New Reactors Programme

GDA close-out for the AP1000 reactor

GDA Issue GI-AP1000-RP-01 Rev 0: Spent Fuel Pool – Criticality Safety Case

Assessment Report: ONR-NR-AR-16-019-AP1000
Revision A
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EXECUTIVE SUMMARY

Westinghouse Electric Company LLC is the reactor design company for the **AP1000**® pressurised water reactor (PWR). This report is the Office for Nuclear Regulation's (ONR's) assessment of the Westinghouse submission to address Generic Design Assessment (GDA) Issue GI-AP1000-RP-01 Revision 0: "Spent Fuel Pool – Criticality Safety Case for the **AP1000** PWR.

GDA Issue GI-AP1000-RP-01 arose in Step 4 because:

- The criticality safety justification for the **AP1000** spent fuel pool design required credit to be taken for burn-up and soluble neutron absorber (boron). These parameters were to be controlled through administrative arrangements and software control systems.
- IAEA guidance suggests that criticality safety within a spent fuel pool should not rely on soluble neutron poison (SSG-15). Where burn-up is credited, IAEA guidance advises that appropriate verification of the specified burn-up is required (SSG-15), alongside substantiation of the human and management systems to control materials (SSG-27).
- The hierarchy of safety measures within ONR's Safety Assessment Principles recognise preference for passive safety systems over active or administrative controls. ONR's expectation is that for spent fuel pools at power stations it should be reasonably practicable to submit an approach that relies on passive safety measures that do not rely on control systems, active safety systems or human intervention.
- At Step 4, Westinghouse had not adequately demonstrated why it is not reasonably practicable to design the **AP1000** spent fuel pool such that criticality control is achieved through geometrical control and fixed poisons alone.

In line with their resolution plan, Westinghouse has submitted its **AP1000** Spent Fuel Pool Design ALARP assessment, which captures the output of a review of spent fuel pool criticality management options. The review proposes a modified spent fuel racking design capable of maintaining criticality safety, both for fresh fuel and spent fuel, without a need to credit soluble boron. This change is captured within an associated Design Change Proposal (DCP).

I have reviewed Westinghouse's submission in this report and conclude that:

- Westinghouse has carried out an adequate review of spent fuel pool criticality safety management to address the GDA issue.
- Westinghouse's ALARP option, to use a Region 1 spent fuel pool storage rack throughout the entire pool, satisfies the action set by the original GDA issue and allows its closure.

A DCP captures the required changes to the plant design and includes mark-ups of impacted sections of the PCSR. Westinghouse is updating the PCSR chapters, and a review of these is being undertaken to address Regulatory Issue GI-AP1000-CC-02, so this is not considered in my report. This does not prevent close-out of the GDA issue in my assessment.

My judgement is based upon the following factors:

- Westinghouse has considered practicable options for spent fuel pool criticality safety management, and has made appropriate reference to relevant practice at other nuclear facilities.
- Westinghouse has drawn on a diversity of expertise to inform the decision-making process to determine which option ensures risks are reduced to ALARP.
- A previous review of the Westinghouse criticality calculation approach at Step 4 concluded that the computational techniques used to evaluate the criticality risk are

comprehensive, conservative and performed adequately. Westinghouse has not produced new calculations, so I consider the existing review to remain valid.

- Westinghouse's forward proposal does not rely on the provision of administrative controls, software systems, or active engineering to manage the criticality hazard.
- Criticality safety of both fresh and spent fuel is achieved without credit taken for soluble boron in the spent fuel pool water, or fuel burn-up characterisation.
- The proposed option achieves the minimum 10 years of fuel cooling specified within the Westinghouse resolution plan (a value Westinghouse have taken from European Utility Requirements Document (EURD)).

No new assessment findings have been raised during closure of this GDA issue, but I make reference to a number of existing assessment findings raised at Step 4 that remain relevant going forward. I propose no addition or amendment to these findings as a result of this work, and they do not prevent close-out of the GDA issue.

In summary, I am satisfied that GDA Issue GI-AP1000-RP-01 Revision 0 can be closed.

LIST OF ABBREVIATIONS

AF	Assessment Finding
ALARP	As Low As Reasonably Practicable
DAC	Design Acceptance Confirmation
DCP	Design Change Proposal
EURD	European Utility Requirements Document
GDA	Generic Design Assessment
GRS	Gesellschaft fur Anlagen und Reaktorscherheit
HOW2	An ONR process management system
IAEA	International Atomic Energy Agency
IDAC	Interim Design Acceptance Confirmation
MDEP	Multinational Design Evaluation Programme
OECD-NEA	Organisation for Economic Co-operation and Development - Nuclear Energy Agency
ONR	Office for Nuclear Regulation
PCSR	Pre-Construction Safety Report
PWR	Pressurised Water Reactor
RGP	Relevant Good Practice
SAPs	Safety Assessment Principles
SFAIRP	So Far As Is Reasonably Practicable
SFP	Spent Fuel Pool
SSG	(IAEA) Specific Safety Guide
TAG	Technical Assessment Guide
TSC	Technical Support Contractor
US NRC	United States (of America) Nuclear Regulatory Commission

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1 INTRODUCTION

1.1 Background

1. Westinghouse Electric Company 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 the award of a Design Acceptance Confirmation (DAC) and before any nuclear safety related construction can begin on site. Westinghouse re-entered GDA in 2014 to close the 51 issues.

2. The related GDA Step 4 report is published on our website (www.onr.org.uk\\new-reactors\\ap1000\\reports.htm). This provides the assessment underpinning the GDA issue. Further information on the GDA process in general is also available on our website (www.onr.org.uk\\new-reactors\\index.htm).

3. GDA Issue GI-AP1000-RP-01 Revision 0 (Ref.1) states "Westinghouse has not adequately demonstrated why it is not reasonably practicable to design the AP1000 SFP [spent fuel pool] such that criticality control is achieved through geometrical control and fixed poisons alone.*"* The issue was raised because the criticality safety case for the spent fuel pool presented by Westinghouse at Step 4 relied on controls relating to characterisation of fuel burn-up and use of soluble boron in the pond water. ONR considers that these approaches are not commensurate with current International Atomic Energy Agency (IAEA) and Office for Nuclear Regulation (ONR) good practice guidance for new facilities.

4. This report is the ONR's assessment of the Westinghouse submission to address GDA Issue GI-AP1000-RP-01 Revision 0 – Spent Fuel Pool – Criticality Safety Case for the **AP1000®** pressurised water reactor.

1.2 Scope

5. The scope of the GDA issue is clearly identified within its associated GDA issue resolution plan (Ref. 2). This issue (GI-AP1000-RP-01 Revision 0) is associated with criticality control in the spent fuel pool (SFP). ONR considered that Westinghouse had not adequately demonstrated why it was not reasonably practicable to design the **AP1000** spent fuel pool such that criticality control is achieved through geometrical control and fixed poisons alone.

6. Within their resolution plan, Westinghouse undertook to "provide a safety case, with supporting evidence, which demonstrates that criticality control of the spent fuel pool is assured for all foreseeable operating conditions through geometrical control and fixed poisons alone". To this end, Westinghouse undertook to deliver the following key submissions to address GDA Issue GI-AP1000-RP-01:

   - An overall UK ALARP assessment, including assessment of all options described in the Resolution Plan (in addition to any new options that may have become available since 2011) and a demonstration that risks have been reduced as low as reasonably practicable (ALARP) for the selected solution.
   - Summary document describing criticality analyses for the options presented in the Resolution Plan (in addition to any new options that may have become available since 2011), as well as the criticality analyses themselves and supporting documentation.
   - A proposed design concept for the spent fuel pool, documented in a Design Change Proposal (DCP).
   - Mark-ups of affected licensing documents including chapters 6, 9, 24 and 26 of the Pre-Construction Safety Report (PCSR).

7. The scope of my assessment is detailed in an assessment plan (Ref. 3). Where I judged it necessary in my role as criticality safety specialist, I have undertaken a review of relevant documentation (including selected supporting references) to ensure adequate evidence exists to support criticality safety case claims required to close the GDA issue. During my review, it was not my intention to re-visit areas already found by ONR to be satisfactory unless, during my assessment, important safety issues emerged that require the expansion of my assessment scope.

8. The following items are outside the scope of the assessment:

- Resolution of any Assessment Findings (AFs) identified within either the Step 4 GDA reports, or identified within the assessment reports produced to support closure of GDA issues. Suitable closure of AFs shall be the responsibility of a future licensee and assessment of these will be undertaken post-GDA in site specific activities by ONR.
- Site-specific elements of the **AP1000** PWR design. These will be assessed by ONR as part of any future site-specific activities.
- Aspects in regards to the scope of the Environment Agency's assessment.

1.3 Method

9. The methodology for the assessment follows HOW2 guidance on mechanics of assessment within the ONR (Ref. 4), and has been carried out by sampling a number of key areas of the Westinghouse submissions supporting resolution of the GDA issue.

1.3.1 Sampling Strategy

10. It is rarely possible or necessary to assess a safety submission in its entirety, and therefore ONR adopts an assessment strategy of sampling. The sampling strategy for this assessment considered those options presented in the Westinghouse ALARP review and their relative safety 'weighting' at a high level, with a more detailed consideration of the technical justification underpinning those options that Westinghouse considered to provide the most significant overall benefit in its ALARP review.

2 ASSESSMENT STRATEGY

2.1 Pre-Construction Safety Report (PCSR)

11. 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 Technical Assessment Guide (TAG) 051 (Ref. 6) sets out regulatory expectations for a PCSR.

12. At the end of Step 4, ONR and the Environment Agency raised GDA Issue 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.

13. 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 consider the totality of the **AP1000** PWR PCSR in the context of SFP criticality safety management. This assessment focuses on the supporting documents and evidence specific to GDA Issue GI-AP1000-RP-01. A consideration of adequacy of the PCSR is considered separately as part of closure of GDA Issue GI-AP1000-CC-02 elsewhere.

2.2 Standards and Criteria

14. This assessment has been carried out in accordance with HOW2 guide NS-PER-GD-014, 'Purpose and Scope of Permissioning' (Ref. 29).

15. The ONR Safety Assessment Principles (SAPs) (Ref. 8) constitute the key regulatory principles against which duty holders' safety cases are judged, and they are the basis for ONR's nuclear safety assessment. The SAPs 2014 edition (Revision 0) have been used when performing the assessment described in this report (note, the original Step 4 assessment had used the 2006 edition).

16. The SAPs have been considered alongside internal TAGs (Ref. 9), relevant national and international standards and Relevant Good Practice (RGP) informed from existing practices adopted on UK nuclear licensed sites.

2.3 Safety Assessment Principles

17. The key SAPs considered within the assessment are listed below. This list is not exhaustive.

- ECR.1 – Wherever a significant amount of fissile material may be present, there should be safety measures to protect against unplanned criticality.
- ECR.2 – Criticality safety cases should employ the double contingency approach.
- EKP.3 – Nuclear facilities should be designed and operated so that defence in depth against potentially significant faults or failures is achieved by the provision of multiple independent barriers to fault.

18. It is worth noting 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. The objective of this assessment is primarily to judge the adequacy with which Westinghouse's submissions address the requirements of the GDA issue, rather than to repeat the original assessment against the SAPs.

2.3.1 Technical Assessment Guides

19. The key TAGs that have been used as part of this assessment are set out below (Ref. 9):

- NS-TAST-GD-041 Revision 4 – Criticality Safety
- NS-TAST-GD-005 Revision 7 - Guidance on the Demonstration of ALARP (As Low As Reasonably Practicable)

2.3.2 National and International Standards and Guidance

20. The international standards and guidance that have been considered as part of this assessment are set out below.

- IAEA SSG-15 – IAEA Safety Standards: Storage of Spent Nuclear Fuel (2012) (Ref. 20)
- IAEA SSG-27 – IAEA Safety Standards: Criticality Safety in the Handling of Fissile Material (2014) (Ref. 20)
- British Standard BS 3598:1998 – Fissile Materials – Criticality Safety in Handling and Processing – Recommendations (Ref. 30)
- ISO Standard ISO 1709:1995 – Fissile Materials – Principles of criticality safety in storing, handling and processing (Ref. 31)

21. In addition, I discussed the high-level approach to spent fuel management in the USA with the US NRC. This is discussed later in my assessment.

2.4 Use of Technical Support Contractors (TSCs)

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

23. No additional technical support was used directly at this stage to support close-out of GDA Issue GI-AP1000-RP-01. Westinghouse has used models originally reported and considered during Step 4 of GDA. ONR used a TSC to carry out a technical review of modelling work during Step 4 of GDA, and I refer back to that work when considering the adequacy of the case.

2.5 Integration with Other Assessment Topics

24. GDA requires the submission of an adequate, coherent and holistic generic safety case. Regulatory assessment cannot therefore be carried out in isolation, as there are often safety issues of a multi-topic or cross-cutting nature. No detailed assessment of any cross-cutting issues is presented within this report.

25. As part of my assessment work, I consulted with an ONR fuels specialist about claims on spent fuel cooling time and the potential impact on fuel integrity in downstream storage. As long-term fuel integrity following export from the spent fuel pool is the subject of an existing assessment finding, I have not raised a new assessment finding on it in this report.

2.6 Out of Scope Items

26. This assessment report on GI-AP1000-RP-01 has focused on the adequacy of Westinghouse's spent fuel pool criticality safety case, specifically the action required to

address the GDA issue. A separate GDA issue, GI-AP1000-FS-01, identified issues relating to the spent fuel pool safety case for loss of active cooling and loss of water inventory events, and Westinghouse's response to this GDA issue has been considered outside of this report (in Ref. 17). Assessment of that issue takes into account the impact of changes to the spent fuel decay heat levels as a result of resolution of GI-AP1000-RP-01.

27. A separate regulatory assessment report is provided to consider the adequacy of the PCSR and closure of GDA Issue CC-02, and therefore this report does not attempt to consider the totality of the **AP1000** PWR PCSR in the context of SFP criticality safety management.

28. Additional out of scope items are highlighted in Section 1.2 above.

3 REQUESTING PARTY'S SAFETY CASE

29. The Westinghouse GDA issue resolution plan (Ref. 2) stated that Westinghouse's approach to closing the issues was:

- An overall UK ALARP assessment, including assessment of all options described in the Resolution Plan (in addition to any new options that may have become available since 2011) and an ALARP demonstration for the selected solution.
- A summary document describing criticality analyses for the options presented in the Resolution Plan (in addition to any new options that may have become available since 2011), as well as the criticality analyses themselves and supporting documentation.
- A proposed design concept for the spent fuel pool (SFP), documented in a DCP.
- Mark-ups of affected licensing documents including relevant PCSR chapters.

30. The final UK ALARP assessment for the spent fuel pool criticality case is presented in Ref. 11 – 'AP1000® Spent Fuel Pool Design ALARP Assessment', UKP-GW-GL-113 Revision 2. No new criticality calculations were generated to support the new submission; instead the ALARP assessment referred to existing calculations that were originally prepared to support GDA Step 4. Westinghouse notes that some of these calculations were originally presented and referenced in a specific response to a Regulatory Observation during Step 4. These calculations have since been finalised and moved into their own documents, but no alterations or additions to the models were made (see Refs. 11, 12, 13, 14). The key calculations referenced in the ALARP assessment are presented in Ref. 15.

31. The DCP which captures the proposed change to the spent fuel pool design to address the regulatory issue is given in Ref. 16. The DCP includes mark-ups of affected chapters of the PCSR.

32. In addition to the documents described above, a number of regulatory technical queries have been raised by ONR and responded to by Westinghouse. Responses which form a fundamental part of my decision-making are highlighted later in my assessment.

3.1 UK ALARP Assessment for Spent Fuel Criticality

33. The ALARP assessment presents a consideration of alternative spent fuel pool criticality safety management options. The ALARP assessment submission is presented in Ref. 11, and I use this as a basis of my assessment here.

34. The ALARP assessment proposes eight broad options for consideration. These are:

(i) Maintain current spent fuel pool configuration and proposed management approach – the 'generic **AP1000** spent fuel pool configuration'

(ii) Block 1 out of 4 cells in Region 2

(iii) Fixed poisons in fuel assemblies

(iv) Off-Site storage or extended pool outside the nuclear island

(v) Extended pool within the nuclear island

(vi) Different construction material for fuel racks

(vii) Re-racking to an all-Region 1 configuration

(viii) Blocking 2 out of 4 cells in Region 2

35. Each of these is summarised in turn below.

(i) Westinghouse 'generic' spent fuel pool criticality safety management

36. The original GDA Step 4 proposal for spent fuel pool management for the **AP1000** SFP utilised a two-region SFP design (referred to by Westinghouse in Ref. 11 as the '**AP1000** Generic Plant Design'). The generic **AP1000** SFP contains three Region 1 spent fuel storage rack modules and five Region 2 rack modules. The total storage capacity is 889 locations (or 732, while maintaining 157 cells 'empty' at any time to accommodate a full core offload). The design and layout of the racks is such that a fuel assembly cannot be inserted into a location other than a location designed to receive an assembly. Neutron-absorbing metal matrix composite panels (Metamic™, Holtec International*) are integral to the design, surrounding fuel assemblies in each cell. These neutron-absorbing panels form part of the hazard management strategy to prevent an uncontrolled neutron chain reaction, or criticality accident, in the SFP. An illustration of the layout is given in Figure 1.

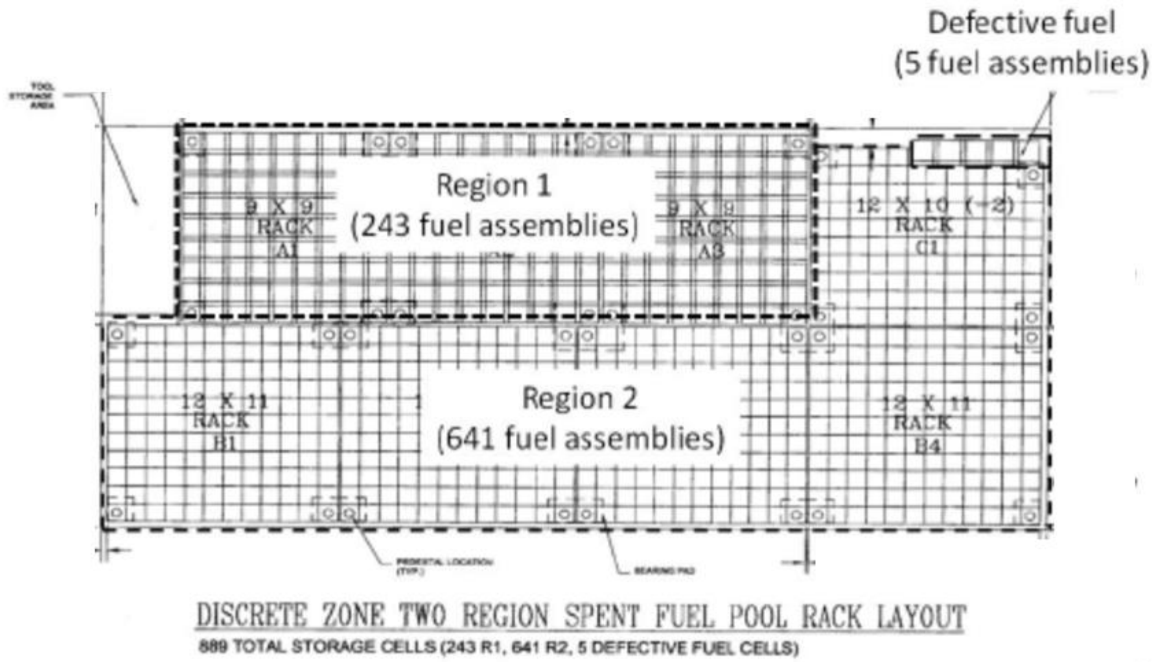

Figure 1: Overall spent fuel pool rack layout for the **AP1000** Generic Plant Design. [Taken from Figure 3 in Ref. 15].

37. The Region 1 rack modules have a centre-to-centre spacing greater than that of the Region 2 rack modules, and the defective fuel assembly storage cells have a greater centre-to-centre spacing than Region 1 racks. The Region 1 racking houses two neutron-absorbing panels between locations, while the Region 2 racking houses one (illustrations are provided in Ref. 15 and repeated in Figure 2). These rack module configurations provide separation between adjacent fuel assemblies, with a neutron absorber to maintain a sub-critical array. The neutron absorber is made up of boron carbide in a metallic matrix.

* *This assessment has considered application of material from this vendor; however, other vendors could be considered if demonstrated to offer an equivalent (or greater) safety performance.*

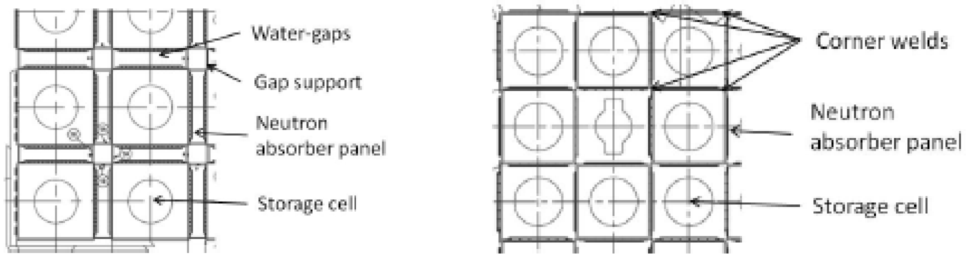

Figure 2: Cross sections (typical) of Region 1 rack configuration (left) and Region 2 configuration (right). [Taken from Figures 4 and 5 of Ref. 15].

38. Unlike Region 2, fuel with an initial enrichment less than or equal to 5.0 wt. percent ^{235}U may be placed anywhere in Region 1, by virtue of the larger distance between the racks, as well as the additional neutron-absorbing material between them (two neutron absorber panels rather than one). The Region 1 racks are designed to hold fresh and spent fuel assemblies, in accordance with the limitations established by the results of the criticality analysis. Water gaps between cells allow for increased cooling of the fuel assemblies.

39. The Region 2 racks are higher-density racks designed to hold fresh and spent fuel assemblies, in accordance with the limitations established by the results of the criticality analysis. The limitations for Region 2 racks include additional restrictions on the number and location of fresh fuel assemblies and spent fuel burn-up. One of the Region 2 racks has fewer storage locations, in order to accommodate five defective fuel assembly storage cells (larger than typical cells), in accordance with the limitations established by the results of the criticality analysis. Fresh or spent fuel may be placed within the defective fuel assembly storage cells.

40. The criticality safety methodology used to support the design of the generic **AP1000** SFP storage takes credit for soluble boron (in the SFP water) and burn-up of the fuel. Credit is also taken for the fixed geometry neutron-absorbing Metamic™ panels within the SFP storage racks. This approach increases the storage capacity of fuel assemblies in the SFP by separating the pool into two distinct regions, and a region for storage of damaged fuel, that have different criticality safety requirements.

41. If credit is not taken for burn-up, the presence of soluble boron is still required for normal operation and to mitigate accidents.

42. This configuration allows for up to 18 years' spent fuel cooling between start-up and the need for a dry storage campaign. Assuming an 18-month cycle in the reactor, this would allow for 16.5 years' fuel cooling prior to subsequent downstream storage (assumed to be dry storage).

43. Within Ref. 11, Westinghouse recognises that managing soluble boron and fuel assembly burn-up are considered to be administratively-controlled safety measures requiring operator action to ensure criticality safety, and hence do not form a passive safety system.

(ii) Blocking 1 out of 4 cells in Region 2 ('3 out of 4' storage configuration)

44. This configuration employs the generic **AP1000** fuel storage rack two-region configuration, but uses a blocking device to block 1 cell out of 4 in the spent fuel rack cells in Region 2. The blocking device prevents a fuel assembly from being placed into a cell. The total spent fuel pool capacity is reduced to 561 (while maintaining 157 cells empty to accommodate a full core offload).

45. Fuel assembly burn-up credit would not be needed in the 3 out of 4 configuration. This configuration would still require credit for soluble boron in the SFP both for normal operation and accident scenarios, to maintain criticality safety.

46. The reduced storage capacity allows for up to 13.5 years' spent fuel cooling between start-up and the need for a dry storage campaign. Assuming an 18-month cycle in the reactor, this would allow for 12 years' fuel cooling prior to dry storage.

(iii) Addition of fixed poisons within fuel assemblies

47. This option uses the generic **AP1000** SFP configuration, but fixed neutron absorber inserts could be installed into the fuel assemblies at any point after core offload, before they are moved from Region 1 to Region 2 in the SFP.

48. Each fuel assembly consists of 264 fuel rods, 24 guide thimbles and 1 instrumentation tube arranged within a supporting structure. A number of the guide thimbles could be used to temporarily house neutron-absorbing 'fingers'.

49. This option has been evaluated as a 'concept' design, and has been assessed as providing criticality control without crediting the presence of soluble boron while maintaining the full capacity of the SFP. However, this option does rely on administrative arrangements to correctly install the fuel assembly neutron-absorbing inserts, and Westinghouse highlights that this would not fully satisfy the requirements of the GDA issue.

(iv) Off-site storage or extended pool outside the nuclear island

50. This option could maintain or increase the spent fuel cooling time in wet storage obtained in the generic plant design, by transferring spent fuel from the SFP to another wet fuel storage facility, either off-site or on the plant site, but off the **AP1000** nuclear island. (Ref. 11 recognises that this proposal would need to complement a modification to the **AP1000** SFP such that it achieves criticality safety without crediting fuel assembly burn-up or soluble boron.)

51. A complete design of what such a facility would entail has not been developed, and Westinghouse considers the cost and schedule impact associated with such a modification to be grossly disproportionate to the benefits received in the context of GDA. As such, Westinghouse considers this option impracticable in terms of addressing the GDA issue.

(v) Extending the pool within the nuclear island

52. This design option involved having a larger SFP in place of the current design, so criticality control could be maintained through geometric means alone, while still maintaining a sufficiently long fuel cooling time prior to export. A complete design has not been developed, so the exact capacity has not been determined.

53. Increasing the size of the SFP would require an increase in the size of the entire nuclear island. This would require a modification to many components of the overall **AP1000** design and safety analysis, including (but not limited to) new rack design, fuel handling system, cooling system, modules surrounding the SFP, basemat footprint and associated structural, seismic and thermal/hydraulic analyses. Benefits associated with the standardisation of the **AP1000** plant design would also be lost.

54. Westinghouse considers that the level of effort and technical risk associated with this option is equivalent to starting a new design and is therefore impracticable, and that the benefits gained are grossly disproportionate to the cost and risk of the design change.

(vi) Different construction material for fuel racks

55. This option considers using a different fixed neutron-absorbing material in the fuel storage rack. Westinghouse refers to previous work presented at Step 4, justifying its belief that the metal matrix composite used in the generic design is the best available, state of the industry neutron absorber for use in the **AP1000** fuel storage racks. Accelerated aging testing has indicated material stability expected to last far longer than the actual need for an operating plant. Westinghouse claims that the chemical composition has been optimised to maximise the neutron-absorbing component (Boron-10) while maintaining sufficient ductility to provide appropriate withstand in a seismic event.

56. Issues with alternative boron containing neutron absorber materials are well documented and as such are deemed inappropriate for the **AP1000** plant. Borated stainless steel has a much lower Boron-10 areal density and Westinghouse judges that it cannot be used to achieve the same criticality control performance as a metal matrix composite without compromising performance in seismic events.

57. Westinghouse concludes that there is no material with a proven performance record in the industry whose use in the Region 2 racks would yield better criticality control than the metal matrix composite in the current design.

(vii) Re-racking to an all-Region 1 configuration

58. This configuration employs an all-Region 1 style of fuel storage rack. Region 1 racks are designed to hold fresh fuel and spent fuel assemblies in accordance with the limitations established by the criticality analysis (the limiting enrichment is 4.95 wt. percent U^{235}).

59. Westinghouse recognises that this proposal is a design concept at this stage, and that there are technical areas that would need revisiting, such as a seismic and thermal analysis. However, as with the current **AP1000** SFP Region 1 style of fuel storage rack, water gaps between cells allow for increased cooling of fuel assemblies compared to the Region 2 racks.

60. This concept would not credit the use of soluble boron or burn-up to maintain safe sub-criticality, requiring no administrative controls. Safe sub-criticality is maintained by use of the integral neutron absorber panels and geometric spacing. The capacity would be reduced from the generic 889 locations to approximately 617 locations (or 460 locations when maintaining 157 empty locations for full core offload). Westinghouse claims that this affords 12 years between initial start-up and the need for fuel export to dry cask, or approximately 10.5 years of fuel cooling (assuming an 18-month fuel cycle in the core).

61. Westinghouse recognises that there are technical risks and re-work required for this option, but that these are less than those of a ‘first of a kind’ design such as the extended fuel pool.

(viii) Blocking 2 out of 4 cells in Region 2

62. This configuration employs the generic **AP1000** fuel storage rack two-region configuration, but uses a blocking device to block 2 cells out of 4 cells in Region 2, reducing capacity to 569 locations (or 412 locations when maintaining 157 empty locations for full core offload). The blocking device is a concept level design, but would ultimately be designed such that placing a fuel assembly in the blocked cell is impossible. Westinghouse claims that this approach maintains sub-criticality through passive geometric control.

63. Westinghouse claims that this affords 10.5 years between initial start-up and the need for fuel export to dry cask storage. This would equate to 9 years' fuel cooling (assuming the 18-month fuel cycle in the core).

64. Westinghouse recognises that this option would be relatively simple to implement as a small modification to the existing design, with a relatively low cost burden to design and manufacture suitable inserts to prevent fuel being loaded into certain storage locations.

Westinghouse review of options

65. Westinghouse used an expert panel review process to review the various options. The expert panel consisted of technical experts from all interfacing areas with experience in operations, fuel handling, spent fuel pool design (including criticality safety), human factors and licensing. The expert panel considered key aspects of each design option, including:

- primary means of ensuring criticality safety (including the need to formally credit soluble boron or fuel burn-up)
- necessity of administrative controls
- design impacts and challenges (practicability)
- complexity of fuel handling operations
- capacity and fuel cooling time
- consistency with UK RGP for new-build facilities

66. During the review, each option was presented to the panel followed by a discussion identifying attributes and detriments for each option. While assessing the options against the criteria identified above, some options were eliminated due to practicability or failing to meet RGP for new-build plants in a particular area.

67. The review identified that four of the options considered satisfy the GDA issue:

- increasing the size of the SFP
- additional onsite or offsite storage combined with a 2 out of 4 configuration in the existing SFP
- an all-Region 1 configuration
- a 2 out of 4 configuration

The review panel considered that the cost and effort involved in increasing the size of the SFP and creating additional onsite or offsite storage were grossly disproportionate in the context of the GDA issue. Thus, the two options identified by the panel as providing the greatest practicable risk reduction were the 2 out of 4 configuration and the all-Region 1 style rack configuration.

68. Both options can maintain criticality safety without the need for crediting administrative controls relating to soluble boron and burn-up management. Both rely on geometric control and fixed poisons as the primary means of ensuring safety, though administrative controls on soluble boron will remain present and provide defence in depth.

69. Both options provide a reduced spent fuel cooling time relative to the generic **AP1000** design, but only the all-Region 1 design provided the minimum 10 years' spent fuel cooling (the 2 out of 4 configuration providing approximately 9 years).

70. A second review panel was convened to consider these two options in more detail, and Westinghouse concluded that the all-Region 1 style rack is the option which reduces

risks to ALARP. The key factors influencing the decision were the fact that the 2 out of 4 configuration would not meet the minimum 10-year fuel cooling time specified in the resolution plan, and would carry with it greater administrative burden in checking and maintenance of the blocking devices.

71. The Westinghouse review and conclusions are based on underpinning calculation work. A summary of some of the key underpinning calculations is presented in the following section.

3.2 Supporting criticality calculations

72. The criticality calculations underpinning the ALARP assessment are reported in Ref. 15, which in turn draws from Ref. 19. The criticality calculations supporting the case are derived from a number of different sources, including supporting documentation for submissions in other countries where different safety criteria are applied, and some comparisons made in the text are against these different criteria. However, within the main ALARP paper, the results are evaluated against a neutron multiplication (k-effective) limit of <0.95 for normal operations and <0.98 for fault conditions.

73. The calculations presented inform the ALARP review in terms of identification of those options which satisfy the requirements of the GDA issue. A comparison against the relevant safety criterion is made to determine whether there is a need to formally credit soluble boron or burn-up in the criticality safety controls on plant. No further detailed discussion of the calculations is presented here.

DCP and review of PCSR chapters

74. The DCP reflecting the changes to the UK **AP1000** SFP to address the GDA issue is given in Ref. 16. The DCP outlines that the Region 2 SFP racking will be removed and replaced with an all-Region 1 SFP racking arrangement. A number of ’mark-up‘ changes to various sections of the PCSR are listed in the DCP. The fault of accidental boron dilution in the pond water is removed as a criticality-related fault condition, since the revised design allows criticality safety to be demonstrated without the need to credit soluble boron.

4 ONR ASSESSMENT OF GDA ISSUE GI-AP1000-RP-01

4.1 Scope of Assessment Undertaken

75. My assessment of Westinghouse's submissions for GI-AP1000-RP-01 is set out below, against the scope defined in Section 1 and strategy discussed in Section 2.

4.2 Assessment

76. As Westinghouse's review and decision-making is based on existing Westinghouse criticality calculations, this is the starting point of my assessment. I have considered their use within the ALARP assessment and the ALARP review, then the associated DCP.

77. The assessment plan allowed for additional technical work that might be undertaken by Westinghouse in closing the GDA issue, and identified specialisms that might be involved in the ONR assessment. It was the intention that workloads in these areas would be managed as the submissions were made. In practice, the option proposed by Westinghouse drew heavily on work (particularly criticality calculations) that was considered during Step 4 – this is discussed in the following section. I have not considered it necessary to require formal assessment from other disciplines, though I consulted with ONR fuels specialists over spent fuel cooling requirements.

Assessment of criticality calculations and their application

78. Criticality calculations were produced by Westinghouse to support submissions at GDA Step 4, and were either referenced in individual reports or specific responses to regulatory observations. A regulatory review of the calculation approach was undertaken at GDA Step 4 by a Technical Support Contractor, Gesellschaft fur Anlagen und Reaktorscherheit (GRS), on behalf of ONR. This review is presented in Ref. 18.

79. The review considered the adequacy of Westinghouse's overall approach to criticality safety modelling of the SFP. The calculation tools, methodologies and assumptions were examined to confirm whether they were appropriately used and underpinned by supporting documentation. Calculation models were examined for completeness, reasonability and consistency. The review was undertaken on the assumption that the neutron multiplication factor, k-effective and associated uncertainties, was required to satisfy $k_{eff}<0.95$ under normal operations and $k_{eff}<0.98$ under fault or accident conditions, recognising this as current practice in several European countries. These limits were used as a basis of assessment during the original Step 4 GDA assessment (Ref. 32) and I consider them appropriate for use here.

80. The review concludes that the calculation methodology used by the requesting party is appropriate for application to criticality safety analysis of materials of the type considered, and in the configurations considered. The calculation methodology is reported to be justified and qualified, and approaches underpinned by supporting documentation. Separate calculations performed by the reviewer for cross-checking also confirm the results of the requesting party. (The review also recognises that certain configurations of the spent fuel pool are not in full compliance with basic requirements and current practice in criticality safety, as applied for new reactor design in the UK. This conclusion aligns with the view of ONR during GDA Step 4 and was the reason for raising the GDA issue.) Based on the output of the GRS review, I am satisfied that the overall calculation approach used by Westinghouse is thorough and robust.

81. Westinghouse's criticality calculations investigating the criticality safety of the SFP, without credit for soluble boron or assembly burn-up, were produced during GDA Step

4 and are presented in Ref. 15, supported by calculations in Ref. 19. Westinghouse refers to these calculations as part of its ALARP option review process. I am satisfied with the general approach to the calculations, as the information presented has been drawn from a number of different sources. However, I note that comparisons are made against different safety criteria for k_{eff} within the report. I have reviewed the use of the calculations within the ALARP report, and am satisfied that the key calculations used to underpin the arguments therein satisfy $k_{eff}<0.95$ under normal operations and $k_{eff}<0.98$ under fault or accident conditions.

82. One of the calculations in Ref. 19 previously quoted at GDA Step 4 relates to a possible fault whereby a fuel assembly is misloaded in a 2 out of 4 configuration for the SFP, resulting in the safety criterion being exceeded for that particular configuration. Westinghouse has since clarified that the use of channel inserts/blockers with this configuration would prevent this fault through engineered means, and the fault for this configuration can be dismissed on that basis (Ref. 21). In the context of GDA close-out, I am satisfied the conclusion that the 2 out of 4 configuration is capable of maintaining safe sub-criticality without the need to credit burn-up or soluble boron is valid, though I recognise that a more robust substantiation of the inserts may be required if this were a preferred option going forward.

83. In the calculations, the neutron absorber in Metamic™ is assumed to be homogeneous. Westinghouse provided evidence from studies which demonstrates that a homogeneous approximation for neutron absorber is appropriate for absorber particle sizes in the region of 10-25 microns (Refs. 22, 23). Westinghouse’s conclusion is consistent with observations made in Ref. 25 for similar materials in transport packages. Westinghouse provided a report from the manufacturer, Holtec, which discusses the boron carbide particle size within the Metamic™ neutron absorber panels (Ref. 24), and based on this, I am satisfied that the calculation approach is appropriate to support GDA issue close-out.

84. The physical characteristics of the neutron absorber panels claimed are an important part of the overall basis of criticality safety. An existing assessment finding raised at Step 4 requires substantiation that their make-up is as per the calculations. No further action is raised here as part of closure of the GDA issue.

85. In summary, I am satisfied that the criticality calculations are robust and thorough, and that their application within the ALARP assessment is appropriate.

Assessment of Westinghouse’s ALARP review

86. Westinghouse presented an introduction to the GDA issue, and a summary of RGP pertaining to criticality safety during spent fuel storage. Westinghouse presented an adequate summary of the issues, and an understanding of the need to balance safety requirements to arrive at a solution where risks have been reduced ALARP.

87. The options considered within Westinghouse’s ALARP review capture those discussed within the original GDA issue (Ref. 1). Westinghouse has not explicitly considered the option of “designing rack inserts containing fixed poisons which can be positioned around the fuel assemblies during storage” highlighted in Ref. 1, though they have considered variations in rack design and composition and note that the spacing and water gap between channels is important for the removal of decay heat. Westinghouse recognises that reducing the water gap would reduce decay heat removal efficiency. Westinghouse also notes that the racking design is optimised for the particular purpose and fuel type/geometry, and inserting additional poison material outside the fuel assemblies would displace moderator and not necessarily improve performance. I consider rack inserts to have been covered implicitly in this discussion, and I do not consider this to be an omission.

88. The options considered by Westinghouse focused on variations on existing technology and practice, and limited discussion of new/novel approaches was presented. Given the advantages of using technology proven in a fuel storage environment such as Metamic™, and the issues highlighted with degradation of alternative neutron absorber panel types used in the nuclear industry in the past, I consider this to be a reasonable position.

89. In my opinion, Westinghouse has taken an appropriate approach to reviewing options, using an expert panel made up of personnel from a number of affected disciplines. Each option has been reviewed with an appropriate emphasis on the nuclear safety impact of any design changes, to make judgement against reducing overall risk to ALARP. The only exception to this is where options to extend the SFP size on or off the nuclear island have been considered, where Westinghouse has placed a greater emphasis on the costs of developing and implementing changes which they consider to be disproportionate in the context of the overall GDA issue. This does not preclude the licensee from developing an offsite pool storage capability in the future, to increase wet storage capacity if required for operational (or other) reasons. However, such work is outside the scope of this assessment for GDA. Given that the Westinghouse-preferred ALARP option satisfies the original GDA issue without identification of any disproportionate safety disbenefit, I am satisfied that those options dismissed on high-cost grounds have been considered appropriately in the decision-making process.

90. In my opinion, the Westinghouse review presents an adequate balanced consideration of the options, and I agree with the conclusion that the four options identified clearly satisfy the requirements of the GDA issue from the point of view of offering passive engineered criticality safety within the spent fuel pool.

91. Of the four options that satisfy the GDA issue, extending the SFP size (on or off the nuclear island) would arguably be the most elegant solution as it could remove any reduction to spent fuel cooling time, which the alternative options introduce. However, in evaluating against Westinghouse's chosen option, I consider Westinghouse's conclusion that these options are not reasonably practicable, when compared to the alternative options, to be reasonable.

92. When comparing an all-Region 1 rack design and a 2 out of 4 rack configuration, it is clear that the all-Region 1 rack design offers a clear advantage in terms of additional spent fuel cooling time, allowing it to satisfy the minimum 10-year cooling target set out by Westinghouse (a value Westinghouse have taken from European Utility Requirements Document (EURD)). The all-Region 1 design also allows more effective cooling of fuel during storage, due to the increased water gap present.

93. Westinghouse recognises that there is an absence of definitive guidance or RGP relating to numerical limits for spent fuel cooling prior to onward processing, and that facilities adopt an appropriate philosophy for their operations. I agree that generating generic guidance on appropriate fuel cooling is not simple, since it would be a function of many different parameters such as irradiation time, position in the core and neutron flux. Westinghouse uses a minimum 10 years' spent fuel cooling time as a basis for their case, based on a preferred minimum cooling time quoted in the European Utility Requirements Document.

94. One of the key concerns with fuel cooling times is long-term storage integrity. Westinghouse states that fuel cooled for less than 10 years has been safely stored downstream in facilities elsewhere. I consulted with an ONR fuels expert to consider the adequacy of a 10-year cooling time assumption in the context of UK regulation (Ref. 26). Further consideration of fuel cooling and dry storage of fuel was raised in an assessment finding at Step 4 of GDA. I am content that the finding adequately addresses the concern following the modification to the SFP, and therefore that there

is no impact on close-out of this GDA issue. I list the assessment finding in section 4.5 below for reference.

95. As the criticality safety of the SFP is reliant on the Metamic™ neutron-absorbing spent fuel racking, it is appropriate that adequate arrangements are in place to ensure that the specification of the racking reflects that assumed within the criticality case, and that the integrity of the neutron absorber capability of the racking is maintained throughout its life. These matters are the subject of existing assessment findings raised at Step 4 of GDA. I am content that the findings adequately address the concerns, and that there is no impact on close-out of this GDA issue. I list the findings in section 4.5 below for reference.

96. I therefore judge Westinghouse's final decision identifying an all-Region 1 rack design as a definitive ALARP proposal to be suitably underpinned in the context of satisfying the resolution plan addressing the GDA issue. The proposal reduces risks so far as is reasonably practicable (SFAIRP)[†].

DCP and impact on the PCSR

97. I have sampled the DCP to confirm that it reflects the proposed changes to implement an all-Region 1 SFP design. The DCP includes mark-up changes required to various PCSR chapters.

98. UK regulations do not preclude the use of soluble boron or fuel burn-up in SFP criticality control. However, in evaluating whether risks have been reduced to ALARP, ONR Inspectors must make a judgement against RGP, such as the ONR SAPs and IAEA guidance. The hierarchy of control discussed in the SAPs recognises that passive engineered control is preferable to administrative control arrangements, and IAEA guidance in SSG-15 (Ref. 20) states that "Criticality safety of pool storage should not rely on the use of soluble neutron poison", though it does recognise that for certain facilities this may not be possible. Thus, RGP offers a strong driver for new facilities not to rely on the use of soluble neutron poison in the absence of a compelling safety disbenefit to not doing so. Within its resolution plan, Westinghouse undertook to provide a safety case based upon geometric control and fixed poisons alone. I consider that the DCP adequately addresses the proposed changes to the design.

99. Review of the PCSR is being carried out in support of closure of Regulatory Issue GI-AP1000-CC-02, and is not considered further in this report.

4.3 Comparison with Standards, Guidance and Relevant Good Practice

100. The modification to the fuel pool criticality safety management strategy to address the GDA issue provides a passive storage regime (using fixed geometry neutron-absorbing racking). This reflects the preferred approach to SFP management and using neutron absorbers identified in IAEA guidance SSG-15 and SSG-27 for new facilities (Ref. 20), British and ISO standards (Ref. 30, 31) and meets the expectations of SAPs ECR 1 and EKP 3. The approach removes the criticality hazard associated with boron dilution and burn-up related faults, and Westinghouse claims it meets the double contingency principle (SAP ECR 2), which I consider reasonable based on the information provided. I therefore consider that the preferred option reflects RGP in relation to criticality management of spent fuel storage.

4.4 Overseas Regulatory Interface

101. ONR has formal information exchange agreements with a number of international nuclear safety regulators, and collaborates through the work of the IAEA and the

[†] The terms ALARP and SFAIRP are often used interchangeably. The legal requirement is to demonstrate risk is reduced SFAIRP.

Organisation for Economic Co-operation and Development's Nuclear Energy Agency (OECD-NEA). This enables us to use overseas regulatory assessments of reactor technologies, where they are relevant to the UK. It also enables the sharing of regulatory assessment findings, which can expedite assessment and helps promote consistency.

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

103. As part of my assessment, I held a meeting with the United States Nuclear Regulatory Commission (US NRC) to discuss the approach taken to spent fuel pool criticality management. US NRC outlined the approach taken to crediting of burn-up and borated water within spent fuel pools. Key requirements relating to burn-up credit are captured within prescriptive regulations in the US. These discussions were informative in gaining an understanding of the legal framework applicable in the US. As the proposed ALARP option for criticality safety management of the SFP proposed by Westinghouse does not formally credit burn-up or soluble boron, based on consideration of international RGP, I did not consider it necessary to pursue these discussions further.

4.5 Assessment Findings

104. No new items have been identified in my assessment for a future licensee to take forward in their site-specific safety submissions. However, during my assessment I have made reference to a number of existing assessment findings which are relevant to the topic areas discussed. I consider the wording of these findings to adequately capture the requirements following my assessment. They are repeated below for reference only:

Assessment Finding Reference	Assessment Finding
AF-AP1000-FD-12	The licensee shall provide further justification of the limits on cladding temperature and stress required to ensure adequate ductility in dry storage. Source: www.onr.org.uk/new-reactors/reports/step-four/technical-assessment/ap1000-fcd-onr-gda-ar-11-005-r-rev-0.pdf
AF-AP1000-RP-14	The licensee shall provide evidence at the construction stage that Metamic™ of the specification used in the safety case is installed in compliance with the design intent. Source: www.onr.org.uk/new-reactors/reports/step-four/technical-assessment/ap1000-rp-onr-gda-ar-11-009-r-rev-0.pdf
AF-AP1000-RP-15	The licensee shall establish systems by inactive commissioning to monitor the Metamic™ steel over the lifetime of the plant so as to identify and quantify any degradation. Source: www.onr.org.uk/new-reactors/reports/step-four/technical-assessment/ap1000-rp-onr-gda-ar-11-009-r-rev-0.pdf

105. These matters do not undermine the closure of the GDA issue and are primarily concerned with the provision of site-specific safety case evidence, which will usually become available as the project progresses through the detailed design, construction and commissioning stages.

5 CONCLUSIONS

106. This report presents the findings of the assessment of GDA Issue GI-AP1000-RP-01 relating to the **AP1000** PWR GDA closure phase.

107. Westinghouse has completed a review of options for spent fuel criticality management to ascertain which option reduces risks to ALARP. The ALARP review was informed by calculations carried out during GDA Step 4. These calculations were reviewed by a TSC on behalf of ONR, and the review concluded that the approach taken was appropriate for the configurations modelled.

108. I am satisfied that the methods employed are appropriate and am content that they have demonstrated that the preferred option of an all-Region 1 spent fuel pool design satisfies the GDA issue, and that it represents the option which reduces risks SFAIRP in the context of criticality safety management.

109. In my assessment, I note three existing assessment findings which are relevant to the topic discussed. These findings address the issues adequately and remain valid, and have no impact on closure of the GDA issue.

110. To conclude, I find that this aspect of the **AP1000** PWR safety case is adequate, and risks have been demonstrated to be reduced SFAIRP. I consider that from a criticality safety perspective, the proposed design of **AP1000** PWR spent fuel pool is suitable for construction in the UK. No new assessment findings have been identified.

6 REFERENCES

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3. ONR-GDA-AP-14-012 Rev. 0 “AP1000 Generic Design Assessment Plan for GDA Issue GI-AP1000-RP-01 – Radiological Protection,” TRIM 2016/415861
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19. Westinghouse, “AP1000 Spent Fuel Pool Criticality Analysis without Credit for Soluble Boron or Assembly Burnup”, APP-FS02-N1C-003, TRIM 2015/439202

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