Design Basis Analysis

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

1.2 Overview of GI-AP1000-FS-02

4. Westinghouse spent many years developing the **AP1000** outside of the UK before it put its design forward for GDA. During that period of development, Westinghouse captured the evolving design and supporting accident analysis in successive revisions of the **AP1000** Design Control Document (DCD). At the commencement of GDA in 2008, the DCD had reached Revision 17. For the purposes of GDA, Westinghouse created a new document called the European DCD (EDCD). Revision 0 of the EDCD was considered by ONR during GDA Step 3 and was almost identical to Revision 17 of the DCD. At the end of 2009, Westinghouse supplied Revision 1 of the EDCD to ONR. This included some relatively minor changes to the earlier revision which Westinghouse was also planning to include in a future Revision 18 of the DCD. Revision 1 of the EDCD (Ref. 2) was the main safety case submission considered in ONR's Step 4 fault studies assessment of the **AP1000** reactor (Ref. 1).

5. During the course of the GDA Step 4 fault studies assessment, a number of significant issues became apparent which challenged the completeness of the design basis accident analysis results presented in Chapter 15 of the EDCD:

   - Westinghouse's proposed reference design for the UK **AP1000** plant continued to evolve during GDA Step 4 from that assumed in Revision 1 of the EDCD. This occurred for various reasons, including "normal" design developments, experience from constructing the plants in China, the requirements of potential UK operators, and ONR feedback.
   - Some of the analysis included in Chapter 15 of the EDCD was found to be quite old. To meet UK expectations and to address ONR queries, Westinghouse needed to undertake extra analyses. Sensibly, it used the latest versions of its computer codes and up-to-date design assumptions (rather than trying to resurrect 10-year-old models and design details). However, this meant there was a mixture of analysis generations and designs being put forward.
   - Subsequent to EDCD Revision 1 being produced but contemporaneously with Westinghouse undertaking additional analysis for the UK during GDA Step 4, Westinghouse developed an 'Advanced First Core' (AFC) loading pattern using improvements in the fuel assemblies and core components. It was in the process of repeating all the Chapter 15 analyses using the AFC for

incorporation into future revisions of the DCD (outside of the UK). UK-specific analysis undertaken during GDA Step 4 made assumptions consistent with the AFC but the bulk of analysis assessed by ONR was the older modelling included in EDCD Revision 1.

6. As a result, ONR's GDA Step 4 assessment conclusions on the adequacy of the **AP1000** fault studies safety case were based on a somewhat amorphous design, different generations of analyses methods and computer codes, different core loading patterns, and cognisant of an imminent major renewal of the design basis analysis results. This led to the writing of Action 1 of GI-AP1000-FS-02, requiring Westinghouse to demonstrate that all its design basis analysis for the UK **AP1000** reactor is appropriate for a declared design reference point, if necessary through the provision of new analysis.

7. A key objective of design basis analysis is to generate limits and conditions that ensure a nuclear plant is operated safely in accordance with the safety case. At every refuelling outage, the fuel loaded in the core of a Pressurised Water Reactor (PWR) is moved, swapped or replaced in accordance with a carefully considered core design. Each core design would behave slightly differently during a design basis accident but, to avoid extensive re-evaluations, conservative assumptions are made about the core loading pattern in the safety case's accident analysis so that its demonstration of safety in fault conditions can be assumed to be applicable for all / most patterns. However, this approach requires clarity on what has been assumed in the conservative safety analysis and what needs to be checked for each core design to ensure its specific characteristics are bounded by the extant safety case.

8. The different core designs and generations of analyses put forward by Westinghouse during GDA Step 4 made it difficult to determine the core design limits that result from the UK **AP1000** safety case. It was expected that Westinghouse's internal processes would generate a self-consistent set of core design limits once the AFC work was completed but its application for GDA was uncertain and it did not take cognisance of additional faults included with the UK **AP1000** safety case that do not appear in the DCD / EDCD. As a result, Action 2 of GI-AP1000-FS-02 was written, requiring Westinghouse to provide a complete set of core design limits reflecting the final design basis analysis identified by Action 1.

9. Westinghouse paused its GDA activities at the end of Step 4. However, the **AP1000** design and supporting accident analysis methods have continued to evolve while **AP1000** programmes continued in the US and China. Now Westinghouse has returned to the GDA process after several years, the importance of defining its design reference point for the **AP1000** reactor and declaring which design basis analysis is applicable to the design has increased. GI-AP1000-FS-02 is, therefore, possibly more important now than when it was originally written.

1.3 Scope

10. The scope of this assessment is detailed in the assessment plan (Ref. 3). Consistent with this plan, the assessment is focused on considering whether Westinghouse's submissions to ONR for GI-AP1000-FS-02 provide an adequate response to justify the closure of the issue. As such, this report only presents the assessment undertaken as part of the resolution of the GDA Issue and it is recommended that this report be read in conjunction with the Step 4 fault studies assessment of the Westinghouse **AP1000** plant (Ref. 1) to appreciate the totality of the assessment of the evidence on design basis analysis.

11. In principle, Westinghouse's response to GI-AP1000-FS-02, Action 1 had the potential to reopen almost all of ONR's Step 4 fault studies assessment. If Westinghouse's response had been that certain aspects of its design have changed significantly, its

methods for analysing design basis accidents are radically updated, and the predicted behaviour during transients is now different from that set out in EDCD Revision 1 (Ref. 2), then large swathes of the conclusions made in Ref. 1 could have been in doubt. To mitigate against this and to reinforce the continuing applicability of the GDA Step 4 conclusions, I encouraged Westinghouse to make clear in its submissions the impact of any changes it has identified on its accident analysis results presented in the EDCD and supporting references. A key aspect of my assessment has therefore been to understand the 'delta' between the old and new analysis so that I can come to a judgement on whether the bases of any conclusions in Ref. 1 continue to be supported. The starting assumption is that the size of any deltas will be demonstrated to be small enough to avoid the need to repeat the Step 4 assessment and that the original conclusions still remain valid.

1.4 Method

12. This assessment has been undertaken consistent with internal guidance on the mechanics of assessment within ONR (Ref. 4).

2 ASSESSMENT STRATEGY

2.1 Pre-Construction Safety Report (PCSR)

13. ONR's GDA Guidance to Requesting Parties (Ref. 5) states that the information required for GDA may be in the form of a PCSR, and the Technical Assessment Guide (TAG) NS-TAST-GD-051 sets out regulatory expectations for a PCSR (Ref. 6).

14. At the end of Step 4, ONR and the Environment Agency raised GDA Issue GI-AP1000-CC-02 (Ref. 7) 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. As a result, Westinghouse's proposals for addressing GI-AP1000-CC-02 are vital for this GDA Issue, both in terms of establishing the design reference point and defining the scope of the PCSR.

15. The bulk of the **AP1000** design basis analysis considered during GDA Step 4 was captured in Chapter 15 of the EDCD (Ref. 2), complemented by separately reported UK-specific analyses. Westinghouse has stated as part of its strategy for addressing GI-AP1000-CC-02 that it will no longer maintain EDCD. Instead, the UK **AP1000** safety case will be centred on the consolidated PCSR. As is explained in Section 3, Westinghouse's approach for GI-AP1000-FS-02 has been to replace the EDCD Chapter 15 analysis with a new generation of calculations and a refreshed accompanying commentary. This means that a direct consequence of GI-AP1000-FS-02 is many hundreds of pages within the PCSR (Chapter 9) that are new to GDA. Westinghouse has also chosen to introduce the UK-specific analyses that have never been in a DCD / EDCD scope in the fault studies sections of the PCSR.

16. A separate regulatory assessment report is provided to consider the adequacy of the PCSR and closure of GDA Issue GI-AP1000-CC-02, and therefore this report does not attempt to assess the totality of the **AP1000** PCSR chapters related to fault studies (Chapters 8 and 9). Notably, I have not commented on the structure or internal self-consistency of the PCSR in this report. Westinghouse's work to address the other fault studies GDA Issues has resulted in specific detailed changes to some aspects of Chapter 9 of the PCSR. Again, the adequacy of these changes is outside the scope of this assessment report. However, this GDA Issue has required me to consider at a high level the general adequacy of Chapter 9, the analysis it presents, its consistency with the design reference point, and the clarity of its referencing.

17. As stated in Subsection 1.3, I have made the significant assumption that the majority of the safety case discussion contained in the PCSR is consistent with what was assessed in GDA Step 4. Therefore, my observations in this assessment report regarding the adequacy of the PCSR do not constitute a repeat of the detailed assessment performed of the fault studies sections of the EDCD described in Ref. 1. The basis and acceptability of this approach will be a continuing theme of this assessment report.

2.2 Standards and Criteria

18. The assessment has been undertaken in line with the requirements of the HOW2 BMS document NS-PER-GD-014 (Ref. 8). In addition, the Safety Assessment Principles (SAPs) (Ref. 9) constitute the regulatory principles against which dutyholders' safety cases are judged, and, therefore, are the basis for ONR's nuclear safety assessment. When performing the assessment described in this report, I have used SAPs 2014 Edition (Revision 0); the original GDA Step 4 fault studies assessment used the 2006 Edition.

2.2.1 Safety Assessment Principles and Technical Assessment Guides

19. The following SAPs (Ref. 9) were identified in the assessment plan (Ref. 3) as being appropriate to judge the adequacy of the arguments in the area of fault studies for the UK **AP1000** reactor.

- Fault Analysis SAPs FA.1 to FA.9
- Severe Accidents SAPs FA.15 and FA.16
- Engineering SAPs EKP.2 to EKP.5, ECS.1, ECS.2, EDR.1 to EDR.4, ESS.2, ESS.4, ESS.6 to ESS.9, ESS.11, ERC.1 to ERC.3, EHT.1 to EHT.4
- Computer Codes and Calculation Methods SAPs AV.1 to AV.8
- Numerical Target for DBA Consequences Target 4

20. It is important to note, however, that the scope of the assessment to close out the GDA Issue is narrowly defined and is less than that of a typical ONR assessment, such as that undertaken in GDA Step 4. Although I have had to consider hundreds of pages of fault studies analysis and arguments, I have not repeated the original fault studies assessment which had considered these SAPs.

21. The AV series of SAPs establish some significant expectations which have been at the forefront of my considerations as I have reviewed Westinghouse's submissions:

- AV.1: Theoretical models should adequately represent the facility and site.
- AV.2: Calculation methods used for the analyses should adequately represent the physical and chemical processes taking place.
- AV.3: The data used in the analysis of aspects of plant performance with safety significance should be shown to be valid for the circumstances by reference to established physical data, experiment or other appropriate means.
- AV.5: Documentation should be provided to facilitate review of the adequacy of the analytical models and data.

22. Again, I have not repeated earlier assessments that considered these SAPs. Rather, I have looked for evidence in the form of documentation (SAP AV.5) that Westinghouse is striving to demonstrate the expectations of the SAPs AV.1 to AV.3 for the extant design reference point, and that it will still be clear in several years' time during site licensing which design reference the GDA safety case is applicable for, and what will need to be updated.

23. TAG NS-TAST-GD-051 (Ref. 6) also sets out some key expectations for safety cases against which I have benchmarked Westinghouse's submissions:

- All references and supporting information should be identified and be easily accessible.
- There should be a clear trail from claims through the arguments to the evidence that fully supports the conclusions, together with commitments to any future actions.
- A safety case should accurately represent the current status of the facility in all physical, operational and managerial aspects.
- For new facilities or modifications, the safety case should accurately represent the design intent.
- There should be reference from the safety case to important supporting work, such as engineering substantiation. The safety case should be able to act as an entry point for accessing all relevant supporting information on which it is built.

24. Although the EDCD (Ref. 2) has many of the characteristics of a PCSR, its origins are in the US regulatory regime in which the way the design reference point is controlled and how supporting references are linked is different from the UK. Therefore, despite it

being entirely appropriate for the bulk of PCSR Chapter 9 (ie the transient analysis and supporting descriptions) to be consistent with the DCDs considered in other countries, to close out this GDA Issue I have looked for evidence that this has been complemented in the PCSR with additional information to meet the expectations of NS-TAST-GD-051 for a UK safety case.

2.2.2 National and International Standards and Guidance

25. There are both International Atomic Energy Agency (IAEA) standards (Ref. 10) and Western European Nuclear Regulators Association (WENRA) Reference Levels (Ref. 11) which are relevant to the fault studies assessment of the **AP1000** reactor. The original GDA fault studies assessment undertaken during Steps 3 and 4 took cognisance of the international standards published at the time. The GDA Issues that emerged from that original assessment can generally be characterised as having their origins in the application of the SAPs and UK relevant good practice rather than through the comparison against international guidance. Therefore, the SAPs (and not the international references) are the foremost standards considered. It should be noted that the latest version of the SAPs (Ref. 9) were benchmarked against the extant IAEA and WENRA guidance in 2014.

2.3 Use of Technical Support Contractors (TSCs)

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

27. Based on early discussions with Westinghouse, an expectation was established that its submissions for GI-AP1000-FS-02 would not be using radically different methodologies and design assumptions to those assessed in detail during GDA Step 4. It would have taken a lot of ONR time and resources to carefully re-examine calculations already assessed during GDA Step 4 just to confirm that they have only been trivially changed in the latest submissions. However, closure of the GDA Issue has to be based on evidence and it was vital to undertake appropriate checks of Westinghouse's claims. Therefore, under contract the German company Gesellschaft für Anlagen und Reaktorsicherheit (GRS) has worked on a significant aspect of this assessment in support of ONR. The objectives established for GRS were to:

- review Westinghouse's submissions for GI-AP1000-FS-02 for applicability to the declared design reference point;
- perform an in-depth review of a selection of design basis fault analyses and identify the differences between the equivalent analyses from Westinghouse's GDA Step 4 submissions and its updated submissions for GI-AP1000-FS-02; and
- provide ONR with recommendations on the continuing applicability of ONR's assessment conclusions made during GDA Step 4 for the UK **AP1000** reactor.

28. GRS's report (Ref. 12) details its assessment of Westinghouse's (initial) submissions for GI-AP1000-FS-02 and provides recommendations to ONR on matters to pursue with Westinghouse. I passed on those recommendations I considered appropriate (the majority) to Westinghouse in the form of a Regulatory Query (RQ) (Ref. 13) and asked it to provide a response. I have taken into account Westinghouse's response to the RQ and subsequent updates to major fault studies reports in my overall assessment of the adequacy of Westinghouse's submissions for GI-AP1000-FS-02.

2.4 Integration with Other Assessment Topics

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

30. I have already discussed the relevance of GI-AP1000-CC-02 (Ref. 7) to this GDA Issue in terms of establishing the need for a PCSR against a declared design reference point. With that notable starting point, the majority of the requirements for GI-AP1000-FS-02, Action 1 are exclusively fault studies and other assessment areas are unaffected if the original claims and arguments in Westinghouse's safety case remain fundamentally unchanged from GDA Step 4.

31. GI-AP1000-FS-02, Action 2 has a direct link to the fuel design topic area. I have engaged with my colleagues in that area (including inviting them to relevant meetings with Westinghouse) to ensure that they had full visibility of Westinghouse proposals to ensure that appropriate limits and conditions for future loading patterns are consistent with the design basis analysis.

2.5 Out of Scope Items

32. In principle, the entirety of the design basis reactor transient analyses, including shutdown faults and containment behaviour, are within the scope of this GDA Issue. In practice, while looking at a high level at all of Westinghouse's design basis analysis, both GRS and I have sampled the details of specific transients to come to a view on the overall adequacy of the submissions.

33. The major limitation to the scope of this assessment report defined at the start is that ONR's GDA Step 4 assessment of the adequacy of the **AP1000** fault studies safety case (Ref. 1) would not be repeated unless the findings of the review were that the changes to the design or methodologies were so significant the previous conclusions could no longer be supported.

34. Non-reactor faults and fuel route faults have not been considered as part of this assessment. This is partly a matter of prioritisation, but also reflects the fact that the safety case for these faults is generally supported by much simpler analyses which are generally invariant to minor design changes. The consistency of the Severe Accident Analysis (SAA) and Probabilistic Safety Analysis (PSA) with the design reference point are also excluded from the scope of this fault studies assessment.

35. The details of radiological consequences analyses have not been considered, cognisant that they were looked at during GDA Step 4 and an Assessment Finding (AF-AP1000-FS-46) was written for a future licensee to undertake site-specific calculations using UK methods.

36. It is not ONR's role to be part of Westinghouse's quality assurance process nor to provide a checking service for its calculations. I have made no attempt to verify, for example, that an identified change to piping resistance value has been demonstrably and correctly incorporated into impacted calculations. I have also not checked that individual core design limits identified for GI-AP1000-FS-02, Action 2 have been correctly extracted from Westinghouse's analysis and converted to metric units.

3 REQUESTING PARTY'S DELIVERABLES IN RESPONSE TO THE GDA ISSUE

37. Ultimately, Westinghouse's submission for demonstrating the adequacy of its design basis analysis for its declared design reference point and for showing that all safety case claims are supported by that analysis is the PCSR, in particular Chapter 9 (Ref. 14). However, for most of the time I have been engaged with Westinghouse on this GDA Issue the PCSR has been under development. It was not, for example, available for GRS to review.

38. Westinghouse's strategy for Chapter 9 of the PCSR and the bulk of the analysis it wanted to include within it was available early on. It also declared a preliminary design reference point, and as result useful progress could be made ahead of the receipt of mature versions of Chapter 9 of the PCSR.

3.1 Design Reference Point

39. At the end of GDA Step 4, Westinghouse formalised its declared reference design in Revision 5 of "**AP1000** Design Reference Point for UK GDA" (Ref. 15). This revision of Ref. 15 sets as its reference date 16 September 2010 and then provides through five tables a suite of documents that define the UK **AP1000** design at the time of its issue (October 2011):

- Table 1: A list of the principal reference documents (Tier 1) which describe the criteria to which the **AP1000** reactor was designed and the principles upon which design documentation is dependent.
- Table 2: A list of system specification documents (Tier 2) which describe the safety-significant **AP1000** systems, the safety and environmental issues associated with them and how these issues are addressed and controlled.
- Table 3: A list of design specifications (Tier 3) for safety-significant **AP1000** components and systems which establish the requirements for design, fabrication, quality assurance, inspection, test, analysis, construction and operation of a component and/or embedded software.
- Table 4: A list of design change proposals (DCPs) written before 16 September 2010 that should be considered part of the UK **AP1000** design. These DCPs largely resulted from design work and learning outside of the GDA process and were also applicable to the "standard" **AP1000** design being developed outside of the UK. The level to which they are incorporated in the Tier 1 to 3 design documents was indicated.
- Table 5: A list of GDA-driven and UK-applicable DCPs identified for inclusion in the UK **AP1000** design during GDA Step 4. Many of these were written after the declared reference date of 16 September 2010. Almost all were marked as being unincorporated into the Tier 1 to 3 design documents.

40. It should be noted that GI-AP1000-FS-02 was originally written against this design reference point (Revision 5 of Ref. 15) ie at the end of GDA Step 4. ONR was not satisfied that the mixture of generations of analyses submitted by Westinghouse had been shown to be applicable for the UK **AP1000** design defined by this revision.

41. At the end of GDA Step 4, Westinghouse paused its activities in the UK. While there was little or no development in UK-specific aspects of the design during the hiatus, the standard **AP1000** design continued evolve. This was in no small part due to the ongoing construction programmes for the lead **AP1000** units in China and the US, which inevitably led to design changes. On returning to the UK, Westinghouse recognised the importance, both generally and for this GDA Issue, of re-establishing the design reference point that GDA and the resulting DAC should be considered against. It re-issued Ref. 15 at Revision 6 with the incorporation statuses of the DCPs included in Tables 4 and 5 updated to reflect any progress made during the intervening time, and with two new tables included. The new tables listed the additional DCPs

generated over a four-year period up to 31 January 2015 that Westinghouse requested to be considered part of the UK **AP1000** design.

42. Revision 6 of Ref. 15 has effectively formed the working design reference point for the assessment work undertaken for this GDA Issue (including the work done by GRS). During the course of the interactions with Westinghouse to close out this and the other GDA Issues, Westinghouse has produced three further revisions of Ref. 15. These include an extra 14 months of standard plant DCPs that have arisen from **AP1000** development work overseas up to 31 March 2016, and a smaller number of UK-specific changes mainly generated as a result of GDA Issue closure work (the list of UK-specific changes extend beyond 31 March 2016). However, Westinghouse has asserted that no DCPs identified after the publication of Revision 6 of Ref. 15 have a significant impact on fault studies transient analyses.

3.2 UK Fault Studies Analysis Basis

43. With the initial unavailability of the PCSR, Westinghouse's key submission for GI-AP1000-FS-02 is "UK Fault Studies Analysis Basis" (Ref. 16). It describes:

- a brief history of the transient analysis submitted to ONR during GDA Step 4 for assessment, including both standard plant design basis analysis (ie in the EDCD Revision 1) and UK-specific analysis provided in response to ONR RQs and regulatory observations;
- a summary of reanalysis of design basis faults that was being undertaken outside of the UK at about the same time as GDA Step 4, assuming the AFC and a revised design reference point. The scope of this work was limited to those faults in the EDCD. Note, for practical reasons associated with the US regulatory process, Westinghouse captured this work in a 'Core Reference Report' (Ref. 17) and did not revise its standard plant DCD (site specific safety analysis reports were updated);
- a subsequent re-evaluation of the standard plant design basis faults completed in May 2015 assuming a design reference point up to 31 December 2014 (effectively the same date as assumed by Revision 6 of Ref. 15), referred to as the "2015 analysis of record"[1]; and
- the major design changes that have had a significant impact on the design basis analyses undertaken after the publication EDCD Revision 1 (Ref. 2).

44. To specifically address the requirements of GI-AP1000-FS-02, Action 1, Ref. 16 states the analyses that should be considered applicable and adequate for the revised UK **AP1000** design reference point (Revision 6 of Ref. 15 initially but assumed to be equally applicable to Revision 10) are:

- the "2015 analysis of record" covering all the standard plant design basis events identified in Chapter 15 of the EDCD; and
- UK-specific analyses performed circa 2010 for design basis initiating events and fault sequences not included within the EDCD (eg to demonstrate diverse protection for frequent design basis faults) but that are to be incorporated into the PCSR.

45. The adequacy of this proposal is what GRS was asked to look at and what I will be commenting on in Section 4 of this report.

46. In an appendix to Ref. 16, the calculation notes that support each design basis fault considered in the PCSR are listed.

*[1] The May 2015 work was undertaken to support operation of the first **AP1000** units in China, reflecting the near-final plant design. As a result, it has been identified as the "2015 analysis of record".*

3.3 References to Support the GRS Review

47. GRS undertook its review of the adequacy of Westinghouse's analyses for the proposed design reference point using Revision 6 of Ref. 15 and a preliminary draft of Ref. 16. It also had access to Ref. 2. However, to support its in-depth review of the potential impact of design modifications and the changes made between different generations of design basis transient analysis, it was necessary for Westinghouse to supply significant amounts of additional information. This was mainly in the form of DCPs identified in Ref. 15 and calculation notes supporting Ref. 2 (the historic transient analysis) or Ref. 16 (the newly proposed transient analysis).

48. In a few cases, ONR already had the necessary information from GDA Step 4. In the majority of cases, the information was requested from Westinghouse via RQs.

49. These supporting documents are listed in Annex 1 of this report. The full list of references considered by GRS is included in Ref. 12.

3.4 Pre-Construction Safety Report

50. As the final submission for this GDA Issue, Westinghouse has submitted an updated Chapter 9 of the PCSR (Ref. 14), which sets out the UK **AP1000** design basis safety case for internally initiated faults by implementing the strategy established in Ref. 16.

51. For every design basis reactor fault identified in the fault schedule (Ref. 18), a narrative of the safety case claims and arguments is provided, which is supported by conservative transient analysis of bounding fault sequences. The majority of transient analysis provided to demonstrate the effectiveness of the frontline **AP1000** passive features is taken from the "2015 analysis of record" suite of calculations. To demonstrate diversity for frequent faults (a UK-specific expectation), transient analysis performed during GDA Step 4 has been included.

52. Chapter 9 states that it considers internally initiated reactor faults in all modes of operation, with supporting transient analysis provided as appropriate for faults occurring during shutdown that are not bounded by faults at power. It also includes analysis to demonstrate the effectiveness of the containment vessel and the ability to reach a stable, safe state following a design basis event.

53. At the start of Chapter 9, it clearly states that the design basis analysis presented for each fault is applicable for the design reference point defined in Ref. 15. It identifies Ref. 16 as the justification for this statement and the place to find the source calculations for all the analyses included within Chapter 9.

3.5 SAC and Future Limits

54. Westinghouse's internal processes have a long-standing requirement to generate a Safety Analysis Checklist (SAC) to act as an interface document between its nuclear design group and safety analysis groups such that all the key core design parameters assumed in the design basis safety analysis are well established. The limits / values set out in the SAC are based on evaluations of first cycle and anticipated reload cycles, historical precedence and engineering judgement. Limits are selected to bound expected values in subsequent cycles as part of a conservative analysis approach and to allow for minor reactor and system design updates to be incorporated without adversely affecting the reference safety case conclusions. However, Westinghouse's approach requires the limits to be confirmed during plant operation at every cycle with the anticipated loading pattern.

55. During GDA Step 4, ONR recognised the value of a SAC but, given the uncertainty over the design reference point, the generational mix of analyses submitted and the

limitations in the EDCD Chapter 15 scope to meet ONR expectations for a design basis safety case, it was considered necessary to write GI-AP1000-FS-02, Action 2.

56. As a direct response to the requirements of GI-AP1000-FS-02, Action 2, Westinghouse has produced a UK-specific “Safety Analysis Checklist (SAC) & Future Limits” report (Ref. 19). It states that the contents of the document are consistent with the UK **AP1000** design established by Revision 7 of Ref. 15 and Chapter 9 of the PCSR (Ref. 14). It does the following:

- It incorporates representative core designs for the transition from the AFC design to reload equilibrium. The core design parameters are confirmed not only for Cycle 1, but for a set of representative reload cycles. These include Cycles 2, 3 and an equilibrium cycle with 18-month reload scheme.
- For each reload core design from the above, the key SAC parameters known by experience to be potentially limiting from a core design perspective are identified. They include: moderator temperature coefficient limits, shutdown margin limits, peaking factor limits, and limiting fuel rod design parameters, such as maximum rod burnup.
- It provides a set of limits to support UK-specific analyses undertaken for GDA (including for other fault studies GDA Issues) and those derived from the evaluation of Anticipated Transient Without Scram (ATWS).

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

57. In the following sub-sections I have summarised my assessment of Westinghouse's submissions for this GDA Issue.

58. The majority of the subsections are in support of my assessment of Action 1. To come to my judgements, I have considered in turn the:

- appropriateness of the proposed design reference point;
- significant design changes that impact on the transient analysis results;
- changes in analysis methods and assumptions in the different generations of analyses (referencing GRS's detailed review);
- acceptability of Westinghouse's "two-generation" analyses for the proposed design reference point; and
- adequacy of the PCSR summary of the design basis safety case.

59. Subsection 4.6 deals with Action 2; however, its starting premise is a positive conclusion in the early subsections about the adequacy of the submissions for Action 1.

4.1 Design Reference Point

60. The adequacy of the design reference point established at the end of GDA Step 4 (Revision 5 of Ref. 15) was commented on in Ref. 20 and resulted in GDA Issue GI-AP1000-CC-02 (Ref. 7) being written. As a result, ONR will judge the completeness of the PCSR, the general adequacy of the declared design reference point, and the consistency of the PCSR with the design reference point in its assessment of GI-AP1000-CC-02 outside of this assessment report. However, some commentary on the adequacy of the assumed design reference point is essential for this GDA Issue to allow me to reach a positive conclusion against the expectations of SAP AV.1 (Ref. 9) and NS-TAST-GD-051 (Ref. 6) that the safety case and analysis should accurately represent the design intent.

61. The appropriateness of the submitted design basis transient analysis was never demonstrated for the design reference point defined at the end of GDA Step 4, hence the need for this GDA Issue. The wording of GI-AP1000-FS-02, Action 1 gave Westinghouse the option of justifying the adequacy of the extant analysis but, in hindsight, I consider this was highly unlikely to be achievable. A major reconciliation of the analysis against the design reference point was always going to be necessary. However, beyond that observation, I have chosen not to look in great detail at the historic position at the end of GDA Step 4 and I have instead focused on Westinghouse's revised position following the GDA pause.

62. The "working" design reference point assumed for this GDA Issue has been Revision 6 of Ref. 15, which includes DCPs generated up to 31 January 2015. Therefore, to address the requirements of Action 1, Westinghouse set itself the objective of showing that its "two-generation" approach based on "2015 analysis of record" transient analysis supplemented by 2010 UK-specific analyses is appropriate for a 31 January 2015 design.

63. Westinghouse stated to me during early interactions that the "2015 analysis of record" transient analysis includes all DCPs applicable up to 31 December 2014 (Ref. 21). I have reviewed Revision 6 of Ref. 15 and only found six DCPs approved during January 2015 and none of these have any obvious impact on design basis transient analysis. I am therefore satisfied that as an approach (ie before commenting on the adequacy of the analysis) the application of the "2015 analysis of record" to Revision 6 of Ref. 15 is sensible and entirely appropriate.

64. The applicability of the 2010 UK-specific analyses to Revision 6 of Ref. 15 is a more difficult judgement to make. It depends on the DCPs already included within the 2010 analyses (which were not explicitly linked to a defined design reference point) and the impact of any DCPs added to the design between 2010 and 2015. I will comment on this further in the next subsection.

65. The design of a nuclear power plant is never frozen, especially when the first units are under construction. During the course of the interactions with Westinghouse on this GDA Issue, Ref. 15 was successively updated, eventually reaching Revision 10. There was only one change to the window of standard plant DCPs included within Ref. 15; in going from Revision 6 to Revision 7, standard plant DCPs approved up to the end of March 2016 were included. The subsequent revisions (8, 9 and 10) include just a small number of UK-specific DCPs written to facilitate closure of some of the 51 GDA Issues.

66. It is not realistic to expect Westinghouse to reanalyse every single design basis fault whenever a DCP is generated that has a potential to affect the extant results. What is vital is that each DCP (or more appropriately, Westinghouse's DCP approval process) considers the potential impact of any proposed change on the transient analysis, and anything relevant is tracked until it can be incorporated at an appropriate time. As part of my wider assessment work to close other fault studies GDA Issues, notably GI-AP1000-FS-01, I have reviewed Westinghouse's arrangements for managing DCPs and have been satisfied by their adequacy (Ref. 22). In the context of GI-AP1000-FS-02, through RQs, I have specifically asked Westinghouse how it identifies the impact of changes on the transient analysis and manages any outstanding "design debt". I am satisfied with the descriptions of its processes provided in the responses to the RQs (Refs 23 and 24). From an inspection of a sample of supporting calculation notes identified in Ref. 16, it is clear that Westinghouse's normal processes require its analysts to identify and review any open items and outstanding design debt applicable to the fault sequence under consideration.

67. Westinghouse's assertion, informed by following its normal processes, is that there are no significant changes to either the standard **AP1000** plant or the UK **AP1000** plant introduced since January 2015 which undermine the applicability of either legs of its "two-generation" analyses to the declared design reference point for GDA (Revision 10 of Ref. 15). Given that I have confidence in Westinghouse processes, I have few reasons to doubt this claim. However, I will comment on it further in Subsection 4.3.

68. There is a risk that the cumulative effect of a lot of small changes could have a complex and non-trivial impact on analysis results. However, Ref. 16 states that Westinghouse anticipates that before the start-up of an **AP1000** plant in the UK, all the design basis analyses will be reassessed and updated to be appropriate for the as-designed / as-built configuration of the plant. Its "two-generation" approach set out in Ref. 16 is therefore only meant to be adequate for the purposes of GDA and closing GI-AP1000-FS-02. I am content with this strategy, cognisant that the most likely driver for impactful minor design changes is the construction and commissioning of the first **AP1000** units in China, and the majority of these should already be reconciled within the "2015 analysis of record".

4.2 Significant Design Changes that Impact on the Transient Analysis

69. In general, the design changes that need to be incorporated into the transient analysis originally considered during GDA Step 4 fall into four major categories:

- changes for the AFC;
- standard plant DCPs identified in Ref. 15 that are not included in earlier analyses (notably Chapter 15 of Ref. 2);
- UK-specific DCPs identified in Ref. 15 that are not included in earlier analyses or the standard plant "2015 analysis of record"; and

- miscellaneous changes arising from design finalisation (consistency changes, minor system changes etc).

70. Westinghouse discusses these different categories of DCPs in Ref. 16 and GRS considered the claims made as part of its review on behalf of ONR (Ref. 12). My own views, informed by Refs 12 and 16, are below.

4.2.1 Changes for the AFC

71. Westinghouse acknowledges in Ref. 16 that between the issuance of Revisions 15 and 19 of the standard plant DCD (respectively published before and after Westinghouse's original engagement with the GDA process), changes in plant design and improvements to the fuel, core components and core design had accumulated and had not been incorporated in its Chapter 15 analysis (DCD or EDCD). As mentioned in Subsection 1.2, during GDA Step 4, ONR was aware that Westinghouse had initiated a major programme of work to refresh its standard plant analyses, capturing the changes to the fuel design and accumulated design debt. This programme culminated in the writing of the Core Reference Report (Ref. 17). This effectively replaced all the design basis analysis included in EDCD Revision 1 (Ref. 2). However, the DCP to incorporate this work into the standard **AP1000** design (Ref. 25) was not approved until February 2012 (ie during the period of time that Westinghouse had paused its GDA activities).

72. The headline change introduce by Ref. 25 was the AFC first cycle loading pattern, changing the core from a three-region to a five-region design. However, Westinghouse states in Ref. 16 that this only had a small impact on the safety analyses. Of more significance was an accompanying increase in the Nuclear Enthalpy Rise Hot Channel Factor Limit ($F^N_{\Delta H}$) from 1.65 to 1.72.

73. The key outstanding DCPs that Westinghouse opportunistically included within Ref. 17 which have an effect on safety analysis results are summarised in Table 1 of this report. All but two of these were included in Revision 5 of Ref. 15 for inclusion at the end of GDA Step 4 but they were not reflected in the EDCD Chapter 15 analysis (Ref. 2).

74. Ref. 25, incorporating the revised analysis of the Core Reference Report into the standard plant design, is included in the post-pause revisions of Ref. 15, as are all the changes in Table 1. Although I have not systematically checked, it is my understanding that most of the changes included in Table 1 were also reflected in the 2010 UK-specific analysis. From reviewing the final approval dates given in Ref. 15 for the DCPs in Table 1, I observed that the introduction of the AFC analysis with its associated opportunistic changes (Ref. 17) resulted in both the standard plant analyses and UK-specific GDA Step 4 analyses being broadly consistent with the reference design that existed at the end of 2010. This on its own represents a significant improvement from the position established by ONR during its original assessment. For example, Ref. 1 states that it found three generations of Steam Generator Tube Rupture (SGTR) fault analyses referenced by Westinghouse. The oldest were performed in 2001 (with some AP600 design parameters referenced) while the newest were performed in 2009 referencing AFC information. The effect of Ref. 17 is to replace these hybrid analyses with a single, relatively recent, set of calculations for SGTR faults.

75. I have not assessed the technical merit of the individual DCPs included with Ref. 17 re-evaluations. In part, this is because it is not ONR's role to verify every detailed design decision made by Westinghouse, especially when the DCPs are categorised as having a low safety significance in accordance with Westinghouse's internal arrangements. In addition, informed by GDA Step 4 assessments on fault studies (Ref. 1) and management of safety and quality assurance (MSQA) (Ref. 38), I have sufficient confidence in Westinghouse as the designer and builder of the **AP1000** plant to assume that a DCP is merited and therefore should be included within the UK

design reference point. The analysis ultimately shows that with changes included, safety margins are maintained. GRS looked in more detail at several of the individual DCPs (see Annex 1) and considered the impact on specific fault transients. However, because multiple design and modelling improvements were usually implemented together, GRS found it difficult to identify individual effects (Ref. 12).

76. I have consulted with ONR colleagues who are fuel and core specialists. They have undertaken their own review of the merits of the AFC change to five-regions, the $F^N_{\Delta H}$ limit change and the associated fuel design changes listed in Table 1. Following a detailed assessment from a core design perspective, they have concluded that they are satisfied with the DCPs and are content for them to be included within the UK **AP1000** design (Ref. 26). They also expressed no objections to the change in $F^N_{\Delta H}$ limit, acknowledging that it has been accompanied by improvements in analysis methods, physical changes to the fuel and a tightening of the operational window.

77. It is therefore my judgement, based on Westinghouse's claims and GRS's review, that even if Westinghouse had done nothing further, the inclusion of the Ref. 17 analysis addresses some of the bigger concerns behind GI-AP1000-FS-02, Action 1 and provides a major contribution to meeting the expectation of SAP AV.1 for modelling to adequately represent the facility.

4.2.2 Changes Since the Incorporation of the AFC

78. Revision 6 of Ref. 15 shows that Westinghouse has identified hundreds of additional DCPs for inclusion within the UK **AP1000** design between the end of GDA Step 4 and the start of 2015 when the working design reference point was established. Even more DCPs are included in Revision 10 of Ref. 15, which is intended to be the final design reference point for GDA and PCSR.

79. Westinghouse claims that the modifications that have the biggest impact on design basis transient analysis (relative to the EDCD analyses) were all included in the AFC work for Ref. 25. Subsequent DCPs have had a more limited impact on the analyses. The "2015 analysis of record" transient analysis effectively includes all the DCPs from Revision 6 of Ref. 15 and is therefore Westinghouse's evidence to support this claim.

80. On examination, GRS found this claim to be plausible (Ref. 12). However, GRS noted that, like the AFC changes, because multiple design and modelling improvements were applied together, it was impossible to separate out individual impacts. GRS also observed that it was effectively impossible to establish from Westinghouse's supporting calculation notes up to what point in time DCPs were being considered, and how Westinghouse had determined which of them could have an impact on parameters in transient analysis. I recognise GRS's observations and it is my view that any future licensee should have a greater control of the link between calculations and the design reference point to robustly meet the expectations of SAP AV.5. However, I also acknowledge that Westinghouse's primary reasons for making the design changes and then updating its analysis have been regulatory, construction and commissioning milestones in China and the US that are not linked to Ref. 15. The regulatory framework for ensuring that the plant is constructed and operated consistent with the safety analysis in these countries is also different from the UK safety case approach. Therefore, the supporting calculations do not always meet relevant good practice, as established by the SAPs, because they are not written with that objective.

81. Westinghouse has presented limited evidence to demonstrate that the DCPs introduced after the "2015 analysis of record" analysis was completed (ie DCPs included in Revision 10 of Ref. 15 that are not in Revision 6) will similarly have a small impact on the results. It recognises in Ref. 16 that there could be changes that have an impact but it states that given the fact that Revision 6 of Ref. 15 and the "2015 analysis of record" is intended to be consistent with plants nearing completion in China, none of

the newest DCPs are expected to have measurable impacts on any results for the standard **AP1000** plant.

82. For the purposes of GDA, based on my gained confidence in Westinghouse's processes for identifying changes that impact on safety analysis (as discussed in Subsection 4.1), the results of "2015 analysis of record" analysis and the conclusions GRS was able to reach in Ref. 12, I am content to accept Westinghouse's claim that the impact of DCPs after the AFC work (up to Revision 5 of Ref. 15) is small, and its assumption that the impact of subsequent DCPs will be even less.

4.2.3 UK-specific Design Changes

83. Westinghouse has stated that its strategy for UK-specific design changes is not to undertake any detailed design work (including incorporating them in the design basis transient analysis) until quality assurance arrangements and a programme of deliverables are in place with a UK customer ie during site licensing (Ref. 27). However, they are included in the design reference report (Ref. 15) and credited in the main safety case discussion set out in the PCSR. Reaching a view on the acceptability of this approach is a key aspect of this GDA Issue.[2]

84. The most significant of these UK-specific DCPs with the potential to impact on the fault studies assessment are five modifications requested by the European operators Westinghouse was in discussions with during the early stages of GDA:

- EPS-GW-GEE-001: Normal Residual Heat Removal System (RNS) Changes for Europe (Ref. 28)
- EPS-GW-GEE-002: Spent Fuel Pool Cooling System (SFS) Changes to Meet European Requirements (Ref. 29)
- EPS-GW-GEE-003: Main Feedwater System (FWS) Changes to Meet European Requirements (Ref. 30)
- EPS-GW-GEE-004: Component Cooling Water System (CCS) and Service Water System (SWS) Changes (Ref. 31)
- EPS-GW-GEE-006: KSB Wet Winding Reactor Coolant Pumps (RCPs) Implementation (Ref. 32)

85. The first four of these changes are associated with adding greater separation, segregation and redundancy to cooling systems for both operational and safety reasons. The fifth is to change the design (and manufacturer) of the RCPs to one that uses a wet winding motor with the cooling water flowing directly over the insulated stator windings. Westinghouse states that the advantage of this change is the elimination of the stator can and its associated electrical losses, and the concern of can collapse during the Reactor Coolant System (RCS) vacuum refill process.

86. Westinghouse proposed all five of these changes early on in the GDA process (circa 2009) and were included in Revision 5 of Ref. 15. They were also discussed in the main text of the EDCD Revision 1 (Ref. 2) but crucially they were not included within any of the transient analyses.

87. I established during early interactions on this GDA Issue that Westinghouse intended to continue with its approach of excluding these DCPs from both parts of its "two-generation" analyses. I therefore asked Westinghouse to make it clear in its submissions why this was acceptable. I also asked GRS to consider the impact of these planned changes on the design basis safety case.

88. In Chapter 9 of the PCSR (Ref. 14), Westinghouse states that the design change with the biggest potential to impact on the presented analyses is the change of RCP design

[2] *There are some DCPs that originated from the UK GDA process which have been applied to the standard **AP1000** plant. These have been taken forward by Westinghouse into detail design and are included as appropriate in the transient analysis.*

and vendor. However, it states that key RCP parameters used in the extant safety analysis, such as flow coastdown versus time, will be used as a part of the pump design specification for the future vendor to meet. As a result, it expects that future analysis will continue to show that the **AP1000** design satisfies the applicable safety criteria with appropriate margins. I am satisfied with this argument.

89. Ref. 14 states that the RNS change is expected to have less of an impact because few of the analyses in the chapter consider it. In response to an RQ (Ref. 33), Westinghouse has provided some more information. Although there are significant changes in pipe layout and segregation, the role of the RNS and its design requirements (notably, the sizing of the pumps) are unaltered. It explains that the RNS change could have an impact of boron dilution faults in shutdown modes but it is not expected to be limiting. For loss of RNS faults in shutdown modes, the consequences of a total loss of its functionality are considered and therefore a change to the configuration of the (operating) system will not result in more limiting consequences. I agree with this argument.

90. Westinghouse has not mentioned any impacts on the revised claims made on the RNS in Chapter 9 of the PCSR (Ref. 15) for diverse low pressure safety injection following a small-break Loss Of Coolant Accident (LOCA). This change to the safety case has resulted from work done by Westinghouse to address GI-AP1000-FS-05 (Ref. 34). When the detailed design of the DCP (Ref. 28) is developed, revised pipe losses may have to be included in an update to the GI-AP1000-FS-05 transient analysis. However, this information is not available now and I see little value in demanding that Westinghouse demonstrates anything other than what it has currently assumed for the performance of the RNS. I expect a change in RNS layout will only have a limited impact on the results.

91. Ref. 30 proposes a change from three 33% feedwater pumps to three 50% feedwater pumps, with the third spare being auto-started upon failure of one of the two normally operating. In response to an RQ (Ref. 35), Westinghouse stated that this DCP could modify the some of the inputs to its transient analysis but it did not expect the overall results and conclusions to be impacted.

92. Westinghouse says little about the impact of DCPs Refs 29 and 31, other than to imply that their impact on the reactor transient analysis will be less than that of the other changes. This is consistent with my own expectations, noting that spent fuel pool transient analysis is beyond the scope of this assessment report.

93. GRS reviewed Westinghouse’s claims and concluded that they were plausible (Ref. 12). However, it did express concerns that the impact of the Main Feedwater System (FWS) change (Ref. 30) could be more significant than Westinghouse stated. Specifically, it observes that there could be a negative impact on steam generator overfeeding scenarios. I put these concerns to Westinghouse via a RQ. In its response (Ref. 13), Westinghouse acknowledged that all three pumps operating simultaneously would be a limiting new fault scenario to consider. However, it went on to say that it expects the system piping arrangement to prevent the full capacity of the pumps (ie 150% flow) from reaching the steam generators. It also stated that it does not postulate a feedwater malfunction occurring simultaneously with a SGTR fault, and therefore its SGTR analysis is not impacted.

94. I am broadly content with Westinghouse’s response to GRS’s observations. It has recognised the need for the UK **AP1000** fault studies safety case to be revised in the future when Ref. 30 is incorporated into the design (beyond GDA). However, I believe an Assessment Finding (CP-AF-AP1000-FS-02) is needed to ensure that the full scope of GRS’s concerns is addressed. Inspection of the contents of Ref. 30 shows that it has not limited itself to describing the proposed physical changes to the plant and it clearly identifies a need to modify the plant control system and reanalyse some of the

transient analysis. Unfortunately, it has restricted its prompt for new analysis to loss of main feedwater faults (with an aim to demonstrate that they will not cause a reactor trip). As a result, I propose the following Assessment Finding:

- CP-AF-AP1000-FS-02: The licensee shall demonstrate in its design basis safety case that it has analysed all the implications of the design change to increase the feedwater system capacity on the UK **AP1000** plant (EPS-GW-GEE-003), including, but not necessarily limited to, loss of feedwater faults and increase in feedwater faults.

95. There are many other UK-specific DCPs in Ref. 15 that have been identified for incorporation into the (detail) design at a later date. Through an RQ, I asked Westinghouse to identify any that could impact on the fault studies transient analysis. In its response (Ref. 35), Westinghouse identified only two additional areas (covered by various DCPs) that could have a potential impact:

- The UK Diverse Actuation System (DAS) will include numerous UK-specific changes to functionality, platform and hardware.
- Operation at 50 Hz rather than 60 Hz will result in some specific differences to the design documentation and safety case arguments.

96. Both of these are well known to ONR and have been subject to additional regulatory attention during both the original GDA Step 4 assessment and the current work to close out the 51 GDA Issues, for example GI-AP1000-FS-03 and GI-AP1000-FS-04 (Ref. 36).

97. I am not aware of any other UK-specific DCPs that have yet to be implemented which could have a *significant* effect on the design basis transient analysis. Given the large number of DCPs identified in Revision 10 of Ref. 15, I am reliant on the effectiveness of Westinghouse's internal processes to monitor the potential impact of proposed changes. However, as I have stated previously, following some detailed investigations into Westinghouse's internal arrangements, I have sufficient confidence in its claim that no other UK-specific changes currently included within the GDA design reference point will have a significant impact on the design basis transient analysis included in Chapter 9 of the PCSR (Ref. 14).

4.2.4 Miscellaneous Changes Arising from Design Finalisation

98. Westinghouse states in Ref. 16 that its latest standard plant transient analysis ("2015 analysis of record") includes the latest design information on:

- rod drop times
- piping resistances
- piping configuration
- safety system equipment parameters
- initial conditions uncertainties

99. It claims that this information is consistent with the declared design reference point (specifically, Revision 7 of Ref. 15, but the subsequent revisions maintain the same reference date for standard plant DCPs) and is properly referenced and tracked using its internal processes.

100. I welcome the inclusion of these revised details in the calculations. If the design changes or better information becomes available, it is in line with my expectations established by SAPs AV.1, AV.3 and AV.4 (Ref. 9) that the transient analysis is updated in a controlled manner, even though it means the latest results will not be the same as those considered by ONR in GDA Step 4.

101. In its review, GRS found it could not independently confirm from the calculation notes it examined (see Annex 1) that the changes were consistent with any of the various UK design reference points (Ref. 13). As previously stated, I acknowledge that Westinghouse did not perform its standard plant analyses for the Core Reference Report (Ref. 17) or the “2015 analysis of record” with the UK safety case primarily in mind. It did not write the references reviewed by GRS anticipating that a third party would be contracted to examine their traceability to Ref. 15. I am therefore reliant on Westinghouse’s internal processes for controlling modifications and analysis methods to ensure that its claims have foundation. For the purposes of closing out this GDA Issue, I have sufficient confidence in Westinghouse’s internal processes for including the latest design information within its calculations. However, I recommend that Westinghouse and any future UK licensee look at ways of improving the traceability of its analysis assumptions to what will always be an evolving design reference point (see Section 4.8).

4.3 Changes in Analysis Methods and Assumptions

102. In Ref. 16, Westinghouse has summarised event-specific changes to transient analysis, highlighting where the results and discussion included in Chapter 9 of the PCSR (for the standard plant “2015 analysis of record” design basis analysis) are different from the equivalent EDCD analysis (Ref. 2) assessed by ONR during GDA Step 4. A few of the reasons it gives for differing results are physical modifications to the plant but many are due to changes in assumptions or improvements in methods.

103. An example of such a non-physical change is given for small-break LOCA faults. It states that in the newer analyses the limiting location of the single automatic depressurisation system (ADS) stage 4 failure has moved to the non-pressuriser loop after it had been discovered that this is more onerous than the equivalent failure on pressuriser loop.

104. Another notable change is to modelling of containment back pressure. In older analyses (such as those reported in Ref. 2), Westinghouse assumed bounding constant pressures in LOCA analysis while making no assumptions on containment back pressure in non-LOCA analyses. In the new work, LOCA analyses follow an iterative process that considers the mass and energy in the containment and the RCS, such that a transient containment pressure is used. For non-LOCA faults, a limiting containment pressure is assumed throughout the transient to bound the actual containment pressure.

105. I welcome the visibility provided by Ref. 16 of the changes to the modelling of specific faults. Looking to the future to an operational safety case reflecting the final design and analysis, a historic commentary of the differences between two interim versions of the safety case will be of little value. However, it is important at this stage because the fault studies conclusions set out in Ref. 1 (which supported the issue of the IDAC) were made following a detailed assessment of the previous transient analysis contained in Ref. 2. In addition, there is no intent to repeat this assessment despite the replacement of the majority of the results (presented in the form of tables and figures) and accompanying commentary with new content. Westinghouse asserts that despite the changes in the fine detail, there are no changes that impact on its overall claims on the UK **AP1000** plant’s ability to meet declared design basis acceptance criteria, and by extension no changes that impact on ONR’s Step 4 conclusions.

106. To investigate the basis of this assertion further, I asked GRS to undertake a detailed review of a selected sample of design basis faults. For the following faults, it looked at the original calculations that supported the EDCD (Ref. 2) and the latest calculations identified in Ref. 16 as being the basis for the revised PCSR safety case (Ref. 14):

- inadvertent opening of pressuriser safety valves

- inadvertent ADS
- 2-inch cold-leg small-break LOCA
- SGTR faults
- excessive increase in secondary steam flow
- inadvertent operation of the Passive Residual Heat Removal (PRHR) heat exchanger
- turbine trip
- loss of ac power to the plant auxiliaries
- loss of normal feedwater flow
- feedwater system pipe break
- partial loss of forced reactor coolant flow
- complete loss of forced reactor coolant flow
- reactor coolant pump shaft seizure
- rod withdrawal at power
- rod drop
- control rod ejection

107. These events were carefully chosen. GRS's objective was to a look at a broad range of faults that use different codes and methods (eg there are decreases in reactor coolant inventory faults, intact circuit faults and reactivity faults within the selection). Further down selection of the sample was made by identifying those faults where the new analysis shows a relevant reduction to the safety margins or where there is a large difference between the new and old results.

108. The findings of GRS's review on a fault-by-fault basis are set out in Ref. 12. An assessment at the detailed level GRS went to (changes in individual parameters and correlations used in complex thermal hydraulic codes) inevitably raised some questions. I put these to Westinghouse via an RQ and for the purposes of closing this GDA Issue, I am content with the response provided (Ref. 13). GRS's overall conclusions were that:

- The new calculations are appropriate for the design reference point it considered (Revision 6 of Ref. 15).
- The new calculations show that appropriate acceptance criteria are met.
- Many of the safety demonstrations are improved compared to the old analyses in terms of consistency with the design reference point and appropriateness of the assumptions made.
- In many cases, the changes in methodology and assumptions have a bigger effect on the results than the physical design changes.
- There are no issues that justify ONR changing its main conclusions from Ref. 1.

109. A significant portion of the faults reanalysed in the "2015 analysis of record" show increased safety margins to acceptance criteria to those demonstrated in Ref. 2. Notable exceptions are two of the decrease in reactor coolant inventory faults considered by GRS: inadvertent ADS and 2-inch cold-leg small-break LOCA. For the former, GRS observed that both the old and new calculations have a period without water injection but, where the old calculations did not predict core uncovery, the new ones do. For the latter, the period without injection is extended in the new calculations, and again core uncovery is predicted in a change from before. In both cases, the new calculations show a larger flow rate from the core makeup tanks (CMTs) (resulting in an earlier end to their injection function) and a slower mass flow from the pressuriser. As a result of the core uncovery, increases in peak clad temperature are predicted. Westinghouse attributes this to the change in assumed location of the limiting ADS stage 4 single failure. The safety limits are still met although the new assumptions on containment back pressure have a beneficial effect. "Like-for-like" calculations assuming a constant back pressure show even higher peak clad temperatures as a result of the change in single failure location assumption.

110. In its RQ response (Ref. 13) Westinghouse stated that it perceived no value in discussing in its latest safety case documentation the differences between the old results which contain an error (the non-limiting single failure assumption) and the new analysis which shows safety limits are met. I can accept this position, but these faults do illustrate that some of the detailed discussion included in Ref. 1 on the behaviour of individual transients made to support ONR's conclusions is now outdated. I judge that ONR's fault studies conclusions in Ref. 1 supporting the issue of an IDAC / DAC remain valid. Given the time that has passed since Westinghouse stopped its original GDA activities and the number of changes that have been made to both the **AP1000** design and transient analyses in the intervening period, coming to this judgement has not been a formality. However, it has ultimately been possible to reach this significant outcome as a result of the assessment described in this report and GRS's in-depth review (Ref. 12).

4.4 The Acceptability of Westinghouse's "Two-generation" Analyses for the Proposed Design Reference Point

111. Building upon the assessment conclusions reached in the above subsections, I welcome the replacement of the original standard plant transient analysis in the UK **AP1000** safety case with the "2015 analysis of record" analysis. It is consistent with Revision 6 of Ref. 15 (DCPs generated up to 31 January 2015) and I accept Westinghouse's arguments that this effectively means it is consistent with the final design reference point applied to GDA (Revision 10 of Ref. 15).

112. Westinghouse has chosen not to update the UK-specific analyses performed circa 2010 (unless it was required to close out other fault studies GDA Issues) but it is claiming they are applicable to the final design reference point. This assertion is not as well established as the similar claim for the "2015 analysis of record" analysis. Both GRS and I accept that the biggest impacts to the design basis transient analysis were introduced by the AFC-associated changes, and these were included within the 2010 UK-specific work. Westinghouse has not robustly demonstrated the consistency of the 2010 UK-specific work to a UK design reference point or standard plant analyses described in the Core Reference Report (Ref. 17). The main basis for assuming that the UK-specific work is consistent with Ref. 17 is the fact that the work was being done contemporaneously. However, having accepted that the impact of the post-AFC changes was small, I am satisfied for the purposes of GDA that UK-specific analyses are adequate for Revision 10 of Ref. 15.

113. When combined together, it is my judgement that the "two-generation" approach provides a broadly consistent set of analyses which are appropriate for the design reference point and that they adequately demonstrate that all the major fault studies safety case claims are supported in accordance with SAP FA.7. This is a major conclusion facilitating the closure of Action 1 of GI-AP1000-FS-02.

114. A comparison of the latest design basis analysis available with equivalent analysis that existed at the end of GDA Step 4 is of ever-decreasing value. However, I believe it is worth noting that the current status of the analysis (in terms of self-consistency and traceability to the UK **AP1000** design) is significantly improved from any previous phase of the GDA process.

115. Westinghouse and the future licensee can and should make further improvements, but I am satisfied that this is acknowledged by Westinghouse. It has identified a need to revisit the totality of its design basis analysis during site licensing to demonstrate that it matches the as-built design (see Section 4.2 of Ref. 16). There is also an Assessment Finding from GDA Step 4 (AF-AP1000-FS-24, Ref. 1) for the future licensee to substantiate the RELAP-5 code used extensively for the UK-specific analysis, or more likely, repeat the 2010 analysis with the validated codes used for the standard plant events. When this work is undertaken, there will be an opportunity to provide a single

generation of analysis, with improved visibility to the design reference point applicable at that point in time. ONR will be able to review the adequacy of the analysis as part of routine site licensing regulatory interactions. However, the current provision is adequate for the purposes of GDA.

4.5 The Adequacy of the PCSR Summary of the Design Basis Safety Case

116. ONR's assessment of the design basis safety case was undertaken on the EDCD (Ref. 2) for the standard plant analyses and RQ / regulatory observation responses for the UK-specific analyses. Westinghouse produced a PCSR towards the end of GDA Step 4 which aimed to consolidate the two aspects but it was submitted too late for assessment.

117. To address this GDA Issue, the other fault studies GDA Issues, and GI-AP1000-CC-02 (Ref. 7), Westinghouse has chosen to rewrite the majority of the fault studies chapter of the PCSR (Ref. 14) from that included in the (end of) GDA Step 4 version of the PCSR (Ref. 37). As a result, and in accordance with advice from Westinghouse, I have not assessed the original Ref. 37 for the purposes of closing this GDA Issue.

118. The overall adequacy of the PCSR, including the fault studies-related chapters, is discussed as part of ONR's assessment of GI-AP1000-CC-02 (Ref. 7) outside of this assessment report. However, the wording of GI-AP1000-FS-02, Action 1 is clear that the final GDA PCSR needs to clearly demonstrate why the analysis it references is appropriate for the design reference point. Therefore, as a final step to facilitate closure of Action 1, I have looked at the adequacy with which Ref. 14 sets out the position established by Ref. 16.

119. I make the following observations about Chapter 9 of the PCSR:

- The introduction of Chapter 9 clearly states that the analyses it presents are directly applicable to the UK **AP1000** design reference point (Revision 10 of Ref. 15). It also discusses the expected impact of UK-specific design changes that are not included within the analyses.
- The introduction of Chapter 9 identifies Ref. 16 as the source of the technical information that it presents. Therefore, the safety case reader has a route from the PCSR, via Appendix A of Ref. 16, to the individual calculations that generated the PCSR results. Noting the previously mentioned limitations identified by GRS on linking these calculations to a specific design reference point through this route, it is possible to see the date of a calculation, the methods used and the assumptions made.
- From a broad high-level review, supported by a more detailed examination of a smaller sample, I have found Appendix A of Ref. 16 to be a comprehensive and accurate linking document between the PCSR results and the supporting calculations (both the standard plant and UK-specific analyses). This traceability is a notable improvement against ONR's expectations for a safety case from that provided by the EDCD. There are some gaps in Ref. 16 as a result of oversights (for example, the calculations which support the Chapter 9 Appendix D discussion on containment performance) or the work to address a GDA Issue only being finalised after Ref. 16 had been issued. However, in these cases, the text of the PCSR adequately refers directly to an appropriate reference.
- The bulk of Chapter 9 of the PCSR has its origins in Chapter 15 and (in the case of shutdown faults) Chapter 19E of the EDCD. A lot of the generic text on **AP1000** plant systems and behaviour, the level of detail provided, and the tables and figures included are the same as that seen in Ref. 2. However, all the standard plant transient analysis results and supporting commentary has been replaced with new text, tables and figures for the "2015 analysis of record" analysis.

- For the first time, the UK-specific transient analyses have been integrated alongside standard plant analysis to support the claims and arguments identified for a UK design basis safety case, including consideration of events not included in the EDCD and demonstrations of diverse protection for frequent faults.

120. It is therefore my judgement that the updated PCSR (Ref. 14) delivers many of the key expectations for a safety case identified in Subsection 2.2.1 from NS-TAST-GD-051 (Ref. 6), and demonstrates a major improvement from the position at the end of GDA Step 4. I am also satisfied that it, together with Ref. 16, provides an appropriate basis for closing Action 1 of GI-AP1000-FS-02.

4.6 SAC and Future Limits

121. Following a number of discussions with Westinghouse, I have undertaken a high-level review of Ref. 19 to assess its adequacy for meeting the requirements of GI-AP1000-FS-02, Action 2.

122. I have established that Ref. 19 is based on the standard plant version of the SAC maintained by Westinghouse. Westinghouse does not routinely change the SAC every time it repeats its thermal-hydraulic transient analysis. It generated a new SAC for the AFC work, allowing for the expected first cycle and subsequent reloads up to the equilibrium cycle. This SAC has remained largely unchanged since and has formed the basis for subsequent design basis analyses (eg the “2015 analysis of record”). At the end of GDA Step 4, the design basis analysis was a mixture of AFC and pre-AFC work, therefore it was not clear which SAC should apply. As discussed in the previous subsections, all the extant design basis analysis is now of a broadly consistent generation and all assume the AFC. Therefore, I consider it appropriate for Ref. 19 to have its origins in an AFC-informed standard plant SAC.

123. Ref. 19 states that it is an up-to-date document, incorporating some minor changes identified for the standard plant which have yet to be consolidated into a single document SAC outside of the UK. Again, I consider this is to be an appropriate approach to take.

124. It does have some differences from the standard plant SAC:

- It expresses the limits in both metric and non-metric units. Metric units are needed for GDA but I recognise the value in maintaining the original non-metric entries which are routinely used in Westinghouse’s internal computer codes and therefore useful to a SAC user checking values.
- It has a UK-specific section (Section 6) which specifies additional limits that are not needed for the scope of the standard plant design basis analysis. Notably, this section includes limits for ATWS events and some diversity demonstrations for frequent faults. This addresses a key requirement of GI-AP1000-FS-02, Action 2.
- During the design phase of a reactor build programme, Westinghouse’s nuclear design group (responsible for the core design) ‘owns’ the standard plant SAC. Many SAC items are listed as TBD (to be determined) as a prompt for thermal-hydraulic analysts outside of the nuclear design group to check their analysis results for applicability with appropriate safety limits. In Ref. 19, these TBD items have been replaced with referenced values from the transient analysis included in the PCSR, on the basis that they have been confirmed to be acceptable. Again, this addresses a key requirement of GI-AP1000-FS-02, Action 2, providing clarity on what has been assumed / demonstrated during GDA.
- As an internal interface document between Westinghouse groups, it is my understanding that the SAC is not a formal licensing submission in, for

example, the US. However, I consider Ref. 19 to be a useful part of the UK **AP1000** safety case, providing the additional traceability (alongside Ref. 16) to claims made in the PCSR.

125. Given the observations above, I am satisfied that Westinghouse has provided a complete set of core design limits that reflect the design reference point (Ref. 15) and the design basis analysis presented in the latest version of the PCSR (Ref. 14). Westinghouse has met the requirements of GI-AP1000-FS-02, Action 2, and introduced a document into the UK **AP1000** safety case which strengthens its compliance with the expectations for referencing and traceability set out in NS-TAST-GD-051 (Ref. 6).

4.7 Assessment Findings

126. Assessment Findings are matters that 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 detail design, construction and commissioning stages.

127. 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.

128. In my assessment I found one example of a matter which met these criteria. As set out in Subsection 4.2.3, the UK **AP1000** design reference point (Ref. 15) includes a change to the feedwater pumps. However, this change is not reflected in any of the design basis analysis presented in Chapter 9 of the PCSR. While the DCP introducing the change does identify several important issues for the future licensee to address when it is eventually incorporated, it does not identify the need for increases in feedwater faults to be revaluated. Therefore, I propose the following Assessment Finding:

- CP-AF-AP1000-FS-02: The licensee shall demonstrate in its design basis safety case that it has analysed all the implications of the design change to increase the feedwater system capacity on the UK **AP1000** plant (EPS-GW-GEE-003), including, but not necessarily limited to, loss of feedwater faults and increase in feedwater faults.

5 CONCLUSIONS

129. This report presents the findings of the assessment of GDA Issue GI-AP1000-FS-02 relating to the **AP1000** GDA closure phase.

130. Westinghouse has defined a new design reference point for the UK **AP1000** plant that includes design changes generated both overseas and in the UK up to 2016. For that design reference point, Westinghouse has proposed two generations of design basis analyses which it claims together demonstrate that all appropriate safety criteria are met:

- the "2015 analysis of record" covering all the standard plant design basis events identified in Chapter 15 of the EDCD; and
- UK-specific analyses performed circa 2010 for design basis initiating events and fault sequences not included within the EDCD (eg to demonstrate diverse protection for frequent design basis faults) but which are to be incorporated into the PCSR.

131. It is my judgement that Westinghouse has robustly demonstrated the applicability of the "2015 analysis of record" to the declared design reference point. The applicability of the UK-specific analyses has not been demonstrated to the same level but I agree with Westinghouse that it is sufficient for the purposes of GDA. Overall, the consistency and traceability of all the analysis is significantly improved from the position at the end of GDA Step 4.

132. Westinghouse has claimed that most significant design changes which impact on the design basis analysis were included in AFC work that was being undertaken contemporaneously with GDA Step 4. I am content with this assertion, informed by the detailed review undertaken by GRS (Ref. 12).

133. Despite the bulk of the analysis assessed during GDA Step 4 being replaced in the PCSR by the new "2015 analysis of record" results, I am satisfied that all relevant safety criteria are still met, and by extension that ONR's fault studies assessment conclusions from GDA Step 4 remain valid (Ref. 1). Again, this judgement is informed by GRS's detailed review (Ref. 12).

134. The PCSR consolidates the standard plant analyses with the UK-specific analyses in a single place. Clear references to the appropriate design reference point and the supporting calculations are provided for the first time, improving the level to which Westinghouse's major fault studies submission meets ONR's expectations for a safety case.

135. Westinghouse has identified a need to revisit its design basis analysis during site licensing to demonstrate that it matches the as-built design (Ref. 16). There is also an Assessment Finding from GDA Step 4 (AF-AP1000-FS-24, Ref. 1) for the future licensee to repeat the UK-specific analysis undertaken with the RELAP-5 code with the validated codes used for the standard plant events. This will provide an opportunity for further strengthening of the consistency between the design basis safety analysis and the applicable design reference point, which ONR will be able to review as part of routine regulatory interactions.

136. A small number of UK-specific design changes included in the design reference point have yet to be incorporated into the transient analysis. I have no objections to this and generally I have confidence in Westinghouse's procedures for ensuring that these changes are appropriately reflected in future design and safety case documentation. However, the DCP introducing a change to FWS does not explicitly identify all the potential fault studies issues that will need to considered. As a result, I have raised

Assessment Finding CP-AF-AP1000-FS-02 to ensure a future licensee will address the concerns identified by GRS on overfeeding faults.

137. Through all these aspects, I am satisfied that Westinghouse has addressed all the requirements of GI-AP1000-FS-02, Action 1.

138. In addition, Westinghouse has generated a UK-specific SAC and future limits document (Ref. 19). This is consistent with the latest design reference point and standard plant safety analysis, but its scope has been extended to include parameters that are unique to the UK design basis safety case. I am satisfied that this document addresses the requirements of GI-AP1000-FS-02, Action 2.

139. On this basis, I recommend that GI-AP1000-FS-02 is closed.

6 REFERENCES

1.	Step 4 Fault Studies – Design Basis Faults Assessment of the Westinghouse **AP1000** Reactor, ONR-GDA-AR-11-004a Revision 0, November 2011, TRIM 2010/581406.
2.	**AP1000** European Design Control Document, EPS-GW-GL-700 Rev. 1, March 2011, TRIM 2011/81804.
3.	UK **AP1000** Assessment Plan for Closure GDA Fault Studies Issues 1 to 8, ONR-GDA-AP-14-002 Revision 0, March 2015, TRIM 2015/51535.
4.	ONR Guidance on Mechanics of Assessment, TRIM 2013/204124.
5.	GDA Guidance to Requesting Parties. www.onr.org.uk/new-reactors/ngn03.pdf
6.	The Purpose, Scope, and Content of Safety Cases, NS-TAST-GD-051 Revision 4. www.onr.org.uk/operational/tech_asst_guides/ns-tast-gd-051.pdf
7.	GDA Issue "PCSR to Support GDA", GI-AP1000-CC-02, Revision 3. www.onr.org.uk/new-reactors/reports/step-four/westinghouse-gda-issues/gi-ap1000-cc-02.pdf
8.	Purpose and Scope of Permissioning, NS-PER-GD-014 Revision 5, TRIM 2015/304735.
9.	Safety Assessment Principles for Nuclear Facilities, 2014 Edition Revision 0, ONR. November 2014. http://www.onr.org.uk/saps/saps2014.pdf
10.	IAEA Standards and Guidance: International Atomic Energy Agency (IAEA) Safety Standards Series – Safety of Nuclear Power Plants: Design, Specific Safety Requirements (SSR) 2/1 Revision 1, 2016 International Atomic Energy Agency (IAEA) Safety Standards Series – General Safety Requirements (GSR) Part 4: Safety Assessment for Facilities and Activities IAEA 2007 International Atomic Energy Agency (IAEA) Safety Standards Series – Safety Guide: Safety Assessment and Verification for Nuclear Power Plants 2001 (This publication has been superseded by GSR Part 4 and SSG-2) www.iaea.org
11.	Western European Nuclear Regulators Association: Reactor Safety Levels for Existing Reactors September 2014 WENRA Statement on safety objectives for new nuclear power plants WENRA November 2010 Safety of new NPP designs WENRA March 2013 www.wenra.org
12.	Review of the Applicability of Submitted UK **AP1000** Design Basis Fault Modelling to the GDA Reference Design, GRS-ONR255-D1.2, February 2016, TRIM 2016/143232.
13.	Request for Feedback on GRS Comments on GI-AP1000-FS02 Submissions, RQ-AP1000-1568, TRIM 2016/255150.
14.	**AP1000** Pre-Construction Safety Report, UKP-GW-GL-793 Revision 1: Chapter 9, January 2017, TRIM 2017/43700.

15.	**AP1000** Design Reference Point for UK GDA, UKP-GW-GL-060 Revision 5, Reference Date 16 September 2010, TRIM 2011/560310 Revision 6, Reference Date 31 January 2015, TRIM 2015/201948 Revision 7, Reference Date 31 March 2016, TRIM 2016/227424 Revision 8, Reference Date 31 March 2016, TRIM 2016/378399 Revision 9, Reference Date 31 March 2016, TRIM 2016/446340 Revision 10, Reference Date 31 March 2016, TRIM 2017/18158 Note, Revisions 7, 8, 9 and 10 all assume a common reference date for "standard" **AP1000** design. Revisions 8 and 9 included UK-specific changes subsequently identified as a result of closing GDA issues.
16.	UK Fault Studies Analysis Basis, UKP-SSAR-GLR-001 Rev. 0, August 2016, TRIM 2016/333118.
17.	**AP1000** Core Reference Report, APP-GW-GLR-153 Revision 1, May 2015, TRIM 2016/107802.
18.	**AP1000** Pre-Construction Safety Report, UKP-GW-GL-793 Revision 1: Chapter 8, January 2017 TRIM 2017/43700.
19.	**AP1000** Safety Analysis Checklist (SAC) & Future Limits, UKP-SSAR-F5-001, Rev. 0, July 2016, TRIM 2016/278732.
20.	Step 4 Cross-cutting Topics Assessment of the Westinghouse **AP1000** Reactor, ONR-GDA-AR-11-016 Revision 0, November 2011, TRIM 2010/581515.
21.	WEC Presentation to ONR on GI-AP1000-FS-02 and GI-AP1000-FS-07, July 2015, TRIM 2015/258080.
22.	GDA Close-out for the **AP1000** Reactor, GDA Issue GI-AP1000-FS-01: Spent Fuel Pool Safety Case, ONR-NR-AR-16-022 Revision 0, March 2017, TRIM 2016/274909.
23.	Request for References to Support TSC Assessment of GI-AP1000-FS-02 Submissions, RQ-AP1000-1390, TRIM 2015/350385.
24.	TSC Assessment of GI-AP1000-FS02 – Questions following December 2015 Meetings, RQ-AP1000-1454, TRIM 2016/16131.
25.	Incorporation of Advanced First Core Design, APP-GW-GEE-3234, February 2012, TRIM 2015/346101.
26.	UK-AP1000 Fuel and Core Design Change Proposals Assessment, ONR-NR-AR-16-087 Revision 0, November 2016, TRIM 2016/424064.
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28.	Normal Residual Heat Removal System (RNS) Changes for Europe, EPS-GW-GEE-001, December 2009, TRIM 2016/197524.
29.	Spent Fuel Pool Cooling System (SFS) Changes to Meet European Requirements, EPS-GW-GEE-002, December 2009, TRIM 2016/197551.
30.	Main Feedwater System (FWS) Changes to Meet European Requirements, EPS-GW-GEE-003, December 2009, TRIM 2016/195197.
31.	Component Cooling Water System (CCS) and Service Water System (SWS) Changes, EPS-GW-GEE-004, December 2009, TRIM 2016/197560.
32.	KSB Wet Winding Reactor Coolant Pumps (RCPs) Implementation, EPS-GW-GEE-006, December 2009, TRIM 2016/195201.

33.	Differences in EDCD and US DCD Modelling Assumptions, RQ-AP1000-1365, TRIM 2015/315103.
34.	GDA Issue "Potential Enhancements to the Diverse Safety Injection System", GI-AP1000-FS-05, www.onr.org.uk/new-reactors/reports/step-four/westinghouse-gda-issues/gi-ap1000-fs-05.pdf
35.	Documents in the UK **AP1000** DRP with foreseen UK-specific versions, RQ-AP1000-1405, TRIM 2015/414306.
36.	GDA close-out for the **AP1000** reactor: GDA issues GI-AP1000-FS-03 "Diversity for Frequent Faults" and GI-AP1000-FS-04 "Use of In-core Detectors to Protect Against Adverse Power Distributions", ONR-NR-AR-16-024, March 2017, TRIM 2016/274914.
37.	**AP1000** Pre-Construction Safety Report, UKP-GW-GL-793 Rev. 0, March 2011, TRIM 2011/192251.
38.	Step 4 Management of Safety and Quality Assurance Assessment of the Westinghouse **AP1000** Reactor, ONR-GDA-AR-11-013 Revision 0, 11 November 2011, TRIM 2010/581518.

Table 1: List of DCPs included within the AFC update to the standard plant design basis analysis

DCP	Description	Included in Rev. 5 of Ref. 15	Included in Rev. 10 of Ref. 15
Core design and reactivity control related changes			
APP-GW-GEE-499	Fuel Design Updates	Y*	Y
APP-GW-GEE-2267	Incorporation of the Robust Protective Grid (RPG)	N	Y
APP-GW-GEE-1951	Enhancements to RCCA for improved reliability / manufacturability	Y*	Y
APP-GW-GEE-2268	Enhanced, tungsten-based GRCA (grey rod) design	N	Y
Other design changes			
APP-GW-GEE-040	Increase in Overall Pressuriser Design Volume	Y*	Y
APP-GW-GEE-056	Addition of Neutron Pads	Y*	Y
APP-GW-GEE-067	PMS Functional Design Changes	Y*	Y
APP-GW-GEE-110	Reactor Coolant Pump Design	Y*	Y*
APP-GW-GEE-111	Addition of Flow Skirt to the Reactor Vessel Lower Head	Y*	Y
APP-GW-GEE-126	Changes associated with MSSV	Y*	Y*
APP-GW-GEE-394	RCCA Drop Time Increase	Y*	Y
APP-GW-GEE-411	Addition of an In-Core Instrumentation Grid and Changes to the Integrated Head Package	Y*	Y

(*) indicates the DCP was marked as not fully incorporated in the design documentation and safety case at the time of issue of the identified revision of Ref. 15.

Annex 1: List of supporting references considered by GRS

In addition to the main submissions provided to address this GDA Issue, ONR's TSC considered a significant number of historic and extant Westinghouse documents as part of a targeted sampling assessment. Further details are provided in Ref. 12.

- **AP1000** RCCA Drop Time Safety Analysis Input, APP-GW-GEE-394, Rev. 3, 26 April 2010
- Changes Associated with the Main Steam Safety Valve, APP-GW-GEE-126, Rev. 1, 2 March 2007
- Addition of Flow Skirt to the Reactor Vessel Lower Head and Tapered Edge to Lower Core Support Plate, APP-GW-GEE-111, Rev. 1, 24 July 2009
- Design Change Proposal for Reactor Coolant Pump Design, APP-GW-GEE-110, Rev. 1, 17 March 2007
- PMS Functional Design Changes, APP-GW-GEE-067, Rev. 1, 2 June 2008
- Reactor Vessel Fluence Reduction-Addition of Neutron Pads and Increase in Reactor Diameter, APP-GW-GEE-056, Rev. 1, 14 October 2008
- **AP1000** Pressurizer Design, APP-GW-GEE-040, Rev. 3, May 2006
- **AP1000** Transient Analysis Safety Analysis Reconciliation, APP-SSAR-GSC-199, Rev. 0, May 2015
- **AP1000** Dropped Rod Analysis for Advanced First Core Analysis Project (AFCAP), APP-SSAR-GSC-138, Rev. 0, July 2010
- **AP1000** Loss of Flow Analyses to Support the Advanced First Core Analysis Project (AFCAP), APP-SSAR-GSC-147, Rev. 1, May 2015
- **AP1000** Plant Small-Break LOCA Steady-State Model, APP-SSAR-GSC-130, Rev. 2, September 2014
- **AP1000** Plant Small-Break Loss-of-Coolant Accident (SBLOCA) 2-Inch & 10-Inch Cold Leg Break and Inadvertent ADS Transients, APP-SSAR-GSC-131, Rev. 1, February 2015
- **AP1000** Steam Generator Tube Rupture Analysis for the Advanced First Core, APP-SSAR-GSC-174, Rev. 0, November 2012
- **AP1000®** Steam Generator Tube Rupture Analysis for the Advanced First Core, APP-SSAR-GSC-174, Rev. 1, July 2013
- **AP1000** Steam Generator Tube Rupture Analysis, APP-SSAR-GSC-516, Rev. 0, May 2002
- **AP1000** Complete Loss of Forced RCS Flow Analysis for SAR, November 2003
- **AP1000** Dropped Rod Analysis, APP-SSAR-GSC-553, Rev. 0, September 2003
- **AP1000** DCD SBLOCA Analysis – 10-Inch Transient Runs, APP-SSAR-GSC-595, Rev. 0, September 2002
- Summary of **AP1000** Plant Core Reference Report Best Estimate Large Break Loss of Coolant Accident Analysis Results and Subsequent Evaluations, APP-SSAR-GSR-001, Rev. 0, August 2014
- **AP1000** – Examination of the Impact of Multiple Steam Generator Tube Ruptures, APP-SSAR-GSC-005, Rev. 0, February 2011
- **AP1000** European Design Control Document, Chapter 15 Accident Analysis, EPS-GW-GL-700, Rev. 1, January 2010
- RQ-AP1000-1372, Requests for references to support the assessment of GI-AP1000-FS-02 submissions, Full Response, 7 August 2015
- RQ-AP1000-1390, Request for references to support TSC assessment of GI-AP1000-FS-02 submissions, Full Response, 17 September 2015
- RQ-AP1000-1405, Documents in the UK **AP1000** DRP with foreseen UK-specific versions, Full Response, 4 November 2015
- Rod Shadowing on Excore Detectors, DCP APP-GW-GEE-1551, Rev. 0, September 2010

- **AP1000** ADS-4 Form Loss Impact On NOTRUMP SBLOCA Transient, APP-SSAR-GSC-627, Rev. 0, November 2003
- **AP1000** AFCAP Small Break Loss-of-Coolant Accident (SBLOCA) Alternate ADS-4 Failure Assessment for IRs-13-169-M037, APP-SSAR-GSC-757, Rev. 1, August 2013
- **AP1000** RCS Depressurization Analyses for DCD, APP-SSAR-GSC-541, Rev. 0, March 2002
- Advanced First Core Analysis Program – RCS Depressurization Analysis, APP-SSAR-GSC-144, Rev. 1, November 2011
- **AP1000** DCD SBLOCA Analysis – Transient Runs, APP-SSAR-GSC-583, Rev. 0, November 2002
- **AP1000** Small Break LOCA Advanced First Core Pressurizer Spray Line Mass and Energy Releases and Transient Cases: 2-inch and 10-inch Cold Leg Breaks, APP-SSAR-GSC-745, Rev. 0, June 2010
- Advanced First Core LOFTRAN Base Deck, APP-SSAR-GSC-135, Rev. 1, December 2014
- **AP1000** Rod Withdrawal at Power Analysis for DCD, APP-SSAR-GSC-539, Rev. 0, May 2002
- **AP1000** – Advanced First Core Rod Cluster Control Assembly (RCCA) Bank Withdrawal at Power, APP-SSAR-GSC-137, Rev. 2, October 2014
- **AP1000** Dropped Rod Analysis, APP-SSAR-GSC-553, Rev. 0, October 2003
- **AP1000** Dropped Rod Analysis for Advanced First Core Analysis Project (AFCAP), APP-SSAR-GSC-138, Rev. 0, July 2010
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- **AP1000** Partial Loss of Flow Event, APP-GW-GSC-070, Rev. 0, (February) 2008
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- Revision 1 of the **AP1000** Reference Input for Non-LOCA Analyses, APP-GW-GSC-010, Rev. 0, January 2002
- Incorporation of Advanced First Core Design, APP-GW-GEE-3234, Rev. 0, February 2012
- LOFTRAN Version 15.1.0 Software Change Specification and Validation Package, CN-TA-11-66, Revision 0, August 31, 2013

- **AP1000** Locked Rotor/Shaft Shear Analysis, APP-SSAR-GSC-509, Rev. 0, November 2003

Annex 2: Assessment Findings to be addressed during the Forward Programme – Fault Studies

Assessment Finding No.	Assessment Finding	Report Section Reference
CP-AF-AP1000-FS-02	The licensee shall demonstrate in its design basis safety case that it has analysed all the implications of the design change to increase the feedwater system capacity on the UK **AP1000** plant (EPS-GW-GEE-003), including, but not necessarily limited to, loss of feedwater faults and increase in feedwater faults.	4.2.3