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-CE-03 Revision 1 – Beyond Design Basis Performance of the Inner Containment

**and**

# GDA Issue GI-UKEPR-CE-04 Revision 1 - Analysis of the Containment

Assessment Report: ONR-GDA-AR-12-003
Revision 0
January 2013

## EXECUTIVE SUMMARY

The Office for Nuclear Regulation (ONR), an agency of the Health and Safety Executive (HSE), has carried out Generic Design Assessment (GDA) of the UK EPR™ nuclear power plant. Step 4 of GDA of the UK EPR™ included an assessment of the civil engineering design and the application of external hazards. The assessment of the design of the inner containment structure found that there was not yet sufficient justification of the following.

- The beyond design basis behaviour of the inner containment structure (**GI-UKEPR-CE-03)**.
- The design analysis of the containment structure had not been demonstrated to capture the behaviour in a sufficiently accurate manner (**GI-UKEPR-CE-04)**.

These topics had been raised by ONR during GDA Step 4 under Regulatory Observations, **RO-UKEPR-037** and **RO-UKEPR-076** respectively. EDF and AREVA submitted revised and additional safety case supporting documents in response to these Regulatory Observations towards the end of Step 4. These submissions were either not reviewed in detail at that time or had outstanding ONR queries. GDA Issues **GI-UKEPR-CE-03** and **GI-UKEPR-CE-04** were therefore raised to allow ONR to complete its assessment.

The objective of **GI-UKEPR-CE-03** Action 1 was for EDF and AREVA to support ONR's assessment associated with the beyond design basis behaviour of the inner containment structure and provide adequate responses to any questions arising. Action 2 required EDF and AREVA to provide a justification of why the containment fragilities used in the UK EPR™ PSA differed from those used for the beyond design basis assessment. This captured the further justification required to complete its response to **RO-UKEPR-037.**

The revised submissions provide a much greater level of detail and justification for the approach used than was provided during GDA Step 4. In particular, the overpressure case is much more clearly presented than previously and the summary of the beyond design basis assessment of the inner containment wall is satisfactory.

I have therefore found EDF and AREVA's response to **GI-UKEPR-CE-03** to be satisfactory and recommend this issue is closed. I have not raised any assessment findings for this issue.

The objective of **GI-UKEPR-CE-04** was for EDF and AREVA to support ONR's assessment of the containment structures analysis, specifically the documents submitted at the end of GDA Step 4 but not reviewed in detail at that time and provide adequate responses to any questions arising. It was also for EDF and AREVA to submit further justification in order to complete its response to **RO-UKEPR-076.**

The final documents submitted, including revisions resulting from my assessment comments, adequately justify the finite element analyses carried out for the design of the Inner Containment for the reference design of the Flamanville 3 plant. EDF and AREVA recognise that the reference design is specific to a site with very hard ground and based on modelling techniques that were developed over the last decade. Therefore, the methodology documents have also confirmed how future analysis models will benefit from up to date software and current good practice, and which factors are generic and which are site specific. I am satisfied that the form of the analysis models, proposed in the documents submitted for the UK EPR™ inner containment, will be sufficiently accurate to model the structural behaviour.

I have therefore found EDF and AREVA's response to **GI-UKEPR-CE-04** to be satisfactory and recommend this issue is closed. I have raised three assessment findings in order to ensure full substantiation is provided by the licensee for the containment analysis during the site specific phase.

## LIST OF ABBREVIATIONS

| | |
|---|---|
| AASHTO | American Association of State Highway and Transportation Officials |
| ACI | American Concrete Institute |
| AF | Assessment Finding |
| AFCEN | Association Française pour les règles de conception et de construction des matériels des Chaudières Électro Nucléaires |
| ALARP | As Low As Reasonably Practicable |
| AREVA | AREVA NP SAS |
| ASCE | American Society of Civil Engineers |
| C1 | Safety class 1 for civil structures |
| CEA | Commissariat à l'énergie atomique et aux énergies alternatives (French Alternative Energies and Atomic Energy Commission) |
| CEEH | Civil Engineering and External Hazards |
| COB | Coyne et Bellier |
| DBE | Design Basis Earthquake |
| EDF | Electricité de France SA |
| ETC-C | EPR Technical Code for Civil Works |
| FA3 | Flamanville 3 EPR Nuclear Power Plant, France. |
| FE | Finite Element |
| FRS | Floor Response Spectra |
| GDA | Generic Design Assessment |
| GI | GDA Issue |
| HCLPF | High Confidence Low Probability of Failure |
| HOW2 | ONR Business Management System (HOW2) |
| HSE | The Health and Safety Executive |
| IAEA | International Atomic Energy Agency |
| IC | Inner Containment |
| LOCA | Loss of Cooling Accident |
| LRFD | Load and Resistance Factor Design |
| MAEVA | MAquette Enceinte en Vapeur et en Air (Steam and Air Containment Model) – French test facility. |
| NI | Nuclear Island |
| NPP | Nuclear Power Plant |
| OL3 | Olkiluoto 3 EPR Nuclear Power Plant, Finland. |
| ONR | Office for Nuclear Regulation (an agency of HSE) |

## LIST OF ABBREVIATIONS

| | |
|---|---|
| PCSR | Pre-construction Safety Report |
| PSA | Probabilistic Safety Assessment |
| R&D | Research and development |
| RCC-G | AFCEN code for civil design of French nuclear power plants. |
| RG | Regulatory Guide (produced by US NRC) |
| RO | Regulatory Observation |
| SAP | Safety Assessment Principles |
| SEPTEN | Service Etudes et Projets Thermiques et Nucléaires (part of EDF) |
| SLB | (Pressuriser) Surge Line Break |
| SMA | Seismic Margins Assessment |
| SSC | System, Structure and Component |
| TAG | (Nuclear Directorate) Technical Assessment Guide |
| TQ | Technical Query |
| TSC | Technical Support Contractor |
| UK CD | UK Companion Document to AFCEN ETC-C 2010 Edition |
| US NRC | Nuclear Regulatory Commission (United States of America) |
| WENRA | Western Europe 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 civil engineering and external hazards. The report specifically addresses the close-out of two GDA Issues which concern the behaviour of the inner containment structure, **GI-UKEPR-CE-03 Rev 1** and **GI-UKEPR-CE-04 Rev 1** (Refs. 1 and 2). These issues were generated as a result of the GDA Step 4 Civil Engineering and External Hazards Assessment of the UK EPR™ (Ref. 3). The assessment has focussed on the deliverables identified within the EDF and AREVA Resolution Plans (Ref. 4 and 5) published in response to the GDA Issues 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 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 Civil Engineering and External Hazards (CEEH) Assessment identified six GDA Issues and 68 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 resulting from all assessment technical topics. The purpose of this report is to provide the assessment which underpins the judgement made in closing GDA Issues **GI-UKEPR-CE-03** and **GI-UKEPR-CE-04** arising from the CEEH assessment.

5 The EDF and AREVA safety case for the UK EPR™ design is contained within the Pre-construction Safety Report (PCSR) with the technical detail presented in the supporting documentation. The PCSR was originally submitted for GDA Step 4 assessment in November 2009. EDF and AREVA revised and resubmitted the PCSR in March 2011 (Ref. 6) in response to the findings of the ONR assessment and this forms the safety case for GDA Step 4. Sub-chapter 3.3 of the March 2011 PCSR describes the design of safety classified civil structures. This has required further revision in order to resolve **GI-UKEPR-CE-03** and **GI-UKEPR-CE-04** with the final issue in October 2012 (Ref. 7). I am satisfied that these revisions, plus the supporting documents discussed in this report reflect the additional justification required by my assessment of the response to the civil engineering GDA issues.

## 1.2 SCOPE

6 This report presents only the assessment undertaken as part of the resolution of these two GDA Issues and it is recommended that this report be read in conjunction with the Step 4 CEEH Assessment Report (Ref. 3) in order to appreciate the totality of the assessment of the evidence undertaken as part of the GDA process.

7 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 site specific phase.

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

## 1.3 METHODOLOGY

9 The methodology applied to this assessment is identical to the approach taken during Step 4 which followed the ONR business management system HOW2 document PI/FWD "Permissioning - Purpose and Scope of Permissioning", Issue 3 (Ref. 8), in relation to mechanics of assessment within ONR.

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

11 The assessment allows ONR to judge whether the submissions provided in response to the GDA Issue are sufficient to allow it to be closed. Where requirements for more detailed evidence have been identified that are appropriate to be provided at the design, construction or commissioning phases of the project these can be carried forward as assessment findings.

12 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 an affect on the claims made for other aspects of CEEH such that the existing case is undermined, these have been addressed.

## 1.4 STRUCTURE OF THIS REPORT

13 This assessment report structure differs slightly from the structure adopted for the previous reports produced within GDA, most notably the Step 4 CEEH Assessment (Ref. 3). The report has been structured with the assessment of two individual GDA Issues 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 GDA ISSUES GI-UKEPR-CE-03 AND GI-UKEPR-CE-04

### 2.1 CLOSE-OUT PLAN

15 The intended assessment strategy for GDA close-out for the Civil Engineering and External Hazards topic area was set out in an assessment plan (Ref. 9). This identified the intended scope of the assessment and the standards and criteria that would be applied.

16 The assessment plan was based on:

- the EDF and AREVA resolutions plans for all six Civil Engineering GDA Issues;
- the project programmes contained in the resolution plans;
- the work scope for technical support contractors (TSC) commissioned by ONR to support the assessment; and
- internal ONR resources and interaction with other topic Inspectors.

17 The scope of work contained within the assessment plan comprised assessment of the following:

- technical submissions made to ONR in accordance with the resolution plans;
- whether an update was required to the March 2011 Pre-construction Safety Report (PCSR) which had been reviewed during the GDA (Ref. 6);
- updates to the various documents supporting the PCSR.

### 2.2 THE APPROACH TO ASSESSMENT FOR GDA ISSUE CLOSE-OUT

18 The approach to the closure of the GDA for the UK EPR™ Project has comprised the 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 Plan for each GDA Issue.

19 During Step 4 of GDA, regular Level 4 technical meetings were held to allow discussion and clarification with EDF and AREVA on its submission documents. Since the majority of deliverables for close-out had already been identified and some GDA Issues were interrelated, points of clarification were progressed via continued dialogue of meetings. During the close-out phase, EDF and AREVA issued new or updated documents for ONR comment, and where appropriate these documents were revised again until convergence was reached on each technical point.

### 2.3 STANDARDS AND CRITERIA

20 The relevant standards and criteria adopted within this assessment are principally the Safety Assessment Principles (SAP), 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 ONR Technical Assessment Guides (TAG) 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.

### 2.3.1 SAFETY ASSESSMENT PRINCIPLES

21 The key SAPs applied within the assessment of GDA Issues **GI-UKEPR-CE-03** and **GI-UKEPR-CE-04** are included within Tables 1 and 2 of this report respectively. These are taken from Safety Assessment Principles for Nuclear Facilities. 2006 Edition Rev 1 (Ref. 12).

### 2.3.2 TECHNICAL ASSESSMENT GUIDES

22 The following Technical Assessment Guides have been used as the major underpinning guides for this assessment (Ref. 13).

- T/AST/013 External Hazards
- T/AST/017 Structural Integrity: civil engineering aspects

23 Other TAGs have been consulted as appropriate. These include:

- T/AST/005 ONR guidance on the demonstration of ALARP (as low as reasonably practicable)
- T/AST/004 Fundamental Principles

### 2.3.3 NATIONAL AND INTERNATIONAL STANDARDS AND GUIDANCE

24 The following international standards and guidance have been used as part of this assessment.

- International Atomic Energy Agency (IAEA) Safety Standard Series No. NS-R-1 (Ref. 14)
- Western European Nuclear Regulators' Association (WENRA) Reactor Reference Safety Levels (Ref. 15)

## 2.4 USE OF TECHNICAL SUPPORT CONTRACTORS

25 Assistance to ONR has been provided by Ramboll UK Ltd (formally Gifford) who provided technical specialism in finite element modelling and analysis.

## 2.5 OUT-OF-SCOPE ITEMS

26 There are no out of scope items. The entirety of GDA Issues **GI-UKEPR-CE-03 Rev 1** and **GI-UKEPR-CE-04 Rev 1** have been addressed. In addition, there are no changes to the scope of the GDA assessment detailed in the Step 4 report (Ref. 3).

## 3 EDF AND AREVA DELIVERABLES IN RESPONSE TO THE GDA ISSUES

### 3.1 RESOLUTION PLANS

27 The information provided by EDF and AREVA in response to these GDA Issues are detailed in EDF and AREVA's resolution plans (Ref. 4 and 5). An overview of the deliverables is provided within Section 4.3 for **GI-UKEPR-CE-03** and Section 5.3 for **GI-UKEPR-CE-04**. It is important to note that some of this information is supplementary to the information provided within the March 2011 PCSR (Ref. 6) which has already been subject to assessment during earlier stages of GDA. In addition, it is important to note that the deliverables are not intended to provide the complete safety case for the Civil Engineering and External Hazards area. Rather, they form further detailed arguments and evidence to supplement those already provided during earlier steps within the GDA Process.

### 3.2 INTERFACE WITH OTHER UK EPR™ DOCUMENTS

#### 3.2.1 MARCH 2011 PCSR

28 The resolution plan for **GI-UKEPR-CE-03** states that the only impact on GDA submission documents was the planned addendum to ENGSGC100106 Rev B. Since this document was not referenced in the March 2011 PCSR (Ref. 6), there would be no impact on the PCSR.

29 The resolution plan for **GI-UKEPR-CE-04** states that there would be no impact on the PCSR, since the documents submitted for justification of the finite element (FE) modelling are not directly referenced by the PCSR but support the technical safety case.

#### 3.2.2 ETC-C AND UK COMPANION DOCUMENT

30 The standard "EPR Technical Code for Civils Works" (ETC-C) was developed by EDF and AREVA for the design of the new fleet of EPR™ nuclear power plants, including Flamanville 3. Each of the civil structures in the reference design was designed using the ETC-C Rev B 2006 Edition (Ref. 16). The current version of this code, AFCEN ETC-C 2010 Edition (Ref. 17), will be used for the UK EPR™, with an accompanying UK Companion Document (Ref. 18) which has been specifically written to specify any changes to the AFCEN ETC-C 2010 that are required for the UK EPR™, in the same way Eurocodes are adapted to national standards by the UK national annexes.

31 The AFCEN ETC-C 2010 has now come under the auspices of AFCEN (French society for design, construction and in-service inspection rules for nuclear island components). AFCEN is a body set up in France to develop design and construction codes for nuclear power stations in light of current good practice and developments in research and development (R&D). It was founded by the French Atomic Energy Commission (CEA) and experts from the French nuclear industry. Therefore, the AFCEN 2010 Edition of the ETC-C (Ref. 17) is a stand alone document. EDF and AREVA use the UK Companion Document (UKCD, Ref. 18) to adapt the AFCEN ETC-C 2010 for the UK EPR™,

32 The resolution plans for either **GI-UKEPR-CE-03** or **GI-UKEPR-CE-04** did not state whether any modifications would be required to the AFCEN ETC-C 2010 or its accompanying UK CD.

## 3.3 INTERFACE WITH OTHER GDA ISSUES

33 GDA Issues **GI-UKEPR-CE-03** and **GI-UKEPR-CE-04** have interfaces with deliverables for other civil engineering GDA Issues, as given in Table 3 below. This means that some of the commitments made by EDF and AREVA in order to resolve **GI-UKEPR-CE-03** and **GI-UKEPR-CE-04** are included in documents produced as deliverables for other GDA Issues. Where this is the case, details of the commitment are given in the appropriate section of this report.

**Table 3: Interface of GI-UKEPR-CE-03 and GI-UKEPR-CE-04 with other Civil Engineering GI Deliverables**

| GDA Issue | Topic | Related Deliverables | CE-03 | CE-04 |
|---|---|---|---|---|
| **GI-UKEPR-CE-01** (Ref. 19) | Hypothesis and Methodology Notes | EPR Nuclear Island Civil Engineering Design Process (Ref. 23) | N | Y |
| **GI-UKEPR-CE-02** (Ref. 20) | Use of the ETC-C | UK Companion Document (to AFCEN ETC-C 2010) (Ref. 18) | N | Y |
| **GI-UKEPR-CE-03** (Ref. 1) | Beyond design basis behaviour of containment | Refer to this report. | - | Y |
| **GI-UKEPR-CE-04** (Ref. 2) | Containment analysis FE modelling | Refer to this report. | Y | - |
| **GI-UKEPR-CE-05** (Ref. 21) | Reliability of the ETC-C | ENGSGC100106 Rev B (Ref. 24) and its update in appendix to letter EPR00802R (Ref. 25) | Y | N |
| **GI-UKEPR-CE-06** (Ref. 22) | Seismic Analysis Methodology | ENGSDS100269 Rev B (Ref. 54) | N | Y |

# 4 GDA ISSUE GI-UKEPR-CE-03

## 4.1 SCOPE OF ASSESSMENT UNDERTAKEN

34 The scope of the assessment has been to consider the expectations detailed under the GDA Issue **GI-UKEPR-CE-03** and its associated two GDA Issue Actions. These are included within Annexe 2 of this report.

35 For **GI-UKEPR-CE-03** further evidence was sought for each of the following areas.

- Demonstrate that there is sufficient beyond design basis capacity in the containment to avoid a disproportionate increase in risk for loading beyond the design basis. This should include justification that the analysis of the containment structure is sufficiently robust to support the claims made on its integrity under fault conditions.
- Demonstrate that the fragilities used in the PSA analysis for the containment are sufficiently representative of the reference design.

## 4.2 BACKGROUND TO THE ISSUE

36 The beyond design basis behaviour of the UK EPR™ inner containment (IC) structure was assessed by ONR during Step 4 of GDA. Each of the civil structures in the reference design was designed using the “EPR Technical Code for Civil Works” (ETC-C) Rev B 2006 (Ref. 16). The current version of this code, AFCEN ETC-C 2010 (Ref. 17), will be used for the UK EPR™, with an accompanying UK Companion Document (Ref. 18) which has been specifically written to adapt the AFCEN ETC-C 2010 to UK standards, similar to a UK National Annexe used with Eurocodes.

37 The ETC-C is a bespoke code, developed by EDF and AREVA for the EPR™ project. It is based upon Eurocodes, European Standards, French Standards and other recognised guidance, but specifies additional criteria to be used for the EPR™. This reflects that some Eurocode rules should be amended and/or extended to apply to the specific demands placed on nuclear structures. These additional criteria have been developed within the French nuclear industry over the past decades.

38 One area which was raised as a Regulatory Observation (RO) in Step 4 of GDA (RO-UKEPR-037, Ref. 27) was the reliability of the AFCEN ETC-C 2010 as a design code, in other words how confident can we be that structures designed to it will meet the safety demands placed upon them. RO-UKEPR-037 had two actions; to clearly identify the target reliabilities and demonstrate that these reliabilities could be achieved using the AFCEN ETC-C 2010.

39 The response to **RO-UKEPR-037** comprised technical reports ENGSDS100093 Rev A, “RO 37 - Reliability of the EPR™ Inner Containment to Earthquake” (Ref. 28) and ENGSGC100106 Rev A, “Study of the Behaviour of the EPR Inner Containment Wall Beyond Design Basis Conditions” (Ref. 29). It was anticipated by ONR that the response on the behaviour against overpressure would provide valuable insights into the beyond design basis performance. However, this was not the case. The fragilities against seismic loading and overpressure used in the PSA analysis presented in Step 4 had been derived from data used for the US EPR™ and the links to the reference design of Flamanville 3 (FA3) were unclear.

40 These initial submissions were therefore found to fall short of Regulator expectations and detailed comments were communicated via ONR letter EPR70288R (Ref. 30). Although both reports were subsequently revised, they were submitted towards the end of GDA Step 4 and so were not reviewed in detail by ONR at that time.

41 The majority of comments made in letter EPR70288R were on the reliability of AFCEN ETC-C 2010 and these have been resolved under GDA Issue **GI-UKEPR-CE-05** (Ref. 31). However, as a result of the uncertainties on the beyond design basis behaviour of the IC and that the information was received towards the end of the Step 4 programme, GDA Issue **GI-UKEPR-CE-03** was raised to facilitate the subsequent assessment.

42 GDA Issue **GI-UKEPR-CE-03** has two actions associated with it.

- Action 1 was for EDF and AREVA to support ONR's assessment associated with the beyond design basis behaviour of the IC structure and provide adequate responses to any questions arising.
- Action 2 required EDF and AREVA to provide a justification of the approach used for the development of the containment fragilities used in the PSA analysis by comparison with the approaches used for beyond design basis assessment.

### 4.3 EDF AND AREVA DELIVERABLES

43 The information provided by EDF and AREVA in response to this GDA Issue is detailed within its resolution plan (Ref. 4). The following deliverables had been submitted towards the end of GDA Step 4, which meant ONR had been unable to review in detail at that time.

- Technical report ENGSDS100093 Rev B, "RO 37 - Reliability of the EPR Inner Containment to Earthquake", EDF and AREVA (Ref. 32).
- Appendix to letter EPR00768N, "Response to Regulatory Observation RO-UKEPR-37", EDF and AREVA (Ref. 33).
- Technical report PEPSPF/11.051, "Target Reliabilities for UK EPR™ Structures built with ETC-C", AREVA (Ref. 34).
- Appendix to letter EPR00802R "Response to Regulatory Observation RO-UKEPR-37", EDF and AREVA (Ref. 25) which included
    - Technical Report 12 680 RP 01-41, Rev A, "Answer to HSE Regulatory Observation RO-UKEPR-37 - Ultimate Pressures in EPR Containment - Comparison of Simplified Method (EPRI Method) to Method Based on Statistical Numerical Simulation" (Ref. 35).
    - Technical Report 12 680 RP 01-45, Rev B, "Answer to HSE Regulatory Observation RO-UKEPR-37 Determination of Failure Mode Ultimate Pressures – Comparison of Simplified (EPRI) or Fully Statistical Methods – Special Case of Low Probabilities" (Ref. 36).
- Technical report ENGSGC100106 Rev B, "Study of the behaviour of the EPR inner containment wall beyond design-basis conditions", EDF (Ref. 24).

44 In addition to the above deliverables EDF and AREVA also stated in the resolution plan that ENGSGC100106 Rev B (Ref. 24) would be revised further by an addendum which would provide a qualitative comparison of the fragilities developed for the PSA and for the beyond design basis assessment. This was submitted as an attachment to letter EPR00978N (Ref. 37) in October 2011.

## 4.4 ASSESSMENT OF THE RESPONSE TO GI-UKEPR-CE-03

### 4.4.1 OVERVIEW

45 The original issue stated that "*There is not yet sufficient justification of the beyond design basis behaviour of the EPR containment structure*". There are many facets to gaining confidence in the beyond design basis for the containment, a number of which were addressed within the Step 4 report (Ref. 3). Those issues which were satisfactorily addressed previously are the sensitivity of the structure to the loss of prestress, both globally and locally, and the ability to detect changes in the stress state of the vessel ahead of breaching the design basis.

46 The remnant concerns which were not fully addressed in the Step 4 assessment were the behaviour of the vessel for pressure loads beyond the design basis. The key SAP of relevance is EHA.7 which states that "*A small change in DBA parameters should not lead to a disproportionate increase in radiological consequences*".

47 The design basis of the containment is essentially elastic for the design basis loading, with some localised plasticity allowed in the liner. It is important to re-iterate that the liner performs no structural function for the containment and simply acts as a barrier to prevent significant leakage of potential releases resulting from a Loss of Cooling Accident (LOCA).

48 EDF and AREVA has assessed the beyond design basis behaviour of the IC structure by calculating the fragilities of the structure under the two dominant load cases; seismic and overpressure. The argument is that the difference between the actual fragilities and the target fragilities gives the measure of margin for beyond design basis events. This argument is acceptable, but is dependent on justification of how the actual fragilities are calculated (Action 1) and whether the target fragilities are appropriate (Action 2).

### 4.4.2 RESPONSE TO ACTION 1

49 The revised submissions ENGSDS100093 Rev B (Ref. 32) and ENGSGC100106 (Ref. 24) and the additional supporting documents (Ref. 25, 33 to 37) provide a much greater level of detail and justification for the approach used than was provided during GDA Step 4. In particular, the overpressure case is much more clearly presented than previously.

50 The updated fragility report ENGSDS100093 Rev B (Ref. 32) provided the clarifications and justifications requested. This report identified the two most critical areas as the design of the containment against seismic loading and against overpressure, along with the target reliabilities.

51 Report ENGSGC100106 Rev B (Ref. 24) provides a summary of the beyond design basis assessment of the IC wall. A range of failure scenarios are considered, with "failure" defined as elements reaching their limits of elongation. Furthermore the failure is one which would lead to a rapid depressurisation of the containment.

52 Assessments of the failure pressure have been undertaken at a High Confidence of Low Probability of Failure (HCLPF) level and at a 50% (Median) confidence level. For the purposes of this report, the 95 percentile values are considered, as these are more appropriate to consider with respect to the original design pressure.

53 Eight locations are considered in Ref. 24, with a number of failure modes considered at each location. The balanced nature of the design means that a number of failure modes needs to be considered at each location, as it is not necessarily clear which the limiting feature is. This approach is acceptable and is in line with SAP EHA.7 and ERL.1 (Refer to Table 1).

54 The failure pressures predicted vary between 1.1 MPa and 1.74 MPa, considerably above the design basis accident pressure of 0.45 MPa. It is considered that there are some conservatisms in the analysis approach which means that there is a greater margin to actual failure than that predicted by the work undertaken. These relate to simplifications in the material modelling and the definition of “failure”.

55 These deliverables demonstrate that there is a significant margin beyond the design basis. Thus I am satisfied that the IC structure is sufficiently robust and there is not a disproportionate increase in risk under fault conditions.

### 4.4.3 RESPONSE TO ACTION 2

56 The original action was to “Provide a justification of the approach used for the development of the containment fragilities used in the PSA analysis by comparison with the approaches used for beyond design basis assessment”. The fragilities used in the UK EPR™ PSA were calculated using a different approach to those used in the beyond design basis assessment for the reference design. The action therefore requested justification of why and how they differed.

57 The response to this action is provided by technical report ENGSGC100106 Rev B (Ref. 24) and its subsequent Appendix B which is contained in letter EPR00978 (Ref. 37). Ref. 37 explains how the fragility functions for the primary containment were derived for the Level 2 PSA for the UK EPR™. The work was originally carried out for the Flamanville 3 EPR™ in France (FA3). The calculations were then revised for the EPR™ plant in Olkiluoto, Finland (OL3) and then for the US EPR™. The UK calculations therefore gain benefit from the development of all these designs.

58 Section 6.10 of Ref. 24 compares the fragility curves derived for FA3 with those used in the UK EPR™ Level 2 PSA. Appendix B (Ref. 37) provides more details of the derivation of the fragility functions used in the PSA and the reasons for the differences from the fragility curves used for the structures. These reasons are that the UK EPR™ Level 2 PSA was developed in 2007 and submitted under GDA Step 3. Although the reference design was for FA3, the most developed fragility information at that time was for the US EPR™. The US EPR™ fragility functions were more conservative than the FA3 and OL3 curves and therefore introduced further safety margin into the UK EPR™ PSA results. This extra margin could accommodate possible future changes in detailed design data for the FA3 containment, which were not then finalised.

59 Appendix B also explains how the OL3 fragility functions were adapted for the US EPR™, to take account of material and reinforcement differences. A comparison is then given in Table B3 of the Annex between the results from FA3, OL3 and the US EPR™ and this demonstrates the conservative nature of the values used for the UK EPR™ PSA.

### 4.4.4 CONCLUSIONS FOR GI-UKEPR-CE-03

60 It is considered that the response in reports ENGSDS100093 Rev B (Ref. 32), ENGSGC100106 Rev B (Ref. 24) and supporting references has justified there is sufficient margin beyond the design basis load case for containment pressure loads, which is the most dominant loadcase for the IC structure. The documents demonstrate that there is no disproportionate increase in risk as a result of changes in the design basis parameters and provide sufficient justification of the beyond design basis behaviour. The response to the GDA Issue **GI-UKEPR-CE-03 Action 1** is therefore acceptable**.**

61 I am satisfied that the additional information given in the new Appendix B (Ref. 37) to ENGSGC100106 Rev B (Ref. 24) has satisfactorily compared the fragilities used in the UK EPR™ Level 2 PSA analysis and those used in the beyond design basis assessment.

Differences between the two approaches have been justified and there is no conflict in the resulting analyses. The response to the GDA Issue **GI-UKEPR-CE-03 Action 2** is therefore acceptable**.**

# 5 GDA ISSUE GI-UKEPR-CE-04

## 5.1 SCOPE OF ASSESSMENT UNDERTAKEN

62 The scope of the assessment has been to consider the expectations detailed under the GDA Issue **GI-UKEPR-CE-04** and its associated single GDA Issue Action. These are included within Annexe 3 of this report.

63 **GI-UKEPR-CE-04** sought further clarification of the overall analytical process for the inner containment (IC) structure and specific aspects of structural performance as follows:

- Further justification of the methods used to create the finite element (FE) models of the IC structure for seismic analysis, in relation to AFCEN ETC-C 2010 requirements.
- Further justification of the damping ratio used in the FE models for the pre-stressed IC structure.
- Comparison between the equivalent static seismic analysis and the global NI model.
- Further justification of the simplifications used in the FE representation of the foundation.

## 5.2 BACKGROUND TO THE ISSUE

64 The finite element analysis of the Class 1 (C1) IC structure was assessed by ONR during Step 4 of GDA. A Regulatory Observation (**RO-UKEPR-076**, Ref 19) was raised to request further justification of the overall analytical process for the IC and of specific modelling details of the FE analysis. There were five actions for **RO-UKEPR-076** which requested more information on the global models and sub-models used whether they had appropriate boundary conditions and whether the models adequately captured local stress conditions, concrete cracking etc. The use of the equivalent static force method for the seismic analysis of the IC was also queried, and this is a cross-over issue with **GI-UKEPR-CE-06**, raised on the seismic analysis methodology.

65 The response to **RO-UKEPR-076** Actions A1, A2 and A3 was contained in letter EPR00830N (Ref. 38) which was received in March 2011 towards the end of Step 4. This meant that a detailed review could not be included in the GDA Step 4 timeframe. As a result, GDA Issue **GI-UKEPR-CE-04** was raised at the end of the Step 4 process to allow assessment of the deliverables for Actions A1, A2 and A3 and to allow submission of the deliverables for the remaining Actions A4 and A5.

66 GDA Issue **GI-UKEPR-CE-04** has a single action which is for EDF and AREVA to provide support during the ONR assessment of the deliverables for this issue. The following four areas are highlighted as requiring further justification.

- Seismic calculations for the IC structure in relation to AFCEN ETC-C 2010 requirements. The stress and strain limits defined in the AFCEN ETC-C 2010 permit structural behaviour that may include cracking of the concrete or yielding of steel, such as reinforcement or liner. GDA Step 4 concluded that further justification was required for the use of linear elastic analysis methods for the design of the IC.
- Damping ratio of the pre-stressed concrete containment structure. GDA Step 4 concluded that further justification was required for the damping values used for the IC structural analysis.
- Comparison between equivalent static seismic analysis of the pre-stressed IC and seismic spectrum analysis with global NI model. This required further details of the

various FE models used and how the equivalent static forces were calculated using an acceleration field generated from the global NI model.

- Simplifications over the representation of the foundation. The GDA Step 4 assessment queried how the foundation had been represented in the various FE models and that model boundaries had been positioned close to the gusset region, which is an area of high local stresses.

## 5.3 EDF AND AREVA DELIVERABLES

67 The information provided by EDF and AREVA in response to this GDA Issue is detailed within their resolution plan (Ref. 5). The following deliverables had been submitted towards the end of GDA Step 4, which meant ONR had been unable to review in detail at that time.

- Technical report 12680-RP01-39 Rev D, "Analysis of Inner Containment" Coyne et Bellier (Ref. 39).
- Technical report ENGSGC110030 Rev A, "Analysis of EPR Inner Containment - GDA/Step4 – Inner Containment Seismic Calculations in Relation with ETC-C Requirements", EDF and AREVA (Ref. 40).
- Technical report 12680-RP01-46 Rev B, "Damping Ratio of the Pre-stressed Concrete Containment Structure", Coyne et Bellier (Ref. 41).
- Technical report 12680-RP01-49 Rev C, "Comparison Between Equivalent Static Seismic Analysis of the Pre-stressed Inner Containment and Seismic Spectrum Analysis with Global NI Model", Coyne et Bellier (Ref. 42).
- Technical report ENGSDS100269 Rev A, "UK EPR™ – Methodology for Seismic Analysis of NI Buildings", EDF and AREVA (Ref. 26). It should be noted that the final version of this document delivered under **GI-UKEPR-CE-06**, seismic analysis methodology, is Rev B (Ref. 54).

68 In addition, the resolution plan stated further documents (not identified) would be submitted in answer to **GI-UKEPR-CE04 Action 1**. These were submitted in July 2011 via letter EPR00903R (Ref. 43) and comprised the following.

- Technical report 10420/R-01, Issue 2, "UK EPR™ – Analysis of Inner Containment – Justification for use of Linear Elastic Methods for Design of the Inner Containment of the UK EPR™" Scanscot Technology Ltd, (Ref. 44).
- Technical report ENGSGC110026, Rev A, "Description and Justification of Analysis Methods Used in the Design of the UK EPR™ Inner Containment" (Ref. 45).

## 5.4 ASSESSMENT OF THE RESPONSE TO GI-UKEPR-CE-04

### 5.4.1 OVERALL ANALYTICAL PROCESS

69 The Step 4 GDA found that the description of the analytical process for the UK EPR™ was contained within a number of documents. This was further complicated due to the analyses for the reference design being carried out by several different firms using different software. **GI-UKEPR-CE-04** therefore requested a coherent description of the overall analytical process for the IC structure. This topic is also partially covered by **GI-UKEPR-CE-06** (Ref. 22) which requested a summary of the seismic analysis methodology and **GI-UKEPR-CE-01** (Ref. 19) which requested a summary design hypothesis document to describe the civil engineering design process for the scope of

GDA i.e. the Nuclear Island and Diesel Building. The ONR assessment reports (Ref. 46 and Ref. 47) should be referred to for assessment of each of these issues.

70 The documents produced for the above GDA Issues have clarified the overall analytical process used for the IC structure of the reference design submitted for GDA. These documents expanded the information contained within ECEIG102044 Rev B (Ref. 48) which is the "EPR Inner Containment Wall Detailed Design Report ("route map")" and is a major reference of Sub-chapter 3.3 of the PCSR. This route map was assessed during Step 4 and noted as an overview of the design evolution as well as a route map through the design process, identifying the key documents (Section 4.3.6.4.5 of Ref. 3).

71 Overall, it is now clear that the method of analysis used is based on the standard response spectrum approach and applied to the whole NI using the global floor response spectra model of the NI, referred to as the global FRS Model (Ref. 46). A sub-modelling process has been followed where acceleration fields obtained from the global FRS model are applied to separate more detailed models of the IC. ECEIG102044 Rev B (Ref. 48) notes in Section 7.3 that "*in order to compute nodal stresses and then forces and moments in the IC wall, 5 distinct FE models are needed for elastic (stress) analysis, though they are geometrically similar*". For the purposes of my assessment I will refer to this set of five models as the detailed IC Model.

72 The sub-modelling process is only correct if the detailed IC model masses, stiffnesses and boundary/support conditions are the same as those represented in the global FRS Model. All analyses also have to be linear. My assessment noted (Ref. 49) that inconsistencies in the boundary conditions between the global FRS model and sub-models in the reference design, could lead to an underestimate of earthquake loads, although it is not clear whether this would be significant or not. The effect of this on the detailed IC model is assessed in Section 5.4.5.1.

73 Overall this analysis methodology developed by EDF and applied by Coyne et Bellier (COB) has been proven as valid although it is not an established technique (Ref. 49). It was also not included as a recommended technique in the ETC-C 2006 Edition (Ref. 16). However, the updated AFCEN ETC-C 2010 Edition (Ref. 17) now includes it under other types of analysis in Section 1.A.10. I am satisfied that the description of the overall analytical process is sufficiently documented by the submission documents. The specific analytical aspects which were queried by my assessment (Ref. 55) are discussed in the following sections.

### 5.4.2 ETC-C REQUIREMENTS

74 Justification had been sought during GDA Step 4 for the use of linear elastic analysis methods for the seismic calculations in relation to the IC, with reference to the AFCEN ETC-C 2010 limits. EDF and AREVA submitted Letter EPR00903R (Ref. 43) plus two documents in response to this action which corresponds to the first item of **GI-UKEPR-CE-04.A1**. It should be noted that the detailed assessment of the AFCEN ETC-C 2010 and its UK Companion Document has been carried out under **GI-UKEPR-CE-02** and my assessment report should be referred to (Ref. 50).

75 The query raised was that the stress and strain limits defined in the AFCEN ETC-C 2010 permit structural behaviour that may include cracking of the concrete or yielding of reinforcement or the steel liner to the containment. Document ENGSGC110026 Rev A (Ref. 45) summarises the approach to concrete cracking, but refers to the Scanscot Technology report 10420/R-01 (Ref. 44) for the detail.

76 Ref. 44 describes that the UK EPR™ design approach for the IC is based on the use of the AFCEN ETC-C 2010 design code with linear elastic analysis methods. The containment is designed against load combinations which are grouped according to the frequency of occurrence as follows:

- Group 1 Load Combinations
  - Construction Loads
  - Normal Operating Loads
  - Periodic Tests
  - Inspection Earthquake
- Group 2 Load Combinations
  - Internal accidents (LOCA or high energy pipe rupture)
  - Severe accident (0.55 MPa)
  - Design Basis Earthquake
- Group 3 Load Combinations
  - Severe accident (0.65 MPa )
  - Large LOCA (due to pressuriser surge line break (SLB)) + Design Basis Earthquake

77 The concrete containment structure is designed against normal and accidental load cases using AFCEN ETC-C 2010 stress limits for materials applicable to the load combination group. Therefore, concrete cracking is allowed in Group 2 combinations and steel yielding is allowed in Group 3 combinations. The stress limits on materials for the containment structure are given in Table 1.4.5-1 in the ETC-C. Ref. 44 demonstrates that the limits for Groups 2 and 3 are more onerous than those in Eurocode 2 and that they are derived from the earlier RCC-G code which has been used for previous French NPPs. Therefore, I am satisfied that the justification given for the AFCEN ETC-C 2010 limits is reasonable.

78 Clause 1.4.4.1 of the AFCEN ETC-C 2010 allows the induced thermal loads to be reduced by a factor to account for "*the cracking of concrete under the effect of heat and depending on the linear or non-linear distribution and on the normal force*". This factor is given as 0.5 for the pre-stressed wall of the containment. The justification for the 0.5 value is given in Section 3 of Ref. 44 which states that this allows for the self-relieving nature of thermal stress due to cracking and deformation of the structural member. However, the AFCEN ETC-C 2010 also allows a reduced value of concrete modulus in Clause 1.A.4.3 for cracked concrete elements, specifically beams and slabs in flexure (0.35) and columns and walls in transverse flexure (0.7).

79 It is usual practice to use a reduced concrete young's modulus (E) in the FE analysis model to account for cracking of concrete in extreme load cases. The query raised in GDA Step 4 was whether the 0.5 was applied to the thermal loads simultaneously as using a reduced E value in the FE model to which those loads were applied. If this is the case, then it could result in double counting the same effect.

80 The justification given in Ref. 44 quotes international practice which confirms that the 0.5 factor applied in Clause 1.4.4.1 of AFCEN ETC-C 2010 is a reasonable value. It is also clear that the examples given apply the reduction to either the thermal loads (as in

American bridge design (Ref. 51)) or the concrete modulus (as in ACI 349 method (Ref. 52)). Section 4 of Ref. 44 also states that the 0.35 and 0.7 factors defined in AFCEN ETC-C 2010 clause 1.A.4.3 (ETC-C 2006 Clause 1.A.3.2) are applied to slender elements where the seismic bending action is transverse and therefore significant cracking could occur. These factors are not applied to the IC structure and so stress relief from concrete cracking for thermal effects is only accounted for by Clause 1.4.4.1 of the AFCEN ETC-C 2010.

81 The "EPR Nuclear Island Civil Engineering Design Process Note" (Ref. 23) submitted under **GI-UKEPR-CE-01** also clarifies that for structures other than the IC, which are subject to thermal loads e.g. ponds, the reduction will be applied to the concrete modulus. Different values are calculated for thermal load cases depending on whether short term or long term thermal effects are considered (Sections 2.3.2.1 and 2.3.3.1).

82 I am therefore satisfied that both reduction factors will not be applied simultaneously to a concrete structure for a specific load case.

83 The final outstanding query with regards to modulii was whether any sensitivity studies on the significance of cracked concrete had been carried out. Section 6 of Ref. 44 states that "*The design of the EPR inner containment, based on linear elastic analysis and ETC-C design rules, is intended to ensure that the behaviour under normal and accidental load cases remains substantially linear and that cracking is minor and does not challenge the functional capability of the containment. The sensitivity to cracking can be verified from feedback experience from containments of the operating reactors in the EDF NPP fleet, and experience from tests in the large scale MAEVA containment mock-up, which was designed according to similar rules."*

84 Experience from NPP fleet includes measurement of actual concrete modulii and Poisson ratios in the containment wall during pressure tests during commissioning through to 20 years operation. The MAEVA mock-up tests (MAquette Enceinte en Vapeur et en Air) are described as "*a good validation of the containment design methodology based on ETC-C rules"*. These tests were also considered in GDA Step 4 and found to be valuable benchmarking of the predicted behaviours (Ref. 3). I accept these two methods as reasonable and that they demonstrate the AFCEN ETC-C 2010 rules adequately take account of concrete cracking in the containment structure.

### 5.4.3 DAMPING

85 The damping values for structures subjected to the design earthquake are specified in Section 1.A.4.2.1 and Table 1.A-1 of the AFCEN ETC-C 2010 (Ref. 17). The UK Companion Document (Ref. 18) produced for the UK EPR™ does not alter these values. The design uses 5% critical damping for pre-stressed concrete for all levels of earthquake.

86 **GI-UKEPR-CE-04** requested further justification of the damping ratio used for the pre-stressed concrete containment structure. This issue had previously been raised during GDA Step 4 which questioned whether the same damping was justified for the inspection earthquake as well as the design basis earthquake. This is because damping is caused by the loss of energy in the structure during an earthquake due to cracking and damage. For the inspection earthquake, the structure should be performing closer to linear-elastic, i.e. no cracking, and so the damping used for service load cases is normally much less.

87 The damping values were compared with current good practice by Ramboll (Ref. 49). The US Nuclear Regulatory Commission (US NRC) produces regulatory guides (RG) on design of nuclear power plants in the US. For pre-stressed concrete structures RG 1.61

(Ref. 53) recommends 5% damping for the safe shutdown earthquake and 3% damping for the operating basis earthquake. These two earthquakes may be compared to the design basis earthquake and the inspection earthquake.

88 The justification of using 5% damping throughout is addressed in EDF and AREVA documents ENGSGC110026 Rev A (Ref. 45), ENGSGC110030 Rev A (Ref. 40) and 12680-RP01-46 Rev B (Ref. 41). Ref. 40 compares the AFCEN ETC-C 2010 with the NRC RG 1.61 and a French standard CEA0606 Rev A, which also uses 5%. Since the stress limits in the ETC-C Group 2 situations are similar to the RG 1.61 stress limits, Ref. 40 concludes that ETC-C "*Group 2 situations requirements meet RG 1.61 rules which justify the use of a 5% critical damping value".* This is accepted.

89 Ref. 41 is provided as a sensitivity study on the effect of the damping coefficient on the global seismic forces at the base of the containment structure. Two values of damping are compared; 5% and 2%, both for the design basis earthquake. Damping of 2%, applied to the design basis earthquake loadcase is more conservative than the 3% recommended by RG 1.61 for the operating basis earthquake. The use of 2% damping results in 30% more reinforcement being required than for 5% damping. However, since the containment pressure loadcase dominates the design, the actual reinforcement provided in the wall of the IC and in the gusset is still far greater than that required for a DBE with 2% damping. This therefore envelopes the case of inspection earthquake with 3% damping.

90 I conclude that the above submission documents have proved that the use of 5% critical damping for the pre-stressed IC structure for the inspection earthquake does not affect the final reinforcement used in the reference design.

### 5.4.4 EQUIVALENT STATIC SEISMIC ANALYSIS

91 **GI-UKEPR-CE-04** requested further justification of the comparison between equivalent static seismic analysis of the pre-stressed IC and seismic spectrum analysis with global NI model. This resulted from **RO-UKEPR-76** Action 3 (i).

92 Document ENGSGC110026 Rev A (Ref. 45) Section 4.3 summarises the EDF and AREVA response to **RO-UKEPR-76** Action 3 (i). It states that "*the equivalent static method is shown to give large safety margins in the evaluation of global forces and over-turning moments compared with those that would be deduced by applying NI seismic spectral analysis directly*." The evidence for this claim is Coyne et Bellier report 12680-RP01-49 Rev C (Ref. 42) which compares a set of calculations of equivalent static seismic forces for the IC with the forces obtained directly from the NI global FE Model for response spectrum analysis (FRS model).

93 The forces compared are the global shear forces and overturning moments in the horizontal directions (Fx, Fy, Mx and My) at base of the containment structure ( -7.85m level). Ref. 42 calculates that the forces from the equivalent static approach are at least 18% larger than those calculated directly from the NI Global FRS FE Model. This is conservative and so is acceptable.

94 The justification provided within 12680-RP01-49 Rev C (Ref. 42) has shown the equivalent static approach to be conservative for the IC structure. It is not a technique generally used within the UK nuclear industry and was not described in the ETC-C 2006 Edition (Ref. 16) which was submitted during Step 4 GDA. The updated version AFCEN ETC-C 2010 (Ref. 17) has been assessed under **GI-UKEPR-CE-02** and now includes this method of analysis in Section 1.A.10.

95 This topic is also considered under resolution of **GI-UKEPR-CE-06** Seismic Analysis Methodology and my assessment report for this issue (Ref. 46) assessed the deliverable ENGSDS100269 Rev A (Ref. 26) which is also a deliverable under this GDA Issue. I concluded in Ref. 46 that the use of the equivalent static analysis was valid provided it was justified to be conservative for each building. ENGSDS100269 had been updated to Rev B (Ref. 54) such that Section 5.5.3 now includes that "*a justification of the conservatism of this approach shall be given on a case by case basis. The consistency between the results obtained from the global and the detailed models shall be justified*."

96 In addition, the UK CD Rev D (Ref. 18) Clause 1.A.10 now includes the statement "*a justification of the conservatism of this static approach shall be given, on a case by case basis*" as a result of my assessment for closure of **GI-UKEPR-CE-02** and **GI-UKEPR-CE-06.**

97 I conclude that the use of the equivalent static analysis for the IC structure has been justified to be adequately conservative in line with SAP ECE.13.

### 5.4.5 SIMPLIFICATIONS OF FE MODEL FOUNDATION

98 **GI-UKEPR-CE-04** requested further justification of the simplifications made in the representation of the foundation in the detailed IC model and the axisymmetric model used for the IC structural analysis. These are remnant queries from the response to **RO-UKEPR-76** Actions 1 and 2.

99 The specific queries considered in my close-out assessment are as follows.

- Justification of the suitability of the boundary being placed at the base of the gusset and its boundary conditions.
- Justification that the mesh density in the gusset region of the detailed IC model is fine enough to model the local stress distribution.
- Justification that the software FERRAIL is applicable for thick sections.

#### 5.4.5.1 BOUNDARY AT BASE OF IC MODEL

100 The ONR queries raised during the Step 4 GDA with respect to the boundary between the detailed IC model and the NI global FRS Model were as follows.

1) Its position had been chosen in the reference design to be to the underside of the gusset which is a region of high local stress. Good practice would normally choose an FE model boundary to be in a region of low stress.
2) The boundary conditions used in the reference design comprised springs attached to the central node of the gusset, spaced every 19m around the circumference. This had not been proven to be fine enough to adequately model the local effects.
3) Calculation of the springs resulted from a separate axisymmetric FE model and justification that this adequately modelled the soil structure interaction of the whole NI and common raft had not been provided.

101 The Coyne et Bellier report 12680-RP01-39 Rev D, "Analysis of Inner Containment" (Ref. 39) states that the choice of boundary location "*is considered to be optimal with regards to:*

- *The actual formwork* [layout] *of the NI and its multiple interfaces to the other NI buildings,*

- *The need for a "manageable" set of boundary conditions at the base of the Inner Containment FE Model, as the interface to the FE models used for the balance of the NI structures".*

102 EDF and AREVA report ENGSGC110026, Rev A, "Description and Justification of Analysis Methods Used in the Design of the UK EPR™ Inner Containment" (Ref. 45) also states that "*the global raft of the Nuclear Island is significantly stiffened by the structures it supports thus making an "almost" infinitely rigid raft regardless of the soil conditions, again indicating a low weight for the applied boundary conditions*."

103 Whilst this does mean that the behaviour of the IC and the NI is closer to that with a rigid base, this has only been justified for the FA3 reference design which is dominated by very hard ground. For a softer site the relative flexibility of the raft foundation/ground with the IC and NI superstructures may become more marked. This effect would need to be analysed adequately for the site specific strata.

104 At the civil engineering Level 4 technical meeting in January 2012 (Ref. 57), EDF and AREVA confirmed that the UK EPR™ detailed IC model would include the common raft such that the boundary adjacent to the gusset would not be required. This methodology has been documented in the "EPR Nuclear Island Civil Engineering Design Process", ECEIG111110 Rev B (Ref. 23) which is a major underpinning document for the GDA PCSR.

105 Section 2.3.3.2.1 of Ref. 23 states that the detailed IC model will include the part of the common raft required "*to enable its contribution to the stiffness of the base of the IC to be taken into account*……*The interfaces between models must be clearly defined and shall include…. which boundary conditions are applied and how the behaviours of both models are reconciled."* Furthermore the boundary conditions *"will be applied at each boundary node of the detailed IC model" and "use of these boundary conditions will allow non-axisymmetric loading to be taken into account".*

106 The methodology stated in Ref. 23 satisfactorily answers the queries 1), 2) and 3) listed above. Although the exact position of the boundary will be finalised by the detailed design of the UK EPR™ during site specific phase, it is clear it will not be adjacent to singularities which are subject to high local stress. Secondly, the springs to the base of the detailed IC model will not be used, and boundary conditions will be applied to all nodes on the boundary, not just central to the concrete section on the cut line. Therefore, the axisymmetric model is no longer required and calculation of soil structure interaction will be based on the actual non-axisymmetric layout of the NI.

107 I therefore raise the following assessment finding,

> ***AF-UKEPR-CE-73****: The licensee shall provide sufficient evidence to justify the boundary interfaces between finite element analysis models and sub-models for the site specific inner containment analysis. Justification shall include the calculation of the boundary conditions, to prove adequate modelling of the soil structure interaction for seismic and non-seismic load cases.*
>
> **Required Timescale:** *first structural concrete.*

108 A second aspect of boundary conditions considered in my assessment (see Section 5.4.1), was whether the boundary conditions for the detailed IC model matched the same boundaries in the global FRS model. For instance the TSC's report (Ref. 49) noted in the case of the reactor building model different earthquake directions have different support conditions whereas in the analysis of the NI acceleration field, results were obtained with fully fixed boundaries around the reactor raft skirt for all earthquake directions. For the

sub-modelling process and the equivalent static analysis to be correct the boundary conditions in model and sub-model must be the same. I therefore raise the following assessment finding,

***AF-UKEPR-CE-74**: The licensee shall provide evidence that the boundary conditions used for sub-models are compatible with the global response spectra model, such that the data generated by the global model e.g. seismic motion or loading, can be applied correctly to the sub-model.*

***Required Timescale:** first structural concrete.*

#### 5.4.5.2 MESH REFINEMENT AT GUSSET

109 ENGSGC110026 (Ref. 45) argues that EN 1992-1-1 sections on analysis do not require mesh density studies. Whilst it is true that the code does not explicitly require such a study, it is assumed the mesh density should be adequate and justified (Ref. 49). **RO-UKEPR-076** requested results of any such studies to be provided because it was not clear that the mesh density was adequate.

110 Section 4.1 of Ref. 45 states that "*Whilst no specific sensitivity studies have been carried out, the use of multiple models with different mesh refinements provides partial verification of the FE model results and provides evidence of convergence with respect to mesh density*." The verification can only be done for load cases which can be analysed in both models being compared, however since there are five different detailed IC models (see Section 5.4.1) covering the full range of loadcases this approach is valid (Ref. 49).

111 It is clear in Section 5.4.5.1 that the FE model of the IC structure is to be modified for future EPR$^{TM}$ designs to include the common raft, or an appropriate part of it. The gusset region is likely to be re-built. Also since it is a singularity (area of high local stress) the mesh size must be fine enough to adequately model the local effects. I therefore raise the following assessment finding,

***AF-UKEPR-CE-75**: The licensee shall provide sufficient evidence to justify the mesh size is adequate to model the local stress concentrations in the gusset region in the site specific detailed inner containment finite element analysis model.*

***Required Timescale:** first structural concrete.*

#### 5.4.5.3 REINFORCEMENT CALCULATIONS USING FERRAIL

112 The query raised during GDA Step 4 was whether the computer design software FERRAIL was applicable for reinforcement design of a thick section such as the gusset that may not be subject to a linear strain distribution. FERRAIL is a COB in-house code which is used to calculate areas of reinforcing steel required according to rules in the AFCEN ETC-C 2010 code, taking loads from FE software codes ANSYS or COBEF as primary input (Ref. 3).

113 COB report 12680-RP01-39 Rev D, "Analysis of Inner Containment" (Ref. 39) confirms that the gusset reinforcement was calculated using the 3D axisymmetric model which includes the common raft such that no boundary is required near the gusset. It argues that this model does not restrain the gusset area and so *"its behaviour remained close to "plane deflection" which was the boundary condition imposed at the base of the detailed IC model*." Ref. 39 also references several design documents for FA3 where hand calculations have been carried out to cross check FERRAIL results, not just for the gusset area, but also for other singularities such as the polar crane area.

114 I am satisfied that the justification provided for the FERRAIL results for the FA3 design has demonstrated that this software is appropriate for reinforcement design of the gusset region in the reference design.

### 5.4.6 CONCLUSIONS FOR GI-UKEPR-CE-04

115 My assessment of the responses to **GI-UKEPR-CE-04** and specific deliverables to interrelated GDA Issues, **GI-UKEPR-CE-01, GI-UKEPR-CE-02** and **GI-UKEPR-CE-06** has found that the further justification of the IC structural analysis requested by **GI-UKEPR-CE-04** has been satisfied, subject to three assessment findings.

116 The overall analytical process has been clarified by the submissions as using a sub-modelling process for the IC structure. Five different sub-models are used which analyses different loadcases and so complement one another. The sub-models depend on input from the global FRS model of the NI, and so accuracy depends on the boundary conditions for the interface between them.

117 The requirements of the AFCEN ETC-C 2010 design code for FE analysis, material properties and stress limits have been examined. I am satisfied that these requirements adequately take account of cracking in the containment concrete and that the IC analysis is in accordance with the AFCEN ETC-C 2010.

118 The damping value used for the IC analysis for the inspection earthquake (5%) is higher than ONR would anticipate. However, the evidence submitted proves that when a conservative value of 2% is used, the final reinforcement design is unaffected.

119 Global forces at the base of the IC calculated from the equivalent static seismic analysis of the detailed IC Model have been compared with forces calculated directly from the global FRS NI Model. The comparison has shown the equivalent static seismic analysis is conservative. My assessment of the response to **GI-UKEPR-CE-06** concluded that the use of the equivalent static analysis was valid provided it was justified to be conservative for each building. This requirement has been included into the UK EPR™ seismic methodology documents.

120 EDF and AREVA propose to revise the detailed IC Model and its interfaces with the global FRS Model of the NI for future EPR™ designs in the UK. These re-built models will include the resolution of the queries raised on the reference design with respect to the FE modelling of the gusset region at the base of the IC, the boundary conditions and how soil structure interaction is modelled. I have raised three assessment findings in this area, such that the licensee provides justification that the re-built models are in accordance with my assessment (refer to Section 7).

## 6 INTERFACE OF GI-UKEPR-CE-03 AND GI-UKEPR-CE-04 WITH KEY DOCUMENTS

### 6.1 REVIEW OF THE PCSR

121 Information on the IC structural analysis presented for GDA Step 4 was contained in the March 2011 PCSR (Ref. 6) within Sub-chapter 3.3 Issue 03 "Design of Category 1 Civil Structures". The sub-chapter is arranged on a structure by structure basis with Section 2.3 covering the design basis of the IC and Section 2.4 covering the reliability of the IC.

122 No changes have been required to the PCSR in order to resolve **GI-UKEPR-CE-03.**

123 The PCSR Sub-chapter 3.3 required minor changes resulting from the resolution of **GI-UKEPR-CE-01** and these were submitted as Issue 04 in June 2012. Some of these changes were also applicable to **GI-UKEPR-CE-04** and are noted below.

- Introduction of the new overarching document, the "EPR Nuclear Island Civil Engineering Design Process" document, ECEIG111110 Rev B (Ref. 23).
- Sections on FE modelling (2.3.3 and 2.4) have been re-ordered and re-titled as 2.3.3 and 2.3.4 to clarify the stages of modelling and what modelling has been done for the FA3 reference design.
- The following statement in Section 2.3.4 (previously 2.3.3) has been deleted
  - The total stiffness of the foundation raft and the soil beneath is represented by springs. The spring stiffness is determined using an asymmetric model, which represents the lower part of the inner and outer containment walls, the foundation raft and soil beneath.

124 The final version of Sub-chapter 3.3 was Issue 05 (Ref. 7) which was submitted in October 2012. No further changes were required between Issues 04 and 05 in response to **GI-UKEPR-CE-04.**

125 I am satisfied that Sub-chapter 3.3 of the PCSR, Issue 05 (Ref. 7), along with the supporting reference documents, are sufficient to describe the civil engineering safety case for the analysis of the IC and its beyond design basis behaviour.

### 6.2 REVIEW OF UK CD TO THE ETC-C

126 The UK Companion Document Rev E (Ref. 18) comprises amended clauses from the AFCEN ETC-C 2010 (Ref. 17) for use for the UK EPR™. The UK CD therefore takes precedence over the AFCEN ETC-C 2010 for the civil engineering works design.

127 No changes have been required to the UK CD for either **GI-UKEPR-CE-03** or **GI-UKEPR-CE-04**. The changes to specific clauses discussed in this report have resulted from resolution of **GI-UKEPR-CE-02** and **GI-UKEPR-CE-06** and have complemented my conclusions in this report. The exact changes and the justification for each are given in "Assessment File of the UK Companion Document to AFCEN ETC-C" (Ref. 56).

### 6.3 INTERFACE WITH OTHER GDA ISSUES

128 Resolution of this issue has required revisions to documents which are deliverables for other GDA Issues, as follows.

- "EPR Nuclear Island Civil Engineering Design Process" (Ref. 23) submitted under **GI-UKEPR-CE-01.**
- UK Companion Document (Ref. 18) submitted under **GI-UKEPR-CE-02.**

- "Study of the Behaviour of the EPR Inner Containment Wall Beyond Design-Basis Conditions" (Ref. 24) submitted under **GI-UKEPR-CE-05.**
- ENGSDS100269 Rev B (Ref. 54) submitted under **GI-UKEPR-CE-06.**

129 The specifics of my assessment of these deliverables with respect to each GDA issue are given in the relevant ONR assessment reports (Refs. 31, 46, 47 and 50) which should be read in conjunction with this report.

# 7 ASSESSMENT FINDINGS

130 The following assessment findings, also listed in Annex 1, should be taken forward as normal regulatory business, in addition to those identified in the Step 4 Civil Engineering Assessment Report (Ref. 3).

## 7.1 ADDITIONAL ASSESSMENT FINDINGS FOR GI-UKEPR-CE-03

131 No additional assessment findings have been raised for the resolution of **GI-UKEPR-CE-03.**

132 The ONR assessment report for the close-out of GDA Issue **GI-UKEPR-CE-05** (Ref. 31) records the regulatory assessment of the detailed calculations of the achieved reliabilities for the containment against the two most critical areas, seismic loading and overpressure. These detailed calculations are also an appraisal of the margin for beyond design basis behaviour and so are linked **GI-UKEPR-CE-03.** The report concluded that the deliverables for **GI-UKEPR-CE-05** demonstrate that the AFCEN ETC-C 2010 does ensure that the necessary reliability can be achieved through its appropriate use and two assessment findings were raised (**AF-UKEPR-CE-69** and **AF-UKEPR-CE-70**).

## 7.2 ADDITIONAL ASSESSMENT FINDINGS FOR GI-UKEPR-CE-04

133 The ONR assessment report for GDA Issue **GI-UKEPR-CE-06** (Ref. 46) records the regulatory assessment of the seismic analysis methodologies which is linked to **GI-UKEPR-CE-04.** The report concluded that the seismic analysis methodology was satisfactory and the documents clarified which aspects of the GDA reference design would need to be modified for the site specific design. Two assessment findings were raised (**AF-UKEPR-CE-71** and **AF-UKEPR-CE-72**).

134 Three assessment findings have been raised for **GI-UKEPR-CE-04** as follows:

> ***AF-UKEPR-CE-73***: *The licensee shall provide sufficient evidence to justify the boundary interfaces between finite element analysis models and sub-models for the site specific inner containment analysis. Justification shall include the calculation of the boundary conditions, to prove adequate modelling of the soil structure interaction for seismic and non-seismic load cases.*
>
> ***Required Timescale:*** *first structural concrete.*
>
> ***AF-UKEPR-CE-74***: *The licensee shall provide evidence that the boundary conditions used for sub-models are compatible with the global response spectra model, such that the data generated by the global model e.g. seismic motion or loading, can be applied correctly to the sub-model.*
>
> ***Required Timescale:*** *first structural concrete.*
>
> ***AF-UKEPR-CE-75***: *The licensee shall provide sufficient evidence to justify the mesh size is adequate to model the local stress concentrations in the gusset region in the site specific detailed inner containment finite element analysis model.*
>
> ***Required Timescale:*** *first structural concrete.*

## 7.3 IMPACTED STEP 4 ASSESSMENT FINDINGS

135 There are no impacted Step 4 findings for either **GI-UKEPR-CE-03** or for **GI-UKEPR-CE-04.**

# 8 ASSESSMENT CONCLUSIONS

## 8.1 GDA ISSUE GI-UKEPR-CE-03

136 I am satisfied that the documents submitted by EDF and AREVA provide sufficient further justification as required by GDA Issue **GI-UKEPR-CE-03** Actions A1 and A2, as follows.

- Justification of the assessment of the beyond design basis behaviour of the inner containment structure.
- Justification of the approach used for the development of the containment fragilities used in the PSA analysis by comparison with the approaches used for beyond design basis assessment.

137 My assessment of the evidence presented, taken in conjunction with the findings of my assessment for **GI-UKEPR-CE-05** (Ref. 31), has confirmed that there is sufficient margin above design basis for the inner containment structure for the most critical loadcase of internal pressure.

138 I therefore conclude that **GI-UKEPR-CE-03** can be closed.

## 8.2 GDA ISSUE GI-UKEPR-CE-04

139 My assessment of the responses to **GI-UKEPR-CE-04** and specific deliverables to interrelated GDA Issues, **GI-UKEPR-CE-01, GI-UKEPR-CE-02** and **GI-UKEPR-CE-06** has confirmed that the further justification of the inner containment structural analysis requested by **GI-UKEPR-CE-04** has been satisfied, subject to three assessment findings.

140 The assessment findings raised are to require the licensee to provide justification that the final FE models used for the detailed design of the UK EPR™ address my queries on the gusset region at the base of the inner containment wall, the boundary conditions and how soil structure interaction is modelled.

141 I therefore conclude that **GI-UKEPR-CE-04** can be closed.

## 9 REFERENCES


**Ref. Document**

1 *GDA Issue GI-UKEPR-CE-03 Revision 1.* ONR. July 2011. TRIM Ref. 2011/311020.

2 *GDA Issue GI-UKEPR-CE-04 Revision 1* ONR. July 2011. TRIM Ref. 2011/361011.

3 *Step 4 Civil Engineering and External Hazards Assessment of the EDF and AREVA UK EPR™ Reactor*. ONR Assessment Report ONR-GDA-AR-11-018 Revision 0. December 2011. TRIM Ref. 2010/581513.

4 *Resolution Plan for GI-UKEPR-CE03* Revision 1. EDF and AREVA. July 2011. TRIM Ref 2011/347665.

5 *Resolution Plan for GI-UKEPR-CE04* Revision 0. EDF and AREVA. June 2011. TRIM Ref 2011/345911.

6 *UK EPR™ GDA Step 4 Consolidated Pre-construction Safety Report – March 2011.* Detailed in EDF and AREVA letter UN REG EPR00997N. Letter from UK EPR™ Project Front Office to ONR. 18 November 2011. TRIM Ref. 2011/552663.

7 *UK EPR™ PCSR – Sub-chapter 3.3 – Design of Safety Classified Civil Structures.* UKEPR-0002-035 Issue 05. EDF and AREVA, October 2012. TRIM Ref. 2012/422397.

8 *PI/FWD Permissioning - Purpose and Scope of Permissioning.* ONR HOW2 Business Management System. Issue 3.

9 *Assessment Plan for Civil Engineering and External Hazards - Closure of GDA for the EPR™.* ONR Assessment Plan ONR-GDA-AP-11-001 Revision 0. November 2011. TRIM Ref. 2011/650014.

10 *NOT USED*

11 *NOT USED*

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

13 ONR HOW2 Business Technical Assessment Guides

- *External Hazards.* T/AST/013 Issue 4. July 2011.
- *Structural Integrity Civil Engineering Aspects*. T/AST/017 Issue 2. HSE. March 2005
- *ONR guidance on the demonstration of ALARP (as low as reasonably practicable).* T/AST/005 Issue 4 Revision 1. January 2009.
- *Fundamental Principles*. T/AST/004 Issue 3. March 2010.

www.hse.gov.uk/nuclear/operational/tech_asst_guides/index.htm.

14 *Safety of Nuclear Power Plants: Design. Safety Requirements.* International Atomic Energy Agency (IAEA). Safety Standards Series No. NS-R-1. IAEA. Vienna. 2000. www.iaea.org.

| Ref. | Document |
|---|---|
| 15 | *Western European Nuclear Regulators' Association. Reactor Harmonization Group. WENRA Reactor Reference Safety Levels.* WENRA. January 2008. www.wenra.org. |
| 16 | *ETC-C* (*EPR Technical Code for Civil Works).* ENGSGC050076 Revision B. EDF. 2006. TRIM Ref. 2010/404165. |
| 17 | *ETC-C – 2010 Edition - EPR Technical Code for Civil Works.* AFCEN. 23 December 2010. TRIM Ref. 2011/430452. |
| 18 | *UK EPR™ - UK Companion Document to AFCEN ETC-C.* ENGSGC110015 Revision E. EDF and AREVA. September 2012. TRIM Ref. 2012/350151. |
| 19 | *GDA Issue GI-UKEPR-CE-01 Revision 1*. ONR. July 2011. TRIM Ref. 2011/385288. |
| 20 | *GDA Issue GI-UKEPR-CE-02 Revision 1.* ONR. July 2011. TRIM Ref. 2011/385289. |
| 21 | *GDA Issue GI-UKEPR-CE-05 Revision 1.* ONR. July 2011. TRIM Ref. 2011/385292. |
| 22 | *GDA Issue GI-UKEPR-CE-06 Revision 1.* ONR. July 2011. TRIM Ref. 2011/385293. |
| 23 | *EPR Nuclear Island Civil Engineering Design Process.* ECEIG111110 Revision B. EDF and AREVA. June 2012. TRIM Ref. 2012/243767. |
| 24 | *Study of the behaviour of the EPR inner containment wall beyond design-basis conditions*. ENGSGC100106 Revision B. EDF. January 2011. TRIM Ref. 2011/128750. |
| 25 | *Response to Regulatory Observation RO-UKEPR-37.* Letter from UK EPR™ Project Front Office to ONR. Unique Number EPR00802R. 24 February 2011. TRIM Ref. 2011/118407. |
| 26 | *UK EPR™ - Methodology for Seismic Analysis of NI Buildings.* ENGSDS100269 Revision A. EDF and AREVA. February 2011. TRIM Ref. 2011/128975. |
| 27 | *EDF and AREVA UK EPR™ - Schedule of Regulatory Observations Raised during GDA Step 1 to Step 4.* HSE-ND. TRIM Ref. 2010/600727. |
| 28 | *RO 37 - Reliability of the EPR Inner Containment to Earthquake.* ENGSDS100093 Revision A. EDF and AREVA. April 2010. TRIM Ref. 2011/155904. |
| 29 | *Study of the behaviour of the EPR inner containment wall beyond design-basis conditions*. ENGSGC100106 Revision A. EDF. April 2010. TRIM Ref. 2011/155919. |
| 30 | *Response to RO-37 Step 2*. EPR70288N. Letter from ONR to UK EPR™ Project Front Office. 21 January 2011. TRIM Ref. 2011/47921. |
| 31 | *GDA Close-out for the EDF and AREVA UK EPR™ Reactor – GDA Issue GI-UKEPR-CE-05 Revision 1 – Reliability of the ETC-C.* ONR Assessment Report ONR-GDA-AR-12-001 Revision 1. May 2012. TRIM Ref. 2012/214232. |

| Ref. | Document |
|---|---|
| 32 | *RO 37 - Reliability of the EPR Inner Containment to Earthquake.* ENGSDS100093 Revision B. EDF and AREVA. January 2011. TRIM Ref. 2011/85930. |
| 33 | *Response to Regulatory Observation RO-UKEPR-37*. Letter from UK EPR™ Project Front Office to ONR. Unique Number EPR00768N. 3 February 2011. TRIM Ref. 2011/70169. |
| 34 | *Target Reliabilities for UK EPR™ Structures built with ETC-C*. PEPSPF/11.051. AREVA. January 2011. TRIM Ref. 2011/128261. |
| 35 | *Answer to HSE Regulatory Observation RO-UKEPR-037 – Ultimate pressures in EPR containment – Comparison of simplified method (EPRI method) to method based on statistical numerical simulation*. 12 680 RP 01-41 Revision A. Coyne et Bellier. December 2010. TRIM Ref. 2011/128748. |
| 36 | *Answer to HSE Regulatory Observation RO-UKEPR-037 – Determination of failure mode ultimate pressures – comparison of simplified (EPRI) with fully statistical methods – Special case of low probabilities*. 12680-RP01-45 Revision B. Coyne et Bellier. January 2011. TRIM Ref. 2011/128749. |
| 37 | *GDA Issue Action GI-UKEPR-CE03.02: Justification of the approach used for the development of the containment fragilities used in the UK EPR™ PSA.* Letter from UK EPR™ Project Front Office to ONR. Unique Number EPR00978N. 6 October 2011. TRIM Ref 2011/514723. |
| 38 | *Response to Regulatory Observation Actions RO-UKEPR-76.A1, A2 and A3.* Letter from UK EPR™ Project Front Office to ONR. Unique Number EPR00830N. 10 March 2011. TRIM Ref. 2011/145112. |
| 39 | *Answer to HSE Regulatory Observation RO-UKEPR-76 – A1 and A2 Analysis of Inner Containment.* 12680-RP01-39 Revision D. Coyne et Bellier. February 2011, TRIM Ref. 2011/145191. |
| 40 | *Analysis of EPR Inner Containment - GDA/Step4 – Inner containment seismic calculations in relation with ETC-C Requirements.* ENGSGC110030 Revision A. EDF SEPTEN. March 2011. TRIM Ref. 2011/145199. |
| 41 | *EPR UK – Answer to RO76 Action A3: Damping ratio of the pre-stressed concrete containment structure.* 12680-RP01-46 Revision B. Coyne et Bellier. March 2011. TRIM Ref. 2011/145192. |
| 42 | *EPR UK – Answer to RO76 Action A3: Comparison between equivalent static seismic analysis of the pre-stressed inner containment and seismic spectrum analysis with global NI model.* 12680-RP01-49 Revision C. Coyne et Bellier. March 2011. TRIM Ref. 2011/145193. |
| 43 | *Response to GI-UKEPR-CE04 Action 1 – Containment Analysis.* Letter from UK EPR™ Project Front Office to ONR. Unique Number EPR00903R. 12 July 2011. TRIM Ref. 2011/379334. |
| 44 | *UK EPR™ – Analysis of Inner Containment – Justification for use of linear elastic methods for design of the inner containment of the UK EPR™.* 10420/R-01 Issue 2. Scanscot Technology. July 2011. TRIM Ref. 2011/369849. |

| Ref. | Document |
|---|---|
| 45 | *Description and Justification of Analysis Methods Used in the Design of the UK EPR™ Inner Containment.* ENGSGC110026 Revision A. EDF and AREVA. July 2011. TRIM Ref. 2011/369853. |
| 46 | *GDA Close-out for the EDF and AREVA UK EPR™ Reactor – GDA Issue GI-UKEPR-CE-06 Revision 1 – Seismic Analysis Methodology for the Design of the UK EPR™.* ONR Assessment Report ONR-GDA-AR-12-002 Revision 0. July 2012. TRIM Ref. 2012/2. |
| 47 | *GDA Close-out for the EDF and AREVA UK EPR™ Reactor – GDA Issue GI-UKEPR-CE-01 Revision 1 – Hypothesis and Methodology Notes for Class 1 Structures.* ONR Assessment Report ONR-GDA-AR-12-006 Revision 0. TRIM Ref. 2012/6. |
| 48 | *EPR Inner Containment Wall detailed design report ("route map").* ECEIG102044 Revision B. EDF. February 2011. TRIM Ref. 2012/128818. |
| 49 | *EPR GDA Inner Containment Issues Review of EDF-Areva Response To GI-UKEPR-CE04. Report* Number 19760_R01 Revision 1. Ramboll. May 2012. TRIM Ref. 2012/264643. |
| 50 | *GDA Close-out for the EDF and AREVA UK EPR™ Reactor – GDA Issue GI-UKEPR-CE-02 Revision 1 – Use of ETC-C for the Design and Construction of the UK EPR™.* ONR Assessment Report ONR-GDA-AR-12-004 Revision 0. TRIM Ref. 2012/4. |
| 51 | *AASHTO LRFD (Load and Resistance Factor Design) Bridge Design Specifications.* 3rd edition. 2007. American Association of State Highway and Transportation Officials. |
| 52 | *Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary*. ACI 349-01. American Concrete Institute. 2001. |
| 53 | *Damping values for seismic design of nuclear power plants,* US NRC, Regulatory Guide 1.61. March 2007. Revision 1. www.nrc.gov |
| 54 | *UK EPR™ - Methodology for Seismic Analysis of NI Buildings.* ENGSDS100269 Revision B. EDF and AREVA. May 2012. TRIM Ref. 2012/184476. |
| 55 | *ONR Comments on the submissions for GI-UKEPR-CE-04 (RO-76).* ONR Comment Sheet. December 2011. TRIM Ref. 2011/630214. |
| 56 | *Assessment File of the UK Companion Document to AFCEN ETC-C.* ENGSGC110033 Revision C. EDF SEPTEN. May 2012. TRIM Ref. 2012/227355.<br><br>*Assessment File of the UK Companion Document to AFCEN ETC-C, (Section 2.2 to 2.5 of ENGSGC110015 D*). EDTGC120392 Revision A. EDF CEIDRE. May 2012. TRIM Ref. 2012/227353. |
| 57 | *Contact Report for TM48 - Level 4 GDA Assessment of UKEPR Reactor Closure of GDA Issues - Civil Engineering - The Qube London - 26 January 2012 - Sarah Jones.* CR12008, ONR, February 2012. TRIM Ref. 2012/69814 |

**Table 1: Relevant SAPs Considered for Close-out of GI-UKEPR-CE-03 Rev 1**

| SAP No. | SAP Title | Description |
|---|---|---|
| ECS.3 | Engineering principles:<br>Safety classification and standards<br>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.*<br>*157 The standards should reflect the functional reliability requirements of structures, systems and components and be commensurate with their safety classification.*<br>*158 Appropriate national or international codes and standards should be adopted for Classes 1 and 2 of structures, systems and components. For Class 3, appropriate non-nuclear-specific codes and standards may be applied.*<br>*159 Codes and standards should be preferably nuclear-specific codes or standards leading to a conservative design commensurate with the importance of the safety function(s) being performed. The codes and standards should be evaluated to determine their applicability, adequacy and sufficiency and should be supplemented or modified as necessary to a level commensurate with the importance of the safety function(s) being performed.*<br>*160 Where a structure, system or component is required to deliver multiple safety functions, and these can be demonstrated to be delivered independently of one another, codes and standards should be used appropriate to the category of the safety function. Where independence cannot be demonstrated, codes and standards should be appropriate to the class of the structure, system or component (i.e. in accordance with the highest category of safety function to be delivered). Whenever different codes and standards are used for different aspects of the same structure, system or component, the compatibility between these should be demonstrated.*<br>*161 The combining of different codes and standards for a single aspect of a structure, system or component should be avoided or justified when used. Compatibility between these codes and standards should be demonstrated.* |

**Table 1: Relevant SAPs Considered for Close-out of GI-UKEPR-CE-03 Rev 1**

| SAP No. | SAP Title | Description |
|---|---|---|
| EHA.7 | Engineering principles:<br>External and internal hazards<br>'Cliff-edge' effects | *A small change in DBA parameters should not lead to a disproportionate increase in radiological consequences.*<br>*282 j) for structures for which the consequence of failure would be high, predictable, gradual and detectable failure modes for severe loadings.*<br>*288 For more severe loadings of structures that provide a principal means of ensuring nuclear safety, predicted failure modes should be gradual, ductile and, for slowly developing loads, detectable.* |
| ERL.1 | Engineering principles:<br>Reliability claims<br>Form of claims | *The reliability claimed for any structure, system or component important to safety should take into account its novelty, the experience relevant to its proposed environment, and the uncertainties in operating and fault conditions, physical data and design methods.* |

**Table 2: Relevant SAPs Considered for Close-out of GI-UKEPR-CE-04 Rev 1**

| SAP No. | SAP Title | Description |
|---|---|---|
| EHA.6 | Engineering principles:<br>external and internal hazards<br>Analysis | *Analyses should take into account simultaneous effects, common cause failure, defence in depth and consequential effects.* |
| ECE.12 | Engineering principles: Civil engineering: structural analysis and model testing<br>Structural analysis and model testing | *Structural analysis or model testing should be carried out to support the design and should demonstrate that the structure can fulfil its safety functional requirements over the lifetime of the facility.*<br>*292 The analysis or model testing should use methods and data that have been validated and verified.* |
| ECE.13 | Use of data | *The data used in any analysis should be such that the analysis is demonstrably conservative.* |
| ECE.14 | Sensitivity studies | *Studies should be carried out to determine the sensitivity of analytical results to the assumptions made, the data used, and the methods of calculation.* |
| ECE.15 | Validation of methods | *Where analyses have been carried out on civil structures to derive static and dynamic structural loadings for the design, the methods used should be adequately validated.* |
| FA.20 | Fault analysis: Assurance of validity of data and models: Computer models | *Computer models and datasets used in support of the analysis should be developed, maintained and applied in accordance with appropriate quality assurance procedures.* |

# Annex 1

GDA Assessment Findings Arising from GDA Close-out for GDA Issue **GI-UKEPR-CE-03 Rev 1** and **GI-UKEPR-CE-04 Rev 1**

| Finding No. | Assessment Finding | MILESTONE<br>(by which this item should be addressed) |
|---|---|---|
| AF-UKEPR-CE-73 | *The licensee shall provide sufficient evidence to justify the boundary interfaces between finite element analysis models and sub-models for the site specific inner containment analysis. Justification shall include the calculation of the boundary conditions, to prove adequate modelling of the soil structure interaction for seismic and non-seismic load cases.* | *First structural concrete.* |
| AF-UKEPR-CE-74 | *The licensee shall provide evidence that the boundary conditions used for sub-models are compatible with the global response spectra model, such that the data generated by the global model e.g. seismic motion or loading, can be applied correctly to the sub-model.* | *First structural concrete.* |
| AF-UKEPR-CE-75 | *The licensee shall provide sufficient evidence to justify the mesh size is adequate to model the local stress concentrations in the gusset region in the site specific detailed inner containment finite element analysis model.* | *First structural concrete.* |

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.

For assessment findings relevant to the operational phase of the reactor, the licensees / operators must adequately address the findings <u>during</u> 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 2

**EDF AND AREVA UK EPR™ GENERIC DESIGN ASSESSMENT**

**GDA ISSUE**

**BEYOND DESIGN BASIS BEHAVIOUR OF THE CONTAINMENT**

**GI-UKEPR-CE-03 REVISION 1**

<table>
<tr><td colspan="2">Technical Area</td><td colspan="3">CIVIL ENGINEERING</td></tr>
<tr><td colspan="2">Related Technical Areas</td><td colspan="3">PSA</td></tr>
<tr><td>GDA Issue Reference</td><td colspan="2">GI-UKEPR-CE-03</td><td>GDA Issue Action Reference</td><td>GI-UKEPR-CE-03.A1</td></tr>
<tr><td>GDA Issue</td><td colspan="4">There is not yet sufficient justification of the beyond design basis behaviour of the EPR containment structure.</td></tr>
<tr><td>GDA Issue Action</td><td colspan="4">Support assessment of the beyond design basis 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.<br><br>Based on a high level review of the documents and assurances provided to date I have sufficient confidence in the design process to conclude that it should be possible to provide a suitable demonstration of the beyond design basis performance.</td></tr>
</table>

**Annex 2**

**EDF AND AREVA UK EPR™ GENERIC DESIGN ASSESSMENT**

**GDA ISSUE**

**BEYOND DESIGN BASIS BEHAVIOUR OF THE CONTAINMENT**

**GI-UKEPR-CE-03 REVISION 1**

<table>
<tr><td colspan="2">Technical Area</td><td colspan="2">CIVIL ENGINEERING</td></tr>
<tr><td colspan="2">Related Technical Areas</td><td colspan="2">None</td></tr>
<tr><td>GDA Issue Reference</td><td>GI-UKEPR-CE-03</td><td>GDA Issue Action Reference</td><td>GI-UKEPR-CE-03.A2</td></tr>
<tr><td>GDA Issue Action</td><td colspan="3">Provide a justification of the approach used for the development of the containment fragilities used in the PSA analysis by comparison with the approaches used for beyond design basis assessment.<br><br>Based on a high level review of the documents and assurances provided to date I have sufficient confidence in the design process to conclude that it should be possible to provide a suitable demonstration of the containment fragility.<br><br>With agreement from the Regulator this action may be completed by alternative means.</td></tr>
</table>

## Annex 3

### EDF AND AREVA UK EPR™ GENERIC DESIGN ASSESSMENT

### GDA ISSUE

### CONTAINMENT ANALYSIS

### GI-UKEPR-CE-04 REVISION 1

<table>
<tr><td colspan="2">Technical Area</td><td colspan="2">CIVIL ENGINEERING</td></tr>
<tr><td colspan="2">Related Technical Areas</td><td colspan="2">None</td></tr>
<tr><td>GDA Issue Reference</td><td>GI-UKEPR-CE-04</td><td>GDA Issue Action Reference</td><td>GI-UKEPR-CE-04.A1</td></tr>
<tr><td>GDA Issue</td><td colspan="3">The analysis of the UK EPR™ containment structure has not been demonstrated to capture the behaviour in a sufficiently accurate manner.</td></tr>
<tr><td>GDA Issue Action</td><td colspan="3">Support assessment within the following areas and provide adequate responses to any questions arising from the assessment by ONR of documents submitted during GDA Step 4 but not reviewed in detail at that time.<br><br>During the Step 4 assessment, the following areas were highlighted as requiring further justification:<br><br>• Inner Containment seismic calculations in relation with ETC-C requirements.<br>• Damping ratio of the pre-stressed concrete containment structure.<br>• Comparison Between Equivalent Static Seismic Analysis of the Pre-stressed Inner Containment and Seismic Spectrum Analysis with Global NI Model<br>• Simplifications over the representation of the foundation<br><br>The combined rationale for the analysis methodology and associated design basis is insufficient in providing a coherent description of the overall analytical process, and fails to adequately address specific analytical aspects necessary to demonstrate a level of structural performance and reliability commensurate with that expected for inner containment.<br><br>Based on a high level review of the documents and assurances provided to date I have sufficient confidence in the approach to conclude that it should be possible to provide a suitable demonstration of both the beyond design basis performance.<br><br>With agreement from the Regulator this action may be completed by alternative means.</td></tr>
</table>