Office for Nuclear Regulation
An agency of HSE

Generic Design Assessment – New Civil Reactor Build

GDA Close-out for the EDF and AREVA UK EPR™ Reactor

GDA Issue GI-UKEPR-SI-01 Revision 2

Structural Integrity - Avoidance of Fracture

Assessment Report: ONR-GDA-AR-12-005
Revision 0
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EXECUTIVE SUMMARY

This report presents the close-out of part of the Office for Nuclear Regulation's (an agency of HSE) Generic Design Assessment (GDA) within the area of Structural Integrity. The report specifically addresses the GDA Issue GI-UKEPR-SI-01 Revision 2 generated as a result of the GDA Step 4 Structural Integrity Assessment of the UK EPR™. The assessment has focussed on the deliverables identified within the EDF and AREVA Resolution Plan published in response to the GDA Issue and on additional deliverables submitted later in response to ONR feedback.

In the UK there is a recognition that there are a few critical components for which it is necessary to demonstrate that the likelihood of gross failure is sufficiently low that it can be discounted, and the normal code requirements are not considered sufficient to provide this level of confidence. EDF and AREVA have accepted the need to make this demonstration in line with UK practice and have designated these components as High Integrity Components (HICs).

The evidence to show that the likelihood of failure is sufficiently low includes an avoidance of fracture demonstration which integrates fracture mechanics analyses, material toughness and qualification of manufacturing inspections. A number of the fracture analysis reports arrived later in the GDA Step 4 assessment timeframe than had been originally planned and it was not possible to undertake a full assessment of these reports during GDA Step 4. In addition, the evidence supporting some of the inspections was not sufficient to show that inspection qualification was likely to be achievable.

GDA Issue GI-UKEPR-SI-01 Revision 2 defines the additional evidence requested to support the demonstration of avoidance of fracture for all the HICs. There are seven Actions, one relating to fracture analysis and six relating to non-destructive testing.

Under Action 1, I have completed the assessment of the fracture mechanics reports and I have further reviewed the fracture assessment methodology proposed by EDF and AREVA including the additional calculations provided by EDF and AREVA to explore the differences between their methodology, based on RSE-M Appendix 5.4, and the R6 approach which is familiar in the UK. I am satisfied that their methodology remains acceptable for the purposes of GDA, and that the predicted sizes of limiting defects can be used in the avoidance of fracture demonstration for GDA, but I have raised a number of Assessment Findings related to this work.

Under Actions 2 to 7, I have assessed additional evidence provided by EDF and AREVA which supports their capability to inspect the HICs during manufacture and demonstrates the accessibility of HICs for in-service inspection. In the case of the main coolant line pipework, important design changes have been introduced which improve the quality of ultrasonic inspection which is achievable for the welds. Where necessary, inspection techniques have been reinforced by additional techniques or beam angles, to provide greater confidence that all defects of concern can be reliably detected. I am now satisfied that there is a realistic prospect of achieving inspections of adequate quality during manufacture and in-service, but I have raised several Assessment Findings to ensure that the detailed design, manufacture, and construction adequately take account of the need for inspection.

In addition, late in the close-out process, I enquired about the integrity claims for the main steam isolation valves (MSIV). EDF and AREVA concluded that the pressure boundary of the MSIV would also need an HIC claim, and provided arguments that such a claim could be made once detailed evidence becomes available as part of the site specific phase. I have accepted that it should be feasible to substantiate the HIC claim for the MSIV during the site specific phase but I have raised a number of Assessment Findings on this aspect.

I am now satisfied that, on the basis of the additional evidence provided during GDA close-out including the important design changes to the main coolant line pipework, that this Issue may be

closed. However I have raised a number of additional Assessment Findings which will need to be addressed subsequently by any Licensee.

LIST OF ABBREVIATIONS

ALARP	As Low As Is Reasonably Practicable
AREVA	AREVA NP SAS
ASN	Autorité de Sûreté Nucléaire (French nuclear safety authority)
ASTM	International Standards Organisation – formerly known as the American Society for Testing and Materials
CEA	(French) Atomic Energy Commission
CIVA	NDT mathematical modelling software developed by CEA
CMF	Change Modification Form
CVCS	Chemical and Volume Control System
DM	Dissimilar Metal (Weld)
DAC	Design Acceptance Confirmation
EASL	Engineering Analysis Services Limited
EDF	Electricité de France SA
ENIQ	European Network for Inspection and Qualification
FA3	Flamanville 3 (A French EPR™ under construction)
FBH	Flat Bottomed Hole
FMA	Fracture Mechanics Analysis
GDA	Generic Design Assessment
HAZ	Heat Affected Zone
HIC	High Integrity Component
HOW2	ONR Business Management System
HSE	The Health and Safety Executive
IAEA	The International Atomic Energy Agency
IDAC	Interim Design Acceptance Confirmation
IRSN	The French Institute for Radiological Protection and Nuclear Safety
ISI	In-Service Inspection
LOCA	Loss of Coolant Accident (IB LOCA – Intermediate Break LOCA: LB LOCA – Large Break LOCA)
LLT	Longitudinal-Longitudinal-Transverse (mode conversion technique)
MCL	Main Coolant Line
MSB with LOOP	Main Steam Line Break with Loss of Offsite Power
MSIV	Main Steam Isolation Valve

LIST OF ABBREVIATIONS

MSRV	Main Steam Relief Valve
MSL	Main Steam Line
MSSV	Main Steam Safety Valve
NDT	Non-Destructive Testing
OL3	Olkiluoto 3 (A Finnish EPR™ plant under construction)
ONR	Office for Nuclear Regulation (an agency of HSE)
PCSR	Pre-construction Safety Report
PSI	Pre-Service Inspection
PT	Penetrant Testing
RCC-M	Règles de Conception et de Construction des Matériels Mécaniques des Ilots Nucléaires (Design and Construction Rules for the Mechanical Components of PWR Nuclear Islands)
RCC-MR	Règles de Conception et de Construction des Matériels Mécaniques des Installations Nucléaires applicables aux structures à haute température et à l'enceinte à vide ITER (Design and Construction Rules for Mechanical Components of Nuclear Installations applicable for high temperature structures and ITER vacuum vessel)
RCP	Reactor Coolant Pump
RP	Requesting Party
RPV	Reactor Pressure Vessel
RSE-M	Règles de Surveillance en Exploitation des Matériels Mécaniques des Ilots Nucléaires (In Service Inspection Rules for the Mechanical Components of PWR Nuclear Islands)
RT	Radiographic Testing
RT_{NDT}	Reference Temperature for Nil Ductility Transition
SAP	Safety Assessment Principle(s) (HSE)
SG	Steam Generator
SIS	Safety Injection System
SZB	Sizewell B Nuclear Power Station
TAG	Technical Assessment Guide(s) (ONR)
TQ	Technical Query
TSC	Technical Support Contractor
U-leg	Designation for the cross-over leg of the MCL pipework between the steam generator and the reactor coolant pump
UK EPR™	EDF and AREVA UK specific pressurised water reactor design
US NRC	Nuclear Regulatory Commission (United States of America)

LIST OF ABBREVIATIONS

UT	Ultrasonic Testing
WENRA	Western European Nuclear Regulators' Association

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1 INTRODUCTION

1.1 Background

1 This report presents the close-out of the Office for Nuclear Regulation's (an agency of HSE) Generic Design Assessment (GDA) within the area of Structural Integrity. The report specifically addresses GDA Issue **GI-UKEPR-SI-01 Revision 2** (Ref. 4), and the associated GDA Issue Actions, generated as a result of the GDA Step 4 Structural Integrity Assessment of the UK EPR™ (Ref. 6). The assessment has focussed on the deliverables identified within the EDF and AREVA Resolution Plans (Ref. 7) published in response to the GDA Issue and on further assessment undertaken of those deliverables.

2 GDA followed a step-wise-approach in a claims-argument-evidence hierarchy. In Step 2 the claims made by the EDF and AREVA were examined and in Step 3 the arguments that underpin those claims were examined. The Step 4 assessment reviewed the safety aspects of the UK EPR™ reactor in greater detail, by examining the evidence, supporting the claims and arguments made in the safety documentation.

3 The Step 4 Structural Integrity Assessment identified a number of GDA Issues and Assessment Findings as part of the assessment of the evidence associated with the UK EPR™ reactor design. GDA Issues are unresolved issues considered by regulators to be significant, but resolvable, and which require resolution before nuclear island safety related construction of such a reactor could be considered. Assessment Findings are findings that are identified during the regulators' GDA assessment that are important to safety, but not considered critical to the decision to start nuclear island safety related construction of such a reactor.

4 The Step 4 Assessment concluded that the UK EPR™ reactor was suitable for construction in the UK subject to resolution of 31 GDA Issues. The purpose of this report is to provide the assessment which underpins the judgement made in closing GDA Issue **GI-UKEPR-SI-01**.

1.2 Scope

5 This report presents only the assessment undertaken as part of the resolution of the GDA Issues and it is recommended that this report be read in conjunction with the Step 4 Structural Integrity Assessment (Ref. 6) in order to appreciate the totality of the assessment of the evidence undertaken as part of the GDA process.

6 This assessment report is not intended to revisit aspects of assessment already undertaken and confirmed as being adequate during previous stages of the GDA. However, should evidence from the assessment of EDF and AREVA's responses to GDA Issues highlight shortfalls not previously identified during Step 4, there will be a need for these aspects of the assessment to be highlighted and addressed as part of the close-out phase or be identified as Assessment Findings to be taken forward to the site specific phase.

7 The possibility of further Assessment Findings being generated as a result of this assessment is not precluded given that resolution of the GDA Issue may leave aspects of the assessment requiring further detailed evidence when the information becomes available at a later stage.

8 The GDA Step 4 report on structural integrity (Ref. 6) concluded that the strategy set down by EDF and AREVA for demonstrating avoidance of fracture for the High Integrity Components (HICs) was generally satisfactory and adequate to support an Interim Design Acceptance Confirmation (IDAC). However further evidence and justification of a

range of topics was considered necessary before a full Design Acceptance Confirmation (DAC) could be recommended.

9 GDA Issue **GI-UKEPR-SI-01** was created to define these additional requirements and the key activities required by EDF and AREVA may be summarised as:

- support the detailed assessment by ONR of the fracture mechanics analyses across a range of relevant components, locations and loading conditions in order to determine limiting defect sizes;
- provide additional evidence that those components classified as HIC are designed to facilitate an adequate inspection, both during manufacture and in-service;
- complete the choice of NDT methods for identified locations and provide evidence that these are likely to be capable of detecting defects smaller by some margin than the calculated limiting defect sizes; and
- support the assessment by ONR of the avoidance of fracture procedure including integration of fracture toughness, limiting defect size and NDT capability.

1.3 Methodology

10 The methodology applied to this assessment is identical to the approach taken during Step 4 and follows the ONR HOW2 document ‘Permissioning - Purpose and Scope of Permissioning’, PI/FWD Issue 3, (Ref. 1), in relation to mechanics of assessment within ONR.

11 This assessment has been focussed primarily on the submissions relating to resolution of the GDA Issue as well as any further requests for information or justification derived from assessment of those specific deliverables.

12 The aim of this assessment is to provide a comprehensive assessment of the submissions provided in response to the GDA Issues to enable ONR to gain confidence that the concerns raised have been sufficiently resolved so that they can either be closed or lesser safety significant aspects be carried forward as Assessment Findings.

1.4 Structure

13 This Assessment Report structure differs slightly from the structure adopted for the previous reports produced within GDA, most notably the Step 4 Structural Integrity Assessment. The report has been structured to reflect the assessment of an individual GDA Issue rather than a report detailing close-out of all GDA Issues associated with this technical area.

14 The reasoning behind adopting this report structure is to allow closure of GDA Issues as the work is completed rather than having to wait for the completion of all the GDA work in this technical area.

2 ONR'S ASSESSMENT STRATEGY FOR STRUCTURAL INTEGRITY

15 The intended assessment strategy for GDA close-out for the Structural Integrity topic area was set out in an assessment plan (Ref. 5) that identified the intended scope of the assessment and the standards and criteria that would be applied.

16 The overall bases for the assessment of the GDA Issues are the Structural Integrity elements of:

- Submissions made to ONR in accordance with the resolution plans.
- Update to the Submission / Pre-construction Safety Report (PCSR) / Supporting Documentation.
- The Design Reference that relates to the Submission / PCSR as set out in UK EPR™ GDA Project Instruction UKEPR-I-002 (Ref. 9) which will be updated throughout GDA Issue resolution. This includes Change Management Forms (CMF).
- Design Change Submissions – which are proposed by EDF and AREVA and submitted in accordance with UK EPR™ GDA Project Instruction UKEPR-I-003 (Ref. 10). There are two design changes, CMF-031 and CMF-032, (Refs 100, 101) relating to the design of the main coolant loop pipework which are discussed in Section 3.4 below.

2.1 The Approach to Assessment for GDA Close-out

17 The approach to the closure of GDA Issues for the UK EPR™ Project involves:

Assessment of submissions made by EDF and AREVA in response to GDA Issues identified through the GDA process. These submissions are detailed within the EDF and AREVA Resolution Plans for each of the GDA Issues.

- In the event of requiring further supporting evidence for the assessment, Technical Queries (TQ) have been generated.
- When requests for further information through production of the aforementioned TQs did not adequately resolve the GDA Issue, formal notification in the form of a letter detailing the shortfall(s) in ONR expectations was sent to EDF and AREVA.

18 The objective of this assessment has been to review submissions made by EDF and AREVA in response to the GDA Issue and the design changes requested and, if judged acceptable, clear the GDA Issue. Assessment Findings, that will need to be addressed by a Licensee during the site specific phase, will be raised as necessary as part of the closure of the Issue.

2.2 Standards and Criteria

19 The relevant standards and criteria adopted within this assessment are principally the Safety Assessment Principles (SAP) (Ref. 2), internal ONR Technical Assessment Guides (TAG), relevant national and international standards and relevant good practice informed from existing practices adopted on UK nuclear licensed sites. The key SAPs and relevant TAGs have been detailed within this section. National and international standards and guidance have been referenced where appropriate within the assessment report. Relevant good practice, where applicable, has also been cited within the body of the assessment.

2.3 Safety Assessment Principles

20 The key SAPs applied within the Structural Integrity assessment of the EDF and AREVA UK EPR™ are included within Table 1 of this report.

2.3.1 Technical Assessment Guides

21 The following Technical Assessment Guide has been used as part of this assessment:

- T/AST/016 Issue 3. Integrity of Metal Components and Structures (Ref. 3).

22 The Structural Integrity related SAPs, and relevant IAEA (International Atomic Energy Agency) standards and WENRA (Western European Nuclear Regulators' Association) reference levels are embodied and enlarged on in Ref. 3 and in practice this guide is the principal reference for assessing the Structural Integrity aspects.

2.3.2 Use of Technical Support Contractors

23 No Technical Support Contractors have been required to assist with assessment of this GDA Issue but results of their work in GDA Step 4 have been used in the assessment.

2.3.3 Out-of-scope Items

24 No out-of-scope items were identified through the GDA close-out assessment for GDA Issue **GI-UKEPR-SI-01** and this Issue has been addressed in its entirety.

3 ONR ASSESSMENT OF GDA ISSUE GI-UKEPR-SI-01

3.1 Background to the GDA Issue and Associated GDA Issue Actions

25 In the UK there is a recognition that there are a few critical components for which it is necessary to argue that gross failure can be discounted by showing that the likelihood is sufficiently low and the normal code requirements are not considered sufficient to provide this level of confidence. EDF and AREVA have accepted the need to make this demonstration in line with UK practice and have designated these components as High Integrity Components (HICs).

26 The evidence to show that the likelihood of failure is sufficiently low includes an avoidance of fracture demonstration which integrates fracture mechanics analyses, material toughness and qualification of manufacturing inspections. My GDA Step 4 assessment (Ref. 6) reviewed the proposals from EDF and AREVA. A number of the fracture analysis reports arrived later in the GDA Step 4 assessment timeframe than had been originally planned and it was not possible to fully assess these reports during GDA Step 4. In addition, the evidence supporting some of the inspections was not sufficient to show that inspection qualification was likely to be achievable.

27 GDA Issue **GI-UKEPR-SI-01** defines the additional evidence requested to support the demonstration of avoidance of fracture for all the HICs. Because of the variety of topics involved, the work has been sub-divided into seven Actions; one relating to fracture analysis and six relating to non-destructive testing.

28 Deliverables intended to provide the requisite evidence for each Action were proposed in the Resolution Plan (Ref. 7) provided by EDF and AREVA at the end of Step 4 of GDA.

29 An overview of each of the deliverables is provided under each Action. It is important to note that this information is supplementary to the information provided within the March 2011 PCSR (Ref. 11) which has already been subject to assessment during GDA Step 4. In addition, it is important to note that the deliverables are not intended to provide the complete safety case for this topic. Rather they provide further evidence to supplement that already provided during earlier Steps within the GDA Process.

3.2 Scope of Assessment Undertaken

30 The scope of the assessment has been to consider the expectations set down with the GDA Issue, **GI-UKEPR-SI-01**, and the associated GDA Issue Actions. These are detailed within Annex 3 of this report and summarised below for each Action. The scope of this assessment is not to undertake further assessment of the PCSR nor is it intended to extend this assessment beyond the expectations stated within the GDA Issue Actions. However, should information be identified that has a significant effect on the claims made for other aspects of structural integrity, this has been addressed.

31 In the case of **GI-UKEPR-SI-01** the assessment is directly related to the associated GDA Issue Actions detailed within Annex 3, with the exception of the structural integrity claims for the pressure boundary of the main steam isolation valves (MSIVs). As a result of our assessment the MSIV pressure boundary was identified as needing a HIC claim and additional deliverables to support this claim were submitted by EDF and AREVA and assessed as part of **GI-UKEPR-SI-01** in Section 3.10 of this report.

32 This assessment has been carried out in accordance with the ONR HOW2 documents ‘Permissioning - Purpose and Scope of Permissioning’, PI/FWD Issue 3, (Ref. 1) and ‘Integrity of Metal Components and Structures’, T/AST/016 Issue 3, (Ref. 3).

3.3 GDA Issue GI-UKEPR-SI-01 Action 1

33 This action (Annex 3) relates to the assessment of a number of fracture analysis reports that arrived later in the Step 4 assessment timeframe than had been originally planned. The fracture analyses are used to derive limiting defect sizes which are key inputs to the demonstration of avoidance of fracture.

34 ONR was unable to undertake a full assessment of these reports within the timescales allowed for GDA Step 4 as a result of the reports arriving later than originally planned. However, ONR completed a high level review in order to gain sufficient confidence that it should be possible to provide a suitable demonstration for the safety case, and thereby to support an IDAC. ONR recognised that a more detailed assessment would be required before it would be confident to support a DAC, and Action 1 covers the completion of ONR's assessment of these reports.

3.3.1 Deliverables for Action 1

35 The fracture mechanics reports had already been submitted to ONR. The approach has been to undertake a more detailed assessment of the existing reports. Thus no technical deliverables were identified against Action 1 as the assessment is based on existing reports.

3.3.2 ONR Assessment of Action 1

3.3.2.1 Scope of Assessment Undertaken

36 The fracture analysis reports requiring more detailed assessment are as follows:

- Critical Defect Sizes in the RPV Outlet Dissimilar Metal Weld. PEER-F 10.2068/A (Ref. 19).
- Critical Defect Sizes in the RPV Outlet Set-on Weld. PEER-F 10.1871/A (Ref. 23).
- Critical Defect Sizes in the RPV Cover Head Weld. PEERF 10-1525/A (Ref. 29).
- Critical Defect Sizes in the SG Tubesheet Welded Connection (tubesheet to primary & secondary). PEEG-F 10.1395/B (Ref. 31).
- RCP Casing of EPR™ Fast Fracture Analysis. PEER-F 10.2038/B (Ref. 33).
- Fracture Toughness Properties of Repair Welds in Cast Pump Casing. PEEM-F 11.0567/A (Ref. 34).
- RCP Flywheel Mechanical and Fracture Analysis. PEER-F 10.1674/A (Ref. 35).
- Summary of the FMA Approaches in RSE-M Appendix 5.4. PEER-F 10.1989/A (Ref. 38).
- Specific modified RSE-M Approach consistent with R6 rules to compare with the RSE-M Approach. PEER-F 101936/A (Ref. 41).
- Critical Defect Sizes using modified RSE-M Approach with R6 Rules. PEER-F 10.2069/B (Ref. 42).

37 These reports fall into two categories:

- Fracture mechanics analysis of specific locations.
- Fracture mechanics analysis methodology.

3.3.2.1.1 Fracture mechanics analysis of specific locations

38 The fracture mechanics analysis of specific locations (Refs 19, 23, 29, 31, 33, 34 and 35) cover the following HIC locations:

- RPV Outlet Nozzle Dissimilar Metal Weld.
- RPV Outlet Nozzle Set-on Weld.
- RPV Closure Head Weld.
- SG Tubesheet Welded Connection (primary and secondary).
- RCP Bowl Repair Weld.
- RCP Flywheel.

39 I have therefore undertaken a more detailed assessment of the fracture mechanics analysis reports used to calculate the limiting defect sizes in these locations. In addition I undertook a review of the thermal transients used in these analyses in line with the commitment made in Section 4.2.3.3.1 of the Step 4 Structural Integrity Report (Ref. 6).

3.3.2.1.2 Fracture mechanics analysis methodology

40 EDF and AREVA have calculated limiting defect sizes using an approach based on the French developed RSE-M Appendix 5.4 fracture mechanics analysis methodology (Ref. 17). The methodology has already been subject to significant comment in Section 4.2.3.5 of the GDA Step 4 report (Ref. 6) as the approach is different from the approach generally adopted by Licensees in the UK nuclear industry to date, the R6 Procedure for the Assessment of the Integrity of Structures Containing Defects (Ref. 18). However, three methodology reports (Refs 38, 41 and 42) still required a more detailed assessment.

41 The methodology reports cover:

- Development and validation of the RSE-M Appendix 5.4 methodology.
- Application of a modified RSE-M Appendix 5.4 approach consistent with the R6 plasticity correction factor rules.

42 I have therefore undertaken a more detailed assessment of these reports to complement the comments in Section 4.2.3.5 of the Structural Integrity GDA Step 4 report, Ref. 6.

3.3.2.2 Technical Assessment - RPV outlet nozzle dissimilar metal weld

43 The fracture mechanics analysis of the RPV outlet nozzle dissimilar metal weld is provided in Ref. 19. The weld is a 76 mm thick nickel-based Alloy 52 circumferential weld in the outlet nozzle of the RPV connecting the low alloy ferritic material of the RPV to the stainless steel material used in the MCL pipework. The analysis uses a two-dimensional cracked body finite element analysis to analyse the dissimilar metal weld, and concludes that the limiting defect depth is in excess of 20 mm for both the inner and outer surfaces. As a first order approximation the smallest limiting defect size is of the order of 23 mm on the inner surface, based on initiation toughness.

44 Given the complexity of the fracture mechanics analysis of the dissimilar metal weld I commissioned a technical support contractor, EASL, to undertake a review of the analysis methodology as part of the Step 4 programme of work. Their report, Ref. 20, reviews the approach taken by EDF and AREVA and identifies a number of areas where EASL had potential concerns with regard to the analysis methodology.

45 The EDF and AREVA report on which the EASL review was based arrived later than originally planned, and the EASL review had to take place later than intended. I was

unable to complete my assessment during Step 4, but I undertook a high level review of EDF and AREVA fracture mechanics analysis, Ref. 19, and the areas of potential concerns identified in the EASL report, Ref. 20. I concluded that I had sufficient confidence in EDF and AREVA's approach and results to support an IDAC, but considered that I would need to undertake a more detailed review of the two reports in order to be sufficiently confident in the approach to support a DAC.

46 I have therefore now reviewed both the EDF and AREVA report and the EASL report in more detail, and raised TQ-EPR-1478 (Ref. 15) which asked for clarification on a number of aspects associated with the analysis in order to address the areas of potential concern with regard to the methodology. EDF and AREVA provided a partial response to the TQ initially which addressed the points of clarification individually, and supplemented this by a full response which introduced an updated version of the fracture mechanics analysis report, Ref. 21, which incorporates much of the additional clarification provided in the partial response to the TQ in the overall fracture mechanics approach. I consider this is a helpful approach by EDF and AREVA as the updated report captures the additional clarification in a single document. The limiting defect sizes did not change.

3.3.2.2.1 Assessment at the ferritic to Alloy 52 interface

47 The fracture mechanics analysis assessed a defect postulated at the interface between the ferritic material and Alloy 52 weld, using a residual stress profile derived for the weld centre line, and with an allowable toughness based on the ferritic/Alloy 52 interface. It was not clear that this was a bounding set of assumptions, and the query asked for confirmation that the choice of location and residual stress/toughness assumption leads to a conservative assessment of the weld.

48 The TQ response indicates that the ferritic to Alloy 52 interface was chosen as the limiting location as tearing resistance tests of representative dissimilar metal weld test mock-ups showed that the cracks progressed down the ferritic to Alloy 52 interface.

49 Based on this response I am satisfied that it is appropriate to undertake the fracture assessment at this location, and that deriving the allowable toughness from a conservative assessment of these test results is appropriate. The remaining question is therefore whether the residual stress profile derived for the centreline of the weld is appropriate for the interface.

50 The report on the residual stress profile (Ref. 22) has been updated to present additional information to show that the residual stress profile for the weld centreline is adequate to represent the weld residual stress at the interface. The residual stress profile for the weld centreline has been derived from a pre-existing research and development programme looking at dissimilar metal welds, and is based on numerical welding simulations and residual stress measurements in representative mock-ups. The assumed profile is a normalised parabola peaking in tension at the Alloy 52 room temperature yield stress at the inner and outer surfaces. The additional information shows residual stress numerical welding simulations and measurements in the Heat Affected Zone (HAZ) adjacent to the interface, and demonstrates that the centreline profile is largely bounding for the heat affected zone. The TQ response argues that the results confirm that the stress profile is reasonably conservative for the whole of the dissimilar metal weld.

51 The precise prediction of residual stress profile is particularly difficult in a dissimilar metal weld joint due to the constantly varying properties as you pass through the weld. I believe that EDF and AREVA have presented some persuasive evidence to support the weld centreline profile assumed and the residual stresses in the HAZ adjacent to the interface. I recognise that the assumed profile does lead to Alloy 52 yield stresses at the surface and is therefore conservative at the surface, and whilst there will be some degree

of uncertainty in the profile, it is a not an unreasonable distribution to use for the ferritic to Alloy 52 interface.

52 Hence the responses satisfy me that the ferritic to Alloy 52 interface is an appropriate location to undertake the fracture assessment and, combined with the residual stress profile and allowable toughness values assumed, should lead to a conservative assessment of the weld.

3.3.2.2.2 Mechanical Loading

53 I enquired as to the basis for the pipebreak loads. The TQ-EPR-1478 response shows that the pipebreak loads are a bounding set formed by taking the maximum and minimum load values from every break case. Thus the set does not represent a specific break case, but I accept that they should be bounding.

54 In addition I questioned why the mechanical load sets appeared to differ between the dissimilar metal weld analysis, Ref. 19, the RPV Nozzle Analysis, Ref. 23 and the Main Coolant Line Analysis, Ref. 24. The partial response to the TQ gives a comprehensive explanation of why the differences occur. The basic mechanical load set is consistent throughout, but the way in which it is applied in the different analyses varies and I have not identified any anomalies following the explanation.

55 I also enquired as to the basis for the combination of the design base earthquake loads and pipebreak loads, and was satisfied that an appropriate approach has been taken.

3.3.2.2.3 Analysis Methodology

56 The analysis uses a two dimensional elastic cracked body analysis, applies corrections to account for plasticity and the semi-elliptical nature of the postulated defect, and applies the residual stress contribution as a separate entity. It is therefore a complex methodology, and I raised a number of queries in TQ-EPR-1478 related to the methodology including accounting for plasticity and accounting for the semi-elliptical nature of the defect.

57 The response to TQ-EPR-1478 explains some more of the background behind the methodology and they indicate that the approaches should be conservative. I had a concern that, given this complex approach, it is difficult to conclude that the methodology has been satisfactorily validated as a whole. An alternative approach would have been to use a full elastic-plastic finite element analysis of the cracked structure directly. I therefore asked why a full elastic-plastic finite element analysis had not been undertaken and got the response that a full three-dimensional elastic plastic finite element analysis would have been too complex and time consuming to undertake within the GDA timeframe. I have accepted this response, and will not be expecting such an analysis within GDA. It would, nevertheless, still be useful to compare the results from the methodology adopted for GDA with a more sophisticated elastic-plastic finite element analysis to ensure that the results are comparable.

58 In parallel to this concern over validation of the methodology I had also asked in TQ-EPR-1478 for the evidence to show that the finite element software package used to undertake the cracked body analysis (the SYSTUS code, Ref. 25) would generate accurate crack tip results from contour integrals that cross a material boundary in the presence of both primary and secondary stresses. The TQ response provided some useful confirmation that the contour integral path is not path dependent, but acknowledges that a specific validation for a multi-material case is not yet available. One is currently being developed in support of the Flamanville 3 project in France, but will not be complete till late 2012/early 2013. Hence there is a gap in the level of validation available to support the finite element analysis aspect of the work.

59 Bringing these two aspects of validation together leads to the conclusion that further confirmatory validation work is still required to confirm that the approach has generated suitable results. I consider that it is reasonable for the further confirmatory validation work to take place during the site specific phase because I judge that there are sufficient conservatisms embedded in the analysis for the GDA results to remain conservative. I have therefore raised **AF-UKEPR-SI-43** on validation.

3.3.2.2.4 Choice of Outlet Nozzle

60 I note that the RPV outlet nozzle was chosen for the dissimilar metal weld analysis for GDA. In Section 3.3.2.3.2 I express reservations that the outlet nozzle may not be limiting for the RPV nozzle set-on weld. These reservations potentially apply to this dissimilar metal weld analysis, however, the limiting load condition comes from the mechanical load set rather than the thermal transient. The mechanical load set is more onerous for the outlet nozzle and I am therefore content that the outlet nozzle has been analysed.

3.3.2.2.5 Results

61 The limiting defect size of 23 mm is a first order approximation for an inner skin defect. It is based on initiation toughness, and I recognise that it is possible that an analysis taking account of a limited amount of ductile tearing in the infrequent fault situations could lead to a larger limiting defect size.

62 It is, however, difficult for the analysis to calculate a more representative limiting defect size as the analysis is based on a 20 mm deep postulated defect, with the 23 mm limiting defect size simply a first order approximation that is reasonable where the defect size is within a few millimetres of that analysed, but could not be extrapolated a long way from the depth of defect analysed.

63 ONR’s expectation is that the sizes of crack-like defects of structural concern should be calculated, see SAP EMC.34. Thus rather than showing that a particular depth of defect based on an estimate of the reliably detectable defect size with a target margin of two is acceptable (i.e. showing the acceptability of a 20 mm defect where the reliably detectable defect size is 10 mm and the target margin is two), the expectation would be to calculate a limiting defect size in order to find out the margins related to crack depth.

64 In many types of procedurally based fracture assessment it is relatively straightforward to calculate the limiting defect size, but this can be time consuming where a finite element analysis of the cracked body has been undertaken as the finite element model is only representative of a single defect depth. Thus multiple finite element models would be required in order to determine the actual limiting defect size.

65 In the case of the dissimilar metal weld analysis the applied J integral (measure of crack tip loading) is sufficiently close to the allowable J integral value for a 20 mm deep defect based on initiation toughness that it is reasonable to extrapolate the analysis to estimate the limiting defect size of 23 mm using a first order approximation. However, had there been a more significant difference in applied crack tip loading compared with allowable crack tip loading then such an extrapolation would not have been valid and there would have been a need to analyse finite element models with different defect depths in order to determine the limiting defect size.

66 In addition the effect of plastic collapse has been neglected in the analysis on the basis that it will not have a significant effect given the size of the limiting defect. It is also argued that plastic collapse of the stainless steel section (which has the lowest yield strength) is considered in the analysis of the MCL pipework. I consider this reasonable given that the limiting defect size is only around 30% of the wall thickness, but the

interaction of plastic collapse would have to be considered further if the limiting defect were much larger than this.

67 Overall I accept that the 23 mm limiting defect depth should be conservative based on the analysis work undertaken, and it is based on initiation toughness. Further analysis work would be required to determine a larger limiting defect size as the finite element model only represents a 20 mm deep defect, but given that the case can be based on initiation toughness, it will not be necessary to extend the analysis to address the limiting defect size assuming a degree of stable tearing. Thus in this situation the analysis of a single defect depth has been sufficient, but in general it is ONR's expectation that the sizes of crack like defects of structural concern should be calculated in line with SAP EMC.34. It may therefore be necessary to undertake cracked body finite element analyses of a number of defect depths in order to determine that limiting defect size. I have raised Assessment Finding **AF-UKEPR-SI-44** for the Licensee to address this aspect in general terms.

3.3.2.2.6 Conclusions on the RPV outlet nozzle dissimilar metal weld analysis

68 The dissimilar metal weld analysis methodology is complex but I accept that the 23 mm deep limiting defect size calculated for the inner surface for GDA purposes should be conservative.

69 The re-issue of the analysis to consolidate the responses to the points raised in TQ-EPR-1478 against this analysis, Ref. 21, is considered helpful.

70 Further validation work should take place to confirm that the analysis methodology for the dissimilar metal weld is appropriate but I judge that there are sufficient conservatisms embedded in the analysis undertaken for the GDA results to remain conservative, and this confirmatory validation work can be undertaken during the site specific phase. I have therefore raised **AF-UKEPR-SI-43** on validation.

71 It is ONR's expectation that the sizes of crack like defects of structural concern should be calculated, and it should be recognised that it may be necessary to undertake cracked body finite element analyses of a number of defect depths in order to determine that limiting defect size. In this situation the analysis of a single defect depth has been sufficient, but I have raised **AF-UKEPR-SI-44** for the Licensee to address this aspect in general terms.

3.3.2.3 Technical Assessment - RPV outlet nozzle set-on weld

72 The fracture mechanics analysis of the RPV outlet nozzle set-on weld is provided in Ref. 23. This is the weld between the RPV upper shell course and the forging for the nozzle, and is a low alloy steel weld. The mean diameter of the nozzle is of the order of [redacted], and the thickness of the weld is [redacted]. The nozzle not only provides the connection to the main coolant loop pipework, but also the support pads for the RPV itself.

73 The analysis uses a large three-dimensional elastic finite element model of the nozzle (and a quarter of the RPV shell) to generate the stress distribution through the weld in the uncracked structure due to the thermal transient, pressure stress and mechanical loads, and these are then combined with the weld residual stresses in an RSE-M Appendix 5.4 based fracture assessment (Ref. 17). A limiting defect depth of 77 mm is calculated for the inner surface.

74 I undertook a high level review of the analysis presented in Ref. 23 as part of the Step 4 programme of work, and gained sufficient confidence in the approach and results to

support the IDAC, but considered that I would need to undertake a more detailed review in order to support a DAC.

75 I have therefore now reviewed Ref. 23 in more detail and raised TQ-EPR-1480 (Ref. 15) which asked for clarification on a number of aspects associated with the analysis.

3.3.2.3.1 Analysis Methodology

76 EDF and AREVA used the SYSNUKE module of the general SYSTUS finite element modelling software (Ref. 25) to generate the through thickness stress state across the weld. This finite element package was originally developed by Framatome, a predecessor of AREVA, and since 1997 has been developed as a commercial software package sold through the French based ESI Group.

77 The through thickness stress states are then analysed using the RSE-M Appendix 5.4 methodology, codified in an in-house AREVA software programme, DEFIS (Ref. 26).

78 The approach is conventional in that elastic finite element analyses are used to determine the stress state in the uncracked structure (time dependent in the case of the thermal transient analyses) and this stress state is then analysed in the fracture mechanics procedure, RSE-M Appendix 5.4 in this case. Thus I am satisfied that an appropriate approach has been used.

79 I have previously enquired in TQ-EPR-879 (Ref. 13) about the computer codes used to support the stress and fracture analyses, and the processes used for validation and verification of the results, and was satisfied with the response and processes adopted. I further enquired in TQ-EPR-1480 as to the specifics of the validation adopted in this analysis. The response indicates that a diverse check on the results at the instant of the maximum loading and minimum margin had been undertaken using the analytical formulae from RSE-M, and I am satisfied with the response.

80 I did, however, note that the graphs of stress intensity versus time for the LOCA transient shown in Figures 16 and 17 of Ref. 23 exhibited an unexpected plateau in the maximum stress intensity factor, and questioned this in TQ-EPR-1480. The response showed that the plateau was a function of a simplified coding of the calculation of the plasticity correction factor within the DEFIS programme (Ref. 26), but that the value attained on the plateau was representative of the maximum value after the plasticity correction had been accounted for. I accept the explanation, and that the maximum value is correct.

81 Another issue with the use of the in-house DEFIS programme to undertake the fracture assessment in line with the RSE-M Appendix 5.4 methodology is whether there are any commercially available software implementations of the RSE-M Appendix 5.4 methodology. That is not an adverse comment in a technical sense on the use of this in-house software to implement the RSE-M methodology, but if it turns out there are no commercially available software implementations of the methodology then it makes the adoption of the RSE-M Appendix 5.4 methodology more difficult for any potential Licensee in the UK.

82 I will return to this aspect in Section 3.3.2.9 on the RSE-M Appendix 5.4 methodology.

3.3.2.3.2 Choice of Outlet Nozzle

83 The limiting defect sizes are calculated for an outlet nozzle. The reasons for the choice of the outlet nozzle rather than an Inlet Nozzle were based on a review of the fast fracture work undertaken for non-UK EPR™ stations and are explained in Ref. 27. This review indicates that whilst the thermal transient loading is a little less severe for the outlet nozzle, the mechanical load set is higher for the outlet nozzle, and the thermal ageing would be more significant for the higher temperatures seen by the outlet nozzle. Ref. 27

therefore concluded that the Inlet Nozzle weld would be covered by the analysis of the outlet nozzle set-on weld.

84 I do not find this reasoning convincing. The analysis of the limiting defect depth for the inner skin defect shows that the crack tip loading is dominated by the thermal transient contribution, with the mechanical contribution making up a very small proportion of the total loading. The transient definition for the surge line break LOCA (Figure 18 of Ref. 23, Appendix B) shows that the cold leg temperature drops more steeply than the hot leg temperature and finishes at a lower temperature at the end of the transient. On this basis the Inlet Nozzle weld would be more limiting than the outlet nozzle because the temperature drop is more penalising and the end temperature is lower, thus potentially reducing the allowable toughness. Against this the Inlet Nozzle may have slightly lower thermal ageing shifts due to the lower operating temperature, but overall I think there is good reason to conclude that the Inlet Nozzle will be more limiting than the outlet nozzle.

85 The fracture mechanics analyses provided within GDA were never intended to cover every weld in every component, but were intended to analyse a limiting set of welds that were representative of the most onerous locations in order to give confidence in the design. A more extensive set of fracture mechanics assessments would then be undertaken beyond GDA. This aspect was explicitly registered in Assessment Finding **AF-UKEPR-SI-01** in the Step 4 Structural Integrity Report (Ref. 6):

> ***AF-UKEPR-SI-01:*** *The Licensee shall undertake fracture assessments on a wider range of weld locations on the HIC Components in order to demonstrate that the limiting locations have been assessed. The Licensee shall also undertake fracture assessments on the vulnerable areas of the parent forgings in order to demonstrate that the limiting locations have been assessed.*

86 The analysis of the RPV outlet nozzle set-on weld shows a limiting defect depth of 77 mm deep. In practice the justification will only be challenged if the limiting defect depth drops below 20 mm based on a target margin of two and EDF and AREVA’s assertion that they will be able to qualify the NDT procedures against a 10 mm deep defect. Whilst an analysis of the RPV set-on weld for the Inlet Nozzle may be more limiting, I judge that it is very unlikely that the difference would be so significant as to reduce the limiting defect depth from 77 mm to below 20 mm. Thus for the purposes of GDA I am satisfied that the limiting defect size for the RPV Nozzle set-on welds will be sufficient to support EDF and AREVA’s case i.e. it will be greater than 20 mm for both the Inlet and outlet nozzles, but may not be as high as the 77 mm calculated for the outlet nozzle. I am satisfied that the existing Assessment Finding **AF-UKEPR-SI-01** is adequate to ensure that the Inlet Nozzle will be analysed in the fracture assessments undertaken post-GDA.

3.3.2.3.3 Material Toughness

87 The fracture toughness used in the analysis is based on the weld material thermally aged at 350°C. The material properties report, Ref. 28, shows that the thermal ageing shift for the Heat Affected Zone (HAZ) material exceeds that of the weld material for low alloy steels at 350°C, and I questioned why the analysis had been undertaken on the basis of the fracture toughness for the weld material rather than the HAZ material in TQ-EPR-1480.

88 The response acknowledged that the thermal ageing shift for the HAZ was greater than the weld at the same ageing temperature, but that the thermally aged weld toughness values had been assessed at 350°C which is conservative compared with the hot leg design temperature. They then argued that the thermal ageing shift for the HAZ at the more realistic ageing temperature of 325°C was less than the thermal ageing shift for the

weld metal at 350°C, so the toughness value for the weld material would still be conservative for the HAZ material.

89 The design parameters for the RPV in Chapter 5.3 of the PCSR (Ref. 11) show a hot leg temperature of 328°C, and thus support EDF and AREVA's argument that the toughness value assumed for the analysis would remain conservative for the HAZ material. Thus I accept that the analysis remains valid. In general terms, however, I would expect the fracture mechanics analyses to recognise the differing properties of the HAZ material compared with the weld, and that the limiting defect sizes would be applicable to defects postulated in both the weld material and the HAZ material (and if necessary the base metal if that were limiting). This should be addressed in the more extensive fracture assessments being undertaken beyond GDA, and I have therefore raised Assessment Finding **AF-UKEPR-SI-45** on material toughness properties.

3.3.2.3.4 Conclusions on the RPV outlet nozzle set-on weld analysis

90 I am satisfied with the methodology used to analyse the set-on weld.

91 The analysis of the outlet nozzle set-on weld was intended to cover the set-on weld for the Inlet Nozzle. However, the 77 mm deep limiting defect calculated for the outlet nozzle set-on weld may not be limiting for the Inlet Nozzle set-on weld due to the more severe thermal transients applicable to the Inlet nozzle.

92 I judge that it is very unlikely that the difference in thermal transients would be so significant as to reduce the limiting defect depth from 77 mm to below the 20 mm needed to support EDF and AREVA's case. Thus for the purposes of GDA I am satisfied that the analysis of limiting defect size for the RPV outlet nozzle set-on weld will be sufficient to support the case for the RPV set-on welds.

93 The Inlet Nozzle set-on weld will still need to be analysed as part of the more extensive fracture mechanics analyses planned for beyond GDA and I am satisfied that the existing Assessment Finding **AF-UKEPR-SI-01** is adequate to ensure that the Inlet Nozzle will be analysed.

94 The material toughness properties assumed in the analysis were applicable to the weld material, and although subsequently shown to be conservative for the HAZ material using a more realistic thermal ageing temperature, this aspect should have been taken into account when the analysis was undertaken. I have therefore raised Assessment Finding **AF-UKEPR-SI-45** on material toughness properties to ensure this is addressed in the more extensive fracture assessments being undertaken post GDA.

3.3.2.4 Technical Assessment - RPV Closure Head weld

95 The fracture mechanics analysis of the RPV closure head weld is provided in Ref. 29. The joint is a [redacted] thick low alloy weld, joining the closure ring forging of the head to the dome of the closure head.

96 The analysis uses a three dimensional elastic finite element model to simulate the RPV closure head, RPV body, and bolted connection between the two in order to determine the stress state across the weld in the uncracked structure. The stress state takes account of the mechanical loads due to the bolting/unbolting sequence, pressure and thermal transient stresses. These stresses are then combined with the weld residual stresses in an RSE-M Appendix 5.4 based fracture assessment (Ref. 17).

97 This weld was one of three where I commissioned a technical support contractor EASL, as part of the Step 4 programme of work, to undertake a comparative study of the fracture assessment methodologies using the R6 Revision 4 Procedure for the Assessment of Structures Containing Defects (Ref. 18). EASL's work is reported in Ref.

30 and Section 4.2.3.5 of the Step 4 Structural Integrity report (Ref. 6) provides more background to the comparative study.

98 The EDF and AREVA report arrived later than originally planned, and the EASL comparative study had to be undertaken later than planned. In practice I needed to take account of the results from the EASL comparative study of the fracture assessment procedure during the Step 4 work, and this was reported in the Step 4 report. Unlike the other two comparative studies, the limiting defect depth for an outer skin defect of 57.9 mm calculated by EASL using the R6 procedure compared well to the 62 mm calculated by EDF and AREVA using the RSE-M Appendix 5.4 methodology. I concluded that this was because there were no significant secondary stresses associated with the limiting load case, and therefore the differences in the treatment of the post yield interaction between the primary and secondary stresses between the RSE-M Appendix 5.4 and R6 Procedure did not apply in this situation (see Section 4.2.3.5.1 of the GDA Step 4 Structural Integrity report for more details on these differences (Ref. 6), and Section 3.3.2.8 of this report on the RSE-M Appendix 5.4 methodology).

99 I was able to take account of the EASL comparative study in the Step 4 work, but I was unable to complete a full assessment of the EDF and AREVA report. As I had sufficient confidence in the approach and results I could support an IDAC, but I considered that I should undertake a more detailed review in order to support a DAC.

100 I have therefore now reviewed Ref. 29 in more detail and raised TQ-EPR-1521 (Ref. 15) which includes clarification on two specific points.

3.3.2.4.1 Material Toughness

101 I raised the question on how the thermal ageing shift applied to the HAZ material had been taken into account. This was essentially the same questions that I raised against the RPV outlet nozzle set-on weld (Section 3.3.2.3).

102 The EDF and AREVA response to this TQ refers back to the TQ-EPR-1480 response against the RPV outlet nozzle set-on weld. I accept that the same arguments apply in this case and that the analysis remains valid for the HAZ material, but would again have expected the analysis to recognise the differing properties of the HAZ material compared with the weld. Thus Assessment Finding **AF-UKEPR-SI-45** on material toughness properties applies equally to the analysis of this weld.

3.3.2.4.2 Limiting Load Case

103 The limiting defect depth came from the first stage of the head opening sequence due to the increase in stud load associated with the opening sequence. I queried whether the normal operating transient associated with plant warm-up and the normal stud load could lead to a more onerous load condition.

104 The TQ response explains that the choice of the head closing/opening sequence for limiting load case had been based on the margins against the RCC-M design code criteria (Ref. 16) applied for Flamanville 3, but that the warm-up transient will be assessed as part of the more extensive set of fracture mechanics analyses to be undertaken beyond GDA.

105 The information provided on the Flamanville margins suggests that the absolute margins (as opposed to the margins against the design code criteria) against plant warm-up may be slightly less than the margins seen against opening/closing operations, however the differences are not large enough to have a significant effect on the limiting defect size, particularly given that the limiting defect size is 62 mm and it would have to drop below

20 mm to challenge the justification (see Section 3.3.2.3.2 for an explanation of the significance of the 20 mm deep defect).

106 I accept the assurance that the plant warm-up transient will be assessed as part of the post GDA fracture analyses, and the existing Step 4 Assessment Finding **AF-UKEPR-SI-01** already addresses this point in any case (see Section 3.3.2.3.2 for the wording of the existing finding).

3.3.2.4.3 Conclusions on the RPV closure head weld

107 I am satisfied with the methodology used to analyse the RPV closure head weld. The comparative study undertaken during Step 4 showed a good comparison between the limiting defect size calculated using the RSE-M Appendix 5.4 fracture assessment methodology and the R6 Procedure. This was encouraging and I concluded that the good agreement was linked to the fact that there were no significant secondary stresses associated with the limiting load case, and therefore the differences in the treatment of the post yield interaction between the primary and secondary stresses between the RSE-M Appendix 5.4 and R6 Procedure did not apply in this situation.

108 The opening and closing sequence load case used for the analysis may not prove to be as limiting load case as the plant warm up transient may be more severe. However, I am satisfied that the differences will not be significant to the case given a limiting defect size of 62 mm. The plant warm-up transient will be assessed as part of the more extensive set of post GDA fracture analyses, and the existing Step 4 Assessment Finding **AF-UKEPR-SI-01** already addresses this aspect.

109 The comment I made against the RPV outlet nozzle set-on weld in respect of the HAZ material properties also applies to this analysis, and Assessment Finding **AF-UKEPR-SI-45** will therefore also apply.

3.3.2.5 Technical Assessment - SG tubesheet welded connection (primary and secondary)

110 The fracture mechanics analysis of the SG tubesheet welded connection is provided in Ref. 31 for both the primary and secondary side welds. The tubesheet to primary side weld is approximately [redacted] thick, and the tube sheet to secondary side weld is approximately [redacted] thick. Both are low alloy steel welds.

111 The analysis uses a two dimensional axi-symmetric elastic finite element model of the lower part of the SG, including the primary side head, the tubesheet itself and a portion of the secondary side head. These stresses are then combined with the weld residual stresses in the RSE-M Appendix 5.4 based fracture assessment. The limiting defect depths occur on the inner surface, and are calculated to be 38 mm deep for the primary side weld and 21 mm for the secondary side weld

112 As in the other cases I undertook a high level review of the analysis presented in Ref. 31 as part of the Step 4 programme of work, and gained sufficient confidence in the approach and results to support the IDAC, but considered that I would need to undertake a more detailed review in order to support a DAC.

113 I have therefore now reviewed Ref. 31 in more detail and raised TQ-EPR-1521 (Ref. 15) for clarification on a number of aspects associated with the analysis, and TQ-EPR-1622 on the thermal ageing allowance (Ref. 15).

3.3.2.5.1 Methodology

114 The approach is very similar to that used for the RPV outlet nozzle Set-on weld in that the SYSTUS finite element software (Ref. 25) was used to determine the elastic stress state through the weld in the uncracked body, and the fracture analysis was undertaken to

RSE-M Appendix 5.4, as codified in the in-house AREVA software programme, DEFIS (Ref. 26).

115 I had no additional questions on the methodology itself, but did question the origin of the unreferenced material characteristic curves used to represent the stiffness of the perforated area of the tube plate. The response to TQ-EPR-1521 states that they had come from a CETIM technical note (CETIM - Technical Center for the Mechanical Industry – a French industry sponsored research organisation) dating from the late 1970s, but that they are similar to the ones quoted in the current European standard for unfired pressure vessels. I was reassured with the comment that the values were comparable to those quoted in a current standard, and accept the curves without any more detailed review.

3.3.2.5.2 Material Properties

116 The analysis takes account of the thermal ageing, and the end of life RT_{NDT} of -1°C is fairly consistent with the values used in other low alloy steel analyses, for example -2°C for the analysis of the RPV outlet nozzle weld in Ref. 23. However, and unusually, the value is referred back to an English translation of a fracture assessment undertaken for the FA3 SGs, Ref. 32. I therefore raised TQ-EPR-1622 on the origins of this thermal ageing allowance, as it should have been referred back to the Materials Report provided for GDA purposes, Ref. 28. I also noted that the end of life thermal ageing shift assumed for the HAZ material in the FA3 analysis was much greater than the values given for GDA in Ref. 28, and the end of life RT_{NDT} of -1°C was only achieved by assuming that the start of life RT_{NDT} was 15°C lower in the HAZ material than the base material or weld material.

117 The response explains that the low alloy steel thermal ageing allowances contained in Ref. 28 are based on the information provided in RCC-M Appendix ZG for a 60 year life. Ref. 28 and RCC-M calculate the end of life RT_{NDT} for the HAZ material based on a thermal ageing shift for the HAZ relative to the start of life RT_{NDT} for the base material for GDA whereas Ref. 32 calculates an end of life RT_{NDT} for the HAZ material based on a thermal ageing shift for the HAZ relative to the start of life RT_{NDT} for the HAZ material.

118 The effect is that the FA3 data shows a thermal ageing shift at least 15°C greater than shown in Ref. 28 or RCC-M (actual value depends on temperature, but at 300°C it is 15°C, and is slightly more at 325°C). Conversely the start of life RT_{NDT} is assumed to be 15°C less for the HAZ compared with the parent material.

119 Thus the FA3 data from Ref.32 shows the true ageing shift for the HAZ rather than an artificially reduced one that includes the effect of both the actual thermal ageing shift for the HAZ and an allowance for improved start of life properties as shown in Ref. 28 and RCC-M. The FA3 data from Ref. 32 also identifies that the HAZ needs to achieve better start of life RT_{NDT} than the parent material, a fact which is effectively lost in Ref. 28 and RCC-M information.

120 TQ-EPR-1622 provides data from previous French plants to support the assumption that the start of life RT_{NDT} for the HAZ is at least 15°C lower than the base material. The data are based on the temperatures at which a Charpy impact energy of 56 Joules is achieved. It is not therefore a true measure of RT_{NDT}, but I accept that the clear margin gives credibility to the improved properties of the HAZ.

121 I consider that the response to TQ-EPR-1622 satisfactorily explains the differences between the FA3 information and the GDA information, and provides some evidence to underpin the improved start of life properties for the HAZ material. However, I have a concern that the GDA material properties for the low alloy steel HAZ are being described in terms of an artificially reduced thermal ageing shift and by embedding improved start of

life material properties for the HAZ in a manner that means that the need for these improved properties is not necessarily recognised. As stated at the outset, this does not materially affect the fracture assessment as the overall end of life RT_{NDT} is not significantly different, so these matters can be addressed during the site specific phase. I have therefore raised Assessment Finding **AF-UKEPR-SI-46** for the Licensee to explicitly identify the full thermal ageing shift and improved start of life properties for the HAZ, and for the confirmatory fracture toughness testing to demonstrate the improved start of life properties for the HAZ.

3.3.2.5.3 Results

122 The results for the tube sheet welds are quite difficult to interpret due to the interaction between the thermal transients occurring in both the primary and secondary sides of the tube sheet.

123 I therefore asked, in TQ-EPR-1521, for confirmation that the transient analysis for the Main Steam Line Break with Loss of Offsite Power (MSB with LOOP) transient had been run for a sufficient length of time to ensure that a minimum margin had been obtained, and for an explanation of the differences between the stress intensity versus time graphs provided for the two transients considered for the secondary side weld.

124 The response to TQ-EPR-1521 confirmed that the MSB with LOOP transient had been run for the whole duration of 20,000 seconds, and would therefore have identified any further minima beyond the 648 seconds identified as the instant on the minimum margin for this transient on the primary side weld. Some detailed graphs were also provided showing how the stress intensity factor margin varied with time in order to illustrate why the minimum margin for this transient occurred at 648 seconds. As a result I am satisfied with why the minimum margin for this transient occurs towards the start of the transient and that the transient has been run for a sufficiently long time to identify any other potential minima.

125 The TQ response also provided a more detailed explanation of the interaction between the primary and secondary side transients in order to understand the differences between the stress intensity versus time graphs for transients applied for the secondary side weld. I consider that the detailed explanation provides a useful insight into the differences through considering the interaction between the primary and secondary side transients. The effect of this interaction was otherwise not obvious, and I am now comfortable that the stress intensity factor results that have been presented for the secondary side weld appear reasonable.

3.3.2.5.4 Conclusions on the SG tubesheet welded connection

126 I am satisfied with the analysis methodology and results obtained for the SG tubesheet welded connections, and that the limiting defect sizes should be in excess of 20 mm deep.

127 I identified a difference between the thermal ageing shifts adopted for the low alloy steel HAZ in FA3 and those adopted for GDA. The response to TQ-EPR-1622 explains the difference and provides some evidence to underpin the values used. This does not materially affect the fracture assessment as the overall end of life RT_{NDT} is not significantly different, but I have a concern that that the GDA material properties for the low alloy steel HAZ are described in terms of an artificially reduced thermal ageing shift and embed improved start of life material properties for the HAZ in a manner that means that the need for these improved properties is not necessarily recognised. These matters that can be addressed during the site specific phase and I have therefore raised Assessment Finding **AF-UKEPR-SI-46** for the Licensee to explicitly identify the full

thermal ageing shift and improved start of life properties for the HAZ, and for the confirmatory fracture toughness testing to demonstrate the improved start of life properties for the HAZ.

3.3.2.6 Technical Assessment - RCP bowl repair weld

128 The fracture analysis of the reactor coolant pump bowl is provided in Ref. 33. The pump bowl is a geometrically complex thick structure made from cast austenitic stainless steel and these castings can require large repair welds (exceeding 35 mm in depth) to rectify defect indications found in the base casting. The weld repairs are undertaken using manual metal arc welding with an austenitic stainless steel filler material and are not post-weld stress relieved. The fracture analysis determines the limiting defect size for defects located in these large weld repairs, and the repair welds themselves can be located anywhere within the pump bowl casting. The thickness of the bowl is typically around [redacted], but can be in excess of [redacted] thick in some regions.

129 The analysis uses a three dimensional un-cracked elastic finite element model of the pump bowl to identify two limiting locations for any potential defects based on the applied mechanical and thermal transient loads, along with the residual stresses from the welding procedure. The two limiting locations are on the inner surface of the thickest section of the casting near the outlet nozzle. A full elastic-plastic three dimensional cracked body model is then used to assess the effect of the thermal transients on these two limiting locations. The analysis concludes that the limiting defect depth is in excess of 20 mm.

130 Ref. 33 arrived towards the end of the Step 4 programme due to the complexity of the analysis and the need to use interim results from an ongoing thermal ageing programme to establish the fracture toughness properties of the weld repairs which had only just become available, Ref. 34.

131 As in the other cases I undertook a high level review of the analysis presented in Ref. 33 and supporting material reference, Ref. 34, as part of the Step 4 programme of work, and gained sufficient confidence in the approach and results to support the IDAC, but considered that I would need to undertake a more detailed review in order to support a DAC.

132 I have therefore now reviewed the Refs. 33 and 34 in more detail and raised TQ-EPR-1523, 1531 and 1572 (Ref. 15) to provide further clarification on a number of aspects associated with the analysis and the fracture toughness properties assumed for the weld repair.

3.3.2.6.1 Methodology

133 The identification of the limiting locations and assessment of the mechanical loading used the results from a pre-existing three dimensional elastic finite element model of the un-cracked structure and an analytical based fracture analysis of the RCP bowl using these stresses. The pre-existing work has been modified to incorporate residual stresses in line with UK EPR™ analyses. It has identified limiting locations in the thickest sections of the RCP bowl and I am satisfied that it is adequate to identify the limiting locations and to demonstrate that the mechanical loading should not prove limiting.

134 The analysis of the thermal transients using the three dimensional cracked body finite element analysis uses the SYSTUS finite element software (Ref. 25). I note that it this is a very sophisticated model and analysis. The three dimensional modelling of such a complex casting with a crack like feature is a significant undertaking in the first place. This is further complicated by the bi-metallic nature of the material properties as the weld repair has a higher yield stress than the surrounding cast material. There is then the need to introduce a significant residual stress from the weld repair process and the RP

then chose to apply the shop based hydro-test pressure to the model in order to simulate any relaxation in residual stress relaxation from this overload. At this point the thermal transient and corresponding mechanical loads were applied to the model, and applied crack tip loading compared against the allowable values.

135 As stated, the model and analysis are very sophisticated and I made a number of enquires regarding the approach, results and the level of validation and verification undertaken on the work.

136 I was particularly interested in the effect of the hydro-test on the crack tip loading and how this had been checked as being reasonable. The effect is complex due to the bi-metallic nature of the cast material and weld and re-distribution of plasticity. Additional stress plots provided in the TQ-EPR-1572 response suggest that the model is behaving in line with expectations. Perhaps more importantly an additional plot on crack tip loading for the thermal transient was provided both with and without the effect of the hydro-test having been applied. This showed a minimal change to the applied crack tip loading during the thermal transients. This was explained by the fact that the thermal shock analyses is more severe in terms of plasticity than the hydro-test, so the actual effect of applying the hydro-test is not significant to the result. I am comfortable with such an explanation, and it gives confidence that applying the hydro-test to the model has not distorted the results.

137 I also made enquires in TQ-EPR-1572 on whether the J-integral solutions (a measure of the crack tip loading) in the SYSTUS software were path independent as there have been some concerns on this aspect in other commercial finite element codes when modelling high residual stresses. The response indicates that the software provides path independent solutions and is suitable for determining the crack tip loading in such situations, and I am satisfied with the response.

138 The repair weld is not post weld stress relieved. The residual stress applied to the model equates to the room temperature yield stress of the base material (210 MPa). This was supported by some information for residual stress measurements from a representative mock-up and I am satisfied with the value that has been included.

139 Overall I am satisfied with the responses to my queries. The area of validation and verification is always difficult in such sophisticated analyses. It is clear from the responses to my queries that several checks and balances have been applied to ensure that the model is behaving as expected and that the results are reasonable. I am therefore satisfied that an appropriate methodology has been used, and that sufficient validation and verification has been undertaken to confirm the model and the results for the purposes of the GDA case.

3.3.2.6.2 Material Properties

140 The toughness properties for the weld repairs in the pump bowl are derived in Ref. 34. These are based on the interim results from a then ongoing accelerated thermal ageing programme to establish the fracture toughness properties of the weld repairs. They had to be based on interim results as the final results would not be available within the GDA Step 4 – the results were extrapolated from accelerated ageing results of 400°C at 3000 hours, whereas full accelerated ageing test would continue through to 10000 hours at 400°C.

141 I consider the RP’s decision to provide test-based material-specific thermally-aged toughness data to be an important and positive underpin to the fracture assessment. The need to extrapolate from interim test data at 3000 hours rather than use data from the 10000 test was an unavoidable consequence of the length of time need to undertake

these thermal ageing tests. Provided the extrapolation is undertaken in a conservative manner, then I do not see this as a problem because the final 10000 hour test results will eventually underpin the extrapolation.

142 The testing has used a combination of CT12.5 and CT25 (CT – Compact Tension test specimens, with the number relating to the thickness of the specimen in millimetres) fracture toughness test specimens and RCP cast material that has had a 40 mm deep repair weld. Toughness values are quoted at $J_{0.2}$, J_1 and J_3. The reductions due to the thermal ageing are quite significant, particularly as the Type 308 austenitic weld material used is generally considered quite resistant to thermal ageing. For example the $J_{0.2}$ test value at 3000 hours is 32% lower than the test value from the as-welded condition, and this is further reduced by 30% to give the value to be used in the fracture assessments to represent 10000 hours.

143 I did note that the J_3 test value at 3000 hours was unexpectedly based on extrapolation and I queried this. The response explained that results were only available for the CT12.5 specimens at the time the report had been written, and could not be used to establish J_3 values. However, the extrapolated value had subsequently been shown to be conservative following the test of the larger CT25 specimens that could establish the J_3 value.

144 As noted above, the 10000 hour values used in fracture assessment are based on a 30% reduction in 3000 hour test results. This reduction is to allow for both the additional thermal ageing and in generating lower bound toughness properties from the test results. In practice the basis for the 30% reduction factor is quite subjective, but I consider that it should be conservative particularly as they have based the reduction in part on the values that would normally be expected for an alternative austenitic weld material that is generally considered more susceptible to ageing. The final values used in the post GDA fracture assessment will need to be confirmed by the 10000 hour test results, but I would consider this aspect to be covered by normal business and have not raised the matter as an Assessment Finding.

145 I am therefore content with the extrapolation from 3000 hours to 10000 hours, but I do have a residual question over whether test results from accelerated ageing at 10000 hours and 400°C is adequate to represent the thermal ageing seen over a 60 year reactor life. I queried this aspect, and the response indicated that 10000 hours at 400°C would represent between 20 and 40 years operation at the cold leg temperature, but that the ageing kinetics show a threshold limit that is usually assumed to be reached at 10000 hours and 400°C and any further decrease in toughness should be negligible. A graph was provided for background information to show the threshold effect, but the limited data points did not, in my opinion, give conclusive support to the assertion that any further reduction would be negligible. That is not to say that I do not agree that there is a threshold value, but that the evidence presented did not give conclusive support to this having been reached at 10000 hours and 400°C.

146 The RP confirmed that they had no further data to support their assertion, and it would not be possible within the GDA timeframe to establish any further data from ageing tests.

147 I therefore conclude that further work is required to confirm that the aged toughness values obtained from 10000 hour accelerated testing at 400°C used in the fracture assessments are applicable for a 60 year reactor life. Whilst I raised this question against the reactor coolant pump bowl, the comment would equally apply to other materials where the aged toughness has been obtained from 10000 hour accelerated testing at 400°C. This should be confirmatory work, and I judge that it is sufficiently unlikely that the results will affect the overall demonstration of avoidance fracture that it

can be undertaken during the site specific phase. I have therefore raised **AF-UKEPR-SI-47**.

3.3.2.6.3 Results

148 The results show that the limiting defect size should be in excess of 20 mm deep. The minimum margin occurs in the cold shutdown thermal transient ie a normal operation transient, because whilst the emergency/faulted transient analyses leads to a higher crack tip loading, the allowable toughness is much increased by allowing for 3 mm of stable tearing.

149 The analysis does not calculate, nor estimate, a true limiting defect size. It simply presents the margin between applied J (a measure of crack tip loading) and the allowable J for a 20 mm defect. The minimum margin on J is 1.3. This is a function of basing the analysis on a finite element model of the cracked structure rather than a procedurally based fracture assessment as discussed against the dissimilar metal weld analysis, Section 3.3.2.2.5.

150 As stated in that section, ONR's expectation is that the sizes of crack-like defect of structural concern should be calculated, and the expectation would be to calculate the actual limiting defect size in order to find out what the actual margin is compared with the reliably detectable defect size. This is very time consuming where a finite element analysis of the cracked body has been undertaken as the model is only representative of a single defect size and multiple models would be required.

151 In this case the margin on J of 1.3 with a 20 mm defect suggests that the limiting defect size would not be significantly larger than 20 mm and it will not be necessary to determine the specific size within GDA. Thus the analysis of a single defect depth is sufficient in this case, but in general it is necessary to undertake finite element analysis of a number of defect depths in order to determine the limiting defect size. I have already raised **AF-UKEPR-SI-44** against the RPV outlet nozzle dissimilar metal weld for the Licensee to address this aspect in general terms, and this Assessment Finding also applies to this analysis.

3.3.2.6.4 Conclusions on the RCP bowl repair weld

152 A sophisticated finite element analysis has been used to determine that the limiting defect size for a defect in a weld repair is in excess of 20 mm. I am satisfied that an appropriate methodology has been applied and that sufficient validation and verification has been undertaken to confirm the model and the results for the purposes of the GDA case.

153 The material properties have been derived from interim results from a then ongoing thermal ageing test programme and I am satisfied that the values assumed should be conservative. The final values can be confirmed in the post GDA fracture assessment where the full results from the test programme will be available. I would consider this aspect to be covered by normal business and have not raised the matter as an Assessment Finding.

154 I have a residual question over whether the reduction in fracture toughness due to thermal ageing seen over a 60 year reactor life is adequately represented by accelerated ageing at 10000 hours and 400°C. Whilst I raised this question against the reactor coolant pump bowl, it would equally apply to other materials where the toughness is based on accelerated ageing at 10000 hours and 400°C. It is possible that 10000 hours at 400°C may be adequate, but the evidence presented did not, in my opinion, provide conclusive support for this assertion. Further work is therefore required to confirm that the aged toughness values derived from accelerated thermal ageing of 10000 hours and 400°C are applicable for a 60 year reactor life. This should be confirmatory work, and I judge that it

is sufficiently unlikely that the results will affect the overall demonstration of avoidance fracture that it can be undertaken during the site specific phase. I have therefore raised **AF-UKEPR-SI-47** on thermal ageing.

155 As in the case of the RPV outlet nozzle dissimilar metal weld, it is ONR's expectation that the sizes of crack like defects of structural concern should be calculated. In this situation the analysis of a single defect depth has been sufficient, but I have raised **AF-UKEPR-SI-44** for the Licensee to address this aspect in general terms.

3.3.2.7 Technical Assessment – Reactor Coolant Pump Flywheel

156 The fracture analysis of the Reactor Coolant Pump (RCP) flywheel was provided for GDA Step 4 in Ref. 35. The flywheel is constructed from two plates of nickel-chromium-molybdenum alloy steel (20 NCD 14-7 in RCC-M),

157 The primary loading on the flywheel is due to the centrifugal forces created by the rotation, and radially orientated defect are postulated from the cylindrical hole machined in the centre of the flywheel as the tangential stresses are greatest at this location. Analytical solutions are used to calculate the stresses in the flywheel and the stress intensity factor for a radial crack emanating from the internal hole in a rotating disc.

158 Ref. 35 arrived later than planned, but I undertook a high level review of the analysis as part of the Step 4 programme of work in order to gain sufficient confidence to support an IDAC. The high level review did not raise any concerns with the fracture assessment methodology but identified that a further justification for the overspeed value assumed in the analysis and an estimation of the lifetime fatigue crack growth for a defect occurring in the flywheel would be required. I was content to support the IDAC on the basis of my high level review, but the provision of this additional evidence would be required to support a DAC.

159 The findings from the high level review were included in Action 5 of GDA Issue SI-01 which is a broader action related to the manufacturing inspections, and in-service inspection principles, to be applied to the RCP flywheel. The resolution plan for SI-01 Action 5 included the re-issue of the Ref. 35 fracture analysis to address these high level findings. Thus the fracture analysis was re-issued as Revision B, Ref. 36, as one of the deliverables against Action 5 of SI-01, as shown in Section 3.7 which covers Action 5. Whilst the deliverable is recorded against Action 5, the assessment of the fracture analysis is reported here against Action 1.

160 I have therefore reviewed Ref. 36, and my assessment has focused on the justification of the overspeed value, the limiting defect size and the potential for in-service fatigue crackgrowth. I raised TQ-EPR-1477 which asked for clarification on a number of aspects, and Revision B fracture analysis, Ref. 36, was re-issued as Revision C, Ref. 84, to incorporate the additional clarification provided by the response to TQ-EPR-1477.

3.3.2.7.1 Maximum overspeed of the RCP under accident conditions.

161 The normal operating speed of the RCP is 1500 rpm, whereas the design speed in the Equipment Specification is set 25% higher. Similarly the PCSR (Ref. 12, Sub-Chapter 5.4) states that the RCP including the flywheel receive an overspeed test at 1.25 times the normal operating speed.

162 Ref. 36 states that under accident conditions the maximum overspeed is reached during a turbine overspeed transient but does not exceed 1.2 x normal operating speed. Appendix A of Ref. 36 explains that the most severe LOCA transient for the UK EPR™ is a surge line double-ended guillotine break (PCSR Sub-Chapter 5.4). However, no figure is given in Ref. 36 for the overspeed which would occur with a surge line break. In addition, more

severe LOCAs studied for the EPR™ at Olkiluoto 3 (2A LOCA of MCL but with anti-whip restraints) predicted either no increase in RCP speed or a small speed reduction (to 96%).

163 In order to clarify which faults cause the greatest RCP overspeed transients, and what limits the maximum overspeed, I raised TQ-EPR-1477. The TQ response and Revision C of the fracture analysis, Ref. 84, clarify why the pump overspeed will not exceed 120% of normal operation. The worst fault is a complete loss of electrical load combined with failure of the turbine speed controller so that the protection system trips the turbine at 110% overspeed but inertia (steam in the system) increases this to about 116%.

164 Consequently I accept that it is reasonable to assume a maximum overspeed of 120% of normal operation could occur under accident conditions and that this is bounded by the overspeed test of the RCP which is performed at 125%. Consequently I also accept it is reasonable for the stress analysis of the RCP flywheel to have been performed at an overspeed of 125%. I note that this overspeed of 125% is also the value specified by US NRC Regulatory Guide 1.14 (Ref. 86)

3.3.2.7.2 Limiting defect size and potential in-service growth

165 The maximum tangential stress in the flywheel is more than twice the maximum radial stress and occurs at the edge of the central hole. The fracture analysis is based on a radially oriented defect (perpendicular to the maximum stress) initiated at the central hole (where the stress is greatest).

166 I accept the defect selected for fracture analysis is appropriate but any increased stress at the keyway corners is not explicitly taken into account. Consequently I asked EDF and AREVA (TQ-EPR-1477) to consider how significant is the local increase in stress intensity at the keyways and what is the justification for ignoring this effect in the fracture analysis – both for the limiting defect size and for the fatigue growth predicted for small defects.

167 EDF and AREVA explained (TQ-EPR-1477 response) that, although the fracture mechanics is based on an approximate analytical solution, this is considered acceptable since the limiting defect at 125% overspeed is a large through-thickness defect of 450 mm radial extent measured from the inner radius.

168 Similarly, the fatigue crack growth calculated for a through-thickness defect of [redacted] radial extent is about [redacted] (Ref. 84) so that at end-of-life such a defect would be about [redacted] radial extent or 50% of the size of the limiting defect. A [redacted] defect is large in relation to the keyway depth and hence any localised increases in stress caused by the keyways will have minimal effect on the predicted growth.

169 I also questioned the fatigue crack growth law used in the Revision B analysis, Ref. 36, in TQ-EPR-1477 as it was not specific to the flywheel material. The updated Revision C analysis, Ref. 84, now uses the flywheel material specific growth rate to calculate the [redacted] of growth noted in the previous paragraph.

170 On the basis of the analyses reported in Ref. 84 I accept that the flywheel has a good tolerance to defects and that the lifetime fatigue crack growth of defects not detected during manufacture will be small.

3.3.2.7.3 Conclusions on the RCP Flywheel

171 The assessment concludes that the 125% overspeed used to calculate the limiting defect size has been justified. The flywheel should have a good tolerance to defects as the limiting defect size is 450 mm, and the potential for in-service crack growth is limited as

the lifetime fatigue crack growth of defects not detected during manufacture is shown to be small.

3.3.2.8 Technical Assessment - Thermal Hydraulic Loading

172 In addition to undertaking the detailed assessment of the fracture mechanics analyses received late in the Step 4 assessment timeframe, I needed to confirm that the more accurate transient definitions used in these fracture mechanics analyses were suitable. This work is in line with the commitment made in Section 4.2.3.3.1 of the Step 4 Structural integrity Report (Ref. 6).

173 I therefore arranged for ONR's fault studies assessors to review a sample set of transients used in these fracture mechanics analysis. I chose the thermal hydraulic input data used for the fracture mechanics analysis of the RPV Outlet Set-on Weld as the sample, and their work is reported in Ref. 37.

174 EDF and AREVA provided information on the modelling of the transient analysis studies in response to three TQs, TQ-EPR-1488, TQ-EPR-1544 and TQ-EPR-1588 (Ref. 15).

175 TQ-EPR-1488 explained how EDF and AREVA consider three bounding transients to represent the worst thermal conditions experienced by the weld. These were the: Surge-Line break LOCA; Main Steam Line Break; and Total Loss of Feedwater. The fault studies assessor accepted that the boundary conditions assumed specific analysis reported in TQ-EPR-1488 were conservative, and noted that the Step 4 Fault Studies report (Ref. 49) had concluded that the thermal hydraulic systems code 'CATHARE' used to determine the overall systems response had been adequately validated. Thus the assessor concluded that the overall systems analysis was adequate for use in the fracture mechanics analysis.

176 Further information was supplied in response to TQ-EPR-1544 and TQ-EPR-1588 on the heat transfer correlations used to determine the local temperatures at the weld. The fault studies assessor accepted that well established heat transfer correlations were used for the forced and natural circulation conditions and that the calculation conservatively used whichever correlation provided the most onerous thermal transient. The assessor noted that an exception to this was the cold leg weld temperatures where the 'CREARE' correlation is assumed. This correlation is based on measurements from a 1/5 scale test rig, and the assessor was satisfied that the experimentally derived nature of the correlation satisfied the validation requirements for the correlation.

3.3.2.8.1 Conclusions on the Thermal Hydraulic Loading

177 The ONR fault studies assessor has concluded that the EDF and AREVA approach is adequate to provide conservative thermal transient inputs for the RPV Outlet Set-on Weld fracture mechanics analysis. I am content to use the outcome from this review of a sample set of transient data to judge that the more accurate transient definitions used in the fracture mechanics analyses received late in the Step 4 assessment timeframe should be suitable for their intended use in the fracture mechanics analyses.

3.3.2.9 Technical Assessment – Development and validation of the RSE-M Appendix 5.4 methodology

178 The UK was essentially unfamiliar with the French developed RSE-M Appendix 5.4 (Ref. 17) fracture assessment methodology that was used to determine the limiting defect sizes for GDA. In addition the comparative studies undertaken during Step 4 identified that there is an important difference in the treatment of the post yield interaction between the

primary and secondary stresses in RSE-M Appendix 5.4 compared with the R6 Procedure more generally adopted for fracture assessment in the UK to date.

179 In response the RP provided Ref. 38 to give an overview of the Fracture Mechanics Approaches in RSE-M Appendix 5.4 and it describes both the development and validation of the RSE- M Appendix 5.4 approach.

180 Sections 4.2.3.4 and 4.2.3.5 of the Step 4 Structural Integrity report (Ref. 6) provide further information on these aspects.

181 The difference between the treatment of the post yield interaction between the primary and secondary stresses leads to RSE-M Appendix 5.4 giving less conservative results compared with the R6 Procedure. As a consequence ONR was not prepared to accept safety cases based wholly on RSE-M for GDA and this was addressed by EDF and AREVA undertaking additional calculations to a modified RSE-M approach incorporating the post yield interaction approach from the R6 Procedure.

182 This was only an interim position to allow progress in GDA and it was recognised that for the site specific phase any future Licensee could choose whichever fracture assessment code/procedure they considered appropriate to undertake the post-GDA fracture assessments. It would therefore be the responsibility of any future Licensee to ensure that the fracture assessment procedure used post-GDA to calculate the limiting defect sizes will be suitable for supporting a UK based safety case, and this was taken forward by **AF-UKEPR-SI-06**:

> ***AF-UKEPR-SI-06:*** *The Licensee shall engage with ND to ensure that the fracture assessment procedure used to calculate the limiting defect sizes will be suitable for supporting a UK based safety case. This shall be completed before the generic milestone on RPV installation but in practice there needs a much earlier engagement.*

183 The more detailed assessment of Ref. 38 that I have now undertaken provides additional insights into the application of RSE-M Appendix 5.4 based fracture assessments in the context of a UK based safety case. TQ-EPR-1492 and TQ-EPR-1597 (Ref. 15) were raised as part of this assessment in order to clarify a number of points.

184 Ref. 38 usefully explains the background to the development of RSE-M Appendix 5.4. Although I refer to the use of RSE-M Appendix 5.4 in GDA (Ref. 17), a similar approach is also presented in Appendix A16 of the French Fast Breeder Reactor design code RCC-MR (Ref. 39). This is because the resources supporting the two separate approaches were merged in the mid-1990s, and indeed two parallel options continue to exist in Appendix 5.4 of RSE-M and Appendix A16 of RCC-MR - the Corrected Limit Load Option (CLC) and the Elastic Plastic Stress (CEP) option - reflecting the differing historical context.

185 Publication of the same approach in two codes causes the problem that the two codes are not consistent as they are updated at different times. For example RSE-M Appendix 5.4 1997 Edition with 3rd Addendum dated October 2005 was used for GDA, whereas RCC-MR was available as a 2007 edition. In addition RSE-M has been re-published in 2010, and Appendix 5.4 has nine modifications that are not yet included in RCC-MR 2007. In addition the 2010 version of RSE-M was initially only available in French, and took around 12 months to become available in English. I also noted that previous revisions to RSE-M Appendix 5.4 had resulted in the complete replacement of Appendix 5.4, and enquired in TQ-EPR-1492 on what mechanisms were available to determine whether analyses undertaken to previous version would need to be re-visited if they were now considered non-conservative.

186 The TQ-EPR-1492 response catalogues the differences between the codes and revisions to the codes and concludes that none of the differences are material to the calculations provided for GDA, which I accept. It also notes that the 2010 version of RSE-M Appendix 5.4 has not significantly modified the rules since the 2005 addendum which is re-assuring, but that it would be the responsibility of the users of the code to determine whether previous calculations would need to be re-visited. I accept this latter point, but it reinforces the need to review the effect of changes to the code as they are issued. This is because the fracture assessment procedures are complex and can be subject to more extensive change and evolution than other types of design codes or assessment procedure. This review of the changes should take place when the updates are issued, and given the lag in publishing the English versions, I believe that the review should take place as they are published even if they are only available in French initially. The review must cover the issue of Appendix A16 of RCC-MR updates as well as Appendix 5.4 of RSE-M to ensure that all changes to the procedures are reviewed, and the review must ascertain the effect on both future and existing assessments. In addition it appears reasonable to expect the Licensee to establish a presence on the committees developing Appendix 5.4 of RSE-M and Appendix A16 of RCC-MR in order to ensure that they are aware of ongoing developments and that they have the opportunity to influence them.

187 One of the other important aspects for the adoption of RSE-M Appendix 5.4 is the availability of commercially available software implementations of the code. Obviously the procedure itself is available in the RSE-M/RCC-MR codes but a software based implementation will invariably be required for practical implementation as the fracture assessment procedure is complex. This will be through in-house developed coding or commercially available software. The AREVA developed DEFIS software (Ref. 26) is not available commercially, and the response to TQ-EPR-1492 confirms that the MJSAM software implementation of RSE-M Appendix 5.4 developed by CEA (French government owned technological research organisation) is not publicly available at the present time either.

188 As I noted against the analysis of the RPV outlet nozzle weld, if there are no commercially available software implementations of the methodology it makes the adoption of the RSE-M Appendix 5.4 methodology more difficult for any potential Licensee in the UK. This is part of a wider question on the capability of the Licensee to undertake fracture assessments independently of the company supplying the reactor design. ONR would expect the Licensees to have such capability, and the Licensee will therefore need to satisfy themselves that there is the capability to undertake assessment to RSE-M Appendix 5.4 independently of the company supplying the reactor design to support the ongoing operation of the reactor. They will also need to consider the availability of technical support organisations to allow ONR to commission such assessment work independently should that be necessary.

189 The French Nuclear Safety Authority (ASN) is involved with reviewing methodology, background and validation of the updates to RSE-M Appendix 5.4. I asked in TQ-EPR-1492 whether the interactions were available in the public domain. They are not, but the comments that the French Nuclear Regulator, ASN, and their Technical Support Contractor, IRSN, make against Appendix 5.4 of RSE-M are recorded in an EDF document defining the technical procedures for the application of RSE-M as a whole across the French PWR Fleet - ‘R2SE-M’ (RSE-M is the French in-service inspection code, and the fracture assessment methodology in RSE-M Appendix 5.4 is a small part of that).

190 The response to TQ-EPR-1597 provides an extract of the R2SE-M relevant to Appendix 5.4 translated into English. It concludes that whilst there were no reservations relevant to

Appendix 5.4 in the 2005 revision, three reservations were expressed against the 2010 version of Appendix 5.4. None of the reservations turn out to be material to the analyses undertaken for GDA, which is re-assuring, but it does illustrate that a Licensee will need to be aware of the reservations and limitations of RSE-M Appendix 5.4 identified by ASN in case they are material to the calculations they are undertaking.

191 The UK application of RSE-M Appendix 5.4 differs in a number of respects to the way it would be applied in France as part of RSE-M as a whole. For example in the UK the effect of residual stresses in the weld should be directly accounted for, whereas that is not the case in France, and in the UK the margins for the fracture analyses are usually defined in terms of the margin between the limiting defect size and the reliably detectable defect size, where the target margin is 2.0, whereas in France margins are defined in term of applied crack loading and vary according to the category of the applied load. I therefore queried in TQ-EPR-1492 the extent to which application differs and in TQ-EPR-1597 whether the UK application for pipework and vessel shells remote from discontinuities was still within the validity limits identified in RSE-M Appendix 5.4.

192 The response to TQ-EPR-1492 identifies differences in the application of Appendix 5.4 in terms of residual stress, the dissimilar metal weld and the treatment of elastic finite element analysis without a crack. I also recognise that the margins are defined in Appendix 5.5 of RSE-M and they differ from UK practice as described in the previous paragraph. The response to TQ-EPR-1597 confirms that the RP considers that the application of the methodology for the UK EPR™ cases is within the validity limits set for Appendix 5.4, but that the approach used for the UK EPR™ for pressure vessels remote from discontinuities is not adopted in France.

193 I am satisfied with this explanation, but recognise that it is important to acknowledge that whilst the UK EPR™ fracture analyses are based on Appendix 5.4 of RSE-M, there are a number of important differences in how the analyses are undertaken compared with their application to a defect detected in-service in France where assessment to RSE-M would be applied directly and completely.

194 Thus the definition of the UK methodology for undertaking the fracture assessments based on RSE-M Appendix 5.4 is very important. It needs to clearly specify the UK methodology in relation to where it follows RSE-M and where it differs from RSE-M. For GDA purposes this is defined in Ref. 40, and this will be a significant reference for any Licensee to consider when addressing Assessment Finding **AF-UKEPR-SI-06** on the fracture assessment procedure being used to support a UK based safety case. It should be noted that Section 3.3.2.10.5 (Analytical Fracture Assessment Methodology Applied to the MCL) identifies an omission in Ref. 40 in that an RCC-MR Appendix A16 analytical equation has been used in preference to the equation from RSE-M Appendix 5.4 in the analysis of the MCL, and I would have expected this difference to have been identified and explained/justified in the definition of the UK methodology.

195 In conclusion, the additional insights provided through the more detailed assessment of Ref. 38 identify a number of detailed aspects that would need to be addressed by a Licensee adopting the RSE-M Appendix 5.4 based fracture assessment method used in GDA.

196 These are:

- The Licensee will need to review the updates to Appendix 5.4 of RSE-M and Appendix A16 of RCC-MR as they are released to determine their impact on both future and existing assessments. This should take place when they are first released, even if they are only available in French at that stage. This is due to the significant lag that can exist between publishing the version in French and publishing it in English.

- The Licensee establishes a presence on the committee developing Appendix 5.4 of RSE-M and Appendix A16 of RCC-MR in order to ensure that they are aware of ongoing developments and that they have the opportunity to influence them.
- The Licensee will need to satisfy themselves that there is the capability to undertake assessment to RSE-M Appendix 5.4 independently of the company supplying the reactor design to support the ongoing operation of the reactor, and to consider the availability of technical support organisations to allow ONR to commission such assessment work independently should that be necessary.
- A Licensee will need to be aware of the reservations and limitations of RSE-M Appendix 5.4 identified by the French Nuclear Safety Authority in case they are material to the calculations they are undertaking.
- The Licensee will need to ensure that the UK methodology for undertaking the fracture assessments based on RSE-M Appendix 5.4 is suitable and sufficient to fully define the methodology in relation to RSE-M, and to explain and justify departures from RSE-M.

3.3.2.9.1 Conclusions - Development and validation of the RSE-M Appendix 5.4 methodology

197 As a result of these additional insights, I have raised Assessment Findings **AF-UKEPR-SI-48, AF-UKEPR-SI-49 and AF-UKEPR-SI-50** on the aspects that would need to be addressed by a Licensee if they adopt the RSE-M Appendix 5.4 based fracture assessment method used in GDA. These Assessment Findings complement the existing more general Assessment Finding on the fracture assessment procedure being used to support a UK based safety case, **AF-UKEPR-SI-06**.

3.3.2.10 Technical Assessment - Application of a modified RSE-M Appendix 5.4 approach consistent with the R6 plasticity correction factor rules

3.3.2.10.1 Assessment Approach

198 I undertook a more detailed review of:

- Ref. 41, which describes the modification to the RSE-M Appendix 5.4 approach consistent with R6 Procedure rules.
- Ref. 42, which evaluates the limiting defect sizes at the most limiting location using the modified RSE-M Appendix 5.4 approach described in Ref. 41.

199 The review of Ref. 42 also identified a number of more generic aspects that required more specific consideration:

- Material Properties in the Belt Line region of the RPV.
- Analytical Fracture Assessment Methodology Applied to the MCL.
- Calculational Error in the MCL Analysis.
- Seismic Loading.

3.3.2.10.2 Modified RSE-M approach

200 Ref. 41 describes the modification to the RSE-M Appendix 5.4 approach to incorporate a plasticity correction factor to allow for the post yield interaction of primary and secondary stresses that is consistent with R6 Procedure rules (Ref. 18).

201 As previously noted, the difference between the treatment of the post yield interaction between the primary and secondary stresses leads to RSE-M Appendix 5.4 giving less conservative results compared with the R6 procedure. As a consequence ONR was not prepared to accept safety cases based wholly on RSE-M for GDA and this was addressed by EDF and AREVA undertaking additional calculations to a modified RSE-M approach incorporating the post yield interaction approach from the R6 Procedure.

202 EDF and AREVA arranged for the modification to be reviewed by an expert on the R6 Procedure. The review (Ref. 98) concludes that the modified approach is fit for purpose and the R6 methodology has been correctly interpreted. I remain satisfied with the approach and queries were raised against Ref. 41.

3.3.2.10.3 Limiting defect sizes calculated using modified RSE-M approach

203 Ref. 42 evaluates the limiting defect sizes using the modified RSE-M Appendix 5.4 approach consistent with R6 Procedure rules. It was undertaken as a direct consequence of ONR not being prepared to accept safety cases based on RSE-M alone for GDA. The analysis is used to demonstrate that the limiting defect sizes remain consistent with the target qualified defect sizes when the more onerous plasticity correction factor from R6 is applied. It has only been applied to six locations. This is a subset of the locations analysed for GDA, and the subset represents the most limiting locations where the RSE-M Appendix 5.4 methodology has been applied.

204 I am satisfied with the approach being taken in Ref. 42, and that the results should provide an important underpin to the avoidance of fracture case as ONR is not in a position to accept safety cases based on RSE-M alone for GDA. As stated in the previous section, I am satisfied with the implementation of the R6 Procedure rules in the modified version of RSE-M Appendix 5.4 and consider that the six locations assessed provide a suitable set of limiting locations where RSE-M Appendix 5.4 was applied.

205 My detailed assessment of Ref. 42 identified a number of points relating to the detail of the fracture analyses that required further clarification, and these were raised through TQ-EPR-1510, (Ref. 15). As a result of providing the responses to this TQ, EDF and AREVA re-issued Ref. 42 to incorporate the clarifications and corrections as Ref. 43. I support the decision to re-issue the report but accept that the clarification and corrections do not impact the final results from the work. Thus the limiting defect size results summarised from Ref. 42 in Section 4.2.3.8 of the Structural Integrity Step 4 report, Ref. 6 remain applicable to the re-issued version of the report Ref. 43.

206 The results show that the limiting defect sizes are reduced when using the more conservative R6 plasticity correction factors compared with the RSE-M Appendix 5.4 correction factors. The limiting defect sizes remain compatible with a target margin of 2 on the reliably detectable defect sizes assumed for the NDT purposes, although stable tearing arguments for fault/emergency transients have had to be invoked in some locations whereas the RSE-M Appendix 5.4 justification could be based on initiation toughness alone.

207 As previously stated the clarification and corrections arising from TQ-EPR-1510 are incorporated in the re-issue of the document as Ref. 43, but the following points require further consideration.

3.3.2.10.4 Material Properties in the Belt-Line region of the RPV

208 Earlier work commissioned from our TSC, the National Nuclear Laboratory, in support of the Step 3 structural integrity assessment, Ref. 44, noted that EDF and AREVA appeared to be suggesting that the upper shelf Charpy impact energy and hence upper shelf

fracture toughness was not affected by irradiation, and that this was not in accordance with worldwide experience.

209 This would potentially affect the fracture analysis of the weld in the belt line region of the RPV. The allowable initiation toughness and stable tearing toughness values used in the analysis of this region are taken directly from Table ZG6141 of RCC-M (Ref. 16). I enquired in TQ-EPR-1510 whether these values included any allowance for the effect of neutron irradiation. The TQ response confirmed that the values do not include any allowance for a reduction in initiation toughness as EDF and AREVA believe that irradiation has a low impact on upper-shelf toughness.

210 As stated previously, Ref. 44 indicates that such a position is not in accordance with worldwide experience, and experience from the materials surveillance programme in Sizewell B again supports the view that there is an effect (Ref. 45). It is a complex area, and the effect may differ between initiation toughness and stable tearing. However, ONR does not accept the assertion that there is little effect on upper-shelf toughness without a more detailed consideration of the evidence, and in any case ONR would expect the materials surveillance programme to confirm any assumptions made at the design stage.

211 The net effect of a potential reduction in upper-shelf toughness properties on the limiting defect size cannot be predicted until the extent of any such reduction in toughness is quantified, however, I note that significant margins do exist between the currently calculated limiting defect size and minimum needed to support the reliably detectable defect size with a target margin of 2. I am therefore satisfied that this is an aspect that can be addressed during the site specific phase, and have therefore raised **AF-UKEPR-SI-51** on the effect of irradiation damage on upper shelf toughness.

3.3.2.10.5 Analytical Fracture Assessment Methodology Applied to the MCL

212 Unusually the fracture analysis of the MCL, Ref. 46, uses an analytical equation for imposed displacements that is taken from RCC-MR Appendix A16 (Ref. 39) rather than an analytical solution taken from the main basis for the fracture analysis methodology, RSE-M Appendix 5.4 (Ref. 17). EDF and AREVA discuss the use of this equation in Appendix A of Ref. 46. They consider that the analytical solutions available in RSE-M Appendix 5.4 lead to a significant overestimation of the loading when imposed displacements are involved. The equation from RCC-MR provides a more accurate representation and the response to TQ-EPR-1510 states the equation has been validated using finite element calculations and experimental test. I am satisfied with the technical basis for the RCC-MR equation, but its use raises a question on the compatibility between RSE-M Appendix 5.4 and RCC-MR Appendix A16.

213 As discussed in Section 3.3.2.9, the resources used to develop RSE-M Appendix 5.4 and RCC-MR Appendix A16 were merged in the mid-1990s. I was concerned that differences could occur between RSE-M Appendix 5.4 and RCC-MR Appendix A16 due to the two codes being updated at different times. In the case of the MCL fracture analysis the analytical equation is taken from the 2007 version of RCC-MR, whereas the 2005 update of RSE-M was being generally used for GDA.

214 I therefore enquired in TQ-EPR-1510 whether the analytical equation from the 2007 version of RCC-MR 2007 had been incorporated in the recently issued 2010 version of RSE-M. The response stated that this was not the case as the RCC-MR approach had been thought to be specific to fast neutron reactor piping, and there were no plans to incorporate it in RSE-M. It suggested that a code case could be proposed.

215 Whilst this does not highlight a problem associated with the codes being updated at different times, it does raise the question on how the fracture methodologies are being

applied in the UK and how this is defined. The definition of the fracture analysis methodology applied to the UK EPR™ is provided in Ref. 40. This does not provide any reference to the RCC-MR Appendix A16 analytical methodology applied to the MCL pipework.

216 I consider that to be an omission. The methodology document Ref. 40 needs to clearly define the UK approach in relation to where it follows RSE-M Appendix 5.4 and where it differs from RSE-M Appendix 5.4. It should therefore explain and justify why RCC-MR specific analytical equations are being used in preference to RSE-M.

217 Assessment Finding **AF-UKEPR-SI-48** has been raised to address the detailed aspects that would need to be addressed by a Licensee adopting RSE-M Appendix 5.4 based fracture assessment methods, and the final bullet point on the UK methodology for undertaking fracture assessments has been expanded to explicitly include the need to explain and justify departures from RSE-M Appendix 5.4. .

3.3.2.10.6 Calculational Error in the MCL Analysis

218 My review of Ref. 42 highlighted that application of the modified methodology to the MCL fracture analyses was leading to results that appeared disproportionately sensitive to the input parameters. I therefore asked in TQ-EPR-1510 for an explanation of the results in order to gain confidence in the analysis.

219 Although I was not specific in my query, the problem was particularly apparent in the results for the analysis of the thermal transient for an inner skin defect. The initial assessment calculated a 15.5 mm limiting defect depth (Table 17 of Ref. 42) whereas a modest refinement to the thermal transient definition led to a limiting defect depth exceeding 38 mm (table 18 of Ref. 42), which seemed too large a change in relation to the transient refinement.

220 The response to TQ-EPR-1510 indicated that this was a function of the highly non-linear nature of the analysis, but the re-issued version of Ref. 42, Ref. 43, actually showed that the 15.5 mm limiting defect depth in Table 17 had been replaced with a limiting defect depth exceeding 38 mm, thus indicating that the modest refinement to the transient had not led to the large change in the limiting defect size. There was no explanation of this change in Ref. 43, but subsequent enquiries identified that the original value had been found to be an error in the original calculation. Immediate checks had been undertaken to ensure that it had not been repeated elsewhere, but corrective action procedures had not been invoked at the time of issue of the report.

221 I was encouraged that immediate checks had been undertaken to ensure that this was an isolated error in the work supporting Ref. 43, but remained concerned that corrective action procedures had not been invoked at the time of issue of the report and that the error could be indicative of a failure of the verification processes that had been explained in the response to a TQ-EPR-879 submitted during Step 4. I was also concerned that the correction had not been acknowledged in the introduction to Ref. 43. I therefore brought the error to the attention of my ONR colleagues dealing with the Management of Safety and Quality Assurance.

222 My ONR colleagues followed the matter up with EDF and AREVA, and in response EDF and AREVA provided a further explanation and commentary in Ref. 47. Ref. 47 indicates that a non-conformance report was issued undertaking a cause and impact analysis and specifying actions to prevent recurrence. It concludes that the verification processes described in TQ-EPR-879 remain appropriate, but the verification should have been more stringent as it was a first-of-kind calculation as described in the verification guidelines.

Steps have been taken to reinforce the awareness of managers and engineers that verification steps are identified and planned early in the process.

223 I am now satisfied that an appropriate response has been provided to deal with the error, and that the verification processes identified in TQ-EPR-879 do not appear deficient in themselves based on the response in Ref. 47. EDF and AREVA did take immediate action to ensure that the error had not been repeated elsewhere, but it took an intervention from ONR to prompt a more complete response ie the raising of a non-conformance report The response of Ref. 47 does not address the cultural aspects of why such a report was not issued in the first place, nor why the correction of the error was not acknowledged in the introduction to Ref. 43. These will be aspects that any future Licensee should be addressing as part of its normal business in terms of Leadership and Management for Safety, but it would be difficult to address such cultural matters through an Assessment Finding.

224 I am also aware (Ref. 48) that there is an intention to include an Assessment Finding in the GDA Issue close-out report for Cross-Cutting Issue **GI-UKEPR-CC-02** which relates to ensuring the suitable management and control of the development of the GDA UK EPR™ design reference to the site-specific detailed UK EPR™ design reference. This Assessment Finding, although generic in nature, was generated in part due to concerns regarding the adequacy of the controls associated with the detail design development associated with some civil engineering structures. It therefore has parallels with the problems identified here, and will be a useful generic Assessment Finding in this context.

225 I therefore have decided that an additional Assessment Finding is not required and will rely on the related generic Assessment Finding against Cross-Cutting Issue **GI-UKEPR-CC-02** on controlling the development of the GDA UK EPR™ design reference into the site- specific detailed UK EPR™ design reference to address such matters.

3.3.2.10.7 Seismic Loading

226 The seismic loading used for the mechanical load sets applied in the pipework analyses are based on Flamanville 3 loading spectrum. I asked whether these would cover all potential UK EPR™ sites, and the response confirmed that the seismic load set taken from the Flamanville 3 analyses will be bounding. The response also noted that an existing Assessment Finding from the Civil Engineering discipline (**AF-UKEPR-CE-003**) ensures that the Licensee confirms that magnitude of all external hazards considered generically envelope those for the particular site.

227 I am therefore satisfied that that the loading assumed within GDA should be bounding, but that an appropriate Assessment Finding is already in place to ensure that this aspect is confirmed by the Licensee.

3.3.2.10.8 Conclusions - Application of a modified RSE-M Appendix 5.4 approach consistent with the R6 plasticity correction factor rules

228 Ref. 42 presents the results of a series of calculation to a modified version of the RSE-M Appendix 5.4 procedure which incorporates plasticity correction factors from the R6 defect assessment procedure. These calculations are required because ONR is not prepared to accept a safety case based on RSE-M alone for GDA as RSE-M is less conservative in its treatment of the post yield interaction between primary and secondary stresses compared with the R6 Procedure which has previously been adopted in the UK.

229 I am satisfied that the results provide an important underpin to the avoidance of fracture case. My more detailed review has resulted in a re-issue of Ref. 42 as Ref. 43 incorporating clarification and corrections; however, the re-issue does not affect the final results from the work. Thus the limiting defect size results summarised from Ref. 42 in

Section 4.2.3.8 of the Structural Integrity Step 4 report, Ref. 6, remain applicable to the re-issued version of the report.

230 My review has identified that the material toughness allowable assumed in the current fracture analyses do not account for the effect of irradiation damage on the upper-shelf toughness of the materials. This potentially affects the analysis of the weld in the RPV belt line region. Significant margins exist between the currently calculated limiting defect size and the minimum needed to support a reliably detectable defect size with a target margin of 2. I am therefore satisfied that this can be addressed during the site specific phase, and I have raised **AF-UKEPR-SI-51** on this aspect.

231 My review has also identified that RCC-MR Appendix A16 analytical equations are being used in the fracture assessments instead of RSE-M Appendix 5.4 equations. This is not explained in the methodology document used to define the fracture analysis methodology applied to the UK EPR™, Ref. 40. The methodology document Ref. 40 needs to clearly define the UK approach in relation to where it follows RSE-M Appendix 5.4 and where it differs from RSE-M Appendix 5.4. It should therefore explain why RCC-MR specific analytical equations are being used in preference to RSE-M and explain/justify why they are being adopted. The final bullet point in Assessment Finding **AF-UKEPR-SI-48** on the UK methodology for undertaking fracture assessments has been expanded to explicitly include the need to explain and justify departures from RSE-M Appendix 5.4.

232 My review has also led EDF and AREVA to discover a calculational error in their fracture assessments. The error does not affect the overall results and whilst an immediate check was undertaken to ensure that the error was not more widespread, a formal corrective action procedure was not originally invoked. Following a prompt for ONR this has now been addressed and I am satisfied that the related generic Assessment Finding against Cross-Cutting Issue **GI-UKEPR-CC-02** on controlling the development of the GDA UK EPR™ design reference into the site-specific detailed UK EPR™ design reference should address such matters in the future without the need for an additional Assessment Finding.

3.3.3 Assessment Conclusions for Action 1

233 Action 1 of GDA Issue **GI-UKEPR-SI-01** relates to the completion of a more detailed assessment of a number of existing EDF and AREVA fracture analysis reports that arrived later than planned in the Step 4 assessment timeframe. The reports fall into two categories: fracture mechanics analysis of specific locations; and the fracture analysis methodology. The fracture analyses are used to derive limiting defect sizes which are key inputs to the demonstration of avoidance of fracture.

234 I have therefore completed this more detailed assessment, and EDF and AREVA have responded as necessary to the Technical Queries related to this assessment.

235 My more detailed assessment of the fracture analysis reports has identified a number of aspects that needed clarifying and in some cases correcting. Individual comments and conclusions on these reports are provided in the previous sub-sections, but a number of the reports have been re-issued as a consequence of my detailed assessment and I have raised additional Assessment Findings, **AF-UKEPR-SI-43 to AF-UKEPR-SI-51,** that will need to be addressed during the site specific phase.

236 None of the clarifications/corrections have lead to a reduction in the limiting defect sizes calculated for these locations, and the summary of the limiting defect sizes presented in Section 4.2.3.8 of the Structural Integrity Step 4 report (Ref. 6) remain unchanged. The intent of the avoidance of fracture case is to achieve a margin of at least 2 between the reliably detectable defect size and the limiting defect size (see Section 3.2.3 of the Step 4

Structural Integrity Report, Ref. 6). The limiting defect sizes are greater than 20 mm deep on most of the HICs which supports the use of the 10 mm deep target defect size provisionally assumed for most of the HICs in order to demonstrate the adequacy of the non-destruction examination techniques proposed. The exceptions are the main steam lines where the limiting defect sizes are less than 10 mm deep, and the flywheel where a very large limiting defect size has been calculated. This is reflected in the smaller target defect sizes assumed when considering the non-destructive examination techniques to be applied to the main steam lines welds and in the examination techniques to be applied to the flywheel.

237 The purpose of completing this more detailed assessment was to satisfy myself that the fracture analysis methodology adopted for GDA remained acceptable, and that the limiting defect sizes derived from these fracture analysis reports can be used to support the avoidance of fracture demonstration for a DAC. I conclude that the methodology (including the provision of additional calculations to address the difficulties ONR currently have in accepting the RSE-M Appendix 5.4 methodology) remains acceptable for the purposes of GDA, and that the limiting defect sizes can be used in the avoidance of fracture demonstration. I am therefore satisfied that this action may now be closed.

238 It should be recognised that whilst I am satisfied that the fracture mechanics analyses are suitable for supporting the avoidance of fracture demonstration for GDA, there are a number of Assessment Findings that a Licensee will need to address post-GDA that were raised in the Structural Integrity Step 4 report and this close-out report. In particular the fracture assessment of a more extensive range of locations on the HIC components will need to be undertaken in order to demonstrate that the limiting locations have been assessed (**AF-UKEPR-SI-01**), fatigue crack growth will have to be allowed for, (**AF-UKEPR-SI-02**) and further work will be required to ensure that the fracture assessment procedure will be suitable for supporting a UK based safety case as ONR is not yet prepared to accept a case based on RSE-M Appendix 5.4 alone (**AF-UKEPR-SI-06**).

3.3.4 Assessment Findings for Action 1

239 The following Assessment Findings have been raised:

> ***AF-UKEPR-SI-43:*** *The Licensee shall undertake validation studies to confirm that the methodology used to calculate the limiting defect size for the RPV outlet nozzle dissimilar metal weld is appropriate.*
>
> ***Required timescale:*** *Install RPV*
>
> ***AF-UKEPR-SI-44:*** *The Licensee shall establish the limiting defect size for all High Integrity Components, including situations where cracked body finite element analyses are used to determine the limiting defect size.*
>
> ***Required timescale:*** *Install RPV*
>
> ***AF-UKEPR-SI-45:*** *The Licensee shall use material toughness properties for the fracture mechanics analyses that bound both the weld material and the HAZ material, and the base material if potentially limiting.*
>
> ***Required timescale:*** *Install RPV*
>
> ***AF-UKEPR-SI-46:*** *The Licensee shall explicitly identify the full thermal ageing shift in the HAZ material of the low alloy steel welds and any enhanced start of life properties required of the HAZ material in the materials data handbook used to support the UK EPR™. Any enhanced start of life properties for the HAZ should be demonstrated in the complementary fracture toughness testing.*

***Required timescale:** Install RPV*

***AF-UKEPR-SI-47:** The Licensee shall confirm that the reductions in fracture toughness to account for thermal ageing using values derived from accelerated thermal ageing tests at 10000 hours and 400°C are sufficient to account for a 60 year reactor life.*

***Required timescale:** Install RPV*

***AF-UKEPR-SI-48:** Should the Licensee adopt the RSE-M Appendix 5.4 fracture assessment procedure, the Licensee shall ensure that:*

- *updates to Appendix 5.4 of RSE-M and Appendix A16 of RCC-MR are reviewed as they are released to determine their impact on both future and existing assessments (even if they are only available in French at the time of release);*
- *they establish a presence on the committee developing Appendix 5.4 of RSE-M and Appendix A16 of RCC-MR; and*
- *they have a capability to identify any reservations and limitations on the use of RSE-M Appendix 5.4 as identified by the French Nuclear Safety Authority(ASN).*

***Required timescale:** Install RPV*

***AF-UKEPR-SI-49:** Should the Licensee adopt the RSE-M Appendix 5.4 fracture assessment procedure, the Licensee shall ensure that there is a capability to undertake assessment to RSE-M Appendix 5.4 independently of the company supplying the reactor design in order to support the ongoing operation of the reactor. The availability of technical support organisations to allow the UK Nuclear Regulator (ONR) to commission such assessment work independently should also be considered.*

***Required timescale:** Install RPV*

***AF-UKEPR-SI-50:** Should the Licensee adopt the RSE-M Appendix 5.4 fracture assessment procedure, the Licensee shall ensure that the UK methodology for undertaking the fracture assessments based on RSE-M Appendix 5.4 is suitable and sufficient to define the methodology in relation to RSE-M, and to explain and justify departures from RSE-M* **.**

***Required timescale:** Install RPV*

***AF-UKEPR-SI-51:** The Licensee shall review the upper shelf fracture toughness values used for areas affected by irradiation damage to ensure that they are consistent with the worldwide experience on the effect of irradiation damage on upper-shelf toughness and ensure that the surveillance scheme is adequate to confirm the assumptions made at the design stage.*

***Required timescale:** Install RPV*

3.4 GDA Issue GI-UKEPR-SI-01 Action 2

240 This action (Annex 3) concerns the additional evidence required to demonstrate that the austenitic and dissimilar metal welds in the main coolant line are designed for inspection and that the manufacturing inspection techniques have adequate capability.

241 In the schematic diagram (Figure 1) below, the homogeneous welds are coded as C, H or U for the cold, hot and cross-over leg respectively. The dissimilar metal welds are not shown, but connect the austenitic pipework to the ferritic RPV and to the steam generator.

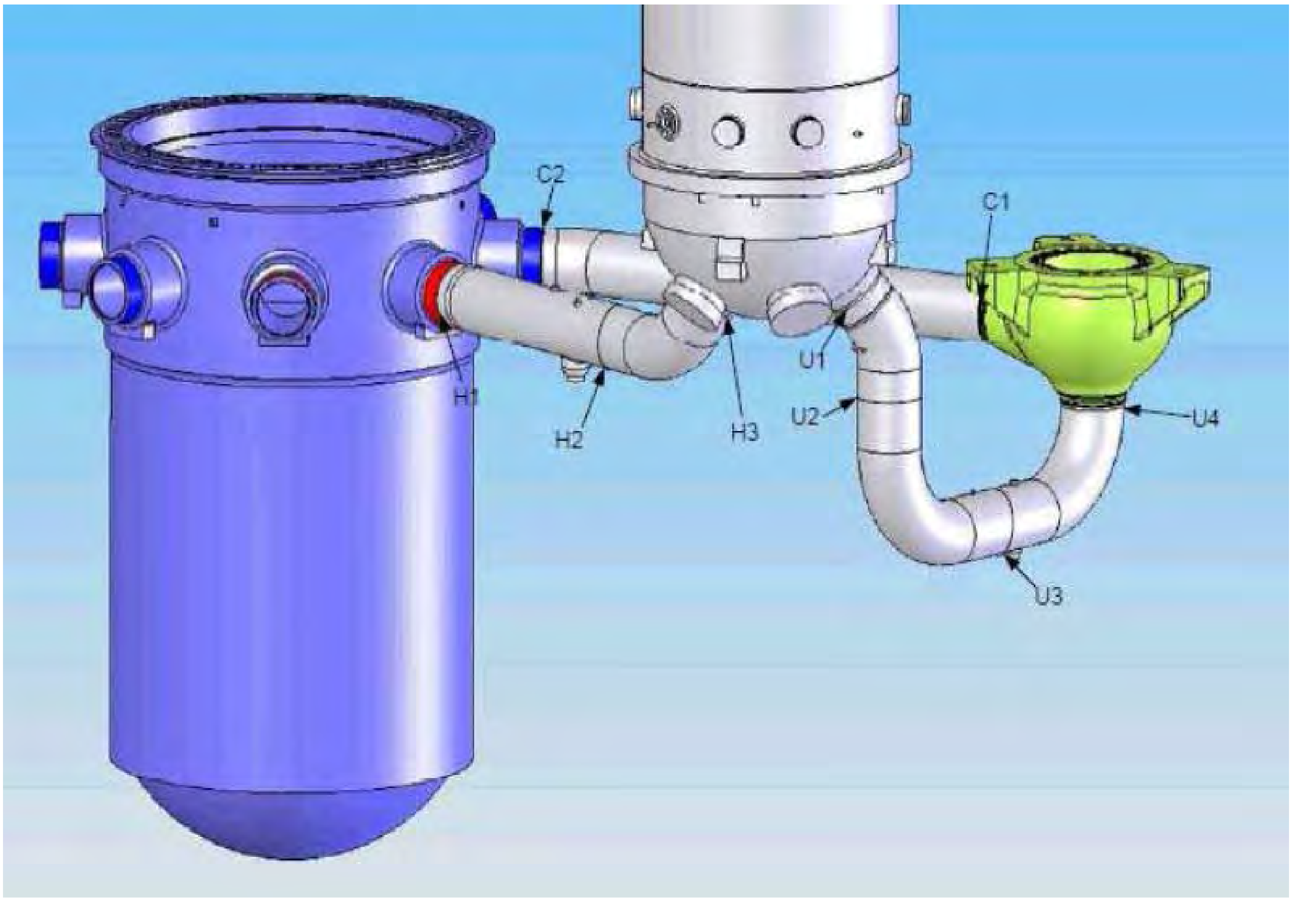

Figure 1. Schematic of the UK EPR™ main coolant line homogeneous welds (from Ref. 65)

3.4.1 Deliverables for Action 2: Original

Deliverable No.	Original plan (O) or revised proposal (R)	Deliverable	Ref.
1	O	UK EPR™ Ultrasonic Examination of MCL Homogeneous and Dissimilar Metal Welds. PEEM-F 11.0505 Rev B. AREVA NP. 7 Sept. 2011.	51
2	O	Design Basis – Main Coolant Line Weld Connections. PEER-F DC 60 Rev A. AREVA NP. 8 September 2011.	53

242 Note that Deliverables 1 and 2 were a commitment of the Resolution Plan dated 29 June 2011 (Ref. 7). An additional deliverable which was included within the original Resolution Plan was postponed pending the work on the design changes and modified as a result of these and is discussed in Sections 3.4.3 and 3.4.4 below.

3.4.1.1 Deliverable 1 (Ref. 51)

243 This updated version of the report provides some more detail of the proposed ultrasonic examination techniques and their capability to detect defects of structural concern in the Main Coolant Line (MCL) welds including near vertical defects parallel to the fusion faces.

3.4.1.2 Deliverable 2 (Ref. 53)

244 This report describes the basic design of the UK EPR™ primary circuit and particularly the homogeneous welds of the MCL and their local design features which may impact ultrasonic manufacturing inspections and PSI/ISI.

3.4.2 ONR Assessment of Action 2 – Original Deliverables

3.4.2.1 Scope of Assessment Undertaken

245 The assessment of the original deliverables included:

- Evidence that the ultrasonic beams selected are able to detect defects of structural concern including those in the planes of the weld fusion faces over their full extent.
- Evidence that the design is such that there are no significant restrictions to inspection from features such as counterbores, changes of section thickness, tapered or curved surfaces, error of form etc.
- Evidence that, when fully developed, the ultrasonic detection and characterisation procedures are likely to have adequate capability for the expected sizes of the defects to be qualified. (As discussed in Section 3.3.3 above, a provisional target defect size of 10mm through-wall extent has been adopted based on the current analyses.)

3.4.2.2 Background to Assessment of the Original Deliverables

246 The original proposals for qualified inspection of the MCL welds were based on radiography (Ref. 104), but it was agreed during GDA Step 4 that qualified ultrasonic inspections would be introduced (Ref. 105). EDF and AREVA proposed either manual UT from both inside and outside surfaces or automated UT from the outside surface only (Ref. 50). As part of the Resolution Plan for this GDA Issue Action, Ref. 50 was updated to Rev B (Ref. 51) to provide more details of the proposals, but only limited changes to the inspections were proposed.

247 The key questions I wished to answer through my assessment were:

- How well are the manufacturing ultrasonic inspections optimised especially for vertically oriented defects on the weld fusion faces?
- Does the design of the components and welds take account of the need for ultrasonic inspection?
- How significant are the restrictions created by counterbores, changes in section thickness, tapered or curved surfaces and error of form?
- Are the NDT procedures used during manufacture likely to be capable of detecting and characterising defects of concern?

- Are the capabilities of the proposed pre-service and in-service ultrasonic inspections of these welds likely to be adequate?

248 The proposed NDT inspections for the MCL welds and associated Dissimilar Metal (DM) welds during manufacture were revised in response to ONR feedback, and I have summarised the key changes in the table below. Originally the volumetric inspection relied only on radiography but qualified ultrasonic inspections were subsequently introduced. Two options were proposed; either manual inspection from outside and inside the components or automated inspection from the outside only.

Evolution of proposals for manufacturing NDT of homogeneous MCL and Dissimilar Metal Welds

			Homogeneous MCL welds		**Dissimilar Metal RPV and SG safe end welds**	
Report No.	**Report title**	**Date**	**RT**	**UT**	**RT**	**UT**
PEEM-F 10.1134B (Ref. 104)	UK Technical report on the manufacturing non destructive testing to be qualified	1 July 2010	Q	None	Q Before and after SRHT	None
PEEM-F 10.1134D (Ref. 105)	UK Technical report on the manufacturing non-destructive testing to be qualified	21 Dec 2010	NQ	Q Outside and Inside (manual) or Outside only (auto)	NQ Before SRHT only	NQ Before SRHT Q After SRHT Outside and Inside (manual) or Outside only (auto)
PEEM-F 11.0505/A (Ref. 50) and PEEM-F 11.0505/B (Ref. 51)	UK EPR™ Ultrasonic examination of MCL homogeneous and dissimilar metal welds	1 April 2011 and 7 Sept 2011	-	As above for 10.1134D	-	As above for 10.1134D

KEY:
Q = Qualified NQ = Not Qualified
RT= Radiographic Testing UT = Ultrasonic Testing
SRHT = Stress Relief Heat Treatment

3.4.2.3 Review of Design Basis Report for Main Coolant Lines (Ref. 53) and Assessment of Proposals for Manufacturing UT (Ref. 51)

249 I reviewed the geometrical features described in Ref. 53 which are likely to have an adverse impact on inspection capability and a few examples of such features are discussed below. I then reviewed the analysis of the access for inspection presented in

Ref. 51. The next two sub-sections cover firstly the homogeneous welds and secondly the dissimilar metal welds.

3.4.2.3.1 Homogeneous Welds

250 The table below summarises restrictions to inspection of the homogeneous welds based on my interpretation of the details presented in the two reports (Refs 51 and 53). The inspectability of the upstream and downstream weld fusion faces is considered separately. My assessment of the access for inspection suggests that the effects of the geometrical restrictions are likely to be more significant than estimated by EDF and AREVA in Ref. 51.

Homogeneous welds – ONR review of restrictions to inspection

Weld Ref.	Description	Upstream Weld Side		Downstream Weld Side	
		Access Y/N	Restrictions	Access Y/N	Restrictions
H1	RPV outlet with hot leg elbow 6°	Y	None See Note 1	Y	Counterbore
H2	Hot leg with elbow 50°	Y	Counterbore	Y	Counterbore
H3	Elbow 50° with SG safe end	Y	Counterbore Taper	Y	None
U1	SG safe end with elbow 40°	Y	None	Y	Counterbore Taper Bend
U2	Elbow 40° with elbow 90°	Y	Counterbore	Y	Counterbore Bend
U3	Elbow 90° with elbow 90°	Y	Counterbore	Y	Counterbore
U4	Elbow 90° with RCP	Y	Counterbore Taper Bend	N	Cast material
C1	RCP to cold leg	N	Cast material	Y	Counterbore
C2	Cold leg 27.5° with RPV inlet	Y	Counterbore	Y	None See Note 1

Key:	Green	No limitations to ultrasonic inspection		
	Yellow	Some limitations	“	“
	Red	Significant limitations	“	“

Grey Ultrasonic inspection not feasible

Note 1. The length of the safe end restricts access for high angle beams, but this is overcome during manufacture by inspecting from both inside and outside.

251 The table shows that all welds have some restrictions on the ultrasonic inspection capability and these are summarised below:

- four welds are unrestricted from one side – but all of these are affected by counterbores on the pipe side and two also have tapers;
- three welds are restricted by counterbores from both sides;
- two welds are only inspectable from one side and of these both are affected by counterbores and one also has a taper and bend; and
- no welds are unrestricted from both sides.

252 The local geometry associated with two of the welds (U1 and U4) at the ends of the U-leg are particularly affected because there is a significant taper in wall thickness near the weld (from 76 mm to 97 mm wall thickness using a 10° taper) as well as the bend and counterbore.

3.4.2.3.2 Dissimilar metal welds

253 The table below summarises restrictions to inspection of the dissimilar metal welds based on my interpretation of the details presented in the two reports (Refs 51 and 53). The inspectability of the weld fusion faces from the vessel or safe end side is considered separately.

Dissimilar metal welds – Review of restrictions to inspection

Weld Ref.	Description	Vessel Side		Safe End Side		
		Access Y/N	Restrictions	Access Y/N	Restrictions	ONR Comment
SG to Safe End	SG inlet and outlet nozzle to safe end welds Thickness: 97 mm	Y	[redacted] straight section Cladding on bore	Y	[redacted] straight section	No tandem or mode conversion inspection is proposed so the most favourable angle for vertical defects is 70°.
RPV to Safe End	RPV inlet and outlet nozzle to safe end welds Thickness: 76 mm	Y	[redacted] straight section Cladding on bore	Y	[redacted] straight section	

254 The narrow gap TIG welds have fusion faces close to vertical and EDF and AREVA make the claim that a pulse-echo 70° beam (20° incidence) is adequate for detection of vertical defects. Little evidence is provided to support this assumption, and beams which are 20° from normal will give weak signals for smooth planar defects. In areas of difficult geometry the misorientation angle may increase up to 25° but this is claimed to be acceptable on the basis that such regions are limited.

255 The only consideration in Refs 51 and 53 of tandem or mode conversion techniques is limited to the possible option of automated phased array inspection of the DM welds. Neither tandem nor mode conversion techniques are included within the RCC-M code. However I believe that accepted international good practice requires consideration of tandem or mode conversion techniques for defects oriented vertically, as discussed below.

256 I consider that reliance on 70° pulse-echo inspection for near-vertical defects is not consistent with EN ISO 17640:2010 "NDT of welds – UT –Techniques, testing levels and assessment" (Ref. 54). This standard requires in Section 6.3.2 that "One of the probe angles used shall ensure that the weld fusion faces are examined at, or as near as possible to, normal incidence." And in Section 12.3 "For such imperfections [vertical defects] specific testing techniques should be considered, particularly for welds in thicker materials."

257 The use of tandem or longitudinal-longitudinal-transverse (LLT) mode conversion techniques is not new. For example, EN 583-4: 2002 'NDT- UT – Examination for discontinuities perpendicular to the surface' (Ref. 55) describes the principles of tandem and LLT inspection and is referenced in EN ISO 17640:2010 (Ref. 54).

258 In the latest draft standard for UT of austenitic welds (Ref. 56), tandem (round trip) is a requirement for detection of vertical defects. Draft ISO/DIS 22825 24 March 2010 (NDT of welds – UT – testing of welds in austenitic steels and nickel-based alloys) states in Section 9.4. "For detection of potential cold cracks, perpendicular to the surface, (round trip) tandem shall be used in addition to the direct and indirect detection functions."

3.4.2.3.3 Discussion of geometrical limitations for MCL homogeneous and DM welds.

259 As a result of my requests for stronger evidence of inspection capability, the extent of ultrasonic inspection proposed during manufacture has evolved significantly since 1 July 2010 when only radiography was proposed during manufacture. However there is little evidence that the detailed design of the pipework has been re-assessed in the light of the proposals for ultrasonic inspection. Aspects of the design which do not appear to have been adequately reviewed are explained in the subsequent four paragraphs.

260 (i) The counterbore near the homogeneous welds is likely to affect scanning and inspection capability when testing from the bore and might create difficulties for interpretation when scanning from the outside. The maximum depth of the counterbore has not apparently been specified but a typical profile shown in Ref. 51 appears to leave a gap of between 1.5-2.0 mm under a probe scanned on the inside surface. This gap is significantly greater than the target value of 0.5 mm quoted elsewhere in the submissions and in specified in international standards.

261 (ii) Although it is claimed that the external surface profiles will be flat and smooth, it is not clear how a satisfactory error of form will be reliably achieved. Hand grinding may produce variable results, especially near bends and changes of section, and the maximum error of form which might occur has not yet been quantified.

262 (iii) The final layer of weld metal added on the external surface of the narrow gap TIG welds, to compensate for contraction or distortion of the joint during welding, may distort

the ultrasonic beams because the coarse-grained weld metal will be anisotropic, unlike the parent material.

263 (iv) Consequently, after allowing for fit-up mismatch, weld shrinkage and overlay welding and hand grinding, the actual profile may be quite different from the nominal. For the elbows of the MCL pipework EDF and AREVA have explained (Ref. 51, Section 5.3) that the bending operation can also form undulations in the surface which create gaps under the probe exceeding 0.5 mm.

264 Finally, since the analysis provided in Ref. 51 is based on assumptions about detection of defects with misoriented beam angles which I am not convinced are valid (as discussed above), it is not yet clear what effect the restricted straight lengths of pipe near the DM welds and some of the homogeneous welds will have on the inspection capability.

3.4.2.3.4 Assessment Conclusions on Original Proposals

265 My assessment of the original deliverables reached two important conclusions:

1. The components and welds have not yet been demonstrated to be designed with the requirements for ultrasonic inspection in mind. Manufacturing UT is a recent proposal introduced in late 2010 some time after the original design of the components and welds.
2. Even with the existing designs of the components and welds, the UT techniques have not necessarily been optimised to detect vertical planar defects.

266 On the basis of my assessment, I wrote letter EPR70373R (Ref. 57) which explained why I was not convinced that the proposed inspection techniques were consistent with our Safety Assessment Principles particularly EMC.3, Para 252 f) and h). In addition, the proposals did not appear to be consistent with relevant good international practice represented in European and International Standards. My letter also recommended that EDF and AREVA should carry out two systematic reviews:

1. A study of which ultrasonic techniques are likely to achieve the required capability of defect detection. This study should include consideration of tandem or mode conversion techniques which may achieve specular reflection for the near-vertical fusion faces in the austenitic and DM welds.
2. A study of the effects of counterbores, final finishing weld layers and any other features such as surface form which are likely to affect the ultrasonic capability. If there are significant limitations in the ability to detect relevant defects caused by the current design details, the requirements for improving the design and imposing profile quality specifications will need to be addressed.

3.4.2.3.5 EDF and AREVA Initial response to ONR letter EPR70373R

267 At a meeting in October 2011 we discussed the concerns raised in my letter (Ref. 57), and although EDF and AREVA had considered the issues they did not propose any significantly new solutions.

268 The ultrasonic inspection proposals remained at an outline stage with two potential techniques still under consideration. Concerning the possibility of deploying self-tandem or mode conversion techniques EDF and AREVA claimed that such techniques were still considered to be at the research stage, although I pointed out that the current development of a qualified phased array system for ISI of the austenitic and DM welds at Olkiluoto 3 (OL3) could be worth exploring further.

269 Other claims made by EDF and AREVA were:

- Evidence of the capability of 70° beams to find defects in narrow gap TIG welds with near vertical fusion faces exists in a report of work performed for Sizewell B and reported in 1992.
- Trials of the effects of weld overlay were performed for qualification of transverse defect detection at OL3 and showed the effect on capability was small, at least for compression waves.
- It was impractical to extend the counterbores beyond the 25 mm design length because of the pipe tolerances and the demanding fit-up required with the narrow gap TIG welds.
- Theoretical modelling of ultrasonic inspection of austenitic and DM welds is very difficult and experimental evidence on the capability is limited.

270 Some of the gaps in evidence of inspection capability acknowledged by EDF and AREVA were:

- It was not clear how a surface profile of 0.5 mm maximum gap under the ultrasonic probe could be achieved with a counterbore depth up to 2.2 mm.
- It was admitted that the qualification test pieces used for OL3 had smooth surface profiles which did not reflect the actual condition likely to occur on the plant, and the test pieces were straight so that the effects of welds near bends were not examined.

271 At a teleconference held on 1 December 2011 EDF and AREVA announced that they were investigating improvements in both the design of the MCL pipes and in the ultrasonic techniques proposed.

272 At a subsequent teleconference on 20 December 2011, EDF and AREVA made two important new proposals:

- The design of the MCL in the vicinity of the reactor coolant pumps (RCP) would be optimised to enable the application of suitable UT techniques, and the straight sections would be increased from [redacted] to about [redacted].
- The manufacturing UT for all the MCL homogeneous welds would use an automated phased array technique, including self-tandem UT to supplement the 70° pulse-echo beam in order to detect smooth vertically orientated defects. The DM weld manufacturing inspections would be supplemented with 0° UT from the end faces.

In addition, the length of the counterbores would be extended from 25 mm to at least 50 mm on all homogeneous welds to avoid geometrical reflections interfering with the UT.

3.4.3 Deliverables for Action 2: Revised

Deliverable No.	Original plan (O) or revised proposal (R)	Deliverable	Ref.
3	R	UK EPR™ – ALARP Justification of Manufacturing Inspection Technique proposed for Main Coolant Lines Welds of the UK EPR™. PEER-F DC 78. AREVA NP. 13 March 2012.	59
4	R	UK EPR™ Ultrasonic Examination of MCL Homogeneous and Dissimilar	52

Deliverable No.	Original plan (O) or revised proposal (R)	Deliverable	Ref.
		Metal Welds. PEEM-F 11.0505 Rev C. AREVA NP. 1 March 2012.	
5	R	Ultrasonic Examination of the Steam Generator Safe-End – NGT Process (used for EPR), EFFQM 12/17004 Rev B. AREVA NP. 17 Feb 2012.	60
6	R	MCL Optimisation – U Leg Lowering Feasibility Study, PEER-F DC 73 Rev B. AREVA NP. 3 Feb 2012.	61
7	R	UK EPR™ Intermediate and Large Break LOCA – Feasibility Study related to GDA Issue GI-UKEPR-SI-01. PEPR-F 11.1421 Rev A. AREVA NP. Jan 2012.	62
8	R	The Capability of Ultrasonic Inspection Procedures N1/5799/UT1 Rev 0 and N1/5799/UT2 Rev 1. Manufacturing Inspection of Reactor Coolant Loop Pipework – Narrow Gap TIG Shop Fabricated Pipe Butt Welds. TD/IRB/REP069 Issue 1. Nuclear Electric. March 1992.	63
9	R	Revision A MCL Optimisation – Counterbore Length Increase Feasibility Study. PEERF-DC-079 Rev A. AREVA NP. 1 March 2012.	64
10	O/R	Demonstration of Integrity of High Integrity Components against Fast Fracture: Fracture Mechanics Analysis – Non-Destructive Testing – Fracture Toughness, PEER-F 10.2070 Rev. C. AREVA NP. 14 May 2012.	65

The commitments made by EDF and AREVA in letter EPR01051N dated 10 January 2012 (Ref. 58) led to the additional deliverables 3 to 9. Deliverable 10 was included within the original Resolution Plan, but was delivered later to incorporate the design changes.

3.4.3.1 Revised Deliverables

3.4.3.1.1 Deliverable 3 (Ref. 59)

273 This report provides an ALARP justification of the proposed design changes and revised inspection techniques. Taking the previous inspection proposals as a base case, the report considers the reasonably practicability of further improvements to adapt the design to facilitate ultrasonic testing (UT), taking account of design constraints.

The ALARP case examines the following options:

- Do nothing i.e. retain the previous MCL design & inspection proposal.
- Modify the geometry of the MCL circuit to improve inspectability.
- Implement the self-tandem UT technique and end-on (0°) inspection of DM welds as supplementary inspection methods.
- Modify the safety case to abandon the HIC claim of the MCL pipework.

3.4.3.1.2 Deliverable 4 (Ref. 52)

274 This report has been updated to take account of the proposed design changes and to provide evidence of the capability of the revised UT techniques to detect defects of structural concern in the welds including near vertical defects parallel to the fusion faces. Further details are also provided on the weld overlay which is applied to compensate for contraction of the joint during welding and its impact on UT inspection.

3.4.3.1.3 Deliverable 5 (Ref. 60)

275 This report describes the tests performed in 1995 and 2011 to analyse the feasibility to deploy manual pulse-echo UT, automated phased-array UT, and self-tandem UT on a steam generator dissimilar metal weld mock-up (from both the ferritic and austenitic sides).

3.4.3.1.4 Deliverable 6 (Ref. 61)

276 This report describes the analyses in the following technical areas to optimise the geometry of the MCL cross-over leg (U-leg) :

- Impact of fault studies (LOCA analyses).
- Impact of layout constraints.
- Impact of manufacturing of the forgings.
- Impact on the mechanical justification of the primary components.

3.4.3.1.5 Deliverable 7 (Ref. 62)

277 This report presents the detailed analyses performed with regards to fault studies (IB/LB LOCA) to optimise the geometry of the MCL U-leg.

3.4.3.1.6 Deliverable 8 (Ref. 63)

278 This report prepared by Nuclear Electric Plc. In 1992 describes the development and validation of manual ultrasonic procedures for manufacturing inspections of narrow gap TIG welds in the MCL pipework at Sizewell B.

3.4.3.1.7 Deliverable 9 (Ref. 64)

279 This report describes the results of the feasibility study of increasing the length of the pipe counterbore. It is a new deliverable that was not described in the letter EPR01051N (Ref. 58).

3.4.3.1.8 Deliverable 10 (Ref. 65)

280 This report provides an overall summary of the qualified manufacturing inspections to be performed on the HIC components. Although proposed as one of the original deliverables its delivery was postponed until the outcome of the proposed design changes had been incorporated.

3.4.4 ONR Assessment of Action 2: Revised Deliverables

281 EDF and AREVA set down their substantially revised proposals for addressing GDA Issue SI-01 Actions 2 and 7 in letter EPR01051N dated 10 January 2012 (Ref. 58). There are two important design changes involving an increase in the straight sections at the ends of the cross-over leg and increased counterbore lengths for all homogeneous austenitic welds. In addition an automated and enhanced phased array ultrasonic inspection is now proposed. I have summarised these important new proposals and the benefits perceived by EDF and AREVA in the three subsequent sub-sections.

3.4.4.1 Modification of the cross-over leg (U-leg)

282 The diagram below, which has been extracted from Ref. 61, shows the optimised design of the U-leg with the straight sections of pipe marked in yellow. The optimised design is overlaid by the original design with the corresponding straight sections shown in light blue.

283 Each end of the cross-over leg (U-leg) is to be extended by 250 mm so that the straight section is increased from about [redacted] to [redacted]. This change has a number of advantages:

- Any ripples that happen to be generated by the induction bending process are now well removed from the weld location. This improves the fit-up achievable at the weld, facilitates a better surface profile at the weld and ensure the ripples caused by bending do not interfere with scanning the ultrasonic probes.
- The longer straight section allows optimum scanning of the welds as well as easier fit-up of the manipulator for these automated inspections.
- Since the induction bending occurs away from the ends of the forgings the manufacturing process is easier.

In addition to the increased straight sections at the ends joined to the SG and RCP, the position of the intermediate weld (weld U2) has been adjusted to improve the straight sections available for ultrasonic inspection on the 90° elbow. The position of weld U3 has been adjusted to assist forging of the U-PP elbow which is the largest of the three forgings of the U-leg. This change has also been progressed via the change management process under UKEPR-CMF-031 (Ref. 100) and is now at Stage 3 ready for handover to the site-specific phase.

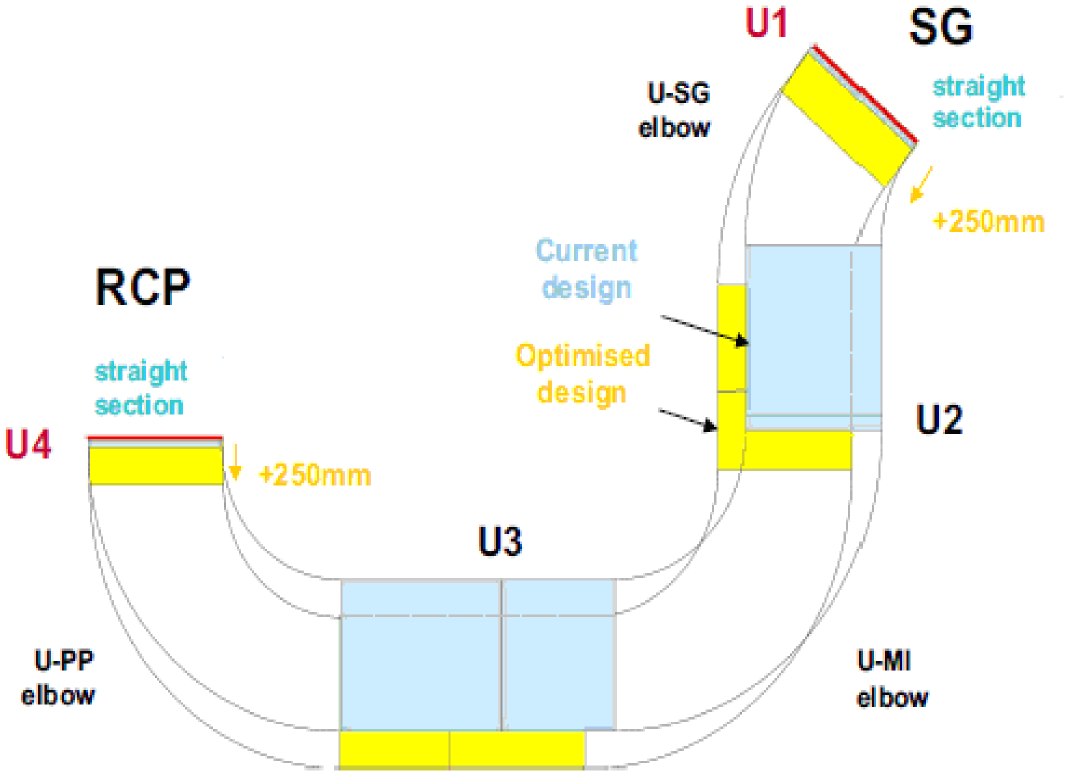

Figure 2. Original and optimised U-leg design (from Ref. 61)

3.4.4.2 Increase in counterbore length.

284 The counterbores on all the MCL homogeneous welds are to be increased from 25 up to 100 mm. This is suggested to be solely to allow the self-tandem technique to be deployed without interference geometrical echoes arising from the counterbore, although I believe there may also be advantages for some of the pulse-echo inspections.

285 Because the narrow gap TIG welds cannot tolerate much misalignment, great care is needed in the fit-up of the MCL welds. EDF and AREVA propose to make several small but important changes to the design criteria:

- Any individual pipe misalignment (bias) will be reduced from [redacted] to [redacted].
- The inner diameter at the counterbore will be increased from 784 to 785.5 mm.

These two modifications, whose combined effects will allow the counterbore length to be increased to 100 mm, are described fully in Ref. 64 which concludes that the modification is feasible with little impact on the UK EPR™ design. The change to the counterbore has been progressed via the change management process under UKEPR-CMF-032 (Ref. 101) and is now at Stage 3 ready for handover to the site-specific phase.

3.4.4.3 Manufacturing inspections and PSI/ISI for the austenitic and DM welds.

286 For the MCL homogeneous welds the qualified manufacturing inspection will involve automated phased array inspection from outside the pipes. The phased array system will also be configured to achieve self-tandem inspection over the full thickness of the weld.

287 For the dissimilar metal (safe end) welds the qualified manufacturing inspection will comprise manual pulse-echo ultrasonic inspection from both inside and outside surfaces of the pipes. This will be supplemented by 0° compression wave testing from the end faces of each safe end.

288 Evidence from three separate programmes support the capability being claimed for these new inspection techniques:

- Sizewell B (SZB) narrow gap TIG shop welds are similar to the UK EPR™ MCL welds and inspection of the SZB welds had been qualified using a combination of manual pulse-echo compression and shear wave transducers.
- Trials undertaken for OL3 give direct evidence of the capability of the proposed phased array system to detect realistic surface-breaking defects. These trials included representative fatigue cracks albeit surface-breaking rather than embedded.
- AREVA have performed trials on mock-ups of homogeneous and DM welds including both manual pulse-echo and self-tandem probes and manual phased array UT.

289 PSI/ISI for the UK EPR™ will be defined during the site specific phase depending on the defect detection requirements. For the homogeneous welds it would be feasible to deploy the same techniques as those used for the manufacturing inspections. However for the DM welds two alternative inspection techniques are available: either automated phased array UT from the outside surfaces (as for the homogeneous welds) or automated immersion UT from the bore using the RPV for access.

3.4.4.4 Assessment of cross-over leg re-design

290 Ref. 61 summarises the design studies performed to check whether modifying the cross-over leg (U-leg) as described above would have any adverse effects on other aspects of the design. Impact analyses have been performed in four areas:

- LOCA studies of the effects of lowering the U-leg.
- Layout studies to check clearances remain adequate and the CVCS nozzle can be accommodated.

- Feasibility of manufacturing the modified forgings and bends.
- Mechanical (stress and seismic) analyses.

3.4.4.4.1 Fault studies

291 EDF and AREVA judge (Ref. 62) that the most significant impact in the fault studies area will be the effect on the thermal hydraulic behaviour in the case of an intermediate or large break LOCA event. Lowering the horizontal part of the U-leg by about 250 mm will increase the pressure head required to remove fluid from the leg during such transients. This delays the time until which steam can be vented through the break and results in the core being uncovered for slightly longer. Transient analysis studies consider a range of break sizes up to a 830 cm^2 double-ended break corresponding to the area of the pressuriser surge line connected to the hot leg. In the worst case, the maximum peak temperature of the fuel clad is predicted to increase from 763°C to 771°C and therefore EDF and AREVA conclude that the modification of the U-leg does not impact significantly on the risks from these faults.

292 I consulted a fault studies colleague who reviewed the analyses by EDF and AREVA and also compared the results with an independent analysis performed by a contractor during GDA Step 4. He came to the judgement that an adequate case for the generic design change has been provided (Ref. 66). I note however that there is already an expectation that further sensitivity analyses for faults will be required during the site specific phase of a UK EPR™. This is specified by a GDA Step 4 Assessment Finding (**AF-UKEPR-FS-08**).

293 Another aspect of the design change with a potential to affect fault studies is the reduced clearance below the pipework which requires increased use of thinner, high performance (Microtherm) insulation. The powder used in this insulation has the potential during a LOCA to be swept into the containment sumps where it might block the filters and consequently the amount of such insulation which can be used is restricted. EDF and AREVA claim that the amount required is within the limits specified for FA3 but these limits have not been accepted by ONR. During GDA Step 4 an Assessment Finding was raised which requires a Licensee to consider eliminating the use of such insulation and replacing it with metal foil (**AF-UKEPR-CSA-07**), and so this issue will need to be reviewed as part of site specific phase.

294 EDF and AREVA have concluded that from a fault studies perspective the potential impacts of the re-design are small and acceptable. Whilst I accept that an adequate justification has been provided for the generic design, further work will be required during the site specific phase as part of the sensitivity studies in **AF-UKEPR-FS-08** and the ALARP review in **AF-UKEPR-CSA-07**. I have also raised a more general Assessment Finding to ensure that the redesign of the cross-over leg does not have any unacceptable safety detriments **(AF-UKEPR-SI-52).**

3.4.4.4.2 Layout studies

295 The layout studies in Ref. 61 consider the impact on neighbouring pipes and supports, insulation and civil works.

296 There are two potential ways of modifying the CVCS discharge line to match the new position of the U-leg: one option involves changing the circumferential position of the nozzle by about 10° whereas the second option involves an extra 45° bend and associated welds. Whilst neither option is completely straightforward, the first option is judged by EDF and AREVA to create less difficulty with access for insulation and maintaining a design suitable for inspection.

297 As discussed above, there is also a need to introduce thinner, high performance insulation in certain locations, particularly close to the Safety Injection System (SIS) lines and RCP legs.

298 I accept the claim by EDF and AREVA that acceptable solutions to these layout issues can be developed at the detailed design stage, but that will need to be demonstrated during the site specific phase.

3.4.4.4.3 Impact on procurement of MCL pipework

299 The modified design increases the overall length of the U-leg by 422 mm (from 8.707 m to 9.129 m) even after adjusting the positions of some of the welds, and the increased length could potentially create difficulties for production of forgings and the associated M140 qualification.

300 The increased lengths of the 90° bends increase the weights of the required forgings to [redacted] whereas the original weights were [redacted] for the pump bend and [redacted] for the bend in the middle. However Ref. 61 explains that the M140 qualification will remain valid, since the original qualification was based on a [redacted] casting (after cutting) which exceeds the combined weight of the two bends ([redacted]). The 40° bends are slightly shorter in the modified design and so the required weights are also within the original M140 qualification.

301 There is no need to modify the sequence of forging operations for the revised design of pipework. Consequently at this stage of the design I accept the arguments advanced by EDF and AREVA that the M140 and the shop qualification are not affected by the U-leg modification. However I would expect this to be confirmed during the site specific phase as part of the detailed design review and I have raised an Assessment Finding which includes this aspect **(AF-UKEPR-SI-53).**

3.4.4.4.4 Impact on Mechanical Analysis

302 The increased weight and length of the U-leg has an impact on its mechanical characteristics. There is only a minor impact on the static loads (weight and thermal expansion), seismic loads could increase by about 10%, and fault loads during a LOCA could increase by 20 to 30% although the absolute values are small.

303 For the steam generator outlet nozzle, stress analysis performed for FA3 shows comfortable margins at the end of the nozzle. For the DM weld at this location, the limiting defect size has not yet been analysed, but for the RPV outlet DM weld (which is judged by EDF and AREVA to be similar in geometry and stresses) the limiting defect was 23 mm through-wall.

304 For the RCP inlet nozzle, the stress analysis for FA3 shows large margins for Category 4 events. The fast fracture analysis studies for FA3 show sufficient margins at the inlet nozzle for design basis events.

305 For the MCL pipework itself, studies for FA3 show sufficient margins in respect of anticipated loads that the potential increases in mechanical loads with the new design can be accommodated.

306 Consequently EDF and AREVA conclude that the impact on mechanical performance of lowering the U-leg is acceptably small and can be managed during the detailed design studies. I accept this claim that the effects will be modest and manageable and that they can be addressed by more detailed analyses during the site specific phase.

3.4.4.4.5 Conclusions of Impact Analyses

307 I support the conclusions reached by EDF and AREVA that there are no fundamental difficulties with implementing the proposed re-design of the U-leg. These counterbore design changes have also been progressed via the change management process under UKEPR-CMF-031 and are now at Stage 3, the point of handover to the site-specific phase (Ref. 100). I consider the proposals are adequate at this stage of the design, and I accept that the change can now be developed in detail during the site-specific phase. However I note the need to undertake more detailed design and assessment during the site specific phase and I note that some local design modifications are likely to be necessary. I have raised Assessment Finding **AF-UKEPR-SI-52** to cover these aspects.

3.4.4.5 Counterbore length increase

308 The narrow gap TIG welding process requires tight tolerances on thickness and alignment of components to be welded. Since pipe ovality may occur during forging, machining or bending, a counterbore is machined on the bore to ensure good alignment of the surfaces to be welded. However this counterbore operation relies on there being an adequate straight section at the end of the pipe so that minimum wall thickness criteria are also met.

309 Although the actual positions of the major vessels may vary by +/- 20 mm relative to the design, the RCL pipework must still satisfy the isometric requirements. This is achieved by making small adjustments to the position of the weld preparations and also cutting a slightly oblique end face (bias cutting) if required. The maximum bias angle currently allowed is [redacted], and the largest value required at OL3 was about [redacted]. However EDF and AREVA believe that by optimising the amount of bias at each weld it will be feasible to reduce this bias limit to [redacted].

310 The proposed modification also includes an increase in the maximum allowable inner diameter of 785.5 mm compared with 784.0 mm which, combined with the tighter tolerance on bias angle, allows the maximum length of counterbore to be increased from 25 mm to 100 mm (Ref. 64). For the crossover leg, the increased counterbore also requires the increased straight sections already proposed to improve inspectability as discussed above.

311 Increasing the allowable inner diameter by 1.5 mm implies a reduced wall thickness of up to 0.75 mm near the weld. Consequently EDF and AREVA have reviewed the stress analysis and fast fracture analysis predicted for MCL pipework at FA3 and concluded that the margins are sufficient to take into account an additional 1 mm decrease in thickness at the weld. GDA analyses of the two bounding welds (Ref. 46) using initiation toughness predicted a limiting defect size of 19.5 mm which is slightly less than the target size of 20 mm. However, since there is the possibility to invoke a less conservative toughness criterion based on limited ductile tearing as the limiting load condition is due to infrequent fault conditions, EDF and AREVA conclude that the limiting defect size is acceptable.

312 EDF and AREVA have also reviewed the tolerance to through-wall defects performed for FA3 and conclude that, although the tolerance to through-wall defects is acceptable, the minimum leak rate which has to be detected is very small and the modification is unfavourable. I have not reviewed the tolerance to through-wall defects within GDA because the design basis analysis for the UK EPR™ does not make claims on leak before break.

313 Whilst the effects of the reduced thickness on the stress and fracture analyses will need to be confirmed during the site specific phase, I am satisfied at this stage that the modification is tolerable.

314 EDF and AREVA have also confirmed that the machining tool which is designed to make a 25 mm long counterbore will need to be modified. It is proposed to cut the counterbore in two stages and to smooth any small unevenness at the junction of the two cuts. I believe that this proposal is acceptable provided the machine is thoroughly tested before use. To cover this aspect I have raised an Assessment Finding on surface profile (**AF-UKEPR-SI-54)** which is listed in Section 3.4.6 below.

315 In summary, EDF and AREVA have proposed a way of increasing the counterbore length from 25 mm to 100 mm using the following criteria:

- Inner counterbore diameter: 785.5 [redacted], (previously 784.0 [redacted]).
- Maximum bias angle: [redacted] (previously [redacted]).

The inner diameter of the pipes remains unchanged at 780 [redacted], but the crossover leg requires the increased straight section at the ends which have been proposed already for other reasons.

316 These counterbore design changes have also been progressed via the change management process under UKEPR-CMF-032 and are now at Stage 3, the point of handover to the site-specific phase. I consider the proposals are adequate at this stage of the design, and I accept that the change can now be developed in detail during the site-specific phase. However I note the need to confirm the detailed analyses before implementation of the modification and this is covered by Assessment Finding **AF-UKEPR-SI-52*.***

3.4.4.6 Assessment of revised proposals for manufacturing inspection and PSI/ISI.

3.4.4.6.1 Evidence on capability of UT techniques

317 I assessed the evidence from three separate programmes which EDF and AREVA provided to support the capability being claimed for these new inspection techniques. The three programmes were: Sizewell B MCL manufacturing inspections, OL3 phased array development for PSI/ISI and related trials by AREVA on homogeneous and DM test pieces.

318 Sizewell B (SZB) narrow gap TIG shop welds are similar to the UK EPR™ MCL welds and inspection of the SZB welds had been qualified using a combination of manual pulse-echo compression and shear wave transducers. Ref. 63 describes the results of trials on defects which were representative of lack-of-sidewall-fusion, centreline solidification cracking and weld metal cluster cracking. The results are encouraging and reasonable capability to detect and size such defects was demonstrated. However the procedure was time-consuming as it employed a large number of scans (e.g. nine beams from both inside and outside surfaces for the homogeneous pipe to pipe welds). The importance of controlling grain size was also emphasised, and the mean size was ASTM 3.5 or better for all forged components. This grain size is significantly smaller than the current RCC-M (M3321) specification of ASTM greater than 1 for UK EPR™ MCL forgings. Consequently it is important for a licensee to ensure that the grain size, and any other properties which may have a significant influence of the ultrasonic inspection capability, are adequately controlled during the procurement, manufacture and installation. I have raised an Assessment Finding **AF-UKEPR-SI-53** to include this requirement.

319 Trials performed by AREVA using manual techniques and a phased array system being developed for PSI/ISI at OL3 show a good capability to detect realistic surface-breaking defects. In addition, the phased array self-tandem technique was tested for the full weld thickness by dividing the wall into five separate depth zones and all the embedded

defects were detected. I also consider that use of an automated phased array system should assist the interpretation of the inspection data since this the raw data will be recorded (in contrast to manual inspection) and may be reviewed by more than one data analyst if required.

320 Recent trials on the DM weld mock-up in 2011 included both manual pulse-echo and self-tandem probes as well as manual phased array UT and hence the trials provide a useful comparison of these alternative techniques. Tests were also performed with 0° probes from the end face of the safe end. Whilst the embedded defects may not be fully representative of smooth planar defects, the results are nevertheless encouraging.

321 One of the factors which could degrade inspection is the overlay welding which is used to compensate for weld shrinkage. Ref. 52 provides some useful evidence on the typical extent of such weld overlays (50 to 60 mm either side of the weld centre-line and up to 5 mm deep at OL3). Measurements have been made on transverse defects to assess how much the weld overlay might affect UT: the amplitude reductions were small for angled compression beams (up to 3dB) but increased to 6dB for angled shear waves at 38°.

322 I accept that the effects of the overlay weld appear to be manageable but I note the intention to undertake further studies as part of inspection qualification. Similarly I note the commitment to measure the error of form on any surfaces which are important for UT, whether because probes are scanned on them or because beams are reflected from them. Because of the importance of these parameters on the quality of inspection achievable I have raised an Assessment Finding **AF-UKEPR-SI-54** which is given in Section 3.4.6 below.

3.4.4.6.2 ONR assessment of capability of inspections of MCL homogeneous welds

323 For the MCL homogeneous welds the qualified manufacturing inspection will involve automated phased array inspection from outside the pipes and will be based on that developed for PSI/ISI at Olkiluoto 3. The phased array system will also be configured to achieve self-tandem inspection over the full thickness of the weld.

324 There will be no UT inspections from the bore either during manufacture or PSI/ISI which will avoid the problems of scanning over counterbores.

325 Ref. 52 assesses the inspectability of the MCL homogeneous welds by estimating whether 70° or 55° beams can reach the weld root. If a 70° beam can reach the weld root with the correct angle, it is assumed there is no restriction on access. If only a 55° beam can reach the weld root, the self-tandem technique should still be unrestricted although pulse-echo beams of higher angles would be restricted.

326 I have repeated my assessment of access for inspection which was reported in Section 3.4.2.3.1 above, and the table below shows that access is now very significantly improved. Extending the counterbores and increasing the straight sections on the end of the U-leg have removed most of the restrictions, and the only serious ones remaining affect the welds to the RCP bowl where the constraint of single-sided access remains unchanged.

327 I have assumed that there will be less need for tapers near the welds on the redesigned U-leg, and that any taper on weld H3 will be manageable by small adjustment of the ultrasonic beam angles used for inspection. Such adjustment should be relatively straightforward with the automated phased array system.

Revised proposals for Homogeneous welds – ONR review of restrictions to inspection

Weld Ref.	Description	Upstream Weld Side		Downstream Weld Side	
		Access Y/N	Restrictions	Access Y/N	Restrictions
H1	RPV outlet with hot leg elbow 6°	Y	None See Note 1	Y	None
H2	Hot leg with elbow 50°	Y	None	Y	None
H3	Elbow 50° with SG safe end	Y	Taper	Y	None
U1	SG safe end with elbow 40°	Y	None	Y	None
U2	Elbow 40° with elbow 90°	Y	None	Y	None
U3	Elbow 90° with elbow 90°	Y	None	Y	None
U4	Elbow 90° with RCP	Y	None	N	Cast material
C1	RCP to cold leg	N	Cast material	Y	None
C2	Cold leg 27.5° with RPV inlet	Y	None	Y	None See Note 1

328 **Key:**

Green	No significant limitations for ultrasonic inspection
Yellow	Some limitations “ “
Grey	Inspection not feasible

Note 1. The length of the safe end restricts access for high angle beams, but this is overcome during manufacture by applying the self-tandem technique.

329 The table shows that the combination of plant re-design and increased capability of the inspection techniques means that most welds should have no significant restrictions to the ultrasonic capability as summarised below:

- six welds have no significant restrictions;
- one weld may have a taper close to the weld; and

- two welds are only inspectable from one side but the opposite side has no significant restrictions.

3.4.4.6.3 ONR assessment of capability of inspections of DM welds

330 For the dissimilar metal welds my assessment of accessibility with the latest proposals is summarised in the table below. This may be compared with my assessment of the original proposals given in the table in Section 3.4.2.3.2 above and I am satisfied with these revised inspection proposals.

Revised Proposals for Dissimilar metal welds – ONR review of restrictions to inspection

Weld Ref.	Description	Vessel Side		Safe End Side		
		Access Y/N	Restrictions	Access Y/N	Restrictions	ONR Comment
SG to Safe End	SG inlet and outlet nozzle to safe end welds 97 mm thick	Y	[redacted] straight section -Cladding on bore	Y	[redacted] straight section	The most favourable angle for vertical defects is 70° using angled shear waves, but this is supplemented by 0° compression from the end face.
RPV to Safe End	RPV inlet and outlet nozzle to safe end welds 76 mm thick	Y	[redacted] straight section -Cladding on bore	Y	[redacted] straight section	

3.4.4.6.4 Potential techniques for PSI/ISI

331 For the MCL homogeneous welds, the automated phased array UT system proposed for manufacturing inspections could also be configured for PSI/ISI. For the DM welds the manual manufacturing techniques are not applicable: for DM welds of both the RPV and SG it would be feasible to develop an automated phased array technique similar to that already proposed for the homogeneous welds. In the case of the RPV DM welds there is also the option to inspect from within the nozzle bore in immersion using access from the RPV.

332 Consequently I accept that there are techniques proposed for PSI/ISI which have a realistic prospect of being developed and successfully qualified for this application.

3.4.5 Assessment Conclusions for Action 2

333 I have drawn the following conclusions based on the submissions from EDF and AREVA and my own interpretation of the evidence:

- The redesign of the cross-over leg provides a significant improvement in inspection capability. There are now straight sections which allow better access for UT as well as facilitating an improved surface profile.

- The manufacturing inspection of MCL homogeneous welds will include an ultrasonic self-tandem technique to improve detection of vertical defects.
- Increasing the counterbore length from 25 mm to 100 mm should improve reliability of the pulse-echo inspections and particularly that of the self-tandem technique.
- The manufacturing inspections of the homogenous welds will use an automated phased array system which I believe should assist the interpretation of the data.
- For the homogeneous welds there will be no UT inspections from the bore either during manufacture or PSI/ISI which will avoid the problems of scanning over counterbores.
- During manufacture the DM welds will have an additional 0° inspection from the end faces to detect vertical defects.
- I accept that there are techniques proposed for PSI/ISI which have a realistic prospect of being developed and successfully qualified for this application.
- As an overall conclusion I believe that the proposals form a well integrated package of improvements and should overcome the main difficulties which caused **GI-UKEPR-SI-01** Action 2 to be raised. Consequently I am satisfied that this action may be closed.

3.4.6 Assessment Findings for Action 2

334 The following Assessment Findings have been raised:

> ***AF-UKEPR-SI-52:*** *The Licensee shall confirm through appropriate analyses and assessment that the detailed redesign of the MCL pipework to increase counterbore lengths and to lower the cross-over leg does not have any unacceptable safety detriments.*
>
> ***Required timescale:*** *Install RPV*
>
> ***AF-UKEPR-SI-53:*** *The Licensee shall demonstrate that the materials properties of the MCL forgings are adequately specified and controlled. This demonstration should include evidence that the M140 and shop qualifications for the MCL pipework remain valid for the modified design, and that the grain size is such that a reliable ultrasonic inspection of the parent material and associated welds can be achieved both during manufacture and in-service.*
>
> ***Required timescale:*** *Install RPV*
>
> ***AF-UKEPR-SI-54:*** *The Licensee shall ensure that the surface profile of the MCL pipework is adequately specified and controlled for all those surfaces on which ultrasonic transducers are scanned or from which ultrasonic beams may be reflected. This should include the effects of any local features such as overlay welding to compensate for welding distortions or profile variations caused by the counterbore cutting machine.*
>
> ***Required timescale:*** *Install RPV*

3.5 GDA Issue GI-UKEPR-SI-01 Action 3

335 This action (Annex 3) specifies additional evidence required to demonstrate that the HIC welds in the main steam lines are suitable for ultrasonic inspection and that the manufacturing inspections are likely to be capable of detecting defects significantly smaller than the limiting defects.

3.5.1 Deliverables for Action 3

Deliverable No.	Original plan (O) or revised proposal (R)	Deliverable	Ref.
1	O	UK EPR™ Ultrasonic examination of MSL girth welds. PEEM-F 11.0959 Rev A. AREVA NP. July 2011.	68
2	O	UK EPR™ Results of simulation trials of Ultrasonic examination on MSL girth welds. PEEM-F 11.1602 Rev A. AREVA NP. Oct 2011.	*70*
3	O	UT Modelling Study for MSSV welds inspection and Steam Isolation Valve weld inspection. NT 28182/1. Intercontrole SA. Oct 2011	*72*
4	R	UK EPR™ Results of simulation trials of Ultrasonic examination on MSL girth welds. PEEM-F 11.1602 Rev C. AREVA NP. Feb 2012	71
5	R	UT Modelling Study for MSSV welds inspection and Steam Isolation Valve weld inspection. NT 28182/2. AREVA NP. Dec 2011	*73*
6	R	UK EPR™ Ultrasonic examination of MSL girth welds. PEEM-F 11.0959 Rev B. AREVA NP. March 2012	*69*

3.5.1.1 Deliverable 1 (Ref. 68)

336 This report describes the capability of the ultrasonic examinations to to detect defects of structural concern in the high integrity Main Steam Line (MSL) welds. It demonstrates the ability to achieve near-specular reflection from the weld fusion faces over the full thickness of components. The analysis includes UT coverage diagrams of each weld to demonstrate the effects of potential pipe restrictions on the inspection capability.

3.5.1.2 Deliverables 2 and 3 (Refs 70 & 72)

337 These reports describe the results of mathematical modelling to examine the capability of the proposed UT examinations to detect defects of, respectively, 4 mm and 5 mm through-wall extent in 23 mm and 60 mm thick MSL welds. Deliverable 3 is a contractor's report on mathematical modelling backed up with some experimental studies of ultrasonic beam characteristics, and Deliverable 2 is a report by EDF and AREVA assessing the implications of these results.

3.5.1.3 Deliverable 4 (Ref. 71)

338 This revised version of Deliverable 2 takes account of ONR comments and queries made in TQ-EPR-1516 relating to the simulation trials report.

3.5.1.4 Deliverable 5 (Ref. 73)

339 This revised version of Deliverable 3 takes account of ONR comments and queries made in TQ-EPR-1516 relating to the mathematical modelling report.

3.5.1.5 Deliverable 6 (Ref. 69)

340 This revised version of Deliverable 1 takes account of all responses to TQ-EPR-1516.

3.5.2 ONR Assessment of Action 3

3.5.2.1 Scope of Assessment Undertaken

341 The assessment included:

- A check on whether the weld preparation angles are such that near-specular reflection is achievable over the full height of the welds.
- A review of evidence showing that the effects of any potentially significant restrictions to inspection (tapered or curved surfaces, counterbores, error of form etc) are acceptable.
- A review of the evidence that, when fully developed, the ultrasonic detection and characterisation procedures are likely to have adequate capability for the expected through-wall sizes (4-5 mm) of the defects to be qualified. As discussed in Section 3.3.3 above, and in Section 4.2.3.8 of Ref. 6, the limiting defect sizes are smaller than 20 mm in the main steam lines and the target defect sizes are typically 4-5mm through-wall. The smallest reported limiting defect size is 6.8 mm for the main steam safety valve (MSSV) weld, and hence a 3mm defect size has been conservatively chosen for assessment of the inspection of this weld.

3.5.2.2 General Comments on the Submissions

342 The introduction of mathematical modelling studies using CIVA software has made a significant contribution to the evidence available on inspection capability of the main steam line welds. The two welds studied are representative of the more difficult situations: they cover both thick and thin welds and in each case the geometry restricts access from one side of the weld. The results of these studies have been reviewed by EDF and AREVA who have subsequently increased the scope, and hence the capability, of the proposed 60° and 70° inspections.

343 My initial assessment of the three original deliverables (Refs 68, 70 & 72) raised five questions which were sent to EDF and AREVA in TQ-EPR-1516 and subsequently the three deliverables were revised (Refs 69, 71 & 73) to take account of the responses.

3.5.2.3 Review of the mathematical modelling studies (Refs 72 & 73) and the EDF and AREVA summary and analysis of results (Refs 70 & 71)

344 The mathematical modelling report (Ref. 72) describes a systematic mathematical modelling of the response of planar defects in two welds using the CIVA software developed by CEA. The accuracy of the software was demonstrated by practical measurements of the probe beams characteristics on calibration reflectors in test blocks which were compared with the CIVA results. This comparison seems good and I agree that any differences between experimental and theoretical results are relatively minor and provide good support for the subsequent theoretical predictions for planar defects.

345 The modelling uses Kirchhoff scattering (specular reflection and corner effect) which is appropriate for this application (i.e. there is no attempt to claim detection using diffracted tip echoes).

346 I queried whether the values quoted for probe near field lengths were correct, and in their response to Question 1 of TQ-EPR-1516 EDF and AREVA conceded that there had been an error in the values quoted. The revised report (Ref. 73) now quotes the measured and

predicted values for each beam angle. These values are plausible and I judge there is a reasonable agreement between the simulated and experimental values.

347 I consider that the simulated defects are representative since they are placed on both fusion faces and on both the 10° and 20° angles of the weld preparation. The defect size is 3 mm width x 30 mm length for the main steam safety valve (MSSV) which is appropriate for this component of 23 mm thickness and is less than the preliminary target size for inspection qualification (4 mm through-wall). For the main steam isolation valve (MSIV) where the wall thickness is 55 mm, the modelled defect size is increased to 5 mm x 50 mm which I also consider appropriate.

348 In most cases the mathematical modelling shows that 45° beams are not able to detect the defects. This is not surprising since the misorientation angle (ie the difference between normal incidence and the actual incident angle) generally exceeds 22.5° and the defects are modelled as smooth and planar. However these results confirm the importance of achieving near-specular reflection to achieve reliable detection of such defects.

349 The theoretical results emphasise the potential value of higher beam angles for these weld geometries, and demonstrate that full skip 60° inspection is possible from at least one side of all welds. It is now proposed that 60° tests are needed at full skip whereas Ref. 74, submitted towards the end of GDA Step 4, had assumed half skip 60° was adequate. In addition, the response to TQ-EPR-1516 Question 4, and Ref. 69, now confirm that, where practicable, partial full skip 70° inspection will also be used where only single-sided access is available. Both these proposed modifications for 60° and 70° inspections should increase the potential capability of the inspections. I also welcome the proposal in Refs 71 and 69 that, although RCC-M only requires two different angled beams for weld inspection, EDF and AREVA intend to apply three angled beams for longitudinal defects in the MSL welds.

350 I believe the theoretical modelling results show that when the beams are about 20° or greater from normal incidence on smooth, planar defects, the detection capability is generally very marginal.

351 When reading the summary report (Ref. 70) it appeared that the weld diagrams were using two different interpretations for the component thickness, t_n. In response to Question 3 of TQ-EPR-1516, EDF and AREVA explained that extruded nozzles and valves are forged and/or machined products and the value of the thickness t_n is the design value after machining which is also the thickness at the weld. However for pipes which are standard products t_n is the standard design value of the thickness used for the procurement of the pipe, which enables the minimum thickness $t_{\text{mini weld end}}$ to be obtained after cutting and boring the end of the pipes. I accept this explanation for the difference in definition of t_n for machined products and standard products such as pipes. However, because of the potential implications for inspection capability as well as any other manufacturing issues, this highlights the need to ensure the actual values for component thickness at welds are clearly understood. I refer to this topic later in the following sub-section.

3.5.2.4 Review of the revised ultrasonic inspection coverage for the main steam line welds (Refs 69, 71, & 73)

352 The latest versions of the reports on ultrasonic examination of the main steam line welds (Refs 69, 71 & 73) are intended to provide the information specified by the GDA Issue Action including:

- A description of local MSL design features.

- A description of the UT techniques proposed.
- Coverage diagrams of each MSL weld using the proposed technique including beam angles and incidence angles to demonstrate that near-specular reflection is achievable over the full thickness of all welds and taking into account local design features of the pipework.
- Justification of the ability to tolerate geometrical features including counterbores, error of form, proximity of bends and diameter changes at welds.

353 Refs 71 and 73 now provide considerably more detail of the final qualified inspections to be performed at the end of manufacture than had been available previously in Ref. 74. For example, Ref. 74 specified that the UT would include at least two angled beams selected from 45°, 60° and 70° and generally 45° and 60° would be selected. The weld profile was specified as flush but this was not quantified.

354 Ref. 71 specifies that in addition to half and full skip 45° and 60° inspections, a 70° half skip inspection would be applied to all welds. The introduction of the 70° inspection is consistent with the modelling studies which showed the increased capability of this beam angle compared with 45° for the defects studied. Following my Question 4 of TQ-EPR-1516, Ref. 69 confirms the proposal to use full skip or at least partial full skip 70° for those welds which can only be inspected from one side. Refs 71 and 69 also specify that all scanning surface would be ground to a profile such that the gap under the ultrasonic probes does not exceed 0.5 mm, and that this requirement will be included in the equipment specification for the MSL.

355 As shown in the weld preparation cross-section below, the standard weld preparation has two slopes; at 20° from the root up to 19 mm from the bore, and at 10° thereafter.

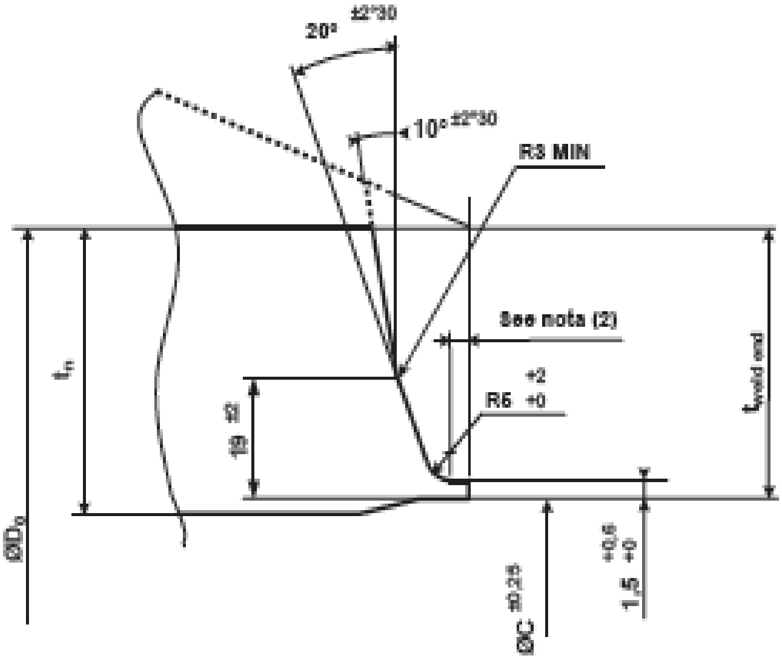

Figure 3. Main Steam Line Weld Preparation Details (from Ref. 69).

Consequently for the thinner welds of about 30 mm thickness the weld preparation angle will be predominantly at 20° whereas, for the thicker welds, the 10° section becomes greater. Hence the achievement of near-specular reflection throughout the weld generally becomes more difficult with increasing weld thickness and this is the case for weld 12 which is a pipe to 90° elbow weld outside the reactor building and is discussed below.

356 The weld numbering system for the MSL welds is given in Ref. 69 where the welds inside the reactor building are illustrated in Figures 4 and 5 and those outside the reactor building are in Figures 10 and 11. I note that weld 3, which connects the steam generator elliptical head with the steam outlet nozzle, is part of the steam generator manufacture. It is a narrow gap TIG weld and Ref. 74 has already specified tandem UT as well as pulse-echo for this weld. This is appropriate because of the near vertical weld preparation associated with this weld.

357 Ref. 69 describes all the HIC welds including those to the main steam relief valve (MSRV) and the main steam safety valve (MSSV). Following my review of these welds, I am generally satisfied with the coverage achievable on those which can be inspected from both sides, but those with only single-sided access merit further consideration. These are welds 10 and 11 which relate to the MSIV, welds 12 and 14 which connect straight pipe sections with 90° bends, and the MSRV and MSSV attachment welds. The locations and geometries of these welds are described more fully in Ref 69, but the figure below shows the geometry for welds 10 and 11 between the MSL pipework and the MSIV.

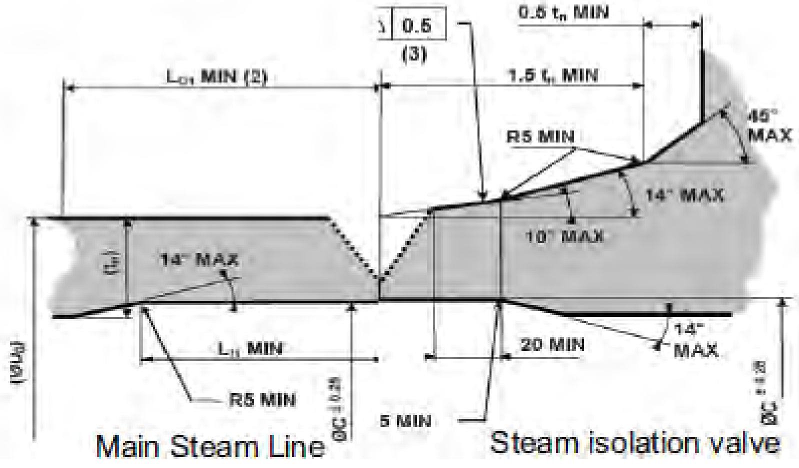

Figure 4. Geometry of Welds 10 and 11 between the MSL pipework and the MSIV (from Ref.71)

358 For those welds with single-sided access, the least favourable angle of incidence on any weld fusion face is generally 20° and occurs for the outer 10° section of the fusion face nearest to the scanning surface. However in the case of weld 12 (40 mm thick) the 60° beam at full skip is 30° from normal on the outer 10° section which is approximately 50% of the weld thickness. A similar misorientation of 30° occurs for the MSRV and MSSV welds but since these are only about 25 mm thick there is only about 6 mm of fusion face affected. Corner effects may improve defect detection, especially for the thinner welds, and some support for this is provided by modelling of the MSSV. I judge that detection of smooth planar defects on the least favourable fusion face of weld 12 may be possible via a mode conversion or a corner echo but that will need to be demonstrated during the

inspection design and qualification. This aspect is included in Assessment Finding **AF-UKEPR-SI-55** listed in Section 3.5.4 below.

359 I accept that because of the difficulties associated with these geometries, EDF and AREVA have increased the range of ultrasonic beam angles used on those surfaces which are available for inspection. I also accept that the mathematical modelling studies performed on the MSSV and MSIV welds have provided valuable evidence on the capability of the various angled beams to detect planar defects on the weld fusion faces when access is only available from one side. Consequently, whilst there are features of some of the welds which are likely to cause difficulties for inspection, I judge nevertheless that there is a reasonable prospect that successful inspection qualification could be achieved provided there is attention paid to the local geometries and surface condition as discussed below.

360 The achievement of an adequate surface profile for inspection is very important and this is particularly the case when only single-sided access is available because of the reduced redundancy in the inspections. It is also important to recognise that the profile should be adequate over the weld surface as well as the (forged) component, which again is most important for single-sided inspection. The quality of surface profile achievable is likely to be affected by local component design details as well as the access for surface preparation.

361 EDF and AREVA have provided more detailed evidence in Ref. 69 that the counterbores on the inside of the pipes will not generally cause difficulties for the ultrasonic inspections. However other local geometrical design features (eg variations in component thickness adjacent to welds) may also have a significant effect on the quality of inspection achievable. Because of the importance of adequate local design features as well as surface profile I believe any licensee should ensure that during the design, manufacture and installation of the MSL components there are explicit checks on the detailed geometry near welds.

362 These checks should ensure that the local component geometry (eg any component thickness changes) and the resultant surface profiles near welds (both inside and outside the component) will satisfy the criteria for adequate inspection. I have raised an Assessment Finding **AF-UKEPR-SI-55** to this effect which is given in Section 3.5.4 below.

3.5.3 Assessment Conclusions for Action 3

363 EDF and AREVA have now made a number of important additions to the original inspection proposals made during GDA Step 4 and have also provided additional evidence on inspection capability. The additions include the use of full skip 60° inspection for all welds, partial full skip 70° where only single-sided access is feasible, and inclusion of a specification for surface profile within the equipment specification for MSL components and welds.

364 On the basis of the additional inspection beam angles and the commitment to achievement of adequate surface profiles, I judge that there is now adequate evidence that successful qualification is achievable for inspection of these welds. The theoretical modelling for two of the more difficult welds provides valuable support for the claim that an adequate detection capability could be achieved for the provisional target defect size of about 4 mm.

365 It is important to ensure that the local design of components near welds takes account of the requirements for inspection, and any licensee will need to take account of

Assessment Finding **AF-UKEPR-SI-55** when designing, manufacturing and installing the MSL components.

366 I am satisfied with the additional evidence provided in response to this action which may now be closed.

3.5.4 Assessment Findings for Action 3

367 The following Assessment Finding has been raised:

> ***AF-UKEPR-SI-55:*** *The Licensee shall ensure that during the design, manufacture and installation of all MSL components there are explicit checks on the detailed geometry near* welds *and other regions which require qualified NDT. These checks should ensure that the local component geometry (eg any component thickness changes or tapers) and the resultant surface profiles (both inside and outside the component) are such that an adequate inspection capability is achievable.*
>
> ***Required timescale:*** *Install RPV*

3.6 GDA Issue GI-UKEPR-SI-01 Action 4

368 This action (Annex 3) specifies additional evidence required to demonstrate that repairs in the reactor coolant pump bowl are designed with the inspection requirements in mind and that the manufacturing inspections are likely to be capable of detecting defects significantly smaller than the limiting defects. The geometry of the pump bowl is shown in the figure below.

Figure 5. Reactor Coolant Pump Bowl (from Ref.65).

3.6.1 Deliverables for Action 4

Deliverable No.	Original plan (O) or revised proposal I	Deliverable	Ref.
1	O	UK EPR™ Pump Casing, Test Report (processes, application and summary of results). EFFQM 10/17210 Rev B. AREVA NP. 30 June 2011.	75
2	O	UK EPR™ Technical proposition for the NDT examination of major repair welds of the primary pump casing. PEEM-F 10.2218 Rev B. AREVA NP. 15 Sept 2011.	77
3	R	UK EPR™ Pump Casing. Test Report (processes, application and summary of results). EFFQM 10/17210 Rev C. AREVA NP. 10 October 2011.	76

3.6.1.1 Deliverable 1 (Ref. 75)

369 This test report describes the programme of non-destructive tests performed on a Reactor Coolant Pump (RCP) bowl mock-up using radiographic and ultrasonic techniques to detect implanted defects in large weld repairs. The radiographic procedure was based on that specified by RCC-M. Two ultrasonic procedures were studied; one developed for manufacturing inspection of RCP bowls for Sizewell B, and one based on the principles of an RCC-M ultrasonic procedure for a ferritic component but adapted for use on an austenitic casting.

3.6.1.2 Deliverable 2 (Ref. 77)

370 This report provides an analysis of the NDT results using radiographic and ultrasonic techniques on a representative mock-up of an RCP bowl with weld repairs. It also provides proposals for manufacturing NDT of any large weld repairs of the RCP bowl of the UK EPR™. Revision B is an updated version of the report submitted during GDA Step 4 which includes a review of the current design and manufacturing requirements. It proposes to update the equipment specification so that large bowl repairs will be designed to allow adequate ultrasonic (and radiographic) inspection. The revised procedures will include consideration of achieving favourable angles of incidence for the ultrasonic (UT) and radiographic (RT) inspection techniques on the fusion faces of the repair.

3.6.1.3 Deliverable 3 (Ref. 76)

371 This is a revised version of Deliverable 1 which takes account of ONR comments on the earlier version.

3.6.2 ONR Assessment of Action 4

3.6.2.1 Scope of Assessment Undertaken

372 The assessment included:

- A review of the detailed results from the inspection trials on the mock-up.
- A review of the evidence that, in addition to minimising the risk of any welding defects, the design of excavations for weld repairs will also take account of the need for NDT and particularly the need to ensure that the ultrasonic beams selected can achieve favourable angles of incidence on the fusion faces.

373 Key questions for this assessment are:

1. What is the capability of RT in absolute terms and in relation to UT (whether using the procedure based on RCC-M principles or the procedure developed for Sizewell B RCP bowls)?
2. What is the capability of the RCC-M UT procedure in absolute terms and in relation to that used for Sizewell B RCP bowls?
3. Does the design of the excavations for welded repairs of the RCP bowl take account of the inspection requirements, particularly the desirability of achieving near normal incidence on the weld fusion faces with the UT beams.
4. What is the capability of the volumetric NDT in relation to the limiting defect size. (As discussed in Section 3.3.3 above, a provisional target defect size of 10mm through-wall extent has been adopted based on the current analyses.)

374 My assessment also took into account a contractor review of the capability of RT and UT for repairs to the RCP bowl which had been undertaken during GDA Step 4 (Ref. 78).

375 My initial assessment of Deliverables 1 and 2 (Refs 75 & 77) raised five questions which were sent to EDF and AREVA in TQ-EPR-1464 and subsequently Deliverable 1 was revised (Ref. 76) to take account of the responses.

376 Before completing my assessment I raised TQ-EPR-1519 concerning the expected macrostructure of the RCP castings. I received satisfactory answers to this TQ which did not require any revision to the reports already submitted.

3.6.2.2 General Comments on the Submissions

377 Because of the size of Ref. 75 it was supplied in three parts:

Part 1 of 3. UK EPR™ Pump Casing – Test Report – Processes, application and summary of results.

Part 2 of 3. Ultrasonic method and technique used on Sizewell B by British Energy.

Part 3 of 3. Ultrasonic method and technique according to RCC-M. (Repairs 1,2,4,6, 8), UT phased array on E6 and R6 results for E1 to E8.

3.6.2.3 Technical Assessment

3.6.2.3.1 Scope of volumetric inspection proposed

378 I queried the strategy for the qualified RT and UT inspections of welded repairs and whether they are to be regarded as separate, diverse, inspections. TQ-EPR-1464 (response to Question 5) confirms that the primary qualified inspection is RT and that qualified UT is performed for the outer 25 mm of any repair which is classified as major according to RCC-M.

379 The proposals from EDF and AREVA limit any volumetric NDT to major repairs, which are defined as exceeding 35 mm depth in the thicker sections. However the limiting defect size is estimated to be 20 mm which is significantly smaller than the depth of major repairs. Consequently I believe that the scope of volumetric NDT on repairs should be extended to smaller repairs, to ensure that defects typically half the size of limiting defects will be detected even if the repairs are classified as minor or superficial according to RCC-M.

380 I consider that any welded repairs which are deeper than the target defect size of 10 mm depth should be subjected to volumetric inspection using an appropriate combination of

qualified RT and qualified UT and I have raised Assessment Finding **AF-UKEPR-SI-56** to address this aspect.

3.6.2.3.2 Nature of the defects in the test pieces.

381 My initial review of Ref. 75 established that there were few details of the characteristics of the defects in the test pieces, although lack-of-fusion, solidification cracks and micro-cracking were known to be included. Since knowledge of features such as crack face separation (gape) and roughness are important when assessing RT and UT capability, I asked for further details.

382 The sizes and orientations of repairs E1, E2, E3, E4, E6 and E8 are now provided in Annex 2 of Ref. 76. Although the defects in the mock-up cannot be sectioned, some defect trials were performed before making the mock-up and macrographs of these defects are in Appendix 2 of Ref. 76.

383 The lack-of-fusion defect is between 50 µm and 100 µm gape whilst the solidification crack has significantly greater gape (typically about 250 µm). However I note that the lack-of-fusion defect shown by Booler et al (in Annex 1 of Ref. 81) has a gape of perhaps 400 µm so there remains some uncertainty about the gape of the defects in the mock-up.

3.6.2.3.3 Radiographic capability

384 The radiographic inspections on the mock-up follow RCC-M Vol. 3 MC3000 but include an axial shot plus two at +/-15°. I note that this is more extensive than the proposed manufacturing procedures where only an axial shot is normally performed. A linear accelerator is used to generate the X-rays because of the thickness of the component.

385 In response to TQ-EPR-1464, the weld repair preparation angles are now shown as +/-15°. For a few cases the full range of beam orientations is not feasible for reasons associated with geometry and thickness of material, and such cases are now explained in Ref. 76.

386 In order to assess the RT capability to detect misoriented defects, I performed an analysis of the data in Ref. 75 and the results are given in the table below.

387 There are three cases of 30° misorientation and all involve lack-of-fusion defects which were detected. Of these, two cases have the defects on the far side (favourable for detection) and in one case the defect is on the near side. The Pollitt calculations by Serco (see Figure 6 below) suggest that a gape of >250 µm would be needed to achieve detection when 30° misaligned, even for a defect on the far side. This suggests that either the defects are wider than the example lack-of-fusion defect in Appendix 2 or there are volumetric features associated with them. However TQ-EPR- 1464 response to Question 3 states that there are no volumetric features in the radiographic images of the defects. At a meeting on 20 October 2011, EDF and AREVA said that the defects were still visible at 30° misorientation although the defect indications were broader and typically 4 mm wide.

Summary of Defect Parameters, Orientations of Radiographic Beams Relative to Defects and Results of Detection Trials.

Defect No. and type	Angle with respect to surface	Defect size (mm)	RT shot alignment. (Key given below the table)	Angle between defect and RT beam	Location with respect to source	Detection result
E1 Lack-of-fusion	15°	20x50	D1	0°	Near side	Detected
			D2	30°	Near side	Detected
E2 Solidification crack	0°	15X50	A	0°	Near side	Detected
			D1	15°	Near side	Detected
E3	No defect					
E4 Solidification crack	0°	10X30	D1	15°	Near side	Detected
			A	0°	Near side	Detected
			D2	15°	Near side	Detected
E6 Lack-of-fusion	15°	10x40	D1	0°	Far side	Detected
			A	15°	Far side	Detected
			D2	30°	Far side	Detected
E6 microcracks	0° transverse	20x20x70				Not detected
E8 Lack-of-fusion	15°	15x60	D1	0°	Far side	Detected
			A	15°	Far side	Detected
			D2	30°	Far side	Detected
E8 microcracks	0° transverse	15x15x60				Detected (Visible on all three films)

Key: Shots coded as A are normally perpendicular to the surface whilst shots coded as D1 or D2 are misaligned by +/- 15°.

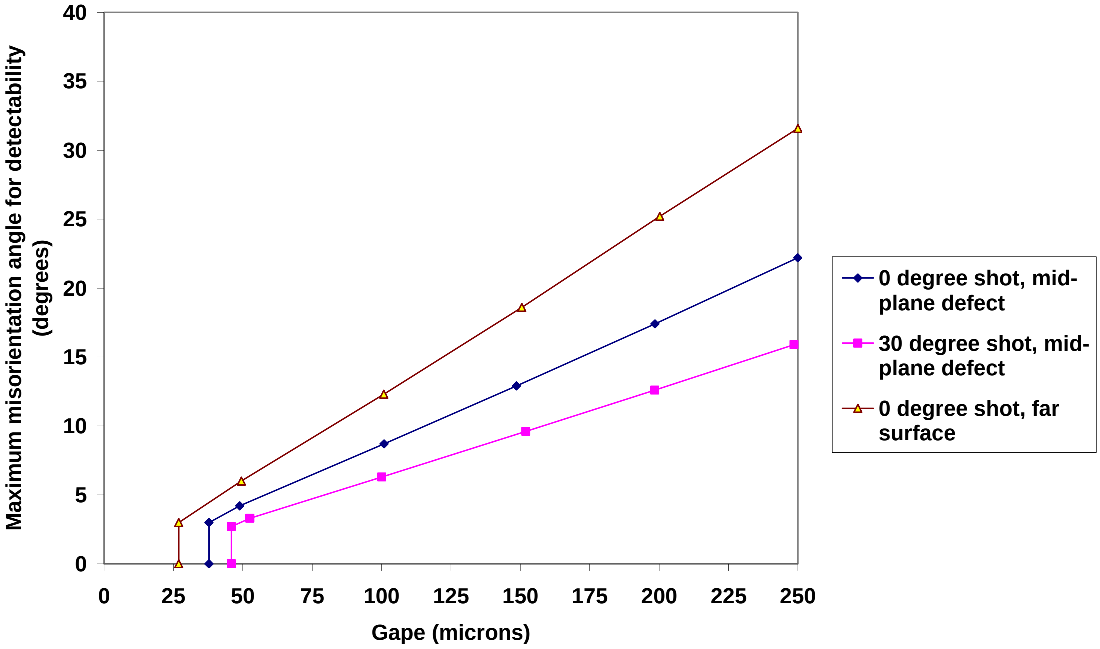

Figure 6. RT Simulation modelling using Pollitt theory (from Ref. 78)

388 I conclude that the RT demonstrated a good capability to detect the planar defects in the mock-up even with shots not aligned with the weld preparation angle. Unfortunately some of the characteristics of the defects which affect their detectability are inevitably very uncertain since the mock-up has not been destructively examined. The good detection rate with RT may be a result of the defects having relatively wide gape.

389 The qualified manufacturing RT is proposed to be carried out using only a single-angled examination, and a radiographic shot along the fusion faces will be used only as a supplementary test in case of uncertainty about an indication. This is justified by EDF and AREVA on the basis of the detection of highly misoriented defects in the test piece. I am prepared to accept this proposal at this stage, but noting the uncertainty which exists about the characteristics of the defects, I would expect the inspection qualification exercise to probe the inspection capability further and have raised an Assessment Finding **AF-UKEPR-SI-57** to include this aspect.

3.6.2.3.4 Ultrasonic capability

390 RCC-M 2007 does not include UT of repairs in austenitic steel so the RCC-M tests are based on requirements for ferritic steels but with probes selected for (coarse-grained) austenitic steel. A wide range of 0° and angled longitudinal wave beams were used: the 0° probe was 2.25MHz and the 45°, 60° and 70° probes were 1, 1.5 and 2 MHz. These probes are similar to those used for the Sizewell B procedure although the latter also included a high angle, creeping wave probe. Both UT procedures limit the examination to 25 mm depth.

391 The UT procedure for Sizewell B provides measurement of through-wall extent as well as defect length, whereas the RCC-M based inspection generally gives lower amplitude signals than the Sizewell B procedure and does not include any measurement of defect through-wall extent. The RCC-M based procedure used defect characterisation defined in standard ISO EN 23279 (Ref. 79). However the time for inspection of the mock-up was almost three times longer in the case of the Sizewell B procedure (14 weeks compared

with 5 weeks). It is also claimed by EDF and AREVA that a large amount of data is collected which is often difficult to analyse but not necessary to sentence the indications.

392 The phased array UT employed a 1.5MHz transducer with beam angles variable between 45° and 75°. This was deployed on a limited area of the mock-up and gave the same results as those obtained using conventional techniques.

393 All defects in the mock-up were detected regardless of whether the Sizewell B or RCC-M based procedures were used, and in each case the sentencing of the defects was the same whichever procedure was used. However this should not be interpreted as implying that the detailed data were the same. Several indications were often detected in each defective region, and more with the Sizewell B procedure, but for each procedure there was always an area of indications which were detectable, recordable and rejectable. The defect length measurements were less precise than with RT.

394 EDF and AREVA propose to use the UT procedure based on RCC-M principles with defect characterisation using standard ISO EN 23279 and including length measurement but no measurement of defect through-wall extent.

395 The RCC-M based procedure is significantly simpler to implement than the SZB UT procedure yet still correctly identified all the planar defects in the mock-up. Consequently, in terms of detection and characterisation capability, the RCC-M based procedure appears adequate. However I judge that it will be important to take a conservative approach in the characterisation and sentencing of defects using the RCC-M based procedure whilst also avoiding an excessive number of volumetric defects being misclassified as planar and leading to unwarranted repairs. I would expect this aspect of the procedure to be investigated as part of inspection qualification and have raised Assessment Finding **AF-UKEPR-SI-57** to include it.

3.6.2.3.5 Design of repairs to take account of inspection.

396 The design of welded repairs in steel castings is specified in RCC-M (S 3413.1), and the design specifies that the sides of an excavation will be 30° +/- 5° whenever technically feasible.

397 In order to take into account the need for NDT, and particularly the detection of lack-of-fusion on the fusion faces by the ultrasonic method, EDF and AREVA propose to add the following requirements:

- The weld preparation angle shall be between 15° and 30°, since with these values a near-specular reflection can be achieved with 60° or 70° refraction angle.
- Excavations shall be made with edges which are sufficiently planar to enable the NDT techniques to be selected and applied appropriately.
- Profile measurement of the excavations shall be achieved before welding. These measurements include the profile of the external shape of the excavation but also the profiles of the internal shapes of the excavation at different locations.

For the UK EPR™ these requirements will be included in the equipment specification for the Reactor Coolant Pump bowl.

398 I judge that these proposals are an adequate means of ensuring that the need for ultrasonic and radiographic inspection are taken into account when designing weld repair profiles.

3.6.2.3.6 Macrostructure of the RCP castings.

399 Research undertaken in connection with ultrasonic inspection of the RCP bowl for Sizewell B identified that the macrostructure of the castings may be either Type A (equi-axed) or Type B (Columnar). The type of macrostructure can be predicted according to the value of the chromium to nickel equivalence ratio. If this ratio is in the range 1.5 to 2.0 then Type B macrostructures result. If the ratio exceeds 2.0 then Type A is more likely – although a mixed Type A/Type B structure may occur for ratios between 2.0 and 2.2. More details are given in Ref. 80.

400 Type B macrostructures are believed to be more problematic for ultrasonic inspection because the distinct anisotropy can severely distort ultrasonic beams. All the pump bowl castings for Sizewell B are reported to have Type A macrostructure (Ref. 81).

401 Since for the UK EPR™ it is only weld repairs (and not the whole surface of the RCP bowl) which are proposed for ultrasonic inspection, it could be argued that the macrostructure of the bowl is of less significance. Nevertheless the bowl macrostructure may affect the signal-to-noise ratio which occurs at the edges of welded repairs, and consequently it would be helpful to know how well the conditions in the mock-up match the conditions which are expected for repair welds in a UK EPR™ pump bowl.

402 In TQ-EPR-1519 I asked EDF and AREVA about the macrostructure in the mock-up and the expected macrostructure for the UK EPR™ pump bowls.

403 For the mock-up, EDF and AREVA have confirmed that the base material was a Type A casting.

404 For future UK EPR™ pump bowls EDF and AREVA have explained that both Type A and Type B macrostructures are possible for castings whose chemical composition lies within the RCC-M M3401 specification for RCP austenitic-ferritic stainless steels, as inferred from using the Suutala and Moisio formulae for the calculation of chromium and nickel equivalents. However, this specification, including the requirement on the ferrite content (12 to 25% as assessed according to the Schaeffler diagram, with 15 to 20% as aimed value), is very likely to promote Type A macrostructure or a mixed Type A/Type B macrostructure.

405 EDF and AREVA also stated that RCP qualification bowls produced for recent UK EPR™ contracts both had chromium to nickel equivalence ratios close to 2.2 which is deemed to promote Type A macrostructure and hence a lower ultrasonic attenuation than would be the case with Type B.

406 I conclude that the RCP bowls of the UK EPR™ are likely to have Type A macrostructure if procured to the same specification and target chemical composition as those for recent EPR™ contracts. I have raised an Assessment Finding to ensure that this feature is considered when specifying target values of composition (see **AF-UKEPR-SI-58** below).

3.6.3 Assessment Conclusions for Action 4

407 For the defects in the mock-up, both RT and UT techniques were able to detect all the planar defects. For near-surface defects there is redundancy in the techniques by using both RT and UT. Consequently there is a reasonable expectation that it will be possible to develop qualified inspection procedures for this application which have adequate capability.

408 To ensure that defects typically half the size of limiting defects will be detected, I consider that any welded repairs which are deeper than the target defect size of 10 mm depth should be subjected to volumetric inspection using an appropriate combination of

qualified RT and qualified UT and I have raised Assessment Finding **AF-UKEPR-SI-56** to address this aspect.

409 The qualified manufacturing RT is proposed to be carried out using only a single-angled examination, and a radiographic shot along the fusion faces will be used only as a supplementary test in case of uncertainty about an indication. Whilst I accept this proposal at this stage, in view of the uncertainty which exists about the characteristics of the defects in the mock-up, I would expect the inspection qualification exercise to probe the inspection capability further.

410 In the case of ultrasonics, the UT procedure derived from RCC-M is simpler to implement than the procedure which was applied during manufacture of Sizewell B but nevertheless detects all the defects in the test piece. Consequently the RCC-M based procedure would seem to be a reasonable basis at this stage in the process but, as in the case of the RT, the capability will be tested more thoroughly when the qualification is performed.

411 The RCP bowls of the UK EPR™ are likely to have Type A macrostructure, which is more favourable for inspection, if procured to the same specification and target chemical composition as those for recent EPR™ contracts. I believe this feature should be considered when specifying target values for the composition.

412 I am satisfied with the additional evidence provided in response to this action which may now be closed.

3.6.4 Assessment Findings for Action 4

413 The following Assessment Findings have been raised:

AF-UKEPR-SI-56: *The Licensee shall ensure that the qualified volumetric inspections of welded repairs on the RCP bowl have the capability to reliably detect defects of the target size (i.e. defects smaller than the calculated limiting defect size by a margin of typically 2). The scope of these qualified inspections should include all repairs down to a size comparable with the target defect size and significantly smaller (typically by a margin of 2) than the limiting defect size.*

Required timescale: *Install RPV*

AF-UKEPR-SI-57: *The Licensee shall ensure that the inspection qualification of the radiographic and ultrasonic procedures for the RCP bowl and potential repairs takes account of the wide variation in the characteristics of potential defects and the need to demonstrate reliable detection and characterisation.*

Required timescale: *Install RPV*

AF-UKEPR-SI-58: *The Licensee shall ensure that when specifying the target values for chemical composition of the RCP pump bowls, the desirability of achieving a Type A macrostructure is taken into account.*

Required timescale: *Install RPV*

3.7 GDA Issue GI-UKEPR-SI-01 Action 5

414 This action (Annex 3) specifies additional evidence required to support the manufacturing inspections of the reactor coolant pump flywheel, and to demonstrate that the principles of the proposed in-service inspection are justified.

3.7.1 Deliverables for Action 5

Deliverable No.	Original plan (O) or revised proposal (R)	Deliverable	Ref.
1	O	Reactor Coolant Pump of EPR: Flywheel mechanical and fracture mechanics analysis. PEER-F 10.1674 Rev B. AREVA NP. 19 August 2011. TRIM: 2011/439051.	36
2	O	Non-Destructive Tests Performed on the Reactor Coolant Pump Flywheel during Manufacturing. PEEO-F 10.0715 Rev B. AREVA NP. 25 Aug 2011 TRIM: 2011/449746.	*82*
3	O	Principles for the RCP Flywheel In-Service Inspection. ECEMA111847 Rev A. EDF SA. 25 August 2011. TRIM: 2011/449744.	*85*
4	R	Reactor Coolant Pump of EPR: Flywheel mechanical and fracture mechanics analysis. PEER-F 10.1674 Rev C. AREVA NP. 30 November 2011. TRIM: 2011/631202.	*84*
5	R	Non-Destructive Tests Performed on the Reactor Coolant Pump Flywheel during Manufacturing. PEEO-F 10.0715 Rev C. AREVA NP. 5 December 2011. TRIM: 2011/631183.	*83*

3.7.1.1 Deliverable 1 (Ref. 36)

415 This report has been updated to provide further justification for the overspeed value considered in the fracture mechanics analysis and an estimation of the lifetime fatigue crack growth for a defect occurring in the flywheel.

3.7.1.2 Deliverable 2 (Ref. 82)

416 This report has been updated to provide further information on the manufacturing NDT applied to the RCP flywheel and notably the ability of the NDT inspections to adequately detect defects of structural concern. The report also explains why NDT of certain RCP flywheel surfaces is considered not to be required.

3.7.1.3 Deliverable 3 (Ref. 85)

417 This report describes the principles of ISI applied to the RCP flywheel based on French practice and compares this approach with the requirements of the US NRC Regulatory Guide 1.14.

3.7.1.4 Deliverable 4 (Ref. 84)

418 Following questions raised in TQ-EPR-1477, Deliverable 1 was revised to include a fuller explanation of the LOCA transient which leads to the maximum overspeed value. The revised report also uses a relationship for crack propagation (Paris Law) which is specific to the flywheel material.

3.7.1.5 Deliverable 5 (Ref. 83)

419 This is a slightly revised version of Deliverable 2 which removes the reference to an RCC-M (Ref. 16) modification sheet (FM1061) since this is not part of the GDA design basis for the UK EPR™.

3.7.2 ONR Assessment of Action 5

3.7.2.1 Scope of Assessment Undertaken

420 The assessment included:

- Justification of the maximum overspeed used to derive the limiting defect size in the fracture mechanics analysis and a review the limiting defect size and potential for in-service growth.
- Evidence that the manufacturing inspections adequately cover all plausible defects of concern. This includes evidence that ultrasonic inspection from the outer curved surface of the plates is not required, that the inspection holes do not require inspection during manufacture, and that the ultrasonic (UT) and penetrant (PT) inspections have the required capability.
- Justification of any ISI proposed in comparison with that required by US NRC Reg. Guide 1.14.

3.7.2.2 General Comments on the Submissions

421 Ref. 82 provides a drawing of the RCP flywheel which is constructed of two plates bolted together. The plates are made from nickel-chromium-molybdenum alloy steel (20 NCD 14-7) in compliance with Part Procurement Specification M2321 of RCC-M (Ref. 16).

3.7.2.3 Technical Assessment

3.7.2.3.1 Updated Fracture Mechanics Analysis of the RCP flywheel

422 The assessment of the justification of the maximum overspeed used to derive the limiting defect size in the fracture mechanics analysis and a review of the limiting defect size and potential for in-service growth are reported in Section 3.3.2.7 against the fracture analysis reports requiring more detailed assessment (Action 1 of this GDA Issue). This covers the assessment work undertaken on Deliverables 1 and 4.

423 The assessment concludes that the 125% overspeed used to calculate the limiting defect size has been justified. This leads to a through thickness radial limiting defect size of 450 mm, which shows that the flywheel should have a good tolerance to defects. The potential for in-service growth of a defect is limited as the fatigue crack growth calculation now included in the fracture mechanics analysis work shows that the lifetime fatigue crack growth of defects not detected during manufacture will be small.

3.7.2.3.2 Non-Destructive Tests Performed on the RCP flywheel during Manufacturing

424 The NDT performed on the flywheel during manufacture is generally as specified in RCC-M (Ref. 16) where MC 7100, MC 4000 And MC 2310 specify the visual, penetrant and ultrasonic techniques respectively.

425 Penetrant inspection is performed at an intermediate machining stage and includes the centre bore, the disc perimeter and the surface of the plates adjacent to the circle of radius 900 mm from the axis.

426 The ultrasonic testing (UT) is performed after any heat treatment for mechanical properties and preferably after the last machining at the forging mill.

427 The UT procedures follow RCC-M MC 2310, but Ref. 83 notes that the European Standard for UT of forgings, EN 10228-3 (Ref. 87), will be used in preference to the French forging standard specified in RCC-M 2007. In fact later versions of RCC-M have this change of standard incorporated via a code modification, MC1061.

428 The European Standard for UT of forgings (EN 10228-3) (Ref. 87) provides a choice of four quality classes with Class 4 being the most stringent. The RCP plates are specified as Quality Class 3 which sets a UT recording level of >3 mm Flat Bottomed Hole (FBH) and an acceptance level of <5 mm FBH. Any reduction in back wall echo must be </= 0.5, and any grouped indications must be </= 3 mm flat bottomed hole (FBH).

429 I queried the basis on which quality Class 3 is assigned in RCC-M M2321 (TQ-EPR-1528). EDF and AREVA explained that the selection of quality Class 3 of EN 10228-3 was made in accordance with RCC-M requirements for all forgings manufactured with M1 requirements (for flywheels this is specified in RCC-M Part Procurement Specification 2321 §6.5). Quality Class 4 has the most stringent criteria (eg for extended or grouped defects the acceptance criterion is 2 mm FBH for Class 4 compared with 3 mm FBH for Class 3 whereas for isolated point type defects the values are 3 mm for Type 4 but 5 mm for Type 3.

430 Because I believe it is difficult to distinguish between extended or isolated defects of such size, I consider that it would be prudent to adopt a conservative approach to classification and defect acceptance and adopt the extended (ie planar) defect acceptance level unless there is very solid evidence that an indication is not planar.

431 The RCP flywheel is a Type 2 product (as defined in EN 10228-3) which is a flattened disc, plate or flywheel. For Type 2 products, this standard requires inspection with a 0° beam from the cylindrical surfaces as well as with a 0° beam from the flat surfaces.

432 I accept that with the large diameter in relation to thickness, UT from the cylindrical surfaces is of limited capability and value. On the other hand, the geometry is more favourable for angled beam inspections from the flat surfaces to detect radially oriented defects. This could be achieved with shear wave, pulse-echo or tandem techniques.

433 Whilst accepting that the plates are most likely to have defects in the transverse plane (ie parallel to the plate surfaces), there are potential benefits from checking that radial defects are not present:

- this is the plane of maximum stress;
- in-service Inspection (ISI) is expected to check for defects in this plane, and start-of-life indications – which could be confused with in-service defects – should be avoided; and
- the bores of the holes drilled in the plates (for UT ISI or for the bolts) are not inspected with PT because of the small diameter. UT of the plate before drilling the holes could demonstrate the absence of any transverse defects in these regions.

434 EN 10228-3 (Ref. 87) specifies angled beam inspections from the cylindrical surfaces of ring shaped forgings. Also, I would expect critical forgings (eg for turbine rotors) to be inspected for radially oriented defects using angled shear wave beams. The flywheel is a HIC and hence inspection from more than one direction should be considered.

435 Although there is no angled shear wave inspection of the flywheel plates, 0° inspection is specified (Refs 82 and 83) to be performed from both sides of each plate, which exceeds the Code requirements. This addition is worthwhile because it helps to overcome the limitations of the dead zone just beneath the probes. The response to TQ-EPR-1528 also confirmed that the UT procedure will include a check on whether defects are recorded at the same through-wall position from opposite faces, and have no measurable through-wall extent. However the two-sided 0° inspections do not compensate for the lack of any inspection for defects in the radial-axial planes of maximum stress.

436 It is claimed that large radial defects (approaching 175 mm radial extension) are inconceivable in plate (Response to TQ-EPR-1477 Question 4). This claim seems reasonable, but implicitly there is an assumption that there is no need to inspect for any defects oriented radially. This assumption is more difficult to accept because small radial defects are not necessarily inconceivable and the component should enter service as free of defects as practicable. In addition, defects in the radial-axial plane are subjected to the highest operating stresses.

437 The claims made about reliable detection of a 175 mm defect apply to a defect in the plane of the plates and not to a radially oriented defect which would not be reliably detected with a 0° beam.

438 I suggested to EDF and AREVA in TQ-EPR-1528 that the potential value of inspecting from the flat surfaces of the plates should be considered for example using angled shear wave pulse-echo or tandem techniques. Such inspection would improve the capability of the manufacturing inspection and help to show that the component enters service free of defects, and to ensure there are no indications near the keyways of the inspection holes which could cause interpretation difficulties for the ISI.

439 I also asked EDF and AREVA for additional evidence to support the claim that the only plausible defects will occur in the plane of the plates (TQ-EPR-1528). Details of the manufacturing process for the plates were provided, and these support the claim that through-wall defects are highly unlikely (rather than unlikely or inconceivable).

440 I agree that it is unlikely that any manufacturing defects would be normal to the plate surface. The steel ingot is made by electric basic furnace with vacuum degassing and then bottom poured: these are good practices which minimise solidification segregation and solidification porosity. The ingot is forged and rolled with a minimum reduction factor of x 3 which would be likely to ‘heal’ microporosity. If there were to be any residual manufacturing defects arising from solidification segregation then these would be predisposed to the plane of the plate following hot working.

441 Another potential defect type is hydrogen-induced cracking: such defects are also likely to have a preferential alignment along the rolling or forging direction and hence likely to be favourably oriented for detection by the 0° ultrasonic beams proposed for the flywheel inspection. Nevertheless it is essential that the sensitivity of the recording and acceptance levels is adequate to detect such defects even if their morphology is more complex than idealised, planar defects parallel to the test surfaces.

442 Consequently, bearing in mind the HIC status of the flywheel, and noting that neither the PT nor UT are to be subjected to inspection qualification, I believe that any Licensee should pay particular attention to the assessments of capability produced for the inspection procedures as required by **AF-UKEPR-SI-07**. In particular, the sensitivity of the UT reporting and acceptance levels should be checked for consistency with the capability which is required and claimed.

443 Consequently I have raised an Assessment Finding **(AF-UKEPR-SI-59)** requiring the Licensee to demonstrate that the assessments of capability of the flywheel NDT procedures (PT and UT) take account of the HIC nature of the component and the full range of defect types which might occur and that the essential inspection parameters will provide adequate capability to detect these defects.

3.7.2.3.3 Principles for RCP Flywheel In-Service Inspection.

444 Although details of in-service inspection (ISI) programmes are outside the scope of GDA, I have nevertheless investigated whether access for ISI is likely to be adequate and this requires some knowledge of the types of inspection which might be necessary.

445 The principles for establishing the In-service inspection (ISI) of the RCP flywheel are set down in Ref. 85, which also details the positive operational experience with these components.

446 There has been a trend internationally to reduce the extent and frequency of ultrasonic ISI of PWR RCP flywheels. For example, the interval for ultrasonic ISI required by US NRC Regulatory Guide 1.14 (Ref. 86) has been increased from three to twelve years because of the favourable operational experience and the absence of any in-service defect growth being detected.

447 The details of the ultrasonic ISI for the UK EPR™ have not yet been specified, but they are likely to be similar to the inspections currently performed on operating reactors in France. These inspections in France are not qualified because the inspections do not concern a pressure boundary and hence inspection qualification is not a regulatory requirement.

448 In common with earlier PWR RCP designs, the EPR™ RCP flywheel includes six axial holes which facilitate ultrasonic ISI of the most highly stressed regions - the bore and keyways. I note that for the EPR™ at Olkiluoto 3 a fully automated phased array ultrasonic system is being qualified for ISI of RCP flywheels which has a demanding detection target size of 4 mm (Ref. 88). Consequently, should it be necessary to perform ultrasonic ISI on the flywheel of the UK EPR™, then it is likely that adequate access will be feasible via these holes.

449 Once the ISI objectives and target defect characteristics and sizes have been defined, I believe that any licensee will need to justify the capability of the ISI techniques proposed for the UK EPR™ and consider whether or not formal inspection qualification is required. I have raised an Assessment Finding to this effect **(AF-UKEPR-SI-60**.)

3.7.3 Assessment Conclusions for Action 5

450 The scope of ultrasonic inspection proposed during manufacture of the flywheel plates is more limited than would normally be required for a forging of this geometry and the reduced scope is justified on the basis that significant defects are only plausible in the plane of the plates. Whilst I accept this, on the basis of the information provided, I consider that the capability of the volumetric and surface inspections during manufacture should be checked by any Licensee especially as this is a HIC component. This check should demonstrate that the procedures take account of the full range of defect types which might occur and that the essential inspection parameters will provide adequate capability to detect these defects.

451 When the details of the in-service inspection requirements have been specified, the Licensee will need to produce a rigorous justification of the ISI capability and consider whether or not formal inspection qualification is required.

452 I am satisfied with the additional evidence provided in response to this action which may now be closed.

3.7.4 Assessment Findings for Action 5

453 The following Assessment Findings have been raised:

> ***AF-UKEPR-SI-59:*** *The Licensee shall demonstrate that the assessments of capability of the manufacturing NDT procedures for the flywheel (PT and UT) take account of the HIC nature of the component and the full range of defect types which might occur and that the inspections will provide adequate capability to detect these defects.*

Required timescale: *Install RPV*

AF-UKEPR-SI-60: *The Licensee shall ensure that, once the details of the in-service inspections of the flywheel have been specified, the inspection capability is justified and the need for inspection qualification is considered.*

Required timescale: *Install RPV*

3.8 GDA Issue GI-UKEPR-SI-01 Action 6

454 During GDA Step 4, EDF and AREVA selected the pressuriser upper shell to upper head weld for a prototype application of NDT inspection qualification. The purpose of this activity was to outline the approach which could subsequently be followed by a Licensee wishing to develop fully qualified inspection procedures. The prototype application was intended to demonstrate the main elements of the qualification process and included production of several reports to provide:

- The justification for selection of the weld used for the prototype application.
- The inspection specification which summaries what the inspection must achieve.
- The qualification proposal which outlines the inspection qualification process.
- The ultrasonic inspection procedures for the prototype application.
- An outline technical justification of the proposed techniques based on existing evidence.

(As discussed in Section 3.3.3 above, a provisional target defect size of 10mm through-wall extent has been adopted based on the current analyses.)

455 As discussed in the GDA step 4 structural integrity report (Ref. 6, Section 4.2.4.6), the main elements of the inspection qualification process were adequately demonstrated by the prototype application. However I identified certain gaps in the evidence which needed to be addressed as part of GDA Issue **GI-UKEPR-SI-01**. I also identified other evidence which would need to be taken forward as Assessment Findings by a future Licensee.

456 Action 6 (Annex 3) specifies the additional evidence required to support the outline technical justification of the prototype application. In particular it requires evidence that when a full inspection qualification is undertaken by a future Licensee:

- The defects used in test blocks will provide a sufficiently challenging test of the inspection procedure.
- The effects of the austenitic cladding on inspection capability will be adequately taken into account.
- The surface profile variations of the component are quantified and justified.
- The surface profile variations will be adequately measured and controlled.
- The flow charts used for defect characterisation by analysis of the ultrasonic data are able to provide the required capability.

3.8.1 Deliverables for Action 6

Deliverable No.	Original plan (O) or revised proposal I	Deliverable	Ref.
1	O	Technical Justification for UT Examination of Prototype Application. PEEM-F 10.2217 Rev B. AREVA NP. 21 October 2011.	89

3.8.1.1 Deliverable 1 (Ref. 89)

457 The Resolution Plan for Action 6 (Ref. 7) includes one deliverable which is an update of the outline technical justification submitted during GDA Step 4. The update of this report discusses the principles for selection of worst case defects for incorporation in test pieces, treatment of the effects of cladding on inspection, and quantification and control of surface profile variations. The report also describes the principles for use of the flowchart for defect characterisation and the capability which can be expected.

3.8.2 ONR Assessment of Action 6

3.8.2.1 Scope of Assessment Undertaken

458 The assessment included a review of:

- Whether the defects proposed in the test piece will take into account the 'worst case defects' and be sufficient to test the weaknesses identified in the inspection procedure.
- How the effects of the cladding (e.g. anisotropy, uneven interface with parent material) on the inspection capability will be taken into account.
- The quantification of the maximum surface profile variations (error of form) on the surfaces of the weld and cladding and justification of its acceptability.
- How surface profile variations (error of form) are controlled and checked.
- The capability likely to be achieved using the flow charts for defect characterisation.

3.8.2.2 General Comments on the Submissions

459 Towards the end of GDA Step 4, EDF and AREVA provided an earlier version (Revision A) of Ref. 89 and Revision B has been updated to provide the additional evidence required by GDA Issue SI-01 Action 6. The ultrasonic procedures to which this technical justification relates are Ref. 90 for the pulse-echo inspection and Ref. 92 for the tandem inspection and I have reviewed these procedures to check they are consistent with the outline technical justification.

3.8.2.3 Technical Assessment

3.8.2.3.1 Selection of defects for test pieces used for practical trials

460 When considering the types of defects proposed for test pieces, I wanted to establish whether they would take account of those defects which are most difficult to detect (worst case defects) and whether they would be sufficient to test the weaknesses which might have been identified in the inspection procedure.

461 The outline technical justification (Ref. 89) provides a tabulation of the key parameters of the component, the inspection techniques and the postulated defects which are likely to

have an important influence on the inspection capability. For example, the geometry of the component surface and of the weld preparation, the orientation and roughness of defects (including any tilt or skew) and the presence of austenitic cladding are all discussed. On the basis of the wide range of influential parameters which are considered in Ref. 89, I judge that the proposed approach will enable the worst case defects to be identified and hence to influence the selection of defects for any test pieces.

462 Ref. 89 proposes an outline design for a test piece which could be used for open trials to support the technical justification. The defects proposed for this test piece are representative of all the defect types defined in the inspection specification for the qualification which includes both rough and smooth defects. The defects would be located at depths which are predicted to be difficult for the inspection technique and at appropriate positions in the weld or heat-affected zone. For example, a number of defects are proposed to be located close to the inner surface of the weld where the effects of the austenitic cladding are likely to be more pronounced.

463 I judge that the principles for selection of test block defects which are outlined in Ref. 89 are adequate to ensure that any weaknesses identified in the inspection procedure are investigated practically.

464 Ref. 89 also proposes to use mathematical modelling to estimate the effects of many of the influential parameters, and to support these predicted results by practical trials on test pieces. Where defects are likely to have appreciable tilt or skew, as in the case of hot cracks in weld metal, the report proposes to introduce misoriented defects in the test piece to supplement the predictions from mathematical modelling. I support this approach, particularly for defects which may be ultrasonically rough, because the mathematical models are less developed for these than for smooth defects.

465 I consider that the proposal to use mathematical modelling in combination with practical trials is fully consistent with the ENIQ methodology (Ref. 99). By examining any potential weaknesses in the inspection procedure, this approach has the potential to provide a robust justification for the capability claimed.

3.8.2.3.2 The effects of austenitic cladding

466 The austenitic cladding deposited by welding on the inside of the pressuriser affects the ultrasonic capability in several ways. The cladding generally has large grains with a preferential alignment normal to the interface with the ferritic parent material. The larger grains cause increased ultrasonic scattering and attenuation, whilst the alignment of the grains results in anisotropic properties which can distort the ultrasonic beams. The effects are likely to vary depending on the welding technique used to apply the cladding as well as the thickness.

467 Ref. 89 recognises that the presence of austenitic cladding is an influential parameter, and that it is particularly important for defects which are located near the cladding (when inspecting from the outside surface). Such defects are often detected in pulse-echo using a corner reflection involving the back wall, and the cladding is likely to reduce the amplitude of this signal as well as increase the background noise level.

468 A combination of clad and unclad test pieces, which are representative of the type of cladding on the component, is proposed to assess the effects of the cladding on inspection sensitivity and signal-to-noise ratio. Mathematical modelling is also proposed to support these studies if necessary, and I support this combination since the use of experimental measurements and theoretical predictions together is likely to be more reliable than the use of either approach in isolation. This approach is also consistent with the ENIQ methodology (Ref. 99).

469 Ref. 89 proposes to calibrate the ultrasonic transducers on a representative clad reference block in the case of pulse-echo techniques, and directly on the component for the tandem technique by taking account of the V-path reflection from the back wall. Such measurements integrate the losses caused by the ultrasonic beam passing through the large and anisotropic grains of the cladding with those associated with transmission through the uneven interface between the cladding and the ferritic base material. I judge that these are appropriate ways of compensating for the average signal loss associated with the cladding. The V-path measurement on the component may also be compared with the signal loss on the clad test piece and hence provide a check on whether the test piece cladding is representative.

470 I consider that the proposal to use a combination of practical trials, mathematical modelling and calibration on clad test pieces or on the clad component should be an adequate basis on which to demonstrate that the effects of the cladding on the pulse-echo and tandem tests are acceptable.

471 When a future Licensee wishes to develop a qualified ultrasonic inspection for weld in a clad component and the manufacturing techniques have been fully defined, I would expect the full technical justification to address more specific parameters of the cladding. For example, one influential parameter which is not discussed in Ref. 89 is the welding technique used to deposit the cladding. Different cladding techniques can give rise to differing grain structures and interfaces with the ferritic parent forging; these in turn affect the ultrasonic beams in different ways. Often automated submerged arc strip cladding is used where practicable on large areas whereas manual welding may be used for smaller regions especially if the geometry is complex. Since the weld root region is clad after welding whereas the majority of the parent forging surface is clad before welding, there may be a mixture of cladding types associated with welds, and ultrasonic measurements made on the parent forging may not be representative of the region near the welds. There are potentially other details of the cladding process which affect the ultrasonic inspection capability, and consequently I would expect a Licensee to consider the parameters of the cladding for each weld and provide evidence that any potential adverse effects are acceptable. I have created Assessment Finding **AF-UKEPR-SI-61** to address this topic.

3.8.2.3.3 Quantification and control of surface profile

472 A reliable ultrasonic inspection is dependent on having a satisfactory test surface on the component and both the fine scale roughness as well as the variations in surface profile (also known as error of form) need to be considered. During GDA Step 4 I was satisfied that the fine scale roughness was adequately specified with an Ra value <6.3µm. However, although the test surfaces were described as flush, the error of form was not generally specified and I considered this to be an important omission.

473 Ref. 89 has now clarified the surface profile specification for those surfaces on which ultrasonic transducers need to be scanned. A flat surface is obtained by controlled grinding and the maximum gap between the probe and the scanning surface is now specified to be <0.5 mm at all locations as measured with a real probe or a template. Ref. 89 also confirms that this requirement will be incorporated in the ultrasonic procedures. This error of form complies with EN ISO Standard 17640:2010 (Ref. 54) and I judge that it is adequate.

474 Another aspect to consider is the quality of the internal clad surface of the component. This surface affects the reflection of ultrasound from the back wall when testing in full skip with pulse-echo techniques, or when using the tandem technique or making V-path attenuation measurements.

475 The internal cladding surface is made flush with a belt grinding machine, and the fine scale roughness, Ra, is <6.3 µm. I judge this level of roughness to be satisfactory since it is unlikely to have a significant effect on either pulse-echo or V-path signals. However, because of the nature of the cladding process, there are often ripples of grooves between adjacent cladding beads or strips which may be difficult to remove completely.

476 Ref. 89 confirms that visual examination will be performed to verify that there are no grooves or ripple on the ground surface of the cladding and I consider this check to provide a valuable baseline for the quality of the cladding surface. EN ISO Standard 17640:2010 (Ref. 54) specifies that surfaces from which sound is reflected shall allow undisturbed coupling and reflection, but there is no quantification of how this is to be achieved.

477 In my opinion the specification of ‘no grooves or ripple’ is not a completely satisfactory description of the cladding surface since this parameter is not quantified and the possibility remains that there could be some error of form on the cladding. Since the detection of defects close to the inner surface (using angled shear wave beams and the corner effect) is likely to be influenced by the error of form of the cladding surface, I believe that a more quantified specification may be needed. The tandem shear wave technique will also be affected by cladding error of form. I believe that a future Licensee should consider refining the specification for the cladding profile as part of the component-specific review of the effects of cladding which are required by Assessment Finding **AF-UKEPR-SI-61**.

3.8.2.3.4 Capability of the flow chart for defect characterisation.

478 Ref. 89 specifies in Section 3.5.3 that the flow chart of EN ISO 23279:2010 (Ref. 79) shall be used for the classification of planar or non-planar defects and this flow chart is specified by the pulse-echo ultrasonic procedure (Ref. 90). During inspection qualification, the suitability of the flow chart is to be demonstrated on a mock-up and the training and qualification of personnel will include the ability to use the flow chart properly.

479 The flow chart is claimed to have a strong pedigree because the principles of the recent EN ISO Standard 23279 are derived from earlier national standards which have been supported by experimental trials. EN ISO 23279:2010 provides well-established examples of the ultrasonic echodynamic patterns generated by various types of defect and explains how these patterns may be used for defect classification.

480 I agree that EN ISO 23279:2010 is an appropriate Standard on which to base the defect classification and the key principles from this Standard are shown below:

> “Classification of indications as planar or non-planar is based on several parameters:
>
> a) welding techniques;
>
> b) geometrical position of the indication;
>
> c) maximum echo amplitude;
>
> d) directional reflectivity;
>
> e) echostatic pattern (i.e. A-scan);
>
> f) echodynamic pattern.
>
> The process of classification involves examining each of the parameters against all the others in order to arrive at an accurate conclusion.

> For guidance, Figure A.1 gives the classification of internal weld indications suitable for general applications.
>
> Figure A.1 should be applied in conjunction with the two first parameters listed above and not taken in isolation."

481 The Standard makes it clear that the process of classification should involve examining all of the six parameters together to arrive at an accurate conclusion, and the flow chart (Figure A.1 in the Standard) is provided as guidance for general applications. Consequently I felt it necessary to explore with EDF and AREVA how they proposed to avoid the risk of using the flow chart outside its validity limits.

482 An example of such a risk was mentioned in the technical support contractor (TSC) review I obtained during GDA Step 4 (Ref. 91) which points out an important restriction on the range of validity of the flow chart. Discrimination based on amplitude differences as a function of incident angle is not reliable unless at least one of the probes generates a strong (near-specular) reflection. As an example, Stage 3 of the flow chart is likely to lead to erroneous results for vertical planar defects if the only data available is from the pulse-echo beams which are typically 20° or more from normal incidence on such defects. One possible way of improving the reliability of the classification would be to combine the information from the pulse-echo and tandem inspections.

483 Because of such potential limitations to the generic applicability of the flowchart, particularly when none of the ultrasonic beams are close to normal incidence on a planar defect, I asked EDF and AREVA in TQ-EPR-1524 to clarify how the results of the pulse-echo and tandem inspections would be combined.

484 EDF and AREVA explained that although the two inspections are analysed separately, they adopt a conservative approach to the classification of any indication. If either inspection method, or indeed any characterisation technique defined in the flowchart, indicates that an indication may be planar then that is the diagnosis reported. This approach should minimise the risk of wrongly classifying a planar defect as volumetric and I consider it to be satisfactory.

3.8.3 Assessment Conclusions for Action 6

485 I judge that the approach outlined in Ref. 89 will enable the worst case defects to be identified and that the principles for selection of test block defects are adequate to investigate any potential weaknesses identified in the inspection procedure.

486 I believe that the proposal to use a combination of practical trials, mathematical modelling and calibration on clad test pieces or on the clad component will be adequate to demonstrate that the effects of the cladding on the pulse-echo and tandem tests are acceptable.

487 The proposal for specification and control of the error of form on the external (ferritic) scanning surface complies with EN ISO Standard 17640:2010 and I judge this to be adequate.

488 However, in view of the component-specific variations in cladding which may occur, I would expect a Licensee to review the parameters of the cladding for each weld (eg the technique for applying the cladding) and provide evidence that any potential adverse effects are acceptable. This component-specific review should also consider refining the specification for the cladding surface profile. I have created Assessment Finding **AF-UKEPR-SI-61** to address this topic.

489 The conservative treatment proposed for analysis of the pulse-echo and tandem signals using the flow chart in the ultrasonic procedure should minimise the risk of wrongly classifying a planar defect as volumetric and I consider it to be acceptable.

490 I judge that EDF and AREVA have now clarified how the technical issues raised by this GDA Issue Action will be addressed when a full technical justification is prepared as part of the qualification programme during the site specific phase. Consequently I am content for this action to be closed.

3.8.4 Assessment Findings for Action 6

491 I have raised one Assessment Finding as follows:

> ***AF-UKEPR-SI-61:*** *The Licensee shall demonstrate that the parameters of the austenitic cladding applied to each HIC component, especially near welds, are adequately controlled and understood so that any potential adverse effects on the inspection capability are tolerable.*
>
> ***Required timescale:*** *Install RPV*

3.9 GDA Issue GI-UKEPR-SI-01 Action 7

492 This action (Annex 3) requires additional evidence that the design and accessibility of all the HIC pipework welds allows adequate in-service inspections to be performed.

3.9.1 Deliverables for Action 7

Deliverable No.	Original plan (O) or revised proposal I	Deliverable	Ref.
1	O	UK EPR™ Main Coolant Lines Design Basis Report. PEER-F DC 60A. AREVA NP. 8 September 2011. TRIM: 2011/469212.	53
2	O	UK EPR™ Ultrasonic examination of MCL homogeneous and dissimilar metal welds. PEEM-F 11.0505 Rev. B. 7 September 2011. TRIM: 2011/469213.	51
3	R	UK EPR™ Ultrasonic examination of MCL homogeneous and dissimilar metal welds. PEEM-F 11.0505 Rev C. 1 March 2012. TRIM:	52
4	O	UK EPR™ Ultrasonic examination of MSL girth welds. PEEM-F 11.0959 Rev A. AREVA NP. 26 July 2011.	68
5	R	UK EPR™ Ultrasonic examination of MSL girth welds. PEEM-F 11.0959 Rev B. 26 March 2012.	69

3.9.1.1 Deliverable 1 (Ref. 53)

493 This report describes the basic design of the UK EPR™ primary circuit and particularly the homogeneous welds of the MCL and the local design features which may impact UT manufacturing inspections and PSI/ISI.

3.9.1.2 Deliverable 2 (Ref. 51)

494 This report covers ultrasonic examination of MCL homogeneous and dissimilar metal welds and examines the access and UT capability for PSI/ISI as well as for manufacturing inspections. The report distinguishes between weld access for

manufacturing NDT which can be performed from both the outer and inner pipe surfaces and PSI/ISI inspections which are performed from the outer pipe surface alone. Two alternative UT techniques are proposed for ISI of the homogeneous MCL welds.

3.9.1.3 Deliverable 3 (Ref. 52)

495 Deliverable 2 has been updated to take account of the proposed design changes and to provide additional evidence of the capability of the revised UT techniques to detect defects of structural concern in the welds including near vertical defects parallel to the fusion faces. Further details are also provided on the weld overlay which is applied to compensate for contraction of the joint during welding and its impact on UT inspection.

3.9.1.4 Deliverable 4 (Ref. 68)

496 This report explains that, for the UK EPR™, the access for ultrasonic ISI of MSL circumferential welds will be based on the analysis of accessibility performed for Flamanville 3 (FA3). This report describes the access and capability of the UT techniques proposed for the MSL manufacturing weld inspections and PSI/ISI to demonstrate that near specular reflection can be achieved across the height of all welds to detect defects of structural concern.

3.9.1.5 Deliverable 5 (Ref. 69)

497 This revised version of Deliverable 4 takes account of responses to TQ-EPR-1516 and proposes additional ultrasonic beam angles to increase the reliability of detection of defects of concern.

3.9.2 ONR Assessment of Action 7

3.9.2.1 Scope of Assessment Undertaken

498 The assessment included:

- A systematic review of the locations proposed for ISI to confirm that, as well as being physically accessible, the design of all the HIC pipework welds facilitates inspections likely to have the required capability and that there are no undue restrictions from any local design features such as counterbores or tapered surfaces.

3.9.2.2 Technical Assessment

499 Because most of the difficulties associated with inspection of the MCL and MSL welds relate to local design features of the components rather than physical access per se, I combined my assessment of Action 7 with that of Action 2 for the MCL welds and with that of Action 3 for the MSL welds. Consequently the technical assessment of these aspects is included within the relevant sections for Actions 2 and 3 above.

3.9.3 Assessment Conclusions for Action 7

500 For the MCL welds, I have extracted the following conclusions from those listed under Action 2 above because they are also relevant to Action 7:

- The redesign of the cross-over leg provides a significant improvement in inspection capability. There are now straight sections which allow better access for UT as well as facilitating an improved surface profile.
- Increasing the counterbore length from 25 to 100 mm should improve reliability of the pulse-echo inspections and particularly that of the self-tandem technique.

- For the homogeneous welds there will be no UT inspections from the bore either during manufacture or PSI/ISI which will avoid the problems of scanning over counterbores.
- I accept that there are techniques proposed for PSI/ISI which have a realistic prospect of being developed and successfully qualified for this application.

501 As an overall conclusion I believe that the proposals form a well integrated package of improvements and should overcome the main difficulties which caused SI-01 Action 7 to be raised.

502 For the MSL welds, I have extracted the following conclusions from those listed under Action 3 above because they are also relevant to Action 7.

- EDF and AREVA have now introduced a number of important additions to the original inspection proposals made during GDA Step 4 and have also provided additional evidence on inspection capability. The additions include the use of full skip 60^0 inspection for all welds, partial full skip 70° where only single-sided access is feasible, and inclusion of a specification for surface profile within the equipment specification for MSL components and welds.
- On the basis of the additional inspection beam angles and the commitment to achievement of adequate surface profiles, I judge that there is now a reasonable likelihood of achieving successful qualification for inspection of these welds. The theoretical modelling for two of the more difficult welds provides valuable support for the claim that an adequate detection capability could be achieved.

503 Any licensee will need to take account of the assessment findings mentioned below when designing, manufacturing and installing the MCL and MSL components, and satisfying these requirements should facilitate adequate PSI/ISI as well as manufacturing inspections.

504 As an overall conclusion for both MCL and MSL welds, I am satisfied with the level of evidence provided at this stage and Action 7 may be closed.

3.9.4 Assessment Findings for Action 7

505 There are no new Assessment Findings specific to this action, but note the relevance of Assessment Findings **AF-UKEPR-SI-53** and **AF-UKEPR-SI-54** for the MCL welds and **AF-UKEPR-SI-55** for the HIC components in the main steam lines as discussed above.

3.10 MSIV HIC Claim

3.10.1 Background

506 During the process of closing GDA Issue **GI-UKEPR-SI-01** I identified a potential anomaly in the overall avoidance of fracture demonstration provided by EDF and AREVA. The Main Steam Line (MSL) from the Steam Generators (SG) to the first fixed point downstream of the Main Steam Isolation Valves (MSIV) had been identified as requiring a HIC demonstration; however the MSIV itself had not been identified as requiring a HIC demonstration yet is within the HIC boundary for the MSL. I therefore raised TQ-EPR-1598 (Ref. 15) to question the integrity claims being made for the MSIV.

507 EDF and AREVA replied that the pressure boundary integrity of the valve body should be considered HIC. It had not previously been identified as such, and no documents had been presented to support an HIC claim. EDF and AREVA therefore proposed an additional set of deliverables against GDA Issue **GI-UKEPR-SI-01** along with the necessary updates to other documents and the PCSR to support an HIC claim for the MSIV pressure boundary, Ref. 93.

3.10.2 Deliverables

508 The main deliverable was a report on the avoidance of fracture demonstration for the MSIV, Ref. 94. In addition the report which identifies the High Integrity Components needed to be updated to include the MSIV as a HIC (updated at Ref. 95), and similarly the report which provides the overall avoidance of fracture demonstration (updated at Ref. 96).

3.10.3 Scope of Assessment

509 Whilst the main deliverable was the report on the avoidance of fracture demonstration for the MSIV, there is an important wider consideration on the identification of HICs. I have therefore undertaken a review of the impact on the identification of HICs, as well as an assessment the avoidance of fracture demonstration provided for the MSIV in Ref. 94. I have also reviewed the updated report on the overall avoidance of fracture demonstration, Ref. 96.

3.10.4 Impact on the Identification of High Integrity Components

510 The identification of components whose likelihood of gross failure is claimed to be so low that it can be discounted was an important part of the Structural Integrity GDA Step 3 and GDA Step 4 assessment process, and was an integral part of GDA Step 3 Regulatory Observation **RO-UKEPR-19** (Ref. 14) which was carried through to Step 4. I concluded, in the Step 4 Structural integrity report (Ref. 6), that I was satisfied with the process for deriving the list of HICs. I have therefore re-visited this conclusion given the discovery that the list of HICs identified at that time was incomplete.

511 The revised version of the report identifying the high integrity components, Ref. 95, explains the basis for including the MSIV pressure retaining boundary as requiring an HIC claim. If the failure of the MSIV pressure retaining boundary cannot be discounted as beyond design basis, then according to the Plant Condition Category rules a conservative single failure would also have to be taken into account, which in this case would be the non-closure of a second MSIV, resulting in the blowdown of two SGs. The blowdown of two SGs is beyond the design basis for the UKEPR, and it is therefore necessary to make an HIC claim for the pressure retaining boundary of the MSIV to discount gross failure.

512 These are the same reasons that the MSL was identified as HIC, so I accept that the overall logic of the approach remains well founded. The reasons why the MSIV was not identified previously appears to stem from a default assumption that gross failure of classified valves does not have to be considered within the design basis on the EPR™ design in France. Such a default assumption is not accepted in the UK EPR™ safety case. Gross failure can only be discounted if a specific case is made to show that the likelihood of failure is so low that it can be discounted. SAP principles EMC.1 to EMC.3 are applied to such cases, and the HIC demonstration being provided for the UK EPR™ addresses these principles.

513 I therefore remain satisfied with the process for indentifying the HICs, and the failure to identify the MSIV pressure boundary was an oversight rather than indicative of a deficiency in the process. However, given the oversight on the MSIV pressure boundary I asked EDF and AREVA to confirm that they had reviewed the UK EPR™ safety case to confirm that there were no other components that would need an HIC claim in TQ-EPR-1632. Their response to TQ-EPR-1632 confirmed that they had reviewed their safety case and that there were no other components which needed a HIC claim at the current stage of the design.

514 The list of components now identified in Ref. 95 as needing an HIC claim is:

- Reactor Pressure Vessel.
- Reactor Coolant Pump Bowl.
- Pressuriser.
- Steam Generator Channel Head Shell, Tubesheet and secondary Shell Pressure boundary.
- Reactor Coolant Pump flywheel.
- Main Coolant Loop Pipework.
- Main Steam Lines between the SGs and the fixed points downstream of the MSIVs, including the MSIV pressure boundary.

515 This list is the same as provided for Step 4, with the exception of the MSIV pressure boundary, and at that time I concluded that the list of HICs was complete provided some residual questions were satisfactorily addressed (Section 4.1.3 of the Structural Integrity Step 4 report). These residual questions related to:

- Assessing the consequences of failure of reactor internals.
- The substantiation of missile generation claims from the failure of RCC-M components.
- The exclusion of failure for non-isolable sections of the fuel pool pipework.

516 The assessment of the consequences of failure of the reactor internals resulted in Assessment Finding **AF-UKEPR-SI-38**:

> ***AF-UKEPR-SI-38:*** *The Licensee shall ensure that the safety cases for component internals include an analysis of the consequences of all the potential modes of failure. Alternatively the components should be added to the list of Highest Integrity Components and a case be developed accordingly.*

517 This has the potential for additions to extend the HIC list, but any such additions will only become apparent during the site specific phase.

518 The substantiation of the claims made in terms of missile generation from the failure of RCC-M components has been taken forward against the Internal Hazards GDA Issue **GI-UKEPR-IH-04**. The resolution of this GDA Issue has not lead to any additions to the HIC list, Ref. 102.

519 The exclusion of failure for non-isolatable sections of the fuel pool pipework has been taken forward against the Fault Studies GDA Issue **GI-UKEPR-FS-03** on the overall safety case for the spent fuel pool pond. The resolution of this issue will not lead to any additions to the HIC list as noted in the Safety Case route map provided in Ref. 97.

3.10.4.1 Conclusions on the Identification of High Integrity Components

520 I remain satisfied with the process for identifying the HICs. EDF and AREVA have confirmed in TQ-EPR-1632 that they have reviewed their safety case in the light of the MSIV pressure boundary omission and concluded that there are no other components which need an HIC claim at this stage of the design. I am therefore satisfied that the list of HICs identified in Ref. 95 should now be complete for the purposes of GDA.

521 It should be recognised that the list could be added to as a result of the detail design progressing at the site specific phase. Assessment Finding **AF-UKEPR-SI-38** has already been raised on the safety case for the reactor internals which would have the potential to affect the reactor internal components. In addition EDF and AREVA have allowed for the possibility that further components could be identified as requiring a HIC claim as the detail design progresses at the site specific phase in their response to TQ-EPR-1632. I will therefore raise an additional Assessment Finding for a Licensee to review the UK EPR™ safety case once the detail design has progressed to ensure that list of components needing an HIC claim is complete, **AF-UKEPR-SI-62**.

3.10.5 Assessment of the Avoidance of Fracture Demonstration for the MSIV

3.10.5.1 Background

522 Ref 94 presents an avoidance of fracture demonstration for the MSIV taking into account the material toughness, fracture analysis and non-destructive testing. It considers the potential for defects to occur in both the base material and any weld repairs, and considers the valve body and valve bonnet.

523 Ref. 94 relies on establishing the principles of the avoidance of fracture demonstration and reading across from existing work to provide evidence that it should be possible to make such a demonstration when the work required has been completed. It then includes commitments to undertake the work necessary to provide the demonstration during the site specific phase. The supporting work to provide the actual demonstration for GDA could not have been undertaken as the need for an avoidance of fracture demonstration was recognised too late in the GDA close-out timeframe.

524 The principles of the avoidance of fracture demonstration established in Ref. 94 are consistent with the approach used throughout GDA to support the HIC claims in the UK EPR™ safety case. I am also aware that a similar avoidance of fracture demonstration has been provided for the MSIV pressure boundary on the Sizewell B reactor (Ref. 103). Given that I am satisfied with the overall approach used to support HIC claims for the UK EPR™, and have confidence that an avoidance of fracture demonstration can be provided for a component of this type, I am content to assess the demonstration for the MSIV pressure boundary on the basis of the read across from existing work and the commitments for further work. I will judge the adequacy of the demonstration on whether the read across and commitments are sufficient to show that it should be possible to make an avoidance of fracture demonstration during the site specific phase, and will raise

Assessment Findings as necessary to ensure that an appropriate site specific justification is provided.

3.10.5.2 Material Toughness

525 Ref. 94 quotes $J_{0.2}$ and J_3 values for the cast carbon steel material, 20MN5N, based on the sulphur content of the castings, Charpy/J correlation curves, and generic tearing resistance curves. Thus the values are not based on representative tests, and deriving toughness values by such means introduces significant uncertainties into the process. Thus the toughness values assumed in Ref. 94 must be treated with a degree of caution. The values may include conservative allowance to account for these uncertainties, and there is a commitment to confirm these values through fracture toughness tests during the site specific phase.

526 There is an existing Assessment Finding which addresses the material data set used for the design and assessment process, and through life support:

> ***AF-UKEPR-SI-16:*** *The Licensee shall produce a comprehensive material data set for use during the design and assessment process, and also to support through life operation. This will need to cover all relevant data including the basic design data and the confirmatory batch and weld specific test data from the complementary fracture toughness testing programme (Section 4.2.5.3). It will need to be clearly presented such that the pedigree of the data can be traced following the literature trail with comparison to other international data sets where possible and will need to be updated through life following developments in the field and in the light of through life testing of materials subject to degradation mechanisms.*

527 This Assessment Finding remains sufficient to ensure the basis for the values included in the material data set in general terms, however, given the uncertainties in the values assumed in Ref. 94 it would be prudent for the Licensee to review the toughness values to ensure that they are confident that the values do in fact contain a number of conservative allowances and will be achieved in practice. I have therefore raised a specific Assessment Finding on the fracture toughness values used in the fracture assessment of the MSIV, **AF-UKEPR-SI-63**.

3.10.5.3 Fracture Toughness Testing

528 Ref. 94 states that the complementary fracture toughness testing will be performed either on an FA3 or on a UK EPR™ mock-up of the MSIV castings and a mock up of the weld repair. Figure 15 of Ref. 96 summarises the fracture toughness testing which will be undertaken in support of the avoidance of fracture demonstration for the HICs, and for the MSIV states that the testing will be performed on coupons from cast carbon steel representative of an EPR™ MSIV body and MSIV bonnet, and that it will also include the testing of large weld repairs.

529 Large carbon steel castings such as used for the MSIV body can have significant variability in properties from casting to casting. It is therefore important that the mock up castings used for the fracture toughness testing are as representative as possible of the ones being produced for the UK EPR™. I think it unlikely that the test results from an FA3 casting produced at a different time would provide the necessary confidence for a UK EPR™ casting. In addition, given the cast-to-cast variability in properties there could also be an argument for testing a casting at the start of each production cycle.

530 Details of the fracture toughness testing programme will be developed during the site specific phase. The questions on the applicability of the castings used for the testing will need to be addressed by the Licensee as part of this process. I have created Assessment Finding **AF-UKEPR-SI-64** for a Licensee to ensure that the castings used in the fracture

toughness test programme will be suitable for establishing data that is fully applicable to the valve bodies and bonnets installed on a UK EPR™.

3.10.5.4 Fracture Mechanics Analysis

531 The objective is to show that the limiting defect size exceeds 20 mm deep. This would then enable EDF and AREVA to demonstrate a target margin of two if they are able to show that they can reliably detect a 10 mm deep defect.

532 Ref. 94 presents a comparison with the Reactor Coolant Pump (RCP) bowl fracture analysis of Ref. 33 as a fracture mechanics analysis for the MSIV as one is not yet available. The RCP bowl analysis shows that the limiting defect size in excess of 20 mm deep. There are important differences between the two castings, not least of which being the RCP bowl is a cast austenitic stainless steel whereas the MSIV is a cast ferritic steel, but Ref. 94 provides a quantitative comparison of the input parameters in order to show that the limiting defect size will be in excess of the 20 mm depth demonstrated for the RCP bowl.

533 The comparison assumes that thermal shock will dominate the limiting load case and compares important parameters such as temperature change, wall thickness, coefficient of expansion, allowable toughness, residual stress from weld repairs etc. The quantitative comparison suggests that the applied J(elastic) for the MSIV may be less than 16% of the RCP value.

534 The comparison relies on a simplistic assessment of the applied loading and cannot account for any plasticity effects, so the numbers must be treated with caution. However, I accept the basic logic that a comparison of the input parameters shows that the net effect is less severe for the MSIV (body, bonnet and weld repair) and that this is the case for each of the input parameters so there are no relative balancing of effects to consider. The main area of concern would be that the material toughness allowable for the MSIV does not fall below that of the RCP. In practice the RCP allowable toughness values are already less than those being assumed for the MSIV and, as all the other parameters suggest the crack tip loading is significantly less than in the RCP, I judge that it is unlikely that the limiting defect size would be less than 20 mm deep even given a reduction in the MSIV toughness.

535 Hence on a like-for-like basis (ie thermal shock to the main body) I accept that there is credibility in the argument that the limiting defect size should be in excess of 20 mm deep based on the RCP bowl fracture analysis, even allowing for a lower allowable toughness in the MSIV than currently assumed. Ref. 94 provides a commitment to verify that the limiting defect size is greater than 20 mm during the site specific phase, but for the avoidance of doubt I have raised Assessment Finding **AF-UKEPR-SI-65** to ensure that a MSIV specific fracture assessment is undertaken rather than a read across from the RCP bowl.

3.10.5.5 Non-Thermal Shock Loading

536 Ref. 94 only makes a comparison in terms of thermal shock. However, thermal shock to the main body/bonnet is not the only load case of interest. This potential is not addressed in the report, but I have identified two further aspects which need to be considered:

- Connection between the body and bonnet.
- Valve body adjacent to the MSL pipework welds.

3.10.5.5.1 Connection between the MSIV body and bonnet

537 The valve bonnet is held in the valve body by means of a multipiece ring or circlip inserted into an internal rebate in the valve body. A fracture assessment will be required across the valve body section where the rebate has been machined to make the connection as this connection needs to be in the HIC category. This aspect is not addressed in Ref. 94.

538 In practice this section is remote from the thermal transient effects, so direct thermal shock should not a problem. The longer range thermal stresses generated by the cooldown transients will have an effect but it may be reasonable to assume that they will be less significant that the direct thermal shock stresses. There are also the direct mechanical loads created by maintaining the pressure boundary. Again it is not known what the effect of these will be, but it may be reasonable to assume that they will be less significant that the direct thermal shock stresses.

539 Thus Ref. 94 does not provide a justification for this connection, but one will be required in order to present an HIC case. I believe it is reasonable to make a judgement that the connection should not prove limiting, but a confirmatory fracture assessment will need to be undertaken of this feature during the site specific phase. I have therefore included this aspect within **AF-UKEPR-SI-65** on calculating limiting defect sizes for the MSIV during the site specific phase.

3.10.5.5.2 Valve body adjacent to the MSL pipework welds

540 The valve body adjacent to the MSL pipework welds is subject to mechanical loads from the MSL pipework. They are equivalent to the loads applied across the welds between the MSL pipework and the MSIV. Consideration of these mechanical loads and the fracture analysis of this area of the valve body is not addressed within Ref. 94, but will be needed in order to make the HIC demonstration.

541 The fracture analysis of the MSL pipework welds is presented in Ref. 67. The results cover all the welds in the HIC section of the MSL pipework and this includes the welds between the MSL pipework and the MSIV. Mechanical loads rather than thermal shock dominate the loading. The allowable toughness values assumed for the MSL pipework welds are comparable to those assumed for the MSIV body in Ref. 94 and the limiting defect size in the welds on the main sections of MSL are of the order of 10 mm deep leading to the need to reliably detect defects of the order of 5 mm.

542 Thus the fracture analysis of the MSL pipework of Ref. 67 does not directly support the objectives of a 20 mm limiting defect size and 10 mm detectable defect size objectives set for the RCP bowl set out in Ref. 94. However, the fracture analysis for the MSL pipework in Ref. 67 is a bounding analysis. Only the most highly loaded welds inside and outside of containment are analysed. The limiting location, which leads to a limiting defect size of approximately 10 mm, is located at the containment penetration within containment. The limiting defect size for the main section of the MSL outside of containment is not calculated, but the maximum crack tip loading is only around 50% of that seen inside containment. That limiting location outside of containment is also at the containment penetration, and the loading at the MSIV will be smaller than this. In addition, the nominal thickness of the weld at the MSIV is 60 mm compared with 38.7 mm in the rest of the line. As the crack tip loading is driven by the mechanical load set, the thicker section means that the stresses on the thicker weld will be reduced, and hence the crack tip loading will also be reduced.

543 I can therefore conclude that the limiting defect size taken from the MSL pipework welds is unnecessarily conservative for the welds between the MSL pipework and MSIV. The mechanical loads and fracture analysis of the valve body adjacent to the MSL pipework weld will need to be addressed in order to make the HIC demonstration during the site

specific phase, but there is enough evidence for me to judge that the limiting defect size will be significantly in excess of 10 mm. I am unable to judge whether it will exceed the objective of having a 20 mm limiting defect size for the valve body as a whole, but that would not preclude the possibility of reducing the reliably detectable defect size locally to ensure a target margin of two is still maintained between the limiting defect size and reliably detectable defect size. Hence I judge that it should be possible to provide an avoidance of fracture demonstration for this area, with the actual fracture mechanics assessment being undertaken during the site specific phase and the process for selection and qualification of the NDT techniques will need to take account of the possibility that the reliably detectable defect size may be smaller in this region. These aspects are included within **AF-UKEPR-SI-65** on calculating limiting defect sizes for the MSIV, and **AF-UKEPR-SI-66** on the process for selecting and qualifying volumetric NDT techniques.

3.10.5.6 Non-Destructive Testing

544 Ref. 94 describes the surface and volumetric inspections specified in the RCC-M Code (Ref. 16) for the MSIV body, bonnet and any welded repairs. The report also describes additional inspections which are currently prescribed in the equipment specification, including ultrasonic inspection of regions near the weld preparations or regions not fully inspected by radiography. However Ref. 94 recognises that in order to make the HIC claim for the MSIV it may be necessary to undertake inspections which exceed those currently specified.

545 For the other HIC components of the UK EPR™, ultrasonics is normally chosen to inspect ferritic forgings whereas radiography is the primary technique used for the cast austenitic RCP bowl. Radiography and ultrasonics often have complementary capabilities for defect detection and their combination can provide the level of confidence in detecting defects which is necessary to ensure component quality and, in particular, to support the avoidance of fracture demonstration. In the case of the MSIV there are additional factors to consider such as the complex geometry of the casting and the possibility of local variations in materials properties. Consequently I believe that the volumetric inspection of the MSIV body, bonnet and any repairs is likely to require a combination of both radiography and ultrasonics.

546 Ref. 94 states that the selection of the combination of the surface and volumetric techniques will be defined during the site specific phase. Consequently there is a commitment to specify the combination of inspection techniques taking account of the defect detection capability required, which is the approach adopted for other HICs. There is a further commitment to consider the need for qualification of the volumetric inspections during the site specific phase once the margins between detectable defect size and limiting defect size have been established. I note that Ref. 94 acknowledges that a combination of radiography and ultrasonic inspection may be required for the valve body, bonnet and weld repairs.

547 Without a definition of the inspections to be undertaken, no specific comments can be provided on the inspection techniques. It will clearly be essential to demonstrate the capability of the NDT to reliably detect defects of the size required and this will be particularly important for any volumetric inspections (RT or UT) which are required. It may well be necessary to extend the scope of the inspection developed for OL3 and FA3 in order to substantiate the HIC claim. Similarly there will be a need to justify the capability of the selected techniques once the defect detection requirements have been specified. Any assessments of capability will need to take account of the complex geometry and any local variations in the parameters which affect inspection capability such as grain size. However, I accept that the need for inspection qualification should be determined during the technique development taking account of the capabilities and

limitations of the techniques and the margin between the size of defect which can be reliably detected and the limiting defect size.

548 I accept that it is not possible to fully specify the range of volumetric inspection techniques required at this stage in the development of the HIC claim. Consequently I have raised an Assessment Finding **AF-UKEPR-SI-66** to ensure that the Licensee determines what techniques are required to support the HIC claim, considers the need for both radiography and ultrasonics, demonstrates the capability of the selected techniques is adequate and justifies the level of qualification applied to the selected techniques.

549 Ref. 94 also includes a chart showing the boundary between major, minor and superficial weld repairs as specified in the RCC-M code. These define the levels of inspection currently undertaken on any weld repair. In general major weld repairs are not anticipated on the MSIV, but it is important to note that the need for volumetric examination on a HIC component is determined by the limiting defect size and the reliably detectable defect size rather than the definition of major, minor or superficial repairs in RCC-M. In general volumetric techniques should be applied where the size of the weld repair approaches the target defect size for qualified NDT as the weld repair could introduce defects of the size that need to be reliably detected. It is also important that the design of welded repairs takes account of the need for inspection and this aspect is included within Assessment Finding **AF-UKEPR-SI-67** which is discussed below.

550 The final machined valve body is a fairly complex shape. For example there are tapered ends and counterbores for the valve body to MSL pipework welds and at the locking ring for the valve bonnet. These will add difficulty to the inspections and it may be necessary to perform some of the volumetric NDT at an intermediate stage before final machining. Thus the inspection requirements should be taken into account at the design stage as they may have an impact on the manufacturing sequence. This aspect can be taken into account during the site specific phase, and I have raised Assessment Finding **AF-UKEPR-SI-67** to address this aspect. This requirement is closely related to an earlier Assessment Finding (**AF-UKEPR-SI-55**) which applies generally to the MSL pipework welds, but **AF-UKEPR-SI-67** is specific to the MSIV and applies to all the inspections of this component whether or not they are qualified.

551 Overall I am satisfied that it should be possible to devise inspection techniques that are capable of reliably detecting defects of the order of 10 mm in line with the objective of showing that there is a target margin of two between that and the postulated limiting defect size of 20 mm. If it were necessary to specify a smaller limiting defect size in the regions of the welds to the MSL pipework, this would place more onerous requirements on the inspections but the evidence already provided for the MSL welds under Action 3 suggests that smaller defects could be detected.

552 I consider that the commitments made for the site specific phase provide a basis for developing the inspections necessary to support the HIC claim, and I have raised Assessment Findings **AF-UKEPR-SI-66** and **AF-UKEPR-SI-67** for the Licensee to address the selection and qualification of the inspection techniques and to ensure that the inspection requirements are taken into account at the design stage.

3.10.5.7 Assessment Conclusions for Avoidance of Fracture Demonstration for the MSIV

553 Ref. 94 presents an avoidance of fracture demonstration for the MSIV taking into account the material toughness, fracture analysis and non-destructive testing. The need to provide such an avoidance of fracture demonstration arose late in the GDA close-out timeframe. As a consequence the demonstration relies on establishing the principles of the HIC demonstration and reading across from existing work to provide evidence that it should be possible to make such a demonstration rather than presenting a demonstration

in its own right. It then includes commitments to undertake the work necessary to provide the demonstration during the site specific phase.

554 The principles are consistent with the approach taken to support the HIC claim for the other HIC components within GDA and I was aware that a similar avoidance of fracture demonstration has been provided for the MSIV pressure boundary on the Sizewell B reactor (Ref. 103). I was therefore content to review the demonstration on the basis that the evidence needs to show that it should be possible to make an avoidance of fracture demonstration and the commitments for further work.

555 I consider that there is sufficient evidence to conclude that it should be possible to make the avoidance of fracture demonstration in order to substantiate an HIC claim for the MSIV.

556 The detail of the demonstration will have to be developed during the site specific stage and Ref. 94 includes the necessary commitments to undertake the work to provide the demonstration during the site specific phase. In addition I have raised five Assessment Findings, **AF-UKEPR-SI-63** to **AF-UKEPR-SI-67**, in relation to the MSIV that will need to be addressed by a Licensee when undertaking this work.

3.10.6 Overall Avoidance of Fracture Demonstration for GDA

557 The overall avoidance of fracture demonstration for GDA, Ref. 96, has been updated to include the HIC claim for the MSIV. I am satisfied that the update to this document reflect the position on the MSIV.

3.10.7 Assessment Findings for the MSIV HIC Claim

558 The following Assessment Finding has been raised in connection with the identification of High Integrity Components:

> ***AF-UKEPR-SI-62:*** *The Licensee shall review their site specific safety case during each significant upgrade to ensure that the list of components requiring an HIC claim is complete.*
>
> ***Required timescale:*** *Initial Criticality*

559 The following Assessment Findings have been raised in connection with the avoidance of fracture demonstration provided for the MSIV pressure boundary:

> ***AF-UKEPR-SI-63:*** *The Licensee shall review the fracture toughness values assumed for the fracture analysis of the MSIV pressure boundary to ensure that they are conservative and are likely to be achieved in practice.*
>
> ***Required timescale:*** *Install RPV*
>
> ***AF-UKEPR-SI-64:*** *The Licensee shall ensure that the castings used in the fracture toughness test programme for the MSIV body/bonnet and weld repairs will be suitable for establishing data that is fully applicable to the valve bodies and bonnets installed on a UK EPR™.*
>
> ***Required timescale:*** *Install RPV*
>
> ***AF-UKEPR-SI-65:*** *The Licensee shall undertake an MSIV specific fracture mechanics analysis to determine the limiting defect size for the MSIV. The analysis should cover the valve body, bonnet, weld repairs and the connection between the valve body and bonnet. It should postulate defects in all limiting locations taking into account all significant loadings applied to the MSIV including thermal shock and mechanical loads including those from the adjoining pipework.*

Required timescale: *Install RPV*

AF-UKEPR-SI-66: *The Licensee shall ensure that the volumetric NDT techniques selected for the MSIV body, bonnet and any potential repairs have the capability to reliably detect flaws of the target defect size (i.e. defects smaller than the calculated limiting defect size by a margin of typically 2). The scope of the inspections should cover the full volume of the component and include all repairs down to a size comparable with the target defect size. The Licensee shall also justify the level of qualification to be applied to the technique(s) selected for this high integrity component.*

Required timescale: *Install RPV*

AF-UKEPR-SI-67: *The Licensee shall ensure that the requirements for all non-destructive inspections of the MSIV body and bonnet (and any potential repairs) are fully specified and taken into account at the design stage. For example, it might be necessary for some inspections to be performed before final machining and weld repairs should be designed so that inspection requirements are satisfied.*

Required timescale: *Install RPV*

560 The required timescale to address Assessment Findings **AF-UKEPR-SI-63** to **AF-UKEPR-SI-67** is recorded against the generic milestone of ‘Install RPV’. In practice the findings should be addressed earlier in order to ensure that an HIC demonstration can be achieved for the MSIV pressure retaining boundary before the manufacturing process for the MSIVs has commenced. This is because it would be time consuming and costly to make any design changes after manufacturing had commenced.

4 REVIEW OF THE UPDATE TO THE PCSR

561 The PCSR has been updated (Ref. 12) to reflect the changes to the safety case as a result of the work undertaken by EDF and AREVA to address the GDA Issues raised by ONR. I have reviewed the Sub-Chapters affected by GDA Issue **GDA-UKEPR-SI-01**, Sub-Chapters 3.1, 3.4, 5.0, 5.2, 5.3, 5.4, 10.3, 10.5 and 17.5, and my main findings are listed below.

4.1 Sub-Chapter 3.1 General Safety Principles.

562 Earlier versions of the PCSR had included the full text of the technical guidelines adopted in 2000 for design and construction of the EPR™. Since the UK EPR™ design diverges from these guidelines in various aspects the full text of the guidelines has been removed and they have become a reference to this PCSR sub-chapter.

563 Sub-Chapter 3.1, along with Sub-Chapters 3.4, 5.0, 5.2, 10.3 and 10.5, were updated to make the relationship between the HIC claim and the break preclusion principle consistent through the PCSR.

4.2 Sub-Chapter 5.2: Integrity of the Reactor Circuit Pressure Boundary

564 The main revision concerns access for in-service inspection of MCL pipework – as required by GDA Issue **GI-UKEPR-SI-01** Action 7. A new reference has been added and is described in Section 5.3 of the PCSR: this is PEEM-F 11.0505 Rev C which is Ref. 52 of this report. This reference is appropriate and includes the design change to the cross-over leg (CMF-031, Ref. 100) and to the counterbores of all the homogeneous MCL welds (CMF-032, Ref. 101).

4.3 Sub-Chapter 5.3: Reactor Vessel

565 Section 7.1 now lists the four welds selected for defect tolerance analyses as bounding or representative cases. This clarification is valuable because, until the RPV inlet set-on weld has been analysed, it remains possible that this weld could have more severe transients (and smaller limiting defect sizes) than the outlet set-on weld which has been analysed during GDA.

566 Section 7.2 on qualified NDT has been revised to explain that the qualified UT of the dissimilar metal welds will involve manual pulse-echo UT from both inside and outside combined with 0° compression wave testing from the end faces.

567 Section 7.4 on materials irradiation monitoring has been reviewed separately in connection with GDA Issue **GI-UKEPR-SI-02** and found to be acceptable.

4.4 Sub-Chapter 5.4: Components and Systems Sizing

568 All HIC components have extra text clarifying that the HIC methodology applies to the whole component but explains why attention has been focussed on welds.

569 The application of the HIC methodology has been clarified for weld repairs in the reactor coolant pump bowl and for determining the threshold for qualified volumetric examination. The revised sub-chapter also includes changes to ensure that the relationship between HIC and break preclusion is applied consistently throughout the PCSR and consistent with the GDA submissions on these topics.

570 Section 1.6 now clarifies that the three-legged HIC approach is applied to both the bowl and the flywheel, except that the inspections of the flywheel are not qualified. The explanation for this is provided in Section 1.6.2 and relates to the tolerance to defects, the good capability to detect the defects considered plausible and operating experience.

4.5 Sub-Chapter 10.3: Main Steam Supply System (Safety Classified Part)

571 Section 0.3.1.7 on HIC classification has now added the MSIV to the list of HICs.

572 Section 6.1 on equipment performance tests has been expanded to take account of additional evidence provided during GDA close-out. The commitment to specify a surface profile with a maximum gap of 0.5 mm under transducers has also been added.

4.6 Sub-Chapter 17.5: Review of Possible Design Modifications to Confirm Design Meets ALARP Principle

573 The new Section 3.6 of this sub-chapter adequately references the design changes for the MCL pipework and associated inspection techniques which have been agreed during the close-out of GDA Issue **GI-UKEPR-SI-01**.

4.7 Overall Conclusion of the PCSR Review

574 The most significant changes to the safety case resulting from GDA Issue **GI-UKEPR-SI-01** have been adequately reflected in the 2012 update of the PCSR.

5 ASSESSMENT FINDINGS

575 I conclude that the following Assessment Findings, also listed in Annex 1, should be programmed during the forward programme of this reactor as normal regulatory business, in addition to those identified in the Step 4 Structural Integrity Assessment report (Ref. 6).

> ***AF-UKEPR-SI-43:*** *The Licensee shall undertake validation studies to confirm that the methodology used to calculate the limiting defect size for the RPV outlet nozzle dissimilar metal weld is appropriate.*
>
> ***Required timescale:*** *Install RPV*
>
> ***AF-UKEPR-SI-44:*** *The Licensee shall establish the limiting defect size for all High Integrity Components , including situations where cracked body finite element analyses are used to determine the limiting defect size.*
>
> ***Required timescale:*** *Install RPV*
>
> ***AF-UKEPR-SI-45:*** *The Licensee shall use material toughness properties for the fracture mechanics analyses that bound both the weld material and the HAZ material, and the base material if potentially limiting.*
>
> ***Required timescale:*** *Install RPV*
>
> ***AF-UKEPR-SI-46:*** *The Licensee shall explicitly identify the full thermal ageing shift in the HAZ material of the low alloy steel welds and any enhanced start of life properties required of the HAZ material in the materials data handbook used to support the UK EPR™. Any enhanced start of life properties for the HAZ should be demonstrated in the complementary fracture toughness testing.*
>
> ***Required timescale:*** *Install RPV*
>
> ***AF-UKEPR-SI-47:*** *The Licensee shall confirm that the reductions in fracture toughness to account for thermal ageing using values derived from accelerated thermal ageing tests at 10000 hours and 400°C are sufficient to account for a 60 year reactor life.*
>
> ***Required timescale:*** *Install RPV*
>
> ***AF-UKEPR-SI-48:*** *Should the Licensee adopt the RSE-M Appendix 5.4 fracture assessment procedure, the Licensee shall ensure that:*
>
> - *updates to Appendix 5.4 of RSE-M and Appendix A16 of RCC-MR are reviewed as they are released to determine their impact on both future and existing assessments (even if they are only available in French at the time of release);*
> - *they establish a presence on the committee developing Appendix 5.4 of RSE-M and Appendix A16 of RCC-MR; and*
> - *they have a capability to identify any reservations and limitations on the use of RSE-M Appendix 5.4 as identified by the French Nuclear Safety Authority (ASN).*
>
> ***Required timescale:*** *Install RPV*
>
> ***AF-UKEPR-SI-49:*** *Should the Licensee adopt the RSE-M Appendix 5.4 fracture assessment procedure, the Licensee shall ensure that there is a capability to undertake assessment to RSE-M Appendix 5.4 independently of the company supplying the reactor design in order to support the ongoing*

operation of the reactor. The availability of technical support organisations to allow the UK Nuclear Regulator (ONR) to commission such assessment work independently should also be considered.

Required timescale: *Install RPV*

AF-UKEPR-SI-50: *Should the Licensee adopt the RSE-M Appendix 5.4 fracture assessment procedure, the Licensee shall ensure that the UK methodology for undertaking the fracture assessments based on RSE-M Appendix 5.4 is suitable and sufficient to define the methodology in relation to RSE-M, and to explain and justify departures from RSE-M.*

Required timescale: *Install RPV*

AF-UKEPR-SI-51: *The Licensee shall review the upper shelf fracture toughness values used for areas affected by irradiation damage to ensure that they are consistent with the worldwide experience on the effect of irradiation damage on upper-shelf toughness and ensure that the surveillance scheme is adequate to confirm the assumptions made at the design stage.*

Required timescale: *Install RPV*

AF-UKEPR-SI-52: *The Licensee shall confirm through appropriate analyses and assessment that the detailed redesign of the MCL pipework to increase counterbore lengths and to lower the cross-over leg does not have any unacceptable safety detriments.*

Required timescale: *Install RPV*

AF-UKEPR-SI-53: The Licensee shall *demonstrate that the materials properties of the MCL forgings are adequately specified and controlled. This demonstration should include evidence that the M140 and shop qualifications for the MCL pipework remain valid for the modified design, and that the grain size is such that a reliable ultrasonic inspection of the parent material and associated welds can be achieved both during manufacture and in-service.*

Required timescale: *Install RPV*

AF-UKEPR-SI-54: The Licensee shall *ensure that the surface profile of the MCL pipework is adequately specified and controlled for all those surfaces on which ultrasonic transducers are scanned or from which ultrasonic beams may be reflected. This should include the effects of any local features such as overlay welding to compensate for welding distortions or profile variations caused by the counterbore cutting machine.*

Required timescale: *Install RPV*

AF-UKEPR-SI-55: *The Licensee shall ensure that during the design, manufacture and installation of all MSL components there are explicit checks on the detailed geometry near welds and other regions which require qualified NDT. These checks should ensure that the local component geometry (eg any component thickness changes or tapers) and the resultant surface profiles (both inside and outside the component) are such that an adequate inspection capability is achievable.*

Required timescale: *Install RPV*

AF-UKEPR-SI-56: *The Licensee shall ensure that the qualified volumetric inspections of welded repairs on the RCP bowl have the capability to reliably detect defects of the target size (i.e. defects smaller than the calculated limiting defect size by a margin of typically 2). The scope of these qualified inspections should include all repairs down to a size comparable with the target defect size and significantly smaller (typically by a margin of 2) than the limiting defect size.*

Required timescale: *Install RPV*

AF-UKEPR-SI-57: *The Licensee shall ensure that the inspection qualification of the radiographic and ultrasonic procedures for the RCP bowl and potential repairs takes account of the wide variation in the characteristics of potential defects and the need to demonstrate reliable detection and characterisation.*

Required timescale: *Install RPV*

AF-UKEPR-SI-58: *The Licensee shall ensure that when specifying the target values for chemical composition of the RCP pump bowls, the desirability of achieving a Type A macrostructure is taken into account.*

Required timescale: *Install RPV*

AF-UKEPR-SI-59: *The Licensee shall demonstrate that the assessments of capability of the manufacturing NDT procedures for the flywheel (PT and UT) take account of the HIC nature of the component and the full range of defect types which might occur and that the inspections will provide adequate capability to detect these defects.*

Required timescale: *Install RPV*

AF-UKEPR-SI-60: *The Licensee shall ensure that, once the details of the in-service inspections of the flywheel have been specified, the inspection capability is justified and the need for inspection qualification is considered.*

Required timescale: *Install RPV*

AF-UKEPR-SI-61: *The Licensee shall demonstrate that the parameters of the austenitic cladding applied to each HIC component, especially near welds, are adequately controlled and understood so that any potential adverse effects on the inspection capability are tolerable*

Required timescale: *Install RPV*

AF-UKEPR-SI-62: *The Licensee shall review their site specific safety case during each significant upgrade to ensure that the list of components requiring an HIC claim is complete.*

Required timescale: *Initial Criticality*

AF-UKEPR-SI-63: *The Licensee shall review the fracture toughness values assumed for the fracture analysis of the MSIV pressure boundary to ensure that they are conservative and are likely to be achieved in practice.*

Required timescale: *Install RPV*

AF-UKEPR-SI-64: *The Licensee shall ensure that the castings used in the fracture toughness test programme for the MSIV body/bonnet and weld repairs will be suitable for establishing data that is fully applicable to the valve bodies and bonnets installed on a UK EPR™.*

Required timescale: *Install RPV*

AF-UKEPR-SI-65: *The Licensee shall undertake an MSIV specific fracture mechanics analysis to determine the limiting defect size for the MSIV. The analysis should cover the valve body, bonnet, weld repairs and the connection between the valve body and bonnet. It should postulate defects in all limiting locations taking into account all significant loadings applied to the MSIV including thermal shock and mechanical loads including those from the adjoining pipework.*

Required timescale: *Install RPV*

AF-UKEPR-SI-66: *The Licensee shall ensure that the volumetric NDT techniques selected for the MSIV body, bonnet and any potential repairs have the capability to reliably detect flaws of the target defect size (i.e. defects smaller than the calculated limiting defect size by a margin of typically 2). The scope of the inspections should cover the full volume of the component and include all repairs down to a size comparable with the target defect size. The Licensee shall also justify the level of qualification to be applied to the technique(s) selected for this high integrity component.*

Required timescale: *Install RPV*

AF-UKEPR-SI-67: *The Licensee shall ensure that the requirements for all non-destructive inspections of the MSIV body and bonnet (and any potential repairs) are fully specified and taken into account at the design stage. For example, it might be necessary for some inspections to be performed before final machining and weld repairs should be designed so that inspection requirements are satisfied.*

Required timescale: *Install RPV*

576 There are no impacted Step 4 Assessment Findings

6 OVERALL CONCLUSIONS ON GDA ISSUE SI-01

577 I believe that EDF and AREVA have now provided sufficient evidence within the GDA to demonstrate the avoidance of fracture for the HIC components of the UK EPR™. Adequate additional evidence has been provided for each of the seven Actions and hence GDA Issue **GI-UKEPR-SI-01** may now be closed.

578 The additional evidence provided to satisfy this GDA Issue includes:

- Detailed explanation of the fracture analysis methodology used to derive limiting defect sizes and clarification of the load transients and material properties assumed.
- Important design changes to the MCL pipework including lowering the U-leg and moving counterbores to improve inspectability.
- Introduction of an automated phased array inspection including a self-tandem technique for inspecting the MCL homogeneous welds during manufacture and construction.
- Commitments to control the geometries and surface condition close to welds to facilitate reliable inspection.
- Expansion of the range of ultrasonic techniques and beam angles where necessary.
- The declaration of an HIC claim for the MSIV pressure boundary, and evidence that it should be possible support the HIC claim.

579 During the close-out of GDA Issue **GI-UKEPR-SI-01** I have satisfied myself that:

- The fracture analysis methodology used by EDF and AREVA remains acceptable for the purposes of GDA, and the limiting defect sizes can be used in the avoidance of fracture demonstration.
- The summary of the limiting defect sizes presented in Section 4.2.3.8 of the Structural Integrity Step 4 report (Ref. 6) remain unchanged in spite of the additional analyses and reviews performed during GDA Issue close-out.
- In most cases the limiting defect sizes are greater than 20 mm which is the nominal value assumed for the purpose of setting a provisional target size for NDT of 10 mm.
- Limiting defect sizes are smaller than 20 mm in the main steam lines and the smallest reported value is 6.8 mm for the main steam safety valve (MSSV) weld. Consequently the NDT techniques deployed will require good capability and the detailed design of the components will need to take full account of the inspection requirements. The target defect size of 3mm assumed for assessment of the MSSV weld is consistent with the 6.8mm limiting defect size.
- The proposals for redesign of the MCL pipework and the associated inspection techniques form a well integrated package of improvements and there is now a realistic prospect that adequate manufacturing and in-service inspections can be developed and qualified.
- For the main steam line welds, the introduction of additional inspection beam angles, the commitment to achievement of adequate surface profiles, and the evidence from mathematical modelling provide confidence that successful qualification should be achievable for inspection of these welds.
- Evidence from practical trials shows that there is a reasonable prospect of developing adequate inspections for weld repairs in RCP bowls.

- The scope of ultrasonic inspection proposed for the flywheel plates is more limited than would normally be required for a forging of this geometry but the reduced scope is justified on the basis that significant defects are only plausible in the plane of the plates.
- The outline technical justification for the prototype application provided is an adequate basis for GDA, but a number of technical aspects will need to be evaluated in more detail when full inspection qualification is undertaken.
- The outline proposals for in-service inspection of the MCL and MSL pipework now have a realistic prospect of being successfully qualified.
- It should be possible to support an HIC claim for the MSIV.

580 As well as the Assessment Findings from GDA Step 4, I have identified a number of additional activities during GDA close-out which will be required during the site specific phase. The most important examples of these activities are:

- A more detailed validation for the fracture analysis methodology which is based on RSE-M Appendix 5.4 (**AF-UKEPR-SI-43, 48 and 50**).
- Validation of materials properties used for fracture analyses (**AF-UKEPR-SI-45, 46, 47, 51 and 64**).
- Attention to the design, procurement and manufacture of the MCL pipework and MSL components to ensure that inspection requirements are properly taken into account (**AF-UKEPR-SI-52, 53 and 54**).
- Ensuring that the scope and capability of the qualified inspections of welded repairs in the RCP bowls take account of the limiting defect sizes, the plausible defect types and the metallurgical macrostructure (**AF-UKEPR-SI-56, 57 and 58**)
- Demonstration that the capabilities of the flywheel manufacturing and in-service NDT procedures (PT and UT) are adequate to detect any potential defects (**AF-UKEPR-SI-59 and 60**).
- Demonstration that the properties of austenitic cladding on HIC components are adequately controlled so that any effects on inspection capability are tolerable (**AF-UKEPR-SI-61**).
- Ensuring that the list of components requiring a HIC claim is complete during each significant upgrade to the site specific safety case (**AF-UKEPR-SI-62**).
- Completing the fracture mechanics analysis for the man steam isolation valve pressure boundary (**AF-UKEPR-SI-63 and 65**).
- Development of the non-destructive inspection techniques to be applied to the main steam isolation valve pressure boundary (**AF-UKEPR-SI-66 and 67**).

7 REFERENCES

1 *ONR HOW2 Business Management System*. Permissioning – Purpose and Scope of Permissioning, PI/FWD Issue 3. August 2011. www.hse.gov.uk/nuclear/operational/assessment/index.htm.

2 *Safety Assessment Principles for Nuclear Facilities.* 2006 Edition Revision 1. HSE. January 2008. www.hse.gov.uk/nuclear/SAP/SAP2006.pdf.

3 *Integrity of Metal Components and Structures.* T/AST/016 Issue 3. HSE. August 2008. www.hse.gov.uk/nuclear/operational/tech_asst_guides/index.htm.

4 *GDA Issue GI-UKEPR-SI-01 Revision 2. Structural Integrity – Avoidance Of Fracture.* ONR. July 2011. TRIM Ref. 2011/385315.

5 *Assessment Plan for Structural Integrity ONR Assessment Report ONR-GDA-AP-11-004. 29 September 2011. TRIM Ref.* 2011/484945

6 *Step 4 Structural Integrity Assessment of the EDF and AREVA UK EPR™ Reactor*. ONR Assessment Report ONR-GDA-AR-11-027 Revision 0. TRIM Ref. 2010/581504.

7 *Resolution Plan for GDA Issue GI-UKEPR-SI-01.* EDF and AREVA. 29.06.2011. TRIM Ref. 2011/347624

9 *Reference Design Configuration*. UKEPR-I-002 Revision 15. UK EPR™. December 2012. EDF and AREVA. TRIM Ref. 2012/478281.

10 *Design Change Procedure.* UKEPR-I-003 Revision 11. EDF and AREVA. December 2012. TRIM Ref. 2012/478287.

11 *UK EPR^TM GDA Step 4 Consolidated Pre-construction Safety Report – March 2011.* EDF and AREVA. Detailed in EDF and AREVA letter UN REG EPR00997N. 18 November 2011. TRIM Ref. 2011/552663.

12 *Final Consolidated UK EPR GDA Pre-Construction Safety Report.* EDF and AREVA letter to the Joint Programme Office dated 30 November 2012, REG EPR01470N. TRIM Ref. 2012/470151.

13 *EDF and AREVA UK EPR™ - Schedule of Technical Queries Raised during GDA Step 1 to Step 4.* HSE-ND. TRIM Ref. 2010/600726*.*

14 *EDF and AREVA UK EPR™ - Schedule of Regulatory Observations Raised during GDA Step 1 to Step 4.* HSE-ND. TRIM Ref. 2010/600727.

15 *EDF and AREVA UK EPR™ - Schedule of Technical Queries Raised during GDA Close-out.* Office for Nuclear Regulation. TRIM Ref. 2011/389411*.*

16 *RCC-M. Design and Construction Rules for Mechanical Components of PWR Nuclear Islands. 2007 Edition. Published by the French Association for Design, Construction and In-service Inspection Rules for nuclear Island Components – AFCEN, Paris. www.afcen.org.*

17 *RSE-M. In Service Inspection Rules for the Mechanical components of PWR nuclear power islands*. Appendix 5.4.- Analytical Methods for Calculating Stress Intensity Factors and Integral J. AFCEN. RSE-M. 1997 Edition with 3rd Addendum. October 2005. *www.afcen.org*

18 *R6, Assessment of the Integrity of Structures containing Defects.* Revision 4, British Energy Generation Ltd.

19 *UK EPR^TM Avoidance of fracture approach – Fast fracture studies for critical defect sizes determination in the RPV outlet Dissimilar Metal Weld*. PEER-F 10.2068 Revision A. AREVA. December 2010. TRIM Ref. 2011/94300.

20 *A review of the UK EPR fast fracture studies for the reactor pressure vessel outlet nozzle dissimilar metal weld.* HSE-NII/1328/11 Issue 1. February 2011. TRIM Ref.2011/107728.

21 *UK EPR Avoidance of fracture approach – Fast fracture studies for critical defect sizes determination in the RPV outlet Dissimilar Metal Weld*. PEER-F 10.2068 Revision B. AREVA. November 2011. TRIM Ref. 2011/612892.

22 *Definition of the residual stress level in Inconel Dissimilar Metal Weld joints for the EPR-UK critical defect size Fracture Mechanics Analyses*. PEER-F 10.2031 Revision B. AREVA. October 2011. TRIM Ref. 2011/612889.

23 *Fast Fracture Studies for critical defect sizes – determination in the RPV outlet set-on weld*. PEER-F 10.1871 Revision A. AREVA. December 2010. TRIM Ref. 2011/94298.

24 *UK EPR Avoidance of fracture approach – Fast fracture analytical studies for critical defect sizes determination in main coolant lines*. PEER-F 10.1286 Revision A. AREVA. September 2010. TRIM Ref. 2011/93017.

25 *SYSTUS Multiphysics Simulation Software. 2009 Version*. ESI Group, 75015 Paris.

26 *DEFIS Software Package Version 9.2*. AREVA Group, 75009 Paris

27 *Justification of FE selected areas*. PEER-F.10.1026 Revision A. AREVA. June 2010. TRIM Ref. 2011/93020.

28 *UK EPR Avoidance of fracture: Fracture mechanics and minimum toughness aspects – Material data*. NEEM-F 10.0179 Revision E. AREVA. TRIM Ref.2011/85962

29 *Fast Fracture Studies for critical defect sizes – determination in the RPV Cover Head weld.* PEER-F 10.1525 Revision A. AREVA. October 2010. TRIM Ref. 2011/94303.

30 *Determination of the Critical Defect size in the EPR RPV Head Weld Using R6 Methods*. ND-HSE. HSE-NII/1316/10 Issue 1. November 2010. TRIM Ref. 2011/89901.

31 *UK EPR Avoidance of fracture approach – Fast fracture studies for critical defect sizes determination in Steam Generator Tubesheet welded connections*. PEEG-F 10.1395 Revision B. AREVA. December 2010. TRIM Ref. 2011/94283.

32 *EPR – Assessment of Fast Fracture Risk in the Most Sensitive Areas.* (Steam Generators). PEEG-F DC 7 Revision A. AREVA. 6 August 2010. TRIM Ref. 2011/94284.

33 *Reactor Coolant Pump casing of EPR – Fast Fracture Analysis*. PEER-F 10.2038 Revision B. AREVA. 31 March 2011. TRIM Ref. 2011/200175.

34 *Fracture toughness properties of repair welds in cast pump casing*. PEEM-F 11.0567 Revision A. AREVA. 31 March 2011. TRIM Ref. 2011/200108.

35 *UK Reactor Coolant Pump of EPR – flywheel mechanical and fracture mechanics analysis*. PEER-F 10.1674 Revision A. AREVA. November 2010. TRIM Ref. 2011/94297.

36 *Reactor Coolant Pump of EPR, Flywheel mechanical and fracture mechanics analysis. PEER-F 10.1674 Rev B. AREVA NP. 19 August 2011. TRIM: 2011/439051.*

37 *UK EPR: Fast Fracture Studies to Determine Hot Leg Critical Defect Sizes.* ONR File Note. TRIM Ref. 2012/337012. 3 September 2012.

38 *Summary of the FMA approaches introduced in RSE-M Appendix 5.4 and RCC-MR Appendix A16 – illustration of their pertinence through an example*. PEER-F 10.1989 Revision A. AREVA. December 2010. TRIM Ref. 2011/123998.

39 *Design and Construction Rules for Mechanical Components of Fast Breeder Reactor Nuclear Island*. Appendix A16 – Analytical Methods for Calculating Stress Intensity Factors and Integral J. ©AFCEN. RSE-MR 2007. www.afcen.org

40 *UK EPR – Methodology to determine the critical defects in terms of fast fracture of unbreakable, no missile, break preclusion components*. NEER-F 10.0298 Revision C. AREVA. December 2010. TRIM Ref. 2011/123964.

41 *UK EPR End of Life critical defect size determination: specific modified RSE-M approach consistent with R6 rules to compare with the RSE-M approach*. PEER-F 10.1936 Revision A. AREVA. November 2010. TRIM Ref. 2011/124539.

42 *UK EPR Avoidance of fracture approach – fast fracture studies for critical defect size determination using surrogate R6 method (RSE-M V' option).* PEER-F 10.2069 Revision B. January 2010. TRIM Ref. 2011/86018.

43 *UK EPR Avoidance of fracture approach – fast fracture studies for critical defect size determination using surrogate R6 method (RSE-M V' option*). PEER-F 10.2069 Revision C December 2011. TRIM Ref. 2011/646255.

44 *Potential for Irradiation Embrittlement of RPV in UKEPR Reactor,* National Nuclear Laboratory document NNL (09) 10160, Issue 2 (Final). TRIM Ref. 2009/324536.

45 *PWR Materials Data Handbook, R96, Issue 3*. British Energy Generation Ltd.

46 *UK EPR Avoidance of Fracture Approach – Fast fracture analytical studies for critical defect sizes determination in main coolant lines*. PEERF 10-1286 Revision B. AREVA. TRIM Ref. 2011/646248.

47 *GI-UKEPR-CC02 – Topic Meeting Action Response and Closure.* Letter from UK EPR™ Project Front Office to ONR. EPR01282N. 2 August 2012. TRIM Ref. 2012/307188.

48 *UK EPR – Resolution of GDA Issue GI-UKEPR-CC-02.* Letter from ONR to UK EPR™ Project Front Office. EPR70419R. 4 May 2012. TRIM Ref. 2012/189414.

49 *Step 4 Fault Studies – Design Basis Faults Assessment of the EDF and AREVA UK EPR™ Reactor*. ONR Assessment Report ONR-GDA-AR-11-020a. Revision 0. November 2011, TRIM Ref. 2010/581404.

50 *UK EPR Ultrasonic examination of MCL homogeneous and dissimilar metal welds.* PEEM-F 11.0505 Rev. A. 1 April 2011. TRIM Ref. 2011/400301.

51 *UK EPR Ultrasonic examination of MCL homogeneous and dissimilar metal welds.* PEEM-F 11.0505 Rev. B. 7 September 2011. TRIM Ref. 2011/469213.

52 *UK EPR Ultrasonic examination of MCL homogeneous and dissimilar metal welds.* PEEM-F 11.0505 Rev C. 1 March 2012. TRIM Ref. 2012/326291

53 *UK EPR Main Coolant Lines Design Basis Report.* PEER-F DC 60A. AREVA NP. 8 September 2011. TRIM Ref. 2011/469212.

54 *BS-EN ISO Standard 17640:2010. NDT of welds – UT – Techniques, testing levels and assessment.*

55 *BS-EN 583-4: 2002, NDT- UT – Examination for discontinuities perpendicular to the surface.*

56 *Draft ISO/DIS 22825 24 March 2010, NDT of welds – UT – testing of welds in austenitic steels and nickel-based alloys.*

57 *Structural Integrity Assessment for GDA: GDA Issue GI-SI-01 on Avoidance of Fracture Actions 2 and 7.* Letter from ONR to UK EPR™ Project Front Office. EPR70373R. 14 October 2011. TRIM Ref. 2011/532215.

58 *GDA Issue GI-UKEPR-SI.01 on Avoidance of Fracture Actions 2 & 7.* Letter from UK EPR™ Project Front Office to ONR*. EPR01051N. 10 January 2012.* TRIM Ref. 2012/16179.

59 *UK EPR- ALARP justification of Manufacturing Inspection Technique proposed for Main Coolant Lines Welds of the UKEPR.* PEER-F DC 78 Rev A. 13 March 2012. TRIM Ref. 2012/116670.

60 *Ultrasonic Examination of the Steam Generator Safe-End – NGT process (used for EPR).* EFFQM 12/17004 Rev B. AREVA NP. 17 Feb 2012. TRIM Ref. 2012/100526.

61 *MCL Optimisation – U Leg Lowering Feasibility Study.* PEER-F DC 73 Rev B. AREVA NP. 3 Feb 2012. TRIM Ref. 2012/326335.

62 *UK EPR ™ Intermediate and Large Break LOCA – Feasibility study related to GDA Issue GI-UKEPR-SI01. PEPR-F 11.1421 Rev A. AREVA NP. Jan 2012. TRIM Ref. 2012/63072.*

63 *The Capability of Ultrasonic Inspection Procedures N1/5799/UT1 Rev 0 and N1/5799/UT2 Rev 1, Manufacturing Inspection of Reactor Coolant Loop Pipework – Narrow Gap TIG Shop Fabricated Pipe Butt Welds.* TD/IRB/REP0694 Issue 1. Nuclear Electric. March 1992. TRIM Ref. 2012/326358.

64 *Revision A MCL Optimisation – Counterbore Length Increase Feasibility Study*. PEERF-DC-079 Rev A. AREVA NP. 1 March 2012. TRIM Ref. 2012/100519.

65 *Demonstration of Integrity of High Integrity Components against fast fracture: Fracture mechanics Analysis – Non destructive Testing – Fracture toughness*. PEER-F 10.2070/C. AREVA NP. 14 May 2012. TRIM Ref. 2012/205370.

66 *UK EPR: Main Coolant Line Welds Optimisation – U-Leg Lowering Feasibility Study – PEER-F DC 73.* ONR File Note. TRIM Ref. 2012/140857. 30 May 2012.

67 *UKEPR Avoidance of fracture approach – Critical defect size in Break Preclusion classified secondary piping.* PESP-F 10.0460 Revision 1. AREVA. September 2010. TRIM Ref. 2011/93036.

68 *UK EPR Ultrasonic examination of MSL girth welds.* PEEM-F 11.0959 Rev A. AREVA NP. 26 July 2011. TRIM Ref. 2012/326524.

69 *UK EPR Ultrasonic examination of MSL girth welds*. PEEM-F 11.0959 Rev B. 26 March 2012. TRIM Ref. 2012/152329.

70 *UK EPR Results of simulation trials of Ultrasonic Examination on MSL girth welds. PEEM-F 11.1602 Rev A. AREVA NP. 10 October 2011.* TRIM Ref. 2011/532805.

71 *UK EPR Results of simulation trials of Ultrasonic examination on MSL girth welds. PEEM-F 11.1602 Rev C. AREVA NP. 29 February 2012.* TRIM Ref. 2012/116763.

72 *UT Modelling Study for MSSV welds inspection and Steam Isolation Valve weld inspection.* DT 28182/1. Intercontrole SA. 12 October 2011. TRIM Ref. 2011/532777.

73 *UT Modelling Study for MSSV welds inspection and Steam Isolation Valve weld inspection.* DT 28182/2. Intercontrole SA. 6 December 2011. TRIM Ref. 2012/116770.

74 *UK EPR Manufacturing Non-Destructive Testing to be Qualified.* PEEM-F 10.1134/D. AREVA NP. 21 Dec 2010. TRIM Ref. 2011/94289.

75 *UK EPR Pump Casing, Test Report (processes, application and summary of results). EFFQM 10/17210 Rev B. AREVA NP. 30 June 2011. TRIM Refs. Part 1: 2011/374833. Part 2: 2011/374836. Part 3: 2011/374839.*

76 *UK EPR Pump Casing, Test Report (processes, application and summary of results). EFFQM 10/17210 Rev. C. AREVA NP. 10 October 2011. TRIM Refs. Part 1: 2011/532726. Part 2: 2011/374836. Part 3: 2011/374839.*

77 *UK EPR Technical proposition for the NDT examination of major repair welds of the primary pump casing. PEEM-F 10.2218 Rev B. AREVA NP. 15 Sept 2011. TRIM Ref. 2011/494698.*

78 *Repairs in UKEPR cast austenitic pump bowls: assessment of potential RT and UT techniques. Serco/TCS/E.003282.54/R01 Issue 1. Nov 2010. TRIM 2011/47100.*

79 *EN ISO Standard 23279:2010. Non-destructive testing of welds — Ultrasonic testing — Characterization of indications in welds. March 2010.*

80 *Development of an Ultrasonic Inspection Technique for the Sizewell B PWR Cast Austenitic Reactor Coolant Pump Bowl. Gilroy K S. Proc. 4th European Conference on NDT. London, Sept 1987, pp. 1634-1646.*

81 *An Ultrasonic Inspection Procedure for the Sizewell B Cast Austenitic Pump Bowls. Booler R V et al. Brit. Jnl. NDT Vol 32 No 7 1990.*

82 *Non-Destructive Tests Performed on the Reactor Coolant Pump Flywheel during Manufacturing. PEEO-F 10.0715 Rev B. AREVA NP. 25 Aug 2011. TRIM: 2011/449746.*

83 *Non-Destructive Tests Performed on the Reactor Coolant Pump Flywheel during Manufacturing. PEEO-F 10.0715 Rev C. AREVA NP. 5 December 2011 TRIM: 2011/631183.*

84 *Reactor Coolant Pump of EPR, Flywheel mechanical and fracture mechanics analysis. PEER-F 10.1674 Rev C. AREVA NP. 30 November 2011. TRIM: 2011/631202.*

85 *Principles for the RCP Flywheel In-Service Inspection. ECEMA111847. EDF SA. 25 August 2011. TRIM: 2011/449744.*

86 *US NRC Regulatory Guide 1.14 rev 1. August 1975.*
US NRC Standard Review Plan Section 5.4.1.1 rev 2 – March 2007, Pump Flywheel Integrity (PWR).

87 *Non-destructive testing of steel forgings – Part 3: Ultrasonic testing of ferritic or martensitic steel forgings. BS EN 10228-3:1998.*

88 *Qualification of RCP Flywheel Keyway Inspection according to ENIQ. Guse G.. Intellige NDT Systems and Services. 8th Intern'l Conf. On NDE in Relation to Structural Integrity for Nuclear and Pressurised Components. Berlin. Sept 2010.*

89 *Technical Justification for UT Examination of Prototype Application.* PEEM-F 10.2217 Rev B. AREVA NP. 21 October 2011. TRIM Ref. 2011/545089.

90 *Ultrasonic Testing of Upper Shell/Upper Head. COUSUK/NPR0200 Revision A. AREVA. December 2010. TRIM Ref. 2011/85884.*

91 *Assessment of Capability of Proposed Inspection Techniques for UKEPR Pressuriser Weld and Comparison with Alternative Techniques. SERCO/TCS/E.003282.48/R01 Issue 1. September 2010. TRIM Ref. 2011/47023.*

92 *Ultrasonic Testing Of Butt Welds Tandem Method. COUSUK/NPR0201. Revision A. AREVA. December 2010. TRIM Ref. 2011/85855.*

93 *GDA Issue GI-UKEPR-SI.01 Avoidance of Fracture – Rebaselined Schedule*. Letter from UK EPR™ Project Front Office to ONR. EPR01220N. 29 June 2012 TRIM Ref. 2012/262627

94 *UKEPR – Avoidance of fracture demonstration of the Main Steam Isolation Valve.* PEEO-F 12.0359 Rev B. AREVA NP. July 2012. TRIM Ref. 2012/289432.

95 *Identification of High Integrity Components: components whose gross failure is discounted*. ENSNDR090183 Rev C. EDF Generation. July 2012. TRIM Ref. 2012/289431

96 *Demonstration of Integrity of High Integrity Components against fast fracture: Fracture mechanics Analysis – Non destructive Testing – Fracture toughness.* PEER-F 10.2070/D. AREVA NP. August 2012. TRIM Ref. 2012/338154

97 *GI-UKEPR-FS03 – Submission of revised safety case route map for the resolution of GI-UKEPR-FS03.* Letter from UK EPR™ Project Front Office to ONR. EPR01332N. 21 August 2012. TRIM Ref. 2012/333157.

98 *Technical Review of UK EPR End of Life Critical Defect Size Determination: Specific Modified RSE-M Approach Consistent With R6 Rules to Compare with RSE-M Approach.* British Energy. 22 December 2010. TRIM Ref. 2011/107749.

99 *European Methodology for Qualification of Non-Destructive testing. 3rd issue. ENIQ 31. EUR 22906 EN. August 2007. ISSN 1018-5593.*

100 *MCL Crossover leg vertical Straight parts Extension, Change Handover Form to Phase 2.*

UKEPR-CMF-031. 16 November 2012. TRIM Ref. 2012/451033.

101 *MCL Welds Counterbore Extension. Change Handover Form to Phase 2.* UKEPR-CMF-032. 12 October 2012. TRIM Ref. 2012/419564.

102 *GDA Close-out for the EDF and AREVA UK EPR™ Reactor- GDA Issue GI-UKEPR-IH-04 - Revision 2 – Consequences of Missile Generation Arising from Failure of RCC-M Components*. December 2012. TRIM Ref. 2012/15

103 *Demonstration of Integrity of Main Steam Line Incredibility of Failure Pipework Components.* Identified Reference IR 10.3(2). Sizewell B Power Station. Station Safety Report. SXB-IP-772001-766. Issue 101, 10 March 2003.

104 *UK Technical Report on the Manufacturing Non-Destructive Testing to be Qualified*. PEEM-F 10.1134 Revision B. AREVA. July 2010. TRIM Ref. 2011/123897.

105 *UK Technical Report on the Manufacturing Non-Destructive Testing to be Qualified*. AREVA. PEEM-F 10.1134 Revision D. December 2010. TRIM Ref. 2011/94289.

Table 1

Relevant Safety Assessment Principles Considered for Close-out of GI-UKEPR-SI-01 Revision 2

SAP No.	SAP Title	Description
EMC.1	Integrity of metal components and structures: highest reliability components and structures. Safety case and assessment	The safety case should be especially robust and the corresponding assessment suitably demanding, in order that an engineering judgement can be made for two key requirements: the metal component or structure should be as defect-free as possible; The metal component or structure should be tolerant of defects.
EMC.2	Integrity of metal components and structures: highest reliability components and structures. Use of scientific and technical issues	The safety case and its assessment should include a comprehensive examination of relevant scientific and technical issues, taking account of precedent when available.
EMC.3	Integrity of metal components and structures: highest reliability components and structures: Evidence	Evidence should be provided to demonstrate that the necessary level of integrity has been achieved for the most demanding situations.
EMC.4	Integrity of metal components and structures: general. Procedural control	Design, manufacture and installation activities should be subject to procedural control.
EMC.5	Integrity of metal components and structures: general. Defects	It should be demonstrated that safety-related components and structures are both free from significant defects and are tolerant of defects.
EMC.6	Integrity of metal components and structures: general. Defects	During manufacture and throughout the operational life the existence of defects of concern should be able to be established by appropriate means.
EMC.7	Integrity of metal components and structures: design. Loadings	For safety-related components and structures, the schedule of design loadings (including combinations of loadings), together with conservative estimates of their frequency of occurrence should be used as the basis for design against normal operating, plant transient, testing, fault and internal or external hazard conditions.
EMC.8	Integrity of metal components and structures: design. Requirements for examination	Geometry and access arrangements should have regard to the requirements for examination.

Table 1

Relevant Safety Assessment Principles Considered for Close-out of GI-UKEPR-SI-01 Revision 2

SAP No.	SAP Title	Description
EMC.9	Integrity of metal components and structures: design. Product form	The choice of product form of metal components or their constituent parts should have regard to enabling examination and to minimising the number and length of welds in the component.
EMC.10	Integrity of metal components and structures: design. Weld positions	The positioning of welds should have regard to high-stress locations and adverse environments.
EMC.11	Integrity of metal components and structures: design. Failure modes	Failure modes should be gradual and predictable.
EMC.12	Integrity of metal components and structures: design. Brittle behaviour	Designs in which components of a metal pressure boundary could exhibit brittle behaviour should be avoided.
EMC.13	Integrity of metal components and structures: manufacture and installation. Materials	Materials employed in manufacture and installation should be shown to be suitable for the purpose of enabling an adequate design to be manufactured, operated, examined and maintained throughout the life of the facility.
EMC.17	Integrity of metal components and structures: manufacture and installation. Examination during manufacture	Provision should be made for examination during manufacture and installation to demonstrate the required standard of workmanship has been achieved.
EMC.21	Integrity of metal components and structures: operation. Safe operating envelope	Throughout their operating life, safety-related components and structures should be operated and controlled within defined limits consistent with the safe operating envelope defined in the safety case.
EMC.23	Integrity of metal components and structures: operation. Ductile behaviour	For metal pressure vessels and circuits, particularly ferritic steel items, the operating regime should ensure that they display ductile behaviour when significantly stressed.

Table 1

Relevant Safety Assessment Principles Considered for Close-out of GI-UKEPR-SI-01 Revision 2

SAP No.	SAP Title	Description
EMC.24	Integrity of metal components and structures: monitoring. Operation	Facility operations should be monitored and recorded to demonstrate compliance with the operating limits and to allow review against the safe operating envelope defined in the safety case.
EMC.27	Integrity of metal components and structures: pre- and in-service examination and testing. Examination	Provision should be made for examination that is reliably capable of demonstrating that the component or structure is manufactured to the required standard and is fit for purpose at all times during service.
EMC.28	Integrity of metal components and structures: pre- and in-service examination and testing. Margins	An adequate margin should exist between the nature of defects of concern and the capability of the examination to detect and characterise a defect.
EMC.29	Integrity of metal components and structures: pre- and in-service examination and testing. Redundancy and diversity	Examination of components and structures should be sufficiently redundant and diverse.
EMC.30	Integrity of metal components and structures: pre- and in-service examination and testing. Control	Personnel, equipment and procedures should be qualified to an extent consistent with the overall safety case and the contribution of examination to the structural integrity aspect of the safety case.
EMC.32	Integrity of metal components and structures: analysis. Stress analysis	Stress analysis (including when displacements are the limiting parameter) should be carried out as necessary to support substantiation of the design and should demonstrate the component has an adequate life, taking into account time-dependent degradation processes.
EMC.33	Integrity of metal components and structures: analysis. Use of data	The data used in analyses and acceptance criteria should be clearly conservative, taking account of uncertainties in the data and the contribution to the safety case.

Table 1

Relevant Safety Assessment Principles Considered for Close-out of GI-UKEPR-SI-01 Revision 2

SAP No.	SAP Title	Description
EMC.34	Integrity of metal components and structures: analysis. Defect sizes	Where high reliability is required for components and structures and where otherwise appropriate, the sizes of crack-like defects of structural concern should be calculated using verified and validated fracture mechanics methods with verified application.
EAD.1	Ageing and degradation. Safe working life	The safe working life of structures, systems and components that are important to safety should be evaluated and defined at the design stage.
EAD.2	Ageing and degradation. Lifetime margins	Adequate margins should exist throughout the life of a facility to allow for the effects of materials ageing and degradation processes on structures, systems and components that are important to safety.
EAD.3	Ageing and degradation. Periodic measurement of material properties	Where material properties could change with time and affect safety, provision should be made for periodic measurement of the properties.
EAD.4	Ageing and degradation. Periodic measurement of parameters	Where parameters relevant to the design of plant could change with time and affect safety, provision should be made for their periodic measurement.
ECS.1	Safety classification and standards. Safety categorisation	The safety functions to be delivered within the facility, both during normal operation and in the event of a fault or accident, should be categorised based on their significance with regard to safety.
ECS.2	Safety classification and standards. Safety classification of structures, systems and components	Structures, systems and components that have to deliver safety functions should be identified and classified on the basis of those functions and their significance with regard to safety.
ECS.3	Safety classification and standards. Standards	Structures, systems and components that are important to safety should be designed, manufactured, constructed, installed, commissioned, quality assured, maintained, tested and inspected to the appropriate standards.

Annex 1

Technical Queries Raised During Close-out Phase

GI-UKEPR-SI-01 Revision 2 – Avoidance of Fracture – Technical Queries Raised

TQ Reference	GDA Issue Action	Related Submission	Description
TQ-EPR-1478	1		Fracture Assessment of the RPV Outlet Nozzle Dissimilar Metal Weld
TQ-EPR-1480	1		Fracture Assessment of the RPV Set-on Weld
TQ-EPR-1488	1		References for PEERF 10-1871
TQ-EPR-1492	1		RSE-M Appendix 5.4 FMA Approach
TQ-EPR-1510	1		RSE-M Option ‘V’
TQ-EPR-1521	1		Fracture Assessment of RPV Head Weld and SG Tubesheet Welded Connections
TQ-EPR-1523	1		RCP Bowl Fracture Assessment
TQ-EPR-1531	1		Aged Toughness Properties for RCP Weld Repair
TQ-EPR-1554	1		References for PEERF 10-1871
TQ-EPR-1572	1		RCP Bowl Fracture Assessment – Residual Stress
TQ-EPR-1588	1		References to TQ-EPR-1554
TQ-EPR-1597	1		RSE-M Appendix 5.4 FMA Limitations
TQ-EPR-1622	1		Thermal Ageing Allowance in Low Alloy Welds
TQ-EPR-1516	3		Main steam line weld inspection capability
TQ-EPR-1464	4		Capability of RT and UT for RCP bowl welded repairs
TQ-EPR-1519	4		Macrostructure of RCP casings

Annex 1

Technical Queries Raised During Close-out Phase

GI-UKEPR-SI-01 Revision 2 – Avoidance of Fracture – Technical Queries Raised

TQ Reference	GDA Issue Action	Related Submission	Description
TQ-EPR-1477	5		Evidence for the adequacy of manufacturing inspection of the RCP flywheel
TQ-EPR-1528	5		Scope of ultrasonic inspection of RCP flywheel during manufacture
TQ-EPR-1524	6		Prototype Technical Justification: Flow chart for defect characterisation
TQ-EPR-1598	-		Integrity Claim on the MSIV
TQ-EPR-1632	-		Identification of High Integrity Components

Annex 2

GDA Assessment Findings Arising from GDA Close-out for GI-UKEPR-SI-01 Rev 2

Finding No.	Assessment Finding	MILESTONE (by which this item should be addressed)
AF-UKEPR-SI-43	The Licensee shall undertake validation studies to confirm that the methodology used to calculate the limiting defect size for the RPV outlet nozzle dissimilar metal weld is appropriate.	Install RPV
AF-UKEPR-SI-44	The Licensee shall establish the limiting defect size for all High Integrity Components, including situations where cracked body finite element analyses are used to determine the limiting defect size.	Install RPV
AF-UKEPR-SI-45	The Licensee shall use material toughness properties for the fracture mechanics analyses that bound both the weld material and the HAZ material, and the base material if potentially limiting.	Install RPV
AF-UKEPR-SI-46	The Licensee shall explicitly identify the full thermal ageing shift in the HAZ material of the low alloy steel welds and any enhanced start of life properties required of the HAZ material in the materials data handbook used to support the UK EPR™. Any enhanced start of life properties for the HAZ should be demonstrated in the complementary fracture toughness testing.	Install RPV
AF-UKEPR-SI-47	The Licensee shall confirm that the reductions in fracture toughness to account for thermal ageing using values derived from accelerated thermal ageing tests at 10000 hours and 400°C are sufficient to account for a 60 year reactor life.	Install RPV

Annex 2

GDA Assessment Findings Arising from GDA Close-out for GI-UKEPR-SI-01 Rev 2

Finding No.	Assessment Finding	MILESTONE (by which this item should be addressed)
AF-UKEPR-SI-48	Should the Licensee adopt the RSE-M Appendix 5.4 fracture assessment procedure, the Licensee shall ensure that: ▪ updates to Appendix 5.4 of RSE-M and Appendix A16 of RCC-MR are reviewed as they are released to determine their impact on both future and existing assessments (even if they are only available in French at the time of release); ▪ they establish a presence on the committee developing Appendix 5.4 of RSE-M and Appendix A16 of RCC-MR; and ▪ they have a capability to identify any reservations and limitations on the use of RSE-M Appendix 5.4 as identified by the French Nuclear Safety Authority (ASN).	Install RPV
AF-UKEPR-SI-49	Should the Licensee adopt the RSE-M Appendix 5.4 fracture assessment procedure, the Licensee shall ensure that there is a capability to undertake assessment to RSE-M Appendix 5.4 independently of the company supplying the reactor design in order to support the ongoing operation of the reactor. The availability of technical support organisations to allow the UK Nuclear Regulator (ONR) to commission such assessment work independently should also be considered.	Install RPV
AF-UKEPR-SI-50	Should the Licensee adopt the RSE-M Appendix 5.4 fracture assessment procedure, the Licensee shall ensure that the UK methodology for undertaking the fracture assessments based on RSE-M Appendix 5.4 is suitable and sufficient to define the methodology in relation to RSE-M, and to explain and justify departures from RSE-M.	Install RPV

Annex 2

GDA Assessment Findings Arising from GDA Close-out for GI-UKEPR-SI-01 Rev 2

Finding No.	Assessment Finding	MILESTONE (by which this item should be addressed)
AF-UKEPR-SI-51	The Licensee shall review the upper shelf fracture toughness values used for areas affected by irradiation damage to ensure that they are consistent with the worldwide experience on the effect of irradiation damage on upper-shelf toughness and ensure that the surveillance scheme is adequate to confirm the assumptions made at the design stage.	Install RPV
AF-UKEPR-SI-52	The Licensee shall confirm through appropriate analyses and assessment that the detailed redesign of the MCL pipework to increase counterbore lengths and to lower the cross-over leg does not have any unacceptable safety detriments.	Install RPV
AF-UKEPR-SI-53	The Licensee shall demonstrate that the materials properties of the MCL forgings are adequately specified and controlled. This demonstration should include evidence that the M140 and shop qualifications for the MCL pipework remain valid for the modified design, and that the grain size is such that a reliable ultrasonic inspection of the parent material and associated welds can be achieved both during manufacture and in-service.	Install RPV
AF-UKEPR-SI-54	The Licensee shall ensure that the surface profile of the MCL pipework is adequately specified and controlled for all those surfaces on which ultrasonic transducers are scanned or from which ultrasonic beams may be reflected. This should include the effects of any local features such as overlay welding to compensate for welding distortions or profile variations caused by the counterbore cutting machine.	Install RPV
AF-UKEPR-SI-55	The Licensee shall ensure that during the design, manufacture and installation of all MSL components there are explicit checks on the detailed geometry near welds and other regions which require qualified NDT. These checks should ensure that the local component geometry (eg any component thickness changes or tapers) and the resultant surface profiles (both inside and outside the component) are such that an adequate inspection capability is achievable.	Install RPV

Annex 2

GDA Assessment Findings Arising from GDA Close-out for GI-UKEPR-SI-01 Rev 2

Finding No.	Assessment Finding	MILESTONE (by which this item should be addressed)
AF-UKEPR-SI-56	The Licensee shall ensure that the qualified volumetric inspections of welded repairs on the RCP bowl have the capability to reliably detect defects of the target size (i.e. defects smaller than the calculated limiting defect size by a margin of typically 2). The scope of these qualified inspections should include all repairs down to a size comparable with the target defect size and significantly smaller (typically by a margin of 2) than the limiting defect size.	Install RPV
AF-UKEPR-SI-57	The Licensee shall ensure that the inspection qualification of the radiographic and ultrasonic procedures for the RCP bowl and potential repairs takes account of the wide variation in the characteristics of potential defects and the need to demonstrate reliable detection and characterisation.	Install RPV
AF-UKEPR-SI-58	The Licensee shall ensure that when specifying the target values for chemical composition of the RCP pump bowls, the desirability of achieving a Type A macrostructure is taken into account.	Install RPV
AF-UKEPR-SI-59	The Licensee shall demonstrate that the assessments of capability of the manufacturing NDT procedures for the flywheel (PT and UT) take account of the HIC nature of the component and the full range of defect types which might occur and that the inspections will provide adequate capability to detect these defects.	Install RPV
AF-UKEPR-SI-60	The Licensee shall ensure that, once the details of the in-service inspections of the flywheel have been specified, the inspection capability is justified and the need for inspection qualification is considered.	Install RPV
AF-UKEPR-SI-61	The Licensee shall demonstrate that the parameters of the austenitic cladding applied to each HIC component, especially near welds, are adequately controlled and understood so that any potential adverse effects on the inspection capability are tolerable.	Install RPV
AF-UKEPR-SI-62	The Licensee shall review their site specific safety case during each significant upgrade to ensure that the list of components requiring an HIC claim is complete.	Initial Criticality

Annex 2

GDA Assessment Findings Arising from GDA Close-out for GI-UKEPR-SI-01 Rev 2

Finding No.	Assessment Finding	MILESTONE (by which this item should be addressed)
AF-UKEPR-SI-63	The Licensee shall review the fracture toughness values assumed for the fracture analysis of the MSIV pressure boundary to ensure that they are conservative and are likely to be achieved in practice.	Install RPV
AF-UKEPR-SI-64	The Licensee shall ensure that the castings used in the fracture toughness test programme for the MSIV body/bonnet and weld repairs will be suitable for establishing data that is fully applicable to the valve bodies and bonnets installed on a UK EPR™.	Install RPV
AF-UKEPR-SI-65	The Licensee shall undertake an MSIV specific fracture mechanics analysis to determine the limiting defect size for the MSIV. The analysis should cover the valve body, bonnet, weld repairs and the connection between the valve body and bonnet. It should postulate defects in all limiting locations taking into account all significant loadings applied to the MSIV including thermal shock and mechanical loads including those from the adjoining pipework.	Install RPV
AF-UKEPR-SI-66	The Licensee shall ensure that the volumetric NDT techniques selected for the MSIV body, bonnet and any potential repairs have the capability to reliably detect flaws of the target defect size (i.e. defects smaller than the calculated limiting defect size by a margin of typically 2). The scope of the inspections should cover the full volume of the component and include all repairs down to a size comparable with the target defect size. The Licensee shall also justify the level of qualification to be applied to the technique(s) selected for this high integrity component.	Install RPV
AF-UKEPR-SI-67	The Licensee shall ensure that the requirements for all non-destructive inspections of the MSIV body and bonnet (and any potential repairs) are fully specified and taken into account at the design stage. For example, it might be necessary for some inspections to be performed before final machining and weld repairs should be designed so that inspection requirements are satisfied.	Install RPV

Note: It is the responsibility of the Licensees / Operators to have adequate arrangements to address the Assessment Findings. Future Licensees / Operators can adopt alternative means to those indicated in the findings which give an equivalent level of safety.

Annex 2

For Assessment Findings relevant to the operational phase of the reactor, the Licensees / Operators must adequately address the findings during the operational phase. For other Assessment Findings, it is the regulators' expectation that the findings are adequately addressed no later than the milestones indicated above.

Annex 3

EDF AND AREVA UK EPR GENERIC DESIGN ASSESSMENT

GDA ISSUE

STRUCTURAL INTEGRITY – AVOIDANCE OF FRACTURE

GI-UKEPR-SI-01 REVISION 2

Technical Area	**STRUCTURAL INTEGRITY**		
Related Technical Areas	None		
GDA Issue Reference	**GI-UKEPR-SI-01**	**GDA Issue Action Reference**	**GI-UKEPR-SI-01.A1**
GDA Issue	Avoidance of Fracture - Margins Based on Size of Crack-Like Defects. Demonstration of defect tolerance and the absence of planar defects in the High Integrity Components (HICs) which requires integration of qualified non-destructive examinations during manufacture and analyses for limiting sizes of crack-like defects using conservative material fracture toughness properties.		
GDA Issue Action	Support assessment of the fracture analysis approach by providing adequate responses to any questions arising from assessment by ONR of documents submitted during GDA Step 4 but not reviewed in detail at that time. A number of fracture assessment reports arrived later in the Step 4 assessment timeframe than had been originally planned. As a result ONR has been unable to undertake a full assessment of all the fracture assessment reports within the timescales allowed for GDA Step 4, but has undertaken a high level review of the reports where a full assesmsent was not possible in order to gain confidence in the approach. This GDA Issue Action has been created to support the full assessment of the reports not yet fully assessed. EDF and AREVA should: • Provide adequate responses to questions arising from the ONR assessment of reports relating to this subject submitted during GDA Step 4 but not yet fully assessed. With agreement from the Regulator this action may be completed by alternative means.		

Annex 3

EDF AND AREVA UK EPR GENERIC DESIGN ASSESSMENT

GDA ISSUE

STRUCTURAL INTEGRITY – AVOIDANCE OF FRACTURE

GI-UKEPR-SI-01 REVISION 2

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<tr><td>Related Technical Areas</td><td colspan="3">None</td></tr>
<tr><td>GDA Issue Reference</td><td>GI-UKEPR-SI-01</td><td>GDA Issue Action Reference</td><td>GI-UKEPR-SI-01.A2</td></tr>
<tr><td>GDA Issue Action</td><td colspan="3">Provide an improved definition and evidence of capability of manufacturing inspection techniques for the austenitic and dissimilar metal welds. Provide more detail of the NDT methods proposed for certain components and provide additional evidence that these are likely to be capable of detecting defects smaller by some margin than the calculated limiting defect sizes (e.g. a target margin of 2). This evidence must include confirmation that the design of components facilitates an adequate inspection.
A high level review of the latest proposals from EDF and AREVA has identified gaps in the evidence required. Although two alternative ultrasonic inspection techniques are proposed, EDF and AREVA should provide the following information for at least one of these options:
• Evidence that the ultrasonic beams selected are able to detect defects of structural concern including those in the planes of the weld fusion faces over their full extent;
• Evidence that the design is such that there are no significant restrictions to inspection from features such as counterbores, changes of section thickness, tapered or curved surfaces, error of form etc;
• Evidence that, when fully developed, the ultrasonic detection and characterisation procedures are likely to have adequate capability for the expected sizes of the defects to be qualified.
• Adequate responses to questions arising from ONR assessment of documents relating to this subject whether submitted already or as a result of the Resolution Plan for this Action.
With agreement from the Regulator this action may be completed by alternative means.</td></tr>
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EDF AND AREVA UK EPR GENERIC DESIGN ASSESSMENT

GDA ISSUE

STRUCTURAL INTEGRITY – AVOIDANCE OF FRACTURE

GI-UKEPR-SI-01 REVISION 2

Technical Area		**STRUCTURAL INTEGRITY**	
Related Technical Areas		None	
GDA Issue Reference	**GI-UKEPR-SI-01**	**GDA Issue Action Reference**	**GI-UKEPR-SI-01.A3**
GDA Issue Action	Provide additional evidence of capability for the main steam line welds. Provide more detail of the NDT methods proposed for certain components and provide additional evidence that these are likely to be capable of detecting defects smaller by some margin than the calculated limiting defect sizes (e.g. a target margin of 2). This evidence must include confirmation that the design of components facilitates an adequate inspection. A high level review of the latest proposals from EDF and AREVA has identified gaps in the evidence required and as a result EDF and AREVA should provide: • Confirmation that the weld preparation angles are such that near-specular reflection is achievable over the full height of all welds. • Evidence confirming that the effects of any potentially significant restrictions to inspection (tapered or curved surfaces, counterbores, error of form etc) are acceptable; • Evidence that, when fully developed, the ultrasonic detection and characterisation procedures are likely to have adequate capability for the expected sizes (4-5mm) of the defects to be qualified. • Adequate responses to questions arising from ONR assessment of documents relating to this subject whether submitted already or as a result of the Resolution Plan for this Action. With agreement from the Regulator this action may be completed by alternative means.		

Annex 3

EDF AND AREVA UK EPR GENERIC DESIGN ASSESSMENT

GDA ISSUE

STRUCTURAL INTEGRITY – AVOIDANCE OF FRACTURE

GI-UKEPR-SI-01 REVISION 2

Technical Area	**STRUCTURAL INTEGRITY**		
Related Technical Areas	None		
GDA Issue Reference	**GI-UKEPR-SI-01**	**GDA Issue Action Reference**	**GI-UKEPR-SI-01.A4**
GDA Issue Action	Provide an improved definition of techniques and evidence of capability for inspection of repair welds in RCP casings. Provide more detail of the NDT methods proposed for certain components and provide additional evidence that these are likely to be capable of detecting defects smaller by some margin than the calculated limiting defect sizes (e.g. a target margin of 2). This evidence must include confirmation that the design of components facilitates an adequate inspection. A high level review of the latest proposals from EDF and AREVA has identified gaps in the evidence required. Activities by EDF and AREVA should comprise: • Submission of the detailed results from the inspection trials on the mock-up. • Evidence that, in addition to minimising the risk of any welding defects, the design of excavations for weld repairs will also take account of the need for NDT and particularly the need to ensure that the ultrasonic beams selected can achieve favourable angles of incidence on the fusion faces. • Adequate responses to questions arising from ONR assessment of documents relating to this subject whether submitted already or as a result of the Resolution Plan for this Action. With agreement from the Regulator this action may be completed by alternative means.		

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EDF AND AREVA UK EPR GENERIC DESIGN ASSESSMENT

GDA ISSUE

STRUCTURAL INTEGRITY – AVOIDANCE OF FRACTURE

GI-UKEPR-SI-01 REVISION 2

Technical Area	**STRUCTURAL INTEGRITY**		
Related Technical Areas	None		
GDA Issue Reference	**GI-UKEPR-SI-01**	**GDA Issue Action Reference**	**GI-UKEPR-SI-01.A5**
GDA Issue Action	Provide evidence justifying the manufacturing inspections of the RCP flywheel and the principles of ISI. Provide more detail of the NDT methods proposed for certain components and provide additional evidence that these are likely to be capable of detecting defects smaller by some margin than the calculated limiting defect sizes (e.g. a target margin of 2). This evidence must include confirmation that the design of components facilitates an adequate inspection. A high level review of the latest proposals from EDF and AREVA has identified gaps in the evidence required. Activities by EDF and AREVA should comprise: • Justification of the maximum overspeed used to derive the limiting defect size and an analysis of potential in-service initiation or growth. • Evidence that the manufacturing inspections adequately cover all plausible defects of concern: e.g. this should include evidence that ultrasonic inspection from the outer curved surface of the plates is not required, that the inspection holes do not require inspection during manufacture, and that the ultrasonic and penetrant inspections have the required capability. • Justification of any ISI proposed in comparison with that required by US NRC Reg. Guide 1.14. • Adequate responses to questions arising from ONR assessment of documents relating to this subject whether submitted already or as a result of the Resolution Plan for this Action. With agreement from the Regulator this action may be completed by alternative means.		

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EDF AND AREVA UK EPR GENERIC DESIGN ASSESSMENT

GDA ISSUE

STRUCTURAL INTEGRITY – AVOIDANCE OF FRACTURE

GI-UKEPR-SI-01 REVISION 2

Technical Area	**STRUCTURAL INTEGRITY**		
Related Technical Areas	None		
GDA Issue Reference	**GI-UKEPR-SI-01**	**GDA Issue Action Reference**	**GI-UKEPR-SI-01.A6**
GDA Issue Action	Provide additional evidence to support the technical justification of the prototype application. Provide more detail of the NDT methods proposed for certain components and provide additional evidence that these are likely to be capable of detecting defects smaller by some margin than the calculated limiting defect sizes (e.g. a target margin of 2). This evidence must include confirmation that the design of components facilitates an adequate inspection. EDF and AREVA should provide: • An explanation of how the defects proposed in the test piece will take into account the ‘worst case defects’ and will be sufficient to test the weaknesses identified in the inspection procedure. • An explanation of how the effects of the cladding (e.g. anisotropy, uneven interface with parent material) on the inspection capability will be taken into account, • Quantification of the maximum surface profile variations (error of form) on the surfaces of the weld and cladding and justification of its acceptability. • Clarification of how surface profile variations (error of form) are controlled and checked. • Clarification of the capability likely to be achieved using the flow charts for defect characterisation. • Adequate responses to questions arising from ONR assessment of documents relating to this subject whether submitted already or as a result of the Resolution Plan for this Action. With agreement from the Regulator this action may be completed by alternative means.		

Annex 3

EDF AND AREVA UK EPR GENERIC DESIGN ASSESSMENT

GDA ISSUE

STRUCTURAL INTEGRITY – AVOIDANCE OF FRACTURE

GI-UKEPR-SI-01 REVISION 2

Technical Area	**STRUCTURAL INTEGRITY**		
Related Technical Areas	None		
GDA Issue Reference	**GI-UKEPR-SI-01**	**GDA Issue Action Reference**	**GI-UKEPR-SI-01.A7**
GDA Issue Action	Provide additional evidence to confirm design and accessibility for in-service inspection (ISI). Provide more detail of the NDT methods proposed for certain components and provide additional evidence that these are likely to be capable of detecting defects smaller by some margin than the calculated limiting defect sizes (e.g. a target margin of 2). This evidence must include confirmation that the design of components facilitates an adequate inspection. EDF and AREVA should provide: • A systematic review of the locations proposed for ISI to confirm that, as well as being physically accessible, the design of all the HIC pipework welds facilitates inspections likely to have the required capability and that there are no undue restrictions from any local design features such as counterbores or tapered surfaces. • Adequate responses to questions arising from ONR assessment of documents relating to this subject whether submitted already or as a result of the Resolution Plan for this Action. With agreement from the Regulator this action may be completed by alternative means.		