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-02 Revision 1 –

Use of ETC-C for the Design and Construction of the UK EPR™

Assessment Report: ONR-GDA-AR-12-004
Revision 0
February 2013

COPYRIGHT

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 civil structures in the reference design, Flamanville 3 in France, were designed using the EPR™ Technical Code for Civil Works (ETC-C) Rev B 2006. The current version of this code, AFCEN ETC-C 2010 Edition will be used for the UK EPR™ with an accompanying UK Companion Document (UK CD) which has been specifically written to specify any changes to the ETC-C that are required for the UK EPR™.

The Step 4 GDA assessment of both versions of the ETC-C and the UK Companion Document found that there was not sufficient guidance given to designers and some of the technical clauses within them had not been fully justified. Furthermore the UK CD did not adapt the ETC-C sufficiently for use in the UK, for instance many French standards were quoted rather than using UK or international standards that are regarded as current good practice. Technical documents submitted to justify the UK CD either had outstanding queries that could not be resolved during the GDA Step 4 process or the documents were received too late in the process to be adequately assessed. Therefore GDA Issue **GI-UKEPR-CE-02** Revision 1 was raised to allow the Regulator to complete assessment of these documents.

The GDA issues had four actions as follows:

Action 1 Support the ONR assessment of supporting documents which justify the technical basis for specific clauses in the AFCEN ETC-C 2010 and the UK CD.

Actions 2, 3 and 4 Revise the UK CD to address the regulatory observations on AFCEN ETC-C 2010 Part 0 (General), Part 1 (Design) and Part 2 (Construction) respectively.

EDF and AREVA produced a Resolution Plan to indentify the deliverables that would be submitted in response to **GI-UKEPR-CE-02** and its actions. This indentified that an updated UK CD would be required in order for the technical clauses of the ETC-C to be adequately modified to comply with UK standards and good practice. A suite of technical documents and methodologies was also submitted and these provided the justification behind the technical clauses. Revisions would also be required to the Pre-Construction Safety Case (PCSR) to resolve the issue.

The technical supporting documents submitted under Action 1 have now provided the additional justification required, although further iterations were required in some cases. Certain technical clauses within the UK CD needed to be modified to accurately specify the general, design or construction requirements which results from the supporting documents. Design values and factors which are dependent on site specific parameters must be confirmed by the licensee during detailed design, and so I have raised Assessment Findings **AF-UKEPR-CE-76** to **78**.

Action 1 also required justification of three specific design methodologies: detailing provisions, pool liner design and drop load analysis. These are summarised below.

The detailing provisions for Class 1 safety structures of the UK EPR™ are based on a fully elastic response with some additional measures based on EDF and AREVA's feedback experience from operating sites and current good practice to avoid cliff edge effects. I have therefore raised Assessment Finding **AF-UKEPR-CE-79** to require the licensee to confirm that there is adequate margin beyond design basis for non-massive structural elements such that if plasticity occurs in any part of those elements for the event considered, this will not lead to sudden failure. I also raise Assessment Finding **AF-UKEPR-CE-80** which requires the licensee to provide the final construction specification and details for the joints within the concrete dome roof to the inner containment, and justify that the finished structure will fulfil the nuclear safety requirements.

The methodology for the design of pool liners has been provided and it was found to be satisfactory. The liner strain limits specified in the AFCEN ETC-C 2010 have been revised to agree with the ASME Section III, Division 2 code for Concrete Containments which is acceptable.

The methodology for analysing the impact of dropped loads onto civil structures has been provided. The AFCEN ETC-C 2010 also specifies the method to calculate impacts on civil structures from internal missiles. This method is included in the dropped load methodology document. I am satisfied that this document provides adequate methods, however, some are only applicable in certain circumstances and so I have raised Assessment Findings **AF-UKEPR-CE-81** and **AF-UKEPR-CE-82** to require the licensee to confirm the correct method is used for the correct dropped load scenario. I also raise **AF-UKEPR-CE-83** to require the licensee to provide the site specific internal missile methodology document and justify the calculation methods used to assess the damage to civil structures due to impact from potential internal missiles. The document shall also confirm that this methodology is consistent with the dropped load methodology.

The deliverable submitted in response to Actions 2, 3 and 4 was an updated UK CD. The final submission, Rev E, comprises amendments of certain technical clauses which address the comments raised by the Regulator in the context of GDA.

The ONR assessment of the information provided in response to **GI-UKEPR-CE-02** concludes that the latest revision of the UK CD (Revision E) provides adequate guidance to designers and that the technical clauses queried are in accordance with the standards expected by the UK Regulator. ONR considers that the ETC-C as modified by the UK CD is now suitable for use as the design code for the nuclear safety related structures of the UK EPR™. It also provides additional criteria for the construction of these structures, for instance special requirements for the pre-stressed containment building, which have benefitted from operational knowledge at existing EPR sites. It should be noted, however, that the ETC-C is not a full construction specification for civil works; as these will only be produced during the detailed design phase

I have therefore found EDF and AREVA's response to **GI-UKEPR-CE-02** to be satisfactory and recommend this issue is closed.

LIST OF ABBREVIATIONS

ABSC	ABS Consulting Ltd
ACI	American Concrete Institute
AF	Assessment Finding
AFCEN	Association Française pour les règles de conception et de construction des matériels des Chaudières Électro Nucléaires (French society for design, construction and in-service inspection rules for nuclear island components)
ALARP	As low as is reasonably practicable
AREVA	AREVA NP SAS
Arup	Ove Arup and Partners Ltd
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
C1	Class 1 civil structures
CEA	Commissariat à l'énergie atomique et aux énergies alternatives (French Alternative Energies and Atomic Energy Commission)
CEB	Comite Euro-International du Beton
CEEH	Civil Engineering and External Hazards
CIRIA	Construction Industry Research and Information Association
CMF	Change Modification Form
CTICM	Centre Technique Industriel de la Construction Metallique i.e. The French equivalent of the UK Steel Construction Institute
CW	Civil works
DAC	Design Acceptance Confirmation
DCH	Ductility Class High (to Eurocode 8)
DCM	Ductility Class Medium (to Eurocode 8)
EDF	Electricité de France SA
ETC-C	EPR Technical Code for Civil Works
FA3	Flamanville 3 EPR Nuclear Power Plant, France
FE	Finite element
FIB	Federation Internationale du Beton
FRS	Floor response spectra
GDA	Generic Design Assessment
HSE	Health and Safety Executive
HOW2	ONR's Business Management System
IC	Inner Containment

LIST OF ABBREVIATIONS

IAEA	International Atomic Energy Agency
MAEVA	MAquette Enceinte en Vapeur et en Air (Steam and Air Containment Model) – French test facility
NI	Nuclear island
ONR	Office for Nuclear Regulation (an agency of HSE)
PCSR	Pre-construction Safety Report
SA	Soft soil type
SAP	Safety Assessment Principle(s) (HSE)
SI	Site Investigation
TAG	Technical Assessment Guide(s) (ONR)
TQ	Technical Query
TSC	Technical Support Contractor (for ONR)
UK CD	UK Companion Document to AFCEN ETC-C
WENRA	Western European Nuclear Regulators’ Association

TABLE OF CONTENTS

Tables

Annexes

1 INTRODUCTION

1.1 BACKGROUND

1 This report presents the close-out of the Office for Nuclear Regulation's (an agency of the HSE) Generic Design Assessment (GDA) within the area of Civil Engineering and External Hazards. The report specifically addresses the GDA Issue **GI-UKEPR-CE-02 Rev 1** and its associated four actions (Ref. 1) generated as a result of the GDA Step 4 Civil Engineering and External Hazards Assessment of the UK EPR™ (Ref. 2). The assessment has focused on the deliverables identified within the EDF and AREVA Resolution Plan (Ref. 3) published in response to the GDA Issue and on further assessment undertaken of those deliverables.

2 GDA followed a step-wise-approach in a claims-argument-evidence hierarchy. In Step 2 the claims made by 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 the 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 Issue **GI-UKEPR-CE-02** arising from the CEEH assessment.

5 The 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. The current version of this code, AFCEN ETC-C 2010 (Ref. 4), has a UK Companion Document (UKCD, Ref. 5) to be used alongside it which specifies any changes to the technical clauses required for application in the UK. In addition, there is a range of supporting references to the UK CD which provide detailed supplementary guidance. During its assessment, ONR raised a series of technical comments, the responses to which were received towards the end of the Step 4 process and so were not reviewed in detail at that time. Therefore, **GI-UKEPR-CE-02** was raised to allow ONR to complete its assessment.

6 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 assessment in June 2008. EDF and AREVA revised and resubmitted the consolidated 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-chapters 3.3 and 3.8 of the March 2011 PCSR describe the design of safety classified civil structures and the codes and standards used in the EPR™ design respectively. EDF and AREVA has proposed in its resolution plan that these may require further revision following the resolution of **GI-UKEPR-CE-02.**

1.2 SCOPE

7 This report presents only the assessment undertaken as part of the resolution of this GDA Issue. This report should be read in conjunction with the Step 4 CEEH Assessment Report (Ref. 2) and the close-out reports for the other CEEH GDA Issues (Ref. 7 to 10) in order to appreciate the totality of the assessment of the evidence undertaken as part of the GDA process.

8 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.

9 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

10 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. 11), in relation to mechanics of assessment within ONR.

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

12 The 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.

13 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 civil engineering structures such that the existing case is undermined, these have been addressed.

1.4 STRUCTURE OF THIS REPORT

14 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. 2). This report has been structured to reflect the assessment of the individual GDA Issue rather than a report detailing close-out of all GDA Issues associated with this technical area.

15 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 CLOSE-OUT

2.1 CLOSE-OUT PLAN

16 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. 12) that identified the intended scope of the assessment and the standards and criteria that would be applied.

17 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.

18 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) (Ref. 6) which had been reviewed during the GDA; and
- updates to the various documents supporting the PCSR.

2.2 THE APPROACH TO ASSESSMENT FOR GDA ISSUE CLOSE-OUT

19 The approach to the closure of GDA Issues for the UK EPR™ Project has involved the assessment of the submissions made by EDF and AREVA in response to the GDA Issue identified through the GDA process. These submissions are detailed within the EDF and AREVA Resolution Plan for the GDA Issue.

20 The majority of deliverables for close-out had been submitted towards the end of Step 4 in response to the queries raised by ONR, but these had not been assessed in detail at that time to confirm if the queries had been addressed. EDF and AREVA adopted the use of a single document to track each of the individual ONR comments by using the ETC-C Tracking Spreadsheet, document ENGSGC110269 (Ref. 13). This allowed a staged response to be made, recorded by this tracking sheet, and comprising updated UK CD clauses in an accompanying modification file, Appendix 1 to ENGSGC110269 (Ref. 14). ONR then provided comments in response to the staged changes. This process was iterated until convergence was reached on the relevant technical point. Both documents were agreed as closed in September 2012 and are ENGSGC110269 Rev E (Ref. 13) and Appendix 1 to ENGSGC110269 Rev E (Ref. 14).

21 During the GDA close-out phase, regular Level 4 technical meetings and workshops have been held to allow discussion and clarification with EDF and AREVA on its submission documents. New or updated documents were submitted in order to justify the technical basis for the revised UK CD clauses. Documents submitted therefore may have been revised two or three times until they met regulatory expectations.

2.3 STANDARDS AND CRITERIA

22 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 TAGs have been detailed within this section. National and international standards and guidance have been referenced where appropriate within the assessment report. Relevant good practice, where applicable, has also been cited within the body of the assessment.

2.3.1 Safety Assessment Principles

23 The key SAPs applied within the assessment of GDA Issue **GI-UKEPR-CE-02** are included within Table 1 of this report. These are taken from Safety Assessment Principles for Nuclear Facilities. 2006 Edition Rev 1 (Ref. 15).

2.3.2 Technical Assessment Guides

24 The following Technical Assessment Guides have been used as the major underpinning guides for this assessment (Ref. 16):

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

25 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

26 The following international standards and guidance have been used as part of this assessment:

- International Atomic Energy Agency (IAEA) Safety Standard Series (Ref. 17)
- Western European Nuclear Regulators' Association (WENRA) Reactor Reference Safety Levels (Ref. 18)
- BS EN 1990, Eurocode 0, Basis of Structural Design (Ref. 19)
- BS EN 1991, Eurocode 1, Actions on Structures (Ref. 20)
- BS EN 1992, Eurocode 2, Design of Concrete Structures (Ref. 21) and its UK National Annex.
- BS EN 1993, Eurocode 3, Design of Steel Structures (Ref. 22) and its UK National Annex.
- BS EN 1998, Eurocode 8, Design of Structures for Earthquake Resistance (Ref. 23) and its UK National Annex.
- ACI 349-06, Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary, American Concrete Institute. 2006 (Ref. 24).
- ACI 318-11, Building Code Requirements for Structural Concrete and Commentary, American Concrete Institute, 2011 (Ref. 25)
- ASME Boiler and Pressure Vessel Code. Code for Concrete Containments – Rules for Construction of Nuclear Facility Components . ACI 359M-07 Section III, Division 2 (Ref. 26)

- Fastenings to Concrete and Masonry Structures, CEB Bulletin No 216, 1994 (Ref. 27)
- Early-age thermal crack control in concrete, CIRIA Guide C660, 2007 (Ref. 28).

2.4 USE OF TECHNICAL SUPPORT CONTRACTORS

27 Technical support to ONR on the assessment of the AFCEN ETC-C 2010 and its accompanying UK CD to confirm the design and construction requirements for the UK EPR™ has been provided by Ove Arup and Partners Ltd (Arup).

28 The ONR assessment of the dropped load methodology was supported by ABS Consulting Ltd (ABSC) who carried out a technical review against the SAPs and against current good practice in the UK nuclear industry.

2.5 OUT-OF-SCOPE ITEMS

29 There are no out of scope items. The entirety of GDA Issue **GI-UKEPR-CE-02** Rev 1 has been addressed. In addition, there are no changes to the scope of the GDA assessment detailed in the Step 4 report (Ref. 2).

3 GDA ISSUE

3.1 BACKGROUND TO THE ETC-C

30 The "EPR Technical Code for Civil Works" (ETC-C) for nuclear safety related structures was the subject of extensive discussions between ONR and EDF and AREVA during Step 4 of GDA. The civil structures in the reference design, Flamanville 3 in France, were designed using the ETC-C Rev B 2006 (Ref. 30). The current version of this code, AFCEN ETC-C 2010 (Ref. 4), will be used for the UK EPR™, with an accompanying UK Companion Document (Ref. 5) which has been specifically written to specify any changes to the ETC-C that are required for the UK EPR™. This is an important document, as its use will be mandatory and will govern over the ETC-C in a similar way that the UK National Annexes govern Eurocodes.

31 The ETC-C is a bespoke code, developed by EDF and AREVA for the design of the new fleet of EPR™ nuclear power plants, including Flamanville 3 (FA3). The ETC-C is intended for Class 1 safety classified structures only and 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.

32 The ETC-C 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 Alternative Energies and Atomic Energy Commission (CEA) and experts from the French nuclear industry. Therefore, the AFCEN 2010 version of the ETC-C is a stand alone document, and EDF and AREVA use the UK Companion Document to adapt it for the UK EPR™.

33 The contents of the ETC-C are as follows.

- **Part 0: General**. This defines the structure and the scope of the ETC-C.
- **Part 1: Design**. This defines the rules or criteria needed to design the C1-classified structures. This includes the actions and combinations of actions to be taken into account in the design of civil works. However, numerical values (intensity of loads) associated to these actions are provided by specific documents for each EPR™ Project.
- **Part 2: Construction**. This provides construction rules (concrete, reinforcement, prestressing system, leaktightness of metal parts, etc).
- Part 3: Leak and Resistance Test and Containment Monitoring. This provides the main principles for containment testing, covering the initial acceptance test and subsequent periodic tests.

34 The UK CD contains amended clauses to all the above parts of the ETC-C and also corrects errata in the AFCEN 2010 version. These are listed in Appendices 1 and 2 of the UK CD (Ref. 5).

3.2 GDA STEP 4 REVIEW

35 This section provides a brief overview of the GDA assessment of the ETC-C and its supporting documents and the outcomes of that assessment which resulted in GDA Issue **GI-UKEPR-CE-02.**

36 The GDA Step 4 review comprised assessment firstly of the ETC-C Rev B 2006 (Ref. 30) and then of the AFCEN ETC-C 2010 (Ref. 4) which was received in December 2010, towards the end of Step 4.

37 During the ONR review of ETC-C Rev B, a number of Technical Queries (TQs) were raised requesting clarification of many aspects of the ETC-C. In order to supplement the ETC-C and especially to collate the clarifications of the many issues raised in the course of the review, EDF developed an ETC-C User Guide which was later to become the UK Companion Document (UK CD).

38 Section 4.3.3 of the ONR Step 4 assessment report (Ref. 2) describes the assessment of the ETC-C and the UK CD. It notes that while the ETC-C Rev B was included in the assessment process, it is the later AFCEN ETC-C which is the GDA design code, along with its UK CD. The first issue of the UK CD, Rev A (Ref. 31) was submitted in February 2011 and was assessed as part of Step 4.

39 The Step 4 review of the AFCEN ETC-C 2010, the UK CD Rev A and the supporting reference documents (refer to Table 2) identified a number of areas where further justification was required. These are outlined in Section 4.3.3.6.2 of the Step 4 assessment report (Ref. 2). The detailed comments from ONR were issued to EDF and AREVA in early 2011 via Letters EPR70291R (Ref. 32), EPR70304R (Ref. 33) and EPR70367R (Ref. 34). The comments in these letters were complied into the ETC-C tracking spreadsheet (Ref. 13) described in Section 2.2.

3.3 GDA ISSUE ACTIONS

40 There are four actions attached to **GI-UKEPR-CE-02 Rev 1** as follows.

41 **Action 1** - Support assessment within the following areas 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:

1) α_{cc} coefficient for concrete compressive strength
2) Load Combination Factors ψi for variable actions
3) Biaxial Stress Limits
4) Shear
5) Fastenings – partial safety factors
6) Pre-stressing Participation
7) Shrinkage
8) Crack width control
9) Pre-stressing partial safety factor,

42 Provide additional supporting documents on the following areas

- Detailing provisions
- Pool Liner Design
- Drop Load Analysis

43 **Action 2** - Provide a revision of the UK companion document which addresses the observations raised on ETC-C Part 0: General, as a result of the Step 4 assessment.

44 **Action 3** - Provide a revision of the UK companion document which addresses the observations raised on ETC-C Part 1: Design, as a result of the Step 4 assessment.

45 **Action 4** - Provide a revision of the UK companion document which addresses the observations raised on ETC-C Part 2: Construction, as a result of the Step 4 assessment.

3.4 EDF AND AREVA RESOLUTION PLAN DELIVERABLES

46 The information provided by EDF and AREVA in response to this GDA Issue, as detailed within its Resolution Plan (Ref. 3), was broken down into the four GDA Issue Actions and then further broken down into specific deliverables for detailed assessment. The documents listed in Table 2 are mainly updates to documents already received and assessed during Step 4, as shown. However, new deliverables were also identified as being required. Those marked * were identified as planned in the Resolution Plan, but an actual document number was not given; this became available later when the documents were submitted but is given for clarity. These versions of the documents underwent several revisions during my assessment until regulatory expectations were satisfied (as described in later sections of this report as noted in Table 2).

47 It is important to note that the information shown in Table 2 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 topic area. Rather they form further detailed arguments and evidence to supplement those already provided during earlier Steps within the GDA Process.

Table 2: Resolution Plan Deliverables for GI-UKEPR-CE-02					
Document Number	**Document Title**	**Revision Assessed in Step 4**	**Resolution Plan Deliverable**	**Final GI Close-Out Submission**	**Discussed in Section # of this Report**
ACTION 1 - NINE TECHNICAL AREAS FROM STEP 4					
1) ENGSGC100384	Determination of the α_{cc} coefficient used in the formula for the design value of the compressive strength in Eurocode 2.	**A**	**B (Ref. 35)**	**B**	**Section 4.3.2.1**
2) ENGSGC100394	Presentation and justification of ψi factors of ETC-C for variable actions in accidental and non-accidental situations	**A**	**B (Ref. 36)**	**C (Ref. 53)**	**Section 4.3.2.2**
3) ENGSGC100415	Justification of the Concrete Maximum Compressive Stress Under Bi-axial / Tri-axial Behaviour	**A**	**B (Ref. 37)**	**B**	**Section 4.3.2.3**
4) ENGSGC100410	EPR™ UK – Shear Design Proposal	**A**	**C (Ref. 38)**	**D (Ref. 54)**	**Section 4.3.2.4**
5) ENGSGC100395	Steel and Concrete Partial Safety Factors for EPR™ Fastening Systems	**A**	**B (Ref. 39)**	**B**	**Section 4.3.2.5**
6) ENGSGC100416	Prestressing Tendons Participation in Reinforced Concrete Calculations for the Inner Containment	**A**	**B (Ref. 40)**	**C (Ref. 55)**	**Section 4.3.2.6**
7) ENGSGC100426	Methodology for Consideration of Shrinkage for EPR™ Concrete Structures	**A**	**B (Ref. 41)**	**B**	**Section 4.3.2.7**
8) ENGSGC100428	Verification of Crack Width for EPR™ - Concrete Structures	**A**	**B (Ref. 42)**	**B**	**Section 4.3.2.7**
7) & 8) ENGSGC110025	Global approach about methodology for consideration of shrinkage and crack limitation	**n/a**	**A (Ref. 43)**	**A**	**Section 4.3.2.7**
9) ENGSGC100402	Justification of the Partial Factor for Prestressing Actions γ_P	**A (Ref. 44)**	**n/a**	**A**	**Section 4.3.2.8**

Table 2: Resolution Plan Deliverables for GI-UKEPR-CE-02

Document Number	Document Title	Revision Assessed in Step 4	Resolution Plan Deliverable	Final GI Close-Out Submission	Discussed in Section # of this Report
ADDITIONAL SUPPORTING DOCUMENTS					
ENGSGC110157*	Good Practice Detailing Rules for Reinforced Concrete and Steel Structures.	**n/a**	**A (Ref. 45)**	**B (Ref. 56)**	**Section 4.4**
ENGSGC110243*	Methodology Report for Pool Liners	**n/a**	**A (Ref. 46)**	**B (Ref. 57)**	**Section 4.5**
ENGSGC100483	Methods with regard to the risk of dropped loads	**n/a**	**A (Ref. 47)**	**B (Ref. 58)**	**Section 4.6**
ACTIONS 2, 3 AND 4					
ENGSGC110015	UK Companion Document to AFCEN ETC-C	**A (Ref. 31)**	**B (Ref. 48)**	**E (Ref. 5)**	**Section 4.7 Section 4.8 and Section 4.9**
ENGSGC110033	Assessment File of the UK Companion Document to AFCEN ETC-C	**n/a**	**B (Ref. 49)**	**C (Ref. 59)**	
ECEIG 111110*	EPR Nuclear Island Civil Engineering Design Process Note (see GDA Issue GI-UKEPR-CE01)	**n/a**	**A (Ref. 50)**	**C (Ref. 60)**	
ETDOIG110305	ETC-C Part 2.10 – Mapping of Changes from ETC-C Rev B to AFCEN ETC-C 2010	**n/a**	**A (Ref. 51)**	**A**	
EDTGC110381	ETC-C Part 2: Construction Update – Mapping of Changes from ETC-C Rev B to AFCEN 2010 ETC-C (Sections 2.2 to 2.5, 2.11, and 2.12)	**n/a**	**A (Ref. 52)**	**A**	

* document which was listed in the Resolution Plan but no document number assigned

3.5 INTERFACE WITH THE PCSR

48 The Resolution Plan for **GI-UKEPR-CE-02** (Ref. 3) states that updates to the March 2011 PCSR will be required on the following sub-chapters.

- "Sub-chapter 3.3 – Design of safety Classified Civil Structure".
- "Sub-chapter 3.8 – Codes and Standards used in the EPR™ design".

3.6 INTERFACE WITH OTHER GDA ISSUES

49 This GDA Issue has interfaces with deliverables for other GDA Issue resolution plans, as given in Table 3 below. This means that some of the commitments made by EDF and AREVA in order to resolve this GDA Issue 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-02 with other GDA Issues

GDA Issue	Topic	Document Deliverables
GI-UKEPR-CE-01 (Ref. 64)	Hypothesis and Methodology Notes	EPR Nuclear Island Civil Engineering Design Process Note Rev C (Ref. 60)
GI-UKEPR-CE-03 (Ref. 65)	Beyond design basis behaviour of containment	N/A
GI-UKEPR-CE-04 (Ref. 66)	Containment analysis FE modelling	UK Companion Document to the ETC-C **(**Ref. 5)
GI-UKEPR-CE-05 (Ref. 67)	Reliability of the ETC-C	N/A
GI-UKEPR-CE-06 (Ref. 68)	Seismic Analysis Methodology	ENGSDS100268 Rev B Seismic Analysis of Foundation Raft **(**Ref. 62) ENGSDS100269 Rev B Methodology for Seismic Analysis of NI Buildings, (Ref. 63)
GI-UKEPR-IH-01 (Ref. 69)	Dropped Loads	Methods with regard to the risk of dropped loads for EPR™ UK for civil works structures, ENGSGC100483 Rev B (Ref. 58)
GI-UKEPR-IH-04 (Ref. 70)	Internal Missiles	Methods with regard to the risk of dropped loads for EPR™ UK for civil works structures, ENGSGC100483 Rev B (Ref. 58)
GI-UKEPR-CC-01 (Ref. 71)	Classification of civil structures	NEPS-F DC 557 Rev D Classification of Structures Systems and Components (Ref. 72)

4 ONR ASSESSMENT

4.1 SCOPE OF ASSESSMENT UNDERTAKEN

50 The scope of the assessment has been to consider the expectations detailed down within the GDA Issue, **GI-UKEPR-CE-02** (Ref. 1), and its four actions. The issue is presented in Annex 2 of this report.

51 Further to the assessment work undertaken during Step 4 (Ref. 2), this assessment focuses on the "EPR™ Technical Code for Civil Structures" AFCEN ETC-C 2010 (Ref. 4) and its application for the UK EPR™ which is specified by the UK Companion Document (UK CD) (Ref. 5). Identified deliverables intended to provide the requisite evidence were provided within the responses contained within the Resolution Plan (Ref. 3) provided by EDF and AREVA at the end of Step 4 of GDA.

52 This assessment has been carried out in accordance with the ONR business management system HOW2 document PI/FWD "Permissioning - Purpose and Scope of Permissioning", Issue 3 (Ref. 11).

53 In summary, the purpose of the assessment was to judge whether the deliverables submitted in response to **GI-UKEPR-CE-02** provided sufficient justification of the AFCEN ETC-C 2010 as amended by the UK CD for use as the design code for the UK EPR™ Class 1 civil structures.

4.2 PROGRESS OF THE ASSESSMENT

54 EDF and AREVA submitted individual technical documents to justify its approach for the nine specific points under Action A1 (refer to paragraph 41). The Step 4 GDA review of Parts 0, 1 and 2 of the ETC-C had remnant queries which were summarised in Actions A2, A3 and A4, and detailed in three ONR letters (Ref. 32, 33 and 34).

55 A workshop was held with EDF and AREVA in July 2011 to discuss how the comments were to be progressed. EDF and AREVA had compiled the comments into a single tracking spreadsheet (Ref. 13), which contained five comments on Part 0, 75 comments on Part 1 and 64 comments on Part 2. It proposed a staged response where individual comments would be cleared by either providing justification for the approach used in the ETC-C or how the UK CD amended that particular clause. A new document referred to as a modification file (Ref. 14) would be used to record the revised UK CD clauses as they were progressed.

56 The ONR assessment comprised review of the individual revised UK CD clauses and was supported by Arup. This staged approach required much iteration and the tracking sheet and the modification file were updated at each stage. This process was repeated until a preliminary version of the complete UK CD Rev D was submitted in March 2012 (Ref. 73). I then commissioned Arup to carry out a consolidated review of the complete document to check its coherency. This generated a final round of comments which were resolved in Rev E of the UK CD (Ref. 5) submitted in September 2012.

57 EDF and AREVA also produced documents called assessment files to accompany the various revisions of the UK CD submitted. The assessment file records the reasons behind each changed clause and the supporting justification. It also records the justification provided for clauses that were scrutinised by ONR, but then subsequently proven to have sufficient justification. Three assessment files were produced for the UK CD during GDA Issue close-out (Refs. 59, 75 and 76).

4.3 ASSESSMENT OF RESPONSE TO ACTION 1

4.3.1 Introduction

58 Action 1 of **GI-UKEPR-CE-02** comprised the assessment of updates to the supporting documents for nine specific technical areas of the UK CD (Refs. 35 to 44 as shown in Table 2). Action 1 also requested additional justification with respect to detailing provisions, pool liners and dropped loads.

59 Earlier versions of the nine technical reports had been assessed during GDA Step 4 by ONR, supported by Arup. Eight reports were found to fall short of regulatory expectations in that insufficient technical justification was made for the approach adopted. The "Justification of the Partial Factor for Prestressing Actions γ_P" (Ref. 44) submitted in Step 4 was satisfactory and so this document did not need to be revised, although it is included in Table 2 for information only. The revised technical documents were reviewed again during GDA Issue Close-out and this is presented in Section 4.3.2.

60 New documents were submitted for the three additional topics in **GI-UKEPR-CE-02.A1.** These are:

- "EPR™ Safety Category 1 (C1) Structures – Good Practice Detailing Rules for Reinforced Concrete and Steel Structures". ENGSGC110157 Rev A (Ref. 45),
- "Pool Liner Design Requirements and Methodology" ENGSGC110243 Rev A (Ref. 46), and
- "Methods with regard to the risk of dropped loads for EPR™ UK for concrete structures" ENGSGC100483 Rev A (Ref. 47).

61 The assessments of these three topics are presented in Sections 4.4 to 4.6 respectively.

4.3.2 Revised Supporting Technical Documents

62 This section comprises the assessment of the technical reports listed in **GI-UKEPR-CE-02.A1**. I requested that Arup carry out a technical review of the new revisions of these reports against the versions it had reviewed during Step 4 GDA. The results are presented in Arup report 209364-10-01 (Ref. 77).

4.3.2.1 Concrete Strength Coefficient α_{cc} - ENGSGC100384 Rev B

63 EDF and AREVA submitted the technical document "Determination of the α_{cc} coefficient used in the formula for the design value of the compressive strength in Eurocode 2" ENGSGC100384 Rev B (Ref. 35) in part response to **GI-UKEPR-CE-02.A1.**

64 The design code Eurocode 2, BS EN 1992 (Ref. 21) is for the design of concrete structures. Part 1-1 introduces a term, α_{cc}, to modify the design strength of concrete. This is specified in Clause 3.1.6 of Eurocode 2, Part 1-1 as follows:

- "The value of the design compressive strength is defined as $f_{cd} = \alpha_{cc}\ f_{ck} / \gamma_C$ (Eqn 3.15) Where γ_C is the partial safety factor for concrete, see 2.4.2.4, and
- α_{cc} is the coefficient taking account of long term effects on the compressive strength and of unfavourable effects resulting from the way the load is applied."

65 The term α_{cc} has a recommended value of 1.0 in Part 1 (general) of Eurocode 2, and a recommended value of 0.85 in Part 2 (bridges). The UK National Annex (Ref. 21) adopts a value of 0.85, for bending and axial load, for both parts of Eurocode 2, whilst the ETC-C takes a value of 1.0. This was questioned by ONR during GDA Step 4 and the justification given at that time (ENGSGC100384 Rev A) stated that 0.85 is generally used

but a value of 1.0 is proposed for certain accidental actions. However, the justification given for this did not meet regulatory expectation.

66 EDF and AREVA submitted ENGSGC100384 Rev B (Ref. 35) in response to **GI-UKEPR-CE-02.A1** with a revised approach that α_{cc} should be 1.0 for accidental loads less than 2 hours duration and for loads which are principally strain induced. This is because the effects on concrete compressive strength, that α_{cc} accounts for, will not develop under such short term loading

67 I am satisfied that the design approach in the AFCEN ETC-C 2010 for α_{cc} is robust and addresses the ONR comments raised under GDA Step 4. The use of the higher coefficient for very short term loading has been adequately justified by ENGSGC100384 Rev B (Ref. 35). The use of α_{cc} as 0.85 for all other types and durations of loads is in accordance with the UK National Annex to BS EN 1992-1.

4.3.2.2 Load Combination Factors ψ_i - ENGSGC100394 Rev C

68 EDF and AREVA's submission for this specific query from **GI-UKEPR-CE-02.A1** is the technical document "GDA – Presentation and justification of ψi factors of ETC-C for variable actions in accidental and non-accidental situations", ENGSGC100394 Rev C (Ref. 53).

69 The Eurocode approach for variable loads uses different combination factors (ψ_i) for different situations depending on the nature of the variable load and what other variable loads are combined with it. These ψ_i factors are defined in Eurocode 0 BS EN 1990 "Basis of Structural Design" (Ref. 19) as follows.

- ψ0 = factor for combination value of a variable action (basic value = 0.7)
- ψ1 = factor for frequent value of a variable action (basic value = 0.5)
- ψ2 = factor for quasi-permanent value of a variable action (basic value = 0.3)

70 In the general accidental load case, the combination factor to be used is a Nationally Determined Parameter and with a choice of ψ_1 or ψ_2 and no recommended value is given. The UK National Annex however recommends ψ_1 is used, whereas ψ_2 is used in France; therefore the UK approach is more conservative.

71 The Step 4 review of ENGSGC100394 Rev A concluded that the AFCEN ETC-C 2010 (Ref. 4) presents a load combinations table that has the factors of safety and the combination factors combined which was not consistent with the Eurocode approach and so lacked transparency. The use of Eurocode 0 combination factors for the UK EPR™ also required further justification, including the use of the French ψ_2. The document did not cover non-accidental load cases and in particular the design of walls for non-accidental ultimate limit state loads.

72 ENGSGC100394 was revised twice; Rev B (Ref. 36) was provided as an interim position, and Rev C (Ref. 53) issued in August 2011 as a final position on this subject. I requested Arup carry out a comparison of Rev C with the Step 4 submission, Rev A. Arup's review is presented in its report (Ref. 77).

73 ENGSGC100394 Rev C is a significant revision since Rev A and includes justification of all ψ_i factors used rather than just ψ_2. The document now shows the factors of safety and the combination factors separately. The ψ_i factors in Table A1.1 of Eurocode 0 are grouped into different categories (A to H) according to building type. EDF and AREVA has adopted Category G for heavily trafficked areas as being the closest to the operational variable loads for structures like the UK EPR™. It is further argued that Category G is a conservative comparison, as the EPR™ only experiences significant

variable imposed loads at the end of construction and during exceptional maintenance. Justification is given that the factors applied in the AFCEN ETC-C 2010 are either equal to, or more conservative than, would be derived using a strict interpretation of Eurocode 0. The use of ψ_2 (French approach) for the main variable load in the accidental non-seismic case is justified on the basis that frequency of load in the EPR™ is much lower than load Category G and so using ψ_1 (UK approach) is too onerous.

74 I am satisfied that Ref. 53 now provides the transparency required by **GI-UKEPR-CE-02.A1**. The factors of safety and the combination factors are identified separately and so this is consistent with the Eurocode approach. I also regard the use of ψ_2 , for Category G loading, acceptable for low frequency loading which is more applicable for nuclear plants than loading due to heavily trafficked areas.

75 ENGSGC100394 Rev C (Ref. 53) has provided a suitable response to the original queries from GDA Step 4. It contains adequate justification for the ψ_i factors adopted and that they are based on the Eurocode approach, with additional consideration for special structures such as nuclear power plants.

4.3.2.3 Biaxial/Triaxial Stress Limits - ENGSGC100415 Rev B

76 EDF and AREVA's submission for this specific query from **GI-UKEPR-CE-02.A1** is the technical document "Justification of the concrete maximum compressive stress under bi axial/triaxial behaviour (accidental thermal conditions for the inner containment)" ENGSGC100415 Rev B (Ref. 37).

77 The compressive strength of concrete in one direction can be enhanced when there is another compressive force in an orthogonal direction. This orthogonal force is known as the confining force. This principle for concrete under biaxial or triaxial stress states is specified in the major internationally recognised design codes for concrete structures, including Eurocode 2, BS EN 1992-2 Design of Concrete Structures (Ref. 21).

78 The ETC-C specifies a rule in Clause 1.4.5.2.1 that

> *Under accidental situations (accidental thermal stresses only), the maximum compressive strength may be taken as 1.2 f_{ck}/γ_C instead of f_{ck}/γ_C when the section is subjected to biaxial compression (case of a variable thermal effect for instance).*
>
> *A more accurate calculation may be made by using EN 1992-2, Appendix LL.*

79 During Step 4, Rev A of ENGSGC100415 was submitted as justification for increasing the compressive stress limit by 20% (i.e. to $1.2f_{ck}/\gamma c$) for concrete under bi-axial or tri-axial stress states. The ONR Step 4 assessment concluded that the method presented was valid, however the document did not specify the minimum stresses in the other two directions to justify a maximum stress of $1.2f_{ck}/\gamma c$ in the third direction. ONR concluded that these limitations should be specified in the relevant ETC-C clause.

80 ONR also commented that the maximum concrete stresses calculated should be based on the actual concrete properties for the inner containment. The issue is that for UK aggregates, the thermal expansion coefficient for concrete could be higher than that assumed in the design. Therefore, further justification was requested that the design values were adequate.

81 ENGSGC100415 Rev B (Ref. 37) was submitted for GDA Close-out. I found the revised document to be acceptable since it adequately detailed the limitations to the application of enhanced strength, and provided justification for the approach adopted based on Eurocode 2 data and on some full scale testing results. However, since the UK Companion Document is the key design specification to the civil works designer, I wanted

to check that the relevant technical clauses were also adequate. Arup supported me in this check under the consolidated review of the UK CD Rev D (Ref. 85).

82 Clause 1.4.5.2.1 bis of the UK CD states that the characteristic compressive strength of concrete (f_{ck}) can be increased by 20% provided the transverse compression in one direction is at least $0.12f_{ck}$ and there is no tension in the other transverse direction. This is mathematically correct for a concrete with an f_{ck} of 60MPa, which is the case for the inner containment concrete. However, it is not universally correct for all strengths of concrete because the equations in BS EN 1992-2 Annex LL, are based on the mean, and not the characteristic, strengths (i.e. f_{cm} rather than f_{ck}). I therefore queried what EDF and AREVA's design rules would be for other strengths of concrete.

83 EDF and AREVA confirmed in the "Assessment File of Revision E of UK Companion Document to the AFCEN ETC-C 2010" ENGSGC120228 Rev A (Ref. 75) that for the UK EPR™, the inner containment wall structure is the only structure subject to such high compressive loads that the strength enhancement must be invoked. Furthermore, the enhancement is only required in the areas where the lateral stress is in the order of $0.66f_{ck}$. Therefore, EDF and AREVA proposed to change the minimum confining stress required to $0.36f_{ck}$ as an additional margin and since Clause 1.4.5.2.1 is within Section 1.4.5 "Specific Design Criteria for the Containment with Steel Liner" it can only be applied to the inner containment concrete.

84 I am satisfied with the final version of Clause 1.4.5.2.1 bis in the UK CD Rev E (Ref. 5) and concur that a minimum confining stress of 0.36 f_{ck} is a conservative requirement.

85 In respect to my comment about using the actual properties of the inner containment concrete for calculations, EDF and AREVA have confirmed that no further justification can be provided until site specific phase when the properties will be known. Therefore, I have raised the following assessment finding.

> ***AF-UKEPR-CE-76:*** *The licensee shall confirm that the enhanced concrete compressive strength used for the design of the inner containment structure accounts for the final concrete mix design specified, and in particular the thermal expansion coefficient for the type(s) of aggregates to be used*
>
> ***Required Timescale:*** *Nuclear Island Safety-Related Concrete.*

86 It should be noted that the existing Step 4 Assessment Finding **AF-UKEPR-CE-68** also applies to the concrete properties of the finished structure.

4.3.2.4 Shear Reinforcement - ENGSGC100410 Rev D

87 EDF and AREVA's submission for this specific query from **GI-UKEPR-CE-02.A1** is the technical document "EPR™ UK – Shear design proposal" ENGSGC100410 Rev D (Ref. 54).

88 The ETC-C design of shear reinforcement is based on the Eurocode 2 Part 1-1 (Ref. 21) approach and the French National Annex to Eurocode 2. However, since this approach is different to that of the UK National Annex further justification was required. Rev A of document ENGSGC100410 was submitted during Step 4 to set out the basis for a proposed revision to the ETC-C for the calculation of shear resistance and shear reinforcement requirements. The principal comments raised on Rev A of this document are summarised as follows:

- The shear link design method had not been justified sufficiently and since it was less conservative than that in the UK National Annex to Eurocode 2, was found to be unacceptable.

- Limitations on concrete strength used in shear design due to the properties of UK aggregates were not considered.
- Minimum link requirements did not include the rules for spacing of links, just the minimum area.

89 Rev B of the document was submitted at the end of Step 4 and was not reviewed at that time. Rev C (Ref. 38) was submitted under the EDF and AREVA Resolution Plan and this was the version initially assessed for GDA Close-out (Ref. 77). Rev C had been substantially revised which had introduced editorial errors. Technically, it was still found to be lacking in a number of areas. The main areas of concern were over the use of spacing rules for shear reinforcement which were outside the requirements of the UK National Annex to Eurocode 2 and UK standard practice.

90 There was also a lack of clarity over the treatment and definition of primary and secondary slabs and the treatment of load redistribution. The document aligns secondary slabs with "*members of minor importance*" as defined in Eurocode 2. ONR disagreed with this definition since the Eurocode defines "*members of minor importance (e.g. lintels with span < 2 m) which do not contribute significantly to the overall resistance and stability of the structure*". The document also allows redistribution of loads based only on slab geometry. The load arrangement must also be considered; for example, a slab with uniform load over most of its area has nowhere to redistribute to.

91 EDF and AREVA proposed an approach outlined in Letter EPR01031N (Ref. 87) in December 2011 and this was discussed with EDF and AREVA at the Level 4 Civil Engineering technical meeting in January 2012. The approach adopted is a considerable improvement on that previously presented. The spacing of shear reinforcement is now fully compliant with Eurocode 2 and the UK National Annex. In addition, the definition of primary and secondary slabs is improved. However, ONR provided a small number of comments to EDF and AREVA (Ref. 88) which mainly discussed improvements to the guidance to be provided in the UK CD. EDF and AREVA submitted a further document ENGSGC110375 Rev B "Out of Plane Shear Reinforcement" (Ref. 89). ONR commented (Ref. 90) that the definitions of the secondary slab and redistribution criteria could still be made clearer.

92 Rev D of document ENGSGC100410 (Ref. 54) was submitted in February 2012 and incorporated the new proposal. This was further reviewed by Arup (Ref. 84). Overall, the proposed method has been revised so as to give a design at least as conservative as that using the recommended values from Eurocode 2. The spacing of minimum shear reinforcement in accordance with the UK National Annex has also now been included. This method is therefore now acceptable.

93 One remnant comment was that justification of shear strength needs to relate to UK aggregates in accordance with the UK National Annex to Eurocode 2 Part 1-1 Subclause 3.2.3 (2)P. EDF and AREVA confirmed this could not be finalised until the actual type of aggregate is chosen by the licensee. Therefore I have raised the following assessment finding.

> ***AF-UKEPR-CE-77:*** *The licensee shall confirm that design shear strength used for reinforced concrete structures accounts for the final type(s) of aggregates used in the concrete mix design in accordance with the UK National Annex to Eurocode 2 BS EN 1992-1-1.*
>
> ***Required Timescale:*** *First Structural Concrete.*

94 There also still remained the question of whether all the requirements for shear reinforcement design had been included in the UK Companion Document. This was assessed under the comprehensive review of the complete UK CD. The detail of this review is reported in Arup report 209364-10-10 (Ref. 85). The main clause, 1.4.4.2.2 bis states that Eurocode 2 requirements are replaced by Appendix 1.H bis. Although, 1.H bis correctly states the UK CD approach is in addition to the Eurocode 2 checks, it could be misinterpreted as replacing them. Therefore, text from 1.H bis which specifies exactly how the checks are to be carried out has been inserted in Clause 1.4.4.2.2 bis in the UK CD Rev E (Ref. 5).

95 I am satisfied that the final submission of the UK CD Rev E under GDA (Ref. 5) provides adequate specification to the designer for provision of shear reinforcement. The justification provided in ENGSGC100410 Rev D is sufficient to satisfy regulatory expectations.

4.3.2.5 Steel Partial Safety Factors for Fastenings - ENGSGC 100395 Rev B

96 EDF and AREVA's submission for this specific query from **GI-UKEPR-CE-02.A1** is the technical document "Steel and concrete partial safety factors for EPR™ fastening systems" ENGSGC100395 Rev B (Ref. 39).

97 The Step 4 review of ETC-C 2006 noted that the factors of safety given for fastenings were lower than those used in industry codes and good practice documents. Document ENGSGC100395 Rev A was submitted as justification at that time for revised values of the partial safety factors for the steel components of the fastenings. The concrete material factors were consistent with those from the "Design of fastenings for use in concrete", Part 4 to Eurocode 2 (in development) (Ref. 29) and so were deemed satisfactory.

98 The new steel material factors of safety proposed in AFCEN ETC-C 2010 were increased from 1.15 to 1.4 for the normal Ultimate Limit State (ULS) and from 1.0 to 1.25 for the accidental ULS cases. This is a significant increase but it was noted that the new factors are still lower than those derived from Eurocode 2 Part 4 when the likely steel properties are considered. The factors of safety are however higher than those recommended in the CEB international good practice guide "Fastenings to Concrete and Masonry Structures" (Ref. 27), and on this basis were deemed to be acceptable by the Step 4 review.

99 The outstanding comment from Step 4 was that the new factors are only applied to the headed anchors and not normal bar reinforcement, which is treated as reinforcement in accordance with Eurocode 2 Part 4 and as such would have lower factors of safety. Reinforcement bars welded to the back of a cast-in plate will be subject to combined tension and shear, unlike normal reinforcement. They form part of the overall safety of the bracket and, as such, further justification was required for using lower material factors than proposed for headed anchors.

100 ENGSGC100395 Rev B (Ref. 39) was submitted for close-out and was reviewed against the outstanding comment (Ref. 77). The principal revision made is to state that the proposed factors of safety apply to both headed and non-headed anchors. Since the same factor of safety is to be applied to all anchors there are no further concerns with this document and I consider it to be acceptable.

4.3.2.6 Prestressing Tendons Participation - ENGSGC100416 Rev C

101 EDF and AREVA's submission for this specific query from **GI-UKEPR-CE-02.A1** is the technical document "Prestressing tendons participation in reinforced concrete calculations for the inner containment" ENGSGC100416 Rev C (Ref. 55).

102 The UK EPR™ inner containment structure uses bonded prestressing steel tendons. The tendons are smooth and so have an inferior bond with the concrete than that of normal reinforcement i.e. deformed bars. When a prestressed concrete element cracks, stresses are induced in reinforcement and any bonded tendons, but stresses in the tendons are less due to the inferior bond. To allow for this, the effective area of prestressing strand is reduced by a factor in Eurocode 2, Part 1-1, known as the prestressing participation factor. The factors in the ETC-C are higher than in Eurocode 2, and therefore the ETC-C considers the prestressing steel to be more effective and subsequently calculates lower reinforcement stresses.

103 The justification for the 2006 ETC-C participation factors was submitted during GDA Step 4 via ENGSGC100416 Rev A. This was satisfactory as the basis for determining the contribution of the horizontal tendons, which are in corrugated ducts. It demonstrated that the ETC-C was more conservative than Eurocode 2 for group 2 and group 3 load combinations, and any discrepancies for group 1 combinations were not significant. However, there was no discussion on the approach for vertical tendons, the approach when tendons are in smooth ducts, or the approach close to singularities (such as major penetrations) when stabilised cracking may not develop. Given the number of tendons in smooth ducts and the tendency for these to be adjacent to major penetrations, which are considered singular zones, the lack of specific rules in this area was questioned by ONR (Ref. 32).

104 ENGSGC100416 Rev B (Ref. 40) was submitted in February 2011 but did not address the comments, and a further revision of the document was requested. Rev C (Ref. 55) was submitted in September 2011 and was reviewed against the previous comments (Ref. 77). Ref. 55 presents a theoretical derivation of the participation of the prestressing steel in smooth ducts, but the numerical examples given did not include the full supporting calculation. However, the document also presents considerable new material on the feedback from the construction and testing of the 900MWe series of power plants in France. Testing was carried out on the tendons in the as-built structures of the power plants. Experimental testing was also carried out on a ½ scale mock-up of a containment structure at test facilities on the Civaux site, France. This mock-up is known as the MAEVA mock-up (MAquette Enceinte en Vapeur et en Air or Steam and Air Containment Model).

105 The research work undertaken compared the theoretical predictions of the behaviour (e.g. cracking) of the containment structure from the FE models, with the experimental results from the MAEVA mock-up. This provides valuable benchmarking of the predicted behaviours.

106 The review of ENGSGC100416 Rev C found that the practical feedback and test results presented demonstrate that the reinforcement/tendons provided result in acceptable crack widths in the actual structures. In addition, the theoretical crack widths calculated are relatively insensitive to the design assumptions made in terms of participation factors, and thus use of a slightly higher factor did not affect the crack widths significantly. Given these two points I am satisfied that the design approach used in the generic design results in a robust structure and ENGSGC100416 Rev C is acceptable.

4.3.2.7 Shrinkage and Cracking of Concrete Structures - ENGSGC100426 Rev B, ENGSGC100428 Rev B and ENGSGC110025 Rev A

107 EDF and AREVA submitted two updated documents in response to **GI-UKEPR-CE-02,** namely “Methodology for Consideration of Shrinkage for EPR™ Concrete Structures” ENGSGC100426 Rev B (Ref. 41) and “Verification of Crack Width for EPR™ Concrete Structures” ENGSGC100428 Rev B (Ref. 42) and a new document “Global approach

about methodology for consideration of shrinkage and crack limitation" ENGSGC110025 Rev A (Ref. 43).

108 Shrinkage of concrete occurs, due to various chemical and physical effects, both in the early stages and the longer term. Where early shrinkage is constrained, for example where a wall is cast onto a raft, the wall will want to shrink more than the raft which has already undergone its first stage of shrinkage. The wall is therefore restrained by the raft and internal tensile forces develop which eventually will cause cracking in the wall.

109 Crack widths are required to be controlled for various reasons including durability, water resistance, compatibility with waterproofing membranes and aesthetics. Accepted design codes specify the maximum allowable crack width that the structure can accommodate depending upon its performance requirements. For the EPR™ strain compatibility of the concrete movement with steel liners used for the assorted pools and containment is a further consideration. The extent of shrinkage cracking in concrete is normally controlled by a combination of concrete mix, pour sequence, curing of the pour, operating temperatures and by the amount of reinforcement provided in the structure. Shrinkage cracking may be considerable in high strength concrete mixes with a low ratio of water to cement or with silica fume added, as is the case for the inner containment concrete proposed.

110 The GDA Step 4 assessment (Ref. 2) noted that the reference design, FA3, had exceptionally high rates of reinforcement and that this was determined by the serviceability limit state including shrinkage, which required significantly more reinforcement than the design earthquake. EDF and AREVA submitted two documents during Step 4 to justify its approach to the control of cracking, ENGSGC100426 Rev A and ENGSGC100428 Rev A. These were assessed but found to fall short of ONR expectations. EDF and AREVA therefore submitted updates ENGSGC100426 Rev B (Ref. 41) and ENGSGC100428 Rev B (Ref. 42) in response to **GI-UKEPR-CE-02** and a new document "Global approach about methodology for consideration of shrinkage and crack limitation" ENGSGC110025 Rev A (Ref. 43). These three documents do not include justification of how the liner design is affected by the control of cracking in the concrete wall; this is justified separately and is assessed in Section 4.5.3 of this report.

111 ENGSGC100426 Rev B (Ref. 41) sets out to present the two different methods proposed for the control of shrinkage for the UK EPR™ and justify the parameters used. The first method, called the equivalent force or load combination method, applies shrinkage as a thermal load; the second method calculates a specific crack width by calculating the strains in the concrete. Rev B has stated more clearly that the strain method (second method) will be used for all elements with additional checks using the force method (first method). The Step 4 assessment found the strain method to be acceptable, however the differential shrinkage should be calculated taking into account the other forms of shrinkage including early thermal and autogenous shrinkage effects.

112 The report confirms the argument that "*it is not necessary to add early age* [thermal] *and autogenous shrinkage to the drying shrinkage for the calculations*". The reasoning for this is that "*the reinforcement designed for other loads can resist the imposed tension stresses*" from early thermal shrinkage and the thermal gradient will be controlled. This is a relevant argument, but no justification is given that the reinforcement provided is sufficient.

113 The method used for calculating crack widths due to drying shrinkage is based on Eurocode 2 Part 2 for concrete bridges. The UK National Annex to Part 2 specifies that the Part 1 (building structures) method should be used in preference. To justify its use of the Part 2 method, EDF and AREVA presents results in Ref. 41 that show the Part 2

method is more conservative than the Part 1 method for thin elements, has similar results for the containment wall, but predicts lower shrinkage in the raft. The raft will typically be the restraining element since it is cast first and would have already undergone its early shrinkage. Therefore predicting lower shrinkage in the raft is conservative when calculating the shrinkage in elements to be cast against it.

114 Overall, I am satisfied that the Part 2 strain method for calculating crack widths due to drying shrinkage has been justified. However the omission of calculating crack widths due to early thermal and autogenous shrinkage does not meet UK current good practice. This is discussed further in paragraph 117 below.

115 ENGSGC100428 Rev B (Ref. 42) sets out to present the need to control cracking and how this is achieved for the UK EPR™. Ref. 42 is now specifically for durability requirements only and refers to ENSGC100426 Rev B for leaktightness requirements, however there is considerable overlap between the two documents. Inconsistencies in crack width criteria and the use of additional unconservative methods of crack control which were present in Rev A have also been removed.

116 EDF and AREVA proposed that the outstanding comments on Ref. 41 and Ref. 42 would be resolved by ENGSGC110025 Rev A.

117 Report ENGSGC110025 Rev A (Ref. 43) was produced to try and bring together the requirements in Ref. 41 and Ref. 42 in a coordinated manner. I commissioned a detailed review of this document (Ref. 79) based on the ONR comments made during GDA Step 4. In order to resolve the outstanding queries the review included independent studies on crack width prediction using actual reinforcement ratios and section sizes from the FA3 project and compared these to acceptable crack width values. In addition, EDF and AREVA agreed to provide some feedback from the FA3 project on measured crack widths to provide confidence in the approach from a practical perspective.

118 The independent calculations have been undertaken by Arup on behalf of ONR and the results are presented in Arup report 209364-10-03 (Ref. 79). Typical wall, beam and slab sections have been examined. The independent approach has been to use the guidance in “Early-age Thermal Crack Control in Concrete” CIRIA Guide C660 (Ref. 28), which is relevant good practice in the UK and is referred to by the UK supporting document to Eurocode 2, document PD6687-1:2010 (Ref. 91). This provides UK non-contradictory, complementary information for controlling crack widths due to restrained imposed deformations.

119 The results of this assessment have shown that, for the assumptions made, cracking is controlled to reasonable levels by the minimum reinforcement provided. The only exception to this is the crack control in a 500mm thick element when subjected to end restraint. End restraint does not govern for the cases considered in the independent review, but it is not possible to say categorically that it will not govern elsewhere in the EPR™. Long walls subject to significant axial restraint at their end are likely to be most at risk. It is therefore suggested that the licensee shall confirm that there are no situations where end restraint is a governing behaviour for walls or slabs and I raise the following assessment finding.

> ***AF-UKEPR-CE-78:*** *The licensee shall provide a list of the safety critical reinforced concrete structural elements whose behaviour under shrinkage is dominated by end restraint. The licensee shall provide justification of the shrinkage control methods and reinforcement provided for such elements.*
>
> ***Required Timescale:*** *Nuclear Island Safety-Related Concrete.*

4.3.2.8 Partial Factor for Prestressing Actions, γ_p - ENGSGC100402 Rev A

120 The “Justification of the Partial Factor for Prestressing Actions γ_P” ENGSGC100402 Rev A (Ref. 44) submitted in Step 4 was judged to be satisfactory and so no further assessment is required for closure of **GI-UKEPR-CE-02**.

4.4 DETAILING PROVISIONS

4.4.1 Introduction

121 The ONR review during GDA Step 4 found that the rules given in the AFCEN ETC-C 2010 for detailing of C1 civil structures, particularly seismic requirements, were not as specific as would normally be expected for NPP structures. EDF and AREVA proposed in its resolution plan to produce a new document which would provide additional rules. ENGSGC110157 Rev A, "EPR™ Safety Category 1 (C1) Structures - Good Practice Detailing Rules for Reinforced Concrete and Steel Structures" (Ref. 45) was submitted in July 2011. The assessment of this report is presented in Section 4.4.2 of this report.

122 The GDA Step 4 review also requested further justification of the construction joint method specified by AFCEN ETC-C 2010. EDF and AREVA submitted a new document "Justification of the AFCEN ETC-C Construction Joint Design Method" ENGSGC110222 Rev A (Ref. 92) in September 2011. The assessment of this is presented in Section 4.4.3 of this report since it affects how construction joints in concrete structures are detailed.

123 The use of projecting bars (bent down bars) in openings was queried by the Step 4 assessment (Ref. 2) since this is not usually permitted in the UK for nuclear structures. This was included in **GI-UKEPR-CE-01**, but is assessed in this report since it is directly specified by the ETC-C. This is presented in Section 4.4.4.

4.4.2 Detailing Rules for Reinforced Concrete and Steel Structures ENGSGC110157

124 EDF and AREVA's final submission for this specific query from **GI-UKEPR-CE-02.A1** is the technical document "EPR™ Safety Category 1 (C1) Structures - Good Practice Detailing Rules for Reinforced Concrete and Steel Structures" ENGSGC110157 Rev B (Ref. 56). This updated the previous version, Rev A (Ref. 45).

125 The Step 4 assessment found that neither ETC-C 2006 nor AFCEN ETC-C 2010 referred to Eurocode 8 (BS EN 1998) "Design of Structures for Earthquake Resistance" (Ref. 23) for the ductile detailing of structures. Therefore, the ETC-C must provide the necessary rules to achieve the required performance of the structure. This comment had been previously raised in technical queries, TQ-EPR-241 and 283 (Ref. 93) and the responses noted that "*the design rules prescribed by ETC-C, and additional good practice rules applied in the design of FA3 buildings…result in principles which comply approximately with those for ductility class "M" as described in Eurocode 8*."

126 Eurocode 8 allows two approaches; non-dissipative structures (low ductility class) and dissipative structures (medium or high ductility class) For the latter, the structures are allowed to enter the plastic domain by becoming ductile, and so provided ductile detailing is used the design loads from the elastic FE analysis model can be reduced by a factor, q. For the former, the behaviour remains approximately elastic and no ductile detailing is required (i.e. standard Eurocode 2 or 3 rules apply) provided the full elastic loads are used (i.e. q =1.0).

127 EDF and AREVA's philosophy is that since the seismic design of C1 structures of the EPR™ is based on an elastic response (q=1) then theoretically no ductility needs to be provided in the structural detailing. However, the responses to the TQs did not clarify exactly what level of ductility was included to avoid brittle failure modes in beyond design conditions and what detailing rules would be used to ensure it was achieved. Therefore further justification was requested via **GI-UKEPR-CE-02** and EDF and AREVA submitted ENGSGC110157 Rev A (Ref. 45) in response.

128 A review of Ref. 45 was commissioned by ONR and is presented in Arup report 209364-10-05 (Ref. 81). The main review conclusion was that the claim of equivalence with the ductility class "medium" (DCM) of Eurocode 8 had not been proven. The review examined the detailing rules in Ref. 45 and found that together with AFCEN ETC-C 2010 they did not include the requirements of Eurocode 8 for a medium ductility class structure and hence cannot be said to ensure adequate ductility. The main omission was an identification of the system used to provide ductility but there were also particular omissions in detailing rules.

129 ONR issued its comments on ENGSGC110157 Rev A to EDF and AREVA via letter EPR70370R (Ref. 94) summarising the above and overall that ductility was claimed to be provided in C1 structures but the detailing rules to be used to provide ductility had not been proven. In response EDF and AREVA submitted a preliminary version of ENGSGC110157 Rev B Prel (Ref. 96) and a justification report from recognised French experts in this field on the aseismic design of reinforced concrete (Ref. 97).

130 The justification given in Ref. 97 for the EPR™ detailing rules is that NPPs are not completely covered by the Eurocodes, which are dedicated to normal buildings and where structural elements are much more slender than in an NPP. EDF and AREVA have therefore provided additional requirements based on operational and construction experience over many years. The EPR™ is designed to remain globally elastic in accidental load cases and no specific measures for ductility are required. A second argument given was that plastic hinge points in normal buildings can be engineered at certain locations in the long, thin structural elements. NPPs mainly consist of intersecting, thick and highly reinforced shear walls and so they would not yield at a particular hinge point as envisaged by Eurocode 8 rules for medium or high ductility classes.

131 Detailing rules for structural steelwork had not been included in Ref. 96 or Ref. 97. Therefore, EDF and AREVA provided a subsequent response via letter EPR01108N (Ref. 98), which enclosed a justification report (Ref. 99) from the French CTICM (Centre Technique Industriel de la Construction Metallique i.e. Steel Construction Institute). This expert report, again argues that if fully elastic design is adopted, then ductile detailing for steelwork is not required. It states that:

- The higher the safety requirements used to design a building under seismic loading, the less it becomes possible to resort to plastic dissipation and therefore the principle of dissipative behaviour.
- The requirements of Eurocode 8 for standard buildings allow for the use of ductility classes DCM or DCH, leading to the optimisation of the design with the risk of irreversible damage to the structure under seismic loading.
- Special buildings such as nuclear power plants, need to remain operable after an earthquake (therefore excluding all damage) and shall be designed with a ductility class of DCL, or even with q=1 regardless of their location.

132 Ref. 99 confirms that the same philosophy is used for C1 steelwork structures of the UK EPR™ as for the concrete structures. Therefore, the additional detailing rules for steelwork structures are based on Eurocode 3 and EPR™ feedback experience.

133 EDF and AREVA submitted the revised report ENGSGC110157 Rev B (Ref. 56) in May 2012. This update clarified that the design of C1 structures is based on non-dissipative behaviour and that the analogy with medium ductility structures is no longer claimed. It also makes clearer that detailing rules are not based on Eurocode 8, but on Eurocodes 2 and 3, with enhancements required for special structures such as NPPs. This document

is to be used in conjunction with the detailing rules given in the UK Companion Document. The final submitted version of the UK CD Rev E (Ref. 5) has included the above detailing rules in Clause 1.4.11.1 bis Reinforcement and 1.7.2.2 bis Seismic Detailing.

134 I am satisfied that designing the UK EPR™ C1 civil structures for the full elastic loads at design basis is appropriate such that the structures remain operable after an earthquake. The question is how the structures behave if subject to a beyond design basis earthquake, i.e. at what margin do plastic hinges form and is there a possibility of brittle (sudden) failure. EDF and AREVA has provided seismic margin assessments for the containment and massive concrete structures and demonstrated there is sufficient margin for the generic design (Ref. 2, Section 4.3.10.3). The beyond design basis behaviour of the inner containment has also been assessed by ONR under **GI-UKEPR-CE-03** (Ref. 8). Therefore, I am satisfied that the design approach in ENGSGC110157 Rev B (Ref. 56) is adequate for such massive concrete structures, which form the majority of the Nuclear Island.

135 I accept the argument that ductile hinges do not tend to form in discrete locations in massive concrete sections and so ductile detailing is not necessarily relevant. However, for smaller structural elements, such as small section concrete columns or steelwork supports the possibility of ductile hinges forming needs to be appraised by the designer. I accept that at the design basis earthquake the sections remain elastic; but as the loads increase beyond this level it should be proven that at the target margin any plasticity in these sections does not cause sudden failure. No evidence has been submitted to justify this beyond design basis behaviour. Since ductile detailing rules have not been adopted for these types of sections the substantiation required at detailed design phase will be more onerous. The Step 4 report (Ref. 2) raised Assessment Finding **AF-UKEPR-CE-66** requiring the licensee to demonstrate that adequate margins beyond the design basis exist for all Class 1 civil structures. I raise the following assessment finding to supplement this requirement, specifically with respect to ductile behaviour in a beyond design basis event.

> ***AF-UKEPR-CE-79:*** *The licensee shall confirm that there is adequate margin beyond design basis for safety critical non-massive structural elements e.g. concrete columns or steel frames, such that if plasticity occurs in any part of those elements for the event considered, this will not lead to sudden failure.*
>
> ***Required Timescale:*** *Nuclear Island Safety-Related Concrete.*

4.4.3 Construction Joint Design Method - ENGSGC110222 Rev A

136 During the GDA Step 4 review ONR requested further justification of the construction joint method specified by AFCEN ETC-C 2010. This request was agreed at the technical workshop in July 2011, and included as part of **GI-UKEPR-CE-02**. EDF and AREVA submitted a new document “Justification of the AFCEN ETC-C Construction Joint Design Method” ENGSGC110222 Rev A (Ref. 92) in September 2011.

137 I commissioned Arup to carry out a review and the findings are presented in report 209364-10-02 (Ref. 78). ENGSGC110222 Rev A sets out to justify the method of shear joint design in the AFCEN ETC-C 2010. It proposes to do this by reference to the American Concrete Institute (ACI) concrete design codes ACI-349, “Code Requirements for Nuclear Safety Related Concrete Structures” (Ref. 24) and ACI-318, “Building Code Requirements for Structural Concrete” (Ref. 25) and with reference to test data.

138 The key findings from the review (Ref. 78) are:

- The shear joint equation in the AFCEN ETC-C 2010 code is not consistent with the level of joint preparation proposed
- The document contains improved definitions of the key variables in the shear joint equation.
- The comparison with the ACI approach shows that the ETC-C approach is generally less conservative, with margins up to 25% (typically 15%). The document reviewed does not attempt to justify or discuss this. Furthermore, no comparison of the loading to be applied is considered. It would appear that the loading to ACI 318 would be higher, additionally reducing the relative safety of the AFCEN ETC-C 2010, and this should be further investigated.
- Data from 10 tests are presented that demonstrate the AFCEN ETC-C 2010 designed sections have a substantial margin between actual capacity to calculated capacity. However, the relevance of these tests to the wide range of situations that are covered by the shear joint equation is not considered.
- The joint in the dome roof of the containment is a special case, since it is within its thickness, and this situation is not explicitly covered.

139 In conclusion, ENGSGC110222 Rev A did not justify that the method given in the AFCEN ETC-C 2010 was equivalent to, or better than, the method in Eurocode 2. ONR also stated that should a construction joint fail to meet the requirements of Eurocode 2, then the position of that joint should be reconsidered.

140 The technical aspects were discussed with EDF and AREVA at the technical meeting November 2011. EDF and AREVA proposed new design rules for construction joints from one of the following options.

1) Provide further justification of the method proposed in AFCEN ETC-C 2010,
2) Provide case by case justification for situations where Eurocode 2 rules are not satisfied, or
3) Transfer the justification for a comprehensive methodology to site specific phase.

141 In January 2012, EDF and AREVA proposed a revised approach using option (2) above via letter EPR01060N (Ref. 100). Clause 1.4.4.2.2 bis - Shear of the UK CD Rev E (Ref. 5) has been revised to the following:

142 "*The design of construction joints shall be verified against the criteria set out in EN 1992-1-1 clause 6.2.5, conservatively using the parameters given for rough surfaces. Where these criteria are not met, justification of the construction joint design shall be made on a case by case basis, submitted to the licensee's Design Authority approval*."

143 I am satisfied that this change in approach will result in adequate design of construction joint details. Eurocode 2 Part 1.1 (BS EN 1992-1-1) is accepted good practice and any deviation from this will be justified on a case by case basis during site specific design. A specific joint sampled during Step 4 GDA was that in the domed roof to the inner containment. The clarification that this will comply with Eurocode 2 rules has answered the design queries raised. However, during the phased construction this joint needs to be kept partially complete and so its protection and preparation for the next concrete pour is a workmanship issue which is outside the scope of GDA. I have therefore raised the following assessment finding.

AF-UKEPR-CE-80: *The licensee shall provide the final construction specification and details for the joints within the concrete dome roof to the inner containment, and justify that the finished structure will fulfil the nuclear safety requirements.*

Required Timescale: *Install Polar Crane.*

4.4.4 Bent Down Bars

144 When an opening is formed in a concrete structure, one technique is to bend the reinforcing bars to avoid having to form holes for them in the formwork. This is not generally permitted in the UK for nuclear structures, and only for small diameter bars in normal structures. This is to avoid the possibility of the bars being overstressed when they are bent back after casting.

145 ONR raised this as a comment in letter EPR70367R (Ref. 34) under Section 2.4 “Reinforcement for Reinforced Concrete”, and it is listed as comment 2-16 in the ETC-C Tracking Spreadsheet (Ref. 13). The use of bent down bars was permitted in the Flamanville 3 “Hypothesis Note on Reactor Building Containment Internals” and so this was queried under **GI-UKEPR-CE-01** (Ref. 7, Section 4.2.3.16).

146 EDF and AREVA has confirmed that Clause 2.4.5.3.3 of the AFCEN ETC-C 2010 (Ref. 4) controls the site bending of bars as follows:

> *“The re-straightening, even in part, of a bent reinforcement is not permitted except for reinforcements which have a certificate of conformity for re-straightening after bending, supplied by an approved and notified certification body.”*

147 I consider this as a satisfactory response to this comment and so consider it closed.

4.5 POOL LINER DESIGN

4.5.1 Introduction

148 The concrete in both the inner containment and the pools is faced with a steel liner. The purpose of these liners is to ensure leaktightness; they do not contribute to the structural strength. The liners are attached to the concrete by various means, including studs and welded angles, such that forces are transferred between the two.

149 The Step 4 review of the AFCEN ETC-C 2010 concluded that this code itself did not provide sufficient guidance in Clause 1.6 for the design of steel lined pools and tanks of the EPR™. Therefore, the production of a methodology document(s) was required which properly explains the detailed design and construction process for these structures.

150 The EDF and AREVA Resolution Plan for **GI-UKEPR-CE-02** listed the "Methodology Report for Pool Liners" as a deliverable, but the document number was not known at that time. The resulting documents submitted were:

- "Pool Liner Design Requirements and Methodology" ENGSGC110243 Rev A (Ref. 46), and
- " UK EPR™ – GDA – Presentation and Justification of the Consequences of Concrete Cracking on Liner Leak-tightness" ENGS110046 Rev A (Ref. 101).

151 Ref 46 was submitted as the primary methodology document for the design process for liners of pools and tanks of the UK EPR™. This is assessed in Section 4.5.2 below. Ref. 101 was submitted as additional justification for the treatment of liner strains due to concrete cracking. This affects the inner containment as well as pool liners; therefore I have included the assessment here since the technical issues are the same. Ref. 101 is assessed in Section 4.5.3 of this report.

4.5.2 Methodology for Pool Liner Design - ENGSGC110243

152 The initial deliverable ENGSGC110243 Rev A (Ref. 46) was submitted at the start of GDA Issue Close-out in August 2011. ONR commissioned Arup to carry out an assessment of this report for **GI-UKEPR-CE-02** and the conclusions are presented in Arup report 209364-10-11 (Ref. 86). ONR comments were issued to EDF and AREVA via letter EPR70366R (Ref. 102) in October 2011.

153 The main comment was that the document did not greatly extend the specification for the methods to be used for the design and construction of steel lined concrete pools and tanks. There was also insufficient guidance on the design of the leak collection system and the design of sluice gates. The context of the document within the generic design was also unclear. Finally, the roles and responsibilities of the generic designers and the site specific design contractors needed to be made clearer.

154 EDF and AREVA provided a preliminary Rev B to ENGSGC110243 (Ref. 103) in response to the comments in the ONR letter. This was intended to provide an overall methodology to support Section 1.6 of the AFCEN ETC-C, and hypothesis notes for each specific structure would be created during the site specific phase in line with this methodology.

155 ONR commented (Ref. 104) that the proposed Rev B of the document was a significant improvement on the previous version in that it included more detail on the design process. Two further technical comments were also made: firstly that Section 5.1 included a statement that there is "*no specific leak tightness requirement associated with the concrete structures*" and secondly that Section 6.5 needed clarification on the non-

linear FE models used. For the former, Assessment Finding **AF-UKEPR-CE-28** had already been raised in the ONR GDA Step 4 report (Ref. 2) which said "*The licensee shall confirm that the concrete portion of all steel lined concrete pools which have a permanent and potentially contaminated fluid shall be confirmed as adequate against the requirements of BS EN 1992 Part 3 (Tightness class 1)*". This means that the concrete will be designed to limit cracking such that it provides an additional line of defence against leakage.

156 ENGSGC110243 Rev B (Ref. 57) was submitted in March 2012 and an explanation given in letter EPR01114N (Ref. 105) of how the ONR comments had been addressed. The responses to the points raised are detailed below.

157 Further details have been added to Ref. 57 to provide liner plate thicknesses and anchoring design guidelines with reference to Section 1.8 of AFCEN ETC-C 2010 for the interface requirements between anchors and concrete. The method for treatment of discontinuities and the requirements for leak detection systems and sluice gates have also been expanded. The minimum reinforcement requirements for crack control in the concrete are referred to in Section 5.1. Guidance for the FE models has also been added at several points in Section 6 “Design Codes and Methodology”.

158 The additional technical details that have been added to Ref. 57 are sufficient to answer the ONR comments raised on the first version of the document. However, it should be noted that the specific detailed design criteria and requirements will be developed further at site specific phase. There is already a Step 4 regulatory requirement for justification of this design hypothesis at that time which is captured by Assessment Finding **AF-UKEPR-CE-17** (Ref. 2). Likewise, justification of the testing of pools and leak detection systems to prove their adequacy is required under **AF-UKEPR-CE-18**.

159 The methodology document (Ref. 57) states that it “*marks the end of the GDA phase and site specific hypothesis shall be created in line with this report*.” The description of the design process, in terms of responsibilities is given in the “EPR Nuclear Island Civil Engineering Design Process Note” (Ref. 60) which has clarified that the detailed design will be based on the hypothesis notes produced by the civil works designers. I am satisfied that this approach ensures they take ownership of the design, under the supervision of the licensee’s Design Authority, but also that their specialist knowledge can contribute to the final detailed design specification.

160 The detailing and construction specifications will be finalised during the site specific phase. This aspect was an exclusion from Step 4 (Ref. 2) and so is not included in the generic pool liner methodology. This is satisfactory and will allow assessment of the specifications at the appropriate time as required.

161 The resulting document submitted ENGSGC110243 Rev B (Ref. 57) is acceptable as a response to **GI-UKEPR-CE-02** in terms of providing a generic methodology which will be used to produce the site specific design hypothesis documents. It has addressed the technical ONR comments raised or, where these cannot be answered until detailed design is in progress, has provided an approach by which it will be achieved. This has been captured in the Step 4 report by Assessment Finding **AF-UKEPR-CE-17** by requiring the licensee to produce a hypothesis note for the pool liner design at site specific stage.

4.5.3 Liner Performance subject to Concrete Cracking - ENGS110046

162 EDF and AREVA submitted a new document, in September 2011 in response to **GI-UKEPR-CE-02,** titled " UK EPR™– GDA – Presentation and Justification of the

Consequences of Concrete Cracking on Liner Leak-tightness" ENGS110046 Rev A (Ref. 101). This document aims to justify the anchor spacing adopted for both the inner containment and pool liners, with reference to results of experimental testing carried out on scale models of containment structures.

163 When cracks form in the concrete wall supporting the liner, all the movement at the crack needs to also be accommodated in the liner, and so high strains could be generated in the liner. During GDA Step 4, ONR sought evidence that the design of liners and anchors into the concrete ensured that the liners would remain leaktight for the design basis and with sufficient margin. However, it was concluded that the treatment of concrete cracking in the calculation of liner strains needed further justification.

4.5.3.1 Pool Liner Strains

164 The review of ENGS110046 Rev A (Ref. 101) was carried out by Arup on behalf of ONR. The conclusions are reported in Arup report 209364-10-04 (Ref. 80). Ref. 101 states it has been written in order to describe and justify how concrete cracking is taken into account in the design of liners and their anchorage systems. It discusses this effect and notes that both local and global testing has been carried out to investigate the issue.

165 Ref. 101 states that for the pool liners, concrete cracking is accounted for by limiting the distance between anchors such that the liner is not over stressed and so leak tight behaviour is maintained. Section 7 describes the analysis and design of pool liners carried out using the ETC-C. The calculation of the localised strain in the liner was related to the concrete crack width limit, but the exact basis of the calculation was unclear.

166 EDF and AREVA submitted an updated version of ENGS110046 Rev B (Ref. 106) under cover of letter EPR01114N (Ref. 105). This has an additional section 7.2 on the “Concrete Leak Tightness via Crack Width Limitation” which details how the crack width and crack spacing is limited by the reinforcement provided in the concrete. Eurocode 2 Part 3 is used for this calculation, but with additional specific measures as specified by ETC-C and its UK CD. This results in the liner anchor spacing being approximately 20% of the crack spacing in order for the strain in the liner to be below 4.5% which is the requirement for austenitic stainless steel.

167 On this basis, I am satisfied that the strain in the pool liner will be controlled by the anchor spacing combined with the reinforcement provided in the concrete to control cracking.

4.5.3.2 Inner Containment Liner

168 ENGS110046 Rev B (Ref. 106) also presents evidence on how experimental testing is used to benchmark the design of the containment liner carried out to ETC-C. Since this is also used to justify the arguments for pool liners, it is discussed below.

169 The experimental tests for the containment liner presented in the first issue of ENGS110046 Rev A (Ref. 101) were undertaken by Sandia National Laboratory in the US on behalf of the US Nuclear Regulatory Commission (NRC). Two specially built scale models were tested. These models were

- Sandia I - a 1:6 scale model of a reinforced concrete containment building, and
- Sandia II - a 1:4 scale model of a prestressed concrete containment building.

170 EDF and AREVA drew the following conclusions in Ref. 101 from these tests.

- "Code criteria have a large margin for both structural capacity and liner leak tightness".
- "The failure mode is a leak before break due to liner tearing".
- "The liner tearing is due to a localisation effect".

171 ONR issued comments to EDF and AREVA (Ref. 107). These were that overall the design approach was adequate and had been benchmarked by the tests. The interpretation of the scale test data was queried, since statements made on the differing responses of reinforced concrete versus prestressed concrete needed further discussion. The liner strain limits in the AFCEN ETC-C 2010 had been changed from the 2006 ETC-C to be the same as those in the ASME III Div 2 Code for concrete containments (Ref. 26). The equivalence of these strain limits was queried and how the average strain is calculated.

172 The updated version of ENGS110046 Rev B (Ref. 106) confirmed that "*a major difference between reinforced and pre-stressed concrete is that tension (and consequently cracking) occurs earlier in the case of passive reinforcement, which is important for determining the design pressure level. Comparing test results helps illustrate the differences between the concepts:*

- For Sandia I (reinforced only): rebar and liner yielding occurred at 0.86 MPa, i.e. a little before the leak, which occurred at 0.875 MPa.
- For Sandia II (pre-stressed): rebar yielding occurred a little before the leak, which occurred at 0.97 MPa.

in both cases leakage occurred far beyond the design pressure (2.69 Pd and 2.5 Pd)."

173 The above test results demonstrate that the pre-stressed containment could resist a higher pressure before it cracked than did the reinforced containment, due to the fact its reinforcement is not "passive" and has applied a pre-compression in the concrete before testing. The response has given adequate additional information on the nature of the failure observed in the Sandia tests, and confirmed that both failures occurred at significant margins beyond the design pressure. Ref. 106 also gave a comparison between the ASME code and the ETC-C for liner design, and how the Sandia test structures differed from the UK EPR™ design in terms of loading and fabrication. This has confirmed that the liner design margin, based on the Sandia results in a beyond design pressure scenario, remain applicable to the EPR™.

174 The justification for adopting the ASME III strain limits in the AFCEN ETC-C 2010 was that the former is an internationally recognised standard and these strains limits had been approved by the US Nuclear Regulatory Commission (US NRC) in its assessment of the Sandia tests. The updated AFCEN ETC-C 2010 document had therefore included the ASME III strain limits as relevant to the EPR™ design.

175 I consider the above as adequate justification that the liner design gives sufficient margin above the design basis pressures for the inner containment.

4.6 DROP LOAD ANALYSIS

4.6.1 Introduction

176 The Step 4 GDA assessment found a shortfall in the methodology for assessing impact damage on civil structures from dropped loads and internal missiles. Therefore, **GI-UKEPR-CE-02** also includes a requirement for an adequate dropped load methodology document to be produced and justified.

177 Section 1.4.7 of AFCEN ETC-C 2010 (Ref. 4) details the requirements for design of concrete structures for impacts from internal projectiles and dropped loads. This simply states that "*in the case of internal projectiles and dropped loads, calculations may be made with a special study. The methods defined in APPENDIX 1.C and APPENDIX 1.D are acceptable to check the design resistance of reinforced concrete structures against perforation by hard projectiles and against punching shear*."

178 The methods in Appendices 1.C and 1.D are very simplistic and no justification was given that they are applicable to all dropped load or missile scenarios. The Step 4 civil engineering assessment of the ETC-C commented via letter EPR70304N (Ref. 33) that "*It is not clear what the role of these appendices is in the design process. It is understood that they are used as initial scoping calculations and not for the final design*."

179 The Step 4 Internal Hazards assessment report (Ref. 108) also concluded that the treatment of dropped loads and internal missiles within the design were not adequate. For dropped loads this primarily concerned the identification of dropped load scenarios and production of a dropped load schedule for the design of structures. The assessment also queried EDF and AREVA's claim that RCC-M classified vessels, pumps, tanks and valves would not generate internal missiles since they were designed for 'no-break'. As a result, GDA Issues **GI-UKEPR-IH-01** (Ref. 69) and **GI-UKEPR-IH-04** (Ref. 70) were raised in the internal hazards topic area, with specific actions which interrelate with Civil Engineering

180 **GI-UKEPR-IH-01.A2** Substantiation and analysis of the consequences of dropped loads and impact from lifting equipment included within the EPR™ design. Provide a description of the approach taken to treat dropped loads on civil structures.

181 **GI-UKEPR-IH-04.A1** Consequences of missile generation arising from failure of RCC-M Components. Provide substantiation of the claims made within the PCSR associated with the preclusion of missile generation from failure of RCC-M components which are not designated as High Integrity Components (HIC) as defined in the consolidated PCSR. In particular justify the analysis of the consequences of failure.

182 This section presents the civil engineering assessment of the dropped load methodology (Section 4.6.2) and my assessment of how that methodology has been applied to civil structures for certain internal missile scenarios (Section 4.6.3).

4.6.2 Dropped Load Methodology – ENGSGC100483

183 The final submission of the document "Methods with regard to the risk of dropped loads for EPR™ UK for civil works structures", ENGSGC100483 Rev B (Ref. 58) was submitted in March 2012.

4.6.2.1 *Progress of the Assessment*

184 The initial response from EDF and AREVA, specific to the dropped load methodology for civil structures, was report "Methods with regard to the risk of dropped loads for EPR™ UK for concrete structures" ENGSGC100483 Rev A (Ref. 47). This was submitted in June 2011 and was a resolution plan deliverable under **GI-UKEPR-CE-02.A1** and **A2** and also **GI-UKEPR-IH-01.A2.**

185 The ONR assessment was supported by ABS Consulting Ltd (ABSC) who carried out a technical review of ENGSGC100483 Rev A. The ABSC review is summarised in report 2120812-R-07, "Review of GDA Issue on Dropped Loads EPR™ Report ENGSGC100483 Rev A" (Ref. 109). The significant aspects of this review are discussed below.

186 Comments on ENGSGC100483 Rev A were issued to EDF and AREVA in August 2011 (Ref. 110). These comments were discussed with EDF and AREVA at the civil engineering technical meetings and convergence was progressed via staged responses to these comments. EDF and AREVA provided a response to each of the ONR comments via letter EPR01098N (Ref. 111) and an updated version of ENGSGC100483 at Rev B (Ref. 58) in March 2012.

4.6.2.2 *Assessment*

4.6.2.2.1 *Scope of Methodology*

187 Rev A of the methodology document (Ref. 47) was a 30 page report which comprised a collection of a number of different methods to assess impact of dropped loads on concrete structures. The abstract stated that "*The current design report has been written in order to verify that the civil engineering structures of the nuclear island are robust enough to withstand "dropped loads"……It provides the principles of methods to check concrete structures for the* UK EPR™." It was therefore not applicable to any other type of structure, e.g. steelwork and not applicable to assessment of damage to plant and equipment from these dropped loads.

188 The title of the ENGSGC100483 Rev B (Ref. 58) has been changed to "Methods with regard to the risk of dropped loads for EPR™ UK for civil works structures". A section had also been added to include dropped load assessment of steel civil structures. Therefore, the methodology is now applicable to both concrete and steel civil structures and I am satisfied with this scope.

189 Ref. 58 explicitly excludes any methods on how to assess the damage that may be caused to the dropped item. For instance, if the dropped load is a package containing nuclear material its integrity following the event would need to be adequate to satisfy the safety case. EDF and AREVA's response was that the safety significance of the dropped item is considered in the safety assessment for each scenario and the design of the package would be based on the safety functional criteria required. I agree that assessment of damage to packages is outwith the scope of the civil engineering topic area and so this has not been sampled further.

4.6.2.2.2 *Methods*

190 The methods presented in Ref. 47 to assess the damage to concrete structures were split into three categories:

- Part 1: Punching Shear - three methods are included for punching shear, i.e. whether the dropped load would punch through a concrete structure.
- Part 2: Bending verification - four methods are included for checking whether the bending induced in the concrete structure by the impact could cause global failure.

- Part 3: Punching and bending verification - two methods are included for the combined effects. The second method is detailed finite element dynamic modelling of the target and of the dropped load.

191 Section 7, Principles, of Ref. 47 indicates that the methods proposed vary in complexity and the intention is that the first stage of analysis is to use a simple, conservative method. If this proves to be too conservative, then a more exact method can be chosen until a realistic conclusion is reached. I consider this graded approach to be a reasonable, engineered solution. However, there was no guidance on which methods are the simplistic ones and which are the more exact; although the FE dynamic modelling in Part 3 is recognised as an exact approach. Ref. 47 also gave no guidance to the designer on how to select the most suitable method.

192 EDF and AREVA's response to this ONR comment (Ref. 111) clarifies that both the punching and bending checks must be carried out for each dropped load scenario. ENGSGC100483 Rev B (Ref. 58) also provides a revised Section 7 to offer further guidance. However there is still a shortfall since the guidance does not stipulate whether there are any restrictions on the combinations of the methods in Parts 1 and 2, i.e. whether all three methods in Part 1 can be used in any combination with those in Part 2. I therefore raise an assessment finding to capture this shortfall as follows:

> ***AF-UKEPR-CE-81:*** *Where separate methods are used to check the punching shear and the bending stresses in concrete civil structures induced by potential dropped loads or internal missiles, the licensee shall justify that the methods are compatible with one another.*
>
> ***Required Timescale:*** *Nuclear Island Safety-Related Concrete.*

193 The ABSC review also compared the methods in Ref. 47 with the R3 Impact Assessment procedure (Ref. 112). The R3 methodology is accepted as current good practice for dropped loads within the UK nuclear industry. This was developed by Magnox Electric plc and is currently used on UK nuclear power plants. R3 comprises a series of different calculation methods, which are applicable in different situations. EDF and AREVA presented comparative calculations between its methodology document and R3 and demonstrated that both methods achieved similar results. Although this study does not justify the UK EPR™ methodologies for the full range of dropped loads, it is a useful benchmark for the particular cases considered.

194 EDF and AREVA's response was to add the R3 methodology as another applicable method to ENGSGC100483 Rev B (Ref. 58). This will allow civil works designers in the UK to use this comprehensive methodology with which they are already familiar. I concur with the decision to include the R3 methodology since this, along with detailed FE analysis are sufficient to cover the range of dropped loads that are applicable to NPPs.

4.6.2.2.3 Range of Dropped Loads

195 Rev A of the methodology document does not specify the range of drop loads that are included or whether the various methods are dependent on the type of missile. In applying recognised techniques such as R3, some knowledge of the missile type and target type must be known before the assessment can be undertaken. The description of dropped loads would be expected to include the following:

- Minimum and maximum weight
- Drop height, or maximum impact velocity
- Material of drop load

- Nature of drop load, e.g. stiff or soft, pointed or blunt impact point.

196 The dropped load methodologies given in Ref. 47 do not specify the limits of their applicability with respect to the above. The examples presented therein are all for smaller masses of dropped loads (<340kg). The examples given in responses to TQ-UKEPR-500 and TQ-UKEPR-669 (Ref. 93) are for much heavier masses (>45te) which is to be expected since these were for loads lifted by the polar crane.

197 In order to provide more evidence of the range of drop loads that can occur, and a demonstration that the methodologies proposed are suitable for their assessment the new Section 3 in Ref. 58 provides the scope of applicability, and Section 8 provides the validity range of postulated dropped loads. Letter EPR01098N (Ref. 111) also clarified that the methodology "*will not include a specific listing of all postulated dropped loads. Instead this report is intended to provide generic guidance on how postulated dropped loads will be treated. Post-GDA, it is the responsibility of the licensee to provide a complete listing of loads to be considered*".

198 Sub-chapter 13.2 of the March 2011 PCSR (Ref. 6) argued that no dropped loads could occur from classified cranes such as the polar crane. The failure of Higher Requirements (RS1) and Additional Requirements (RS2) lifting equipment was screened out by its low frequency. This then meant that potential dropped loads would only be considered for smaller loads from lifting equipment which is non-classified. This was challenged by the Internal hazards Inspector during Step 4 GDA and lead to **GI-UKEPR-IH-01**.

199 EDF and AREVA have now revised Sub-chapter 13.2 to Issue 05 (Ref. 115) and this includes consideration of bounding cases for dropped loads from RS1 and RS2 cranes. This has been assessed under the close-out of Internal Hazards (Ref. 116) and found to be a satisfactory response to **GI-UKEPR-IH-01**. This has meant that the dropped load methodology document has had to include methods that are applicable to heavier loads, and with the addition of R3 along with the use of FE models I am satisfied that ENGSGC100483 Rev B has adequate methods included in order to assess damage from these heavy loads. The remnant shortfall is that the methodology still does not specify when the other methods can be used. I therefore raise an assessment finding as follows,

> ***AF-UKEPR-CE-82:*** *The licensee shall justify that the calculation methods used to assess the damage to civil structures due to impact from potential dropped loads or internal missiles, are applicable to the range of dropped loads or missiles identified by the safety assessment for that structure.*
>
> ***Required Timescale:*** *Nuclear Island Safety-Related Concrete.*

4.6.2.2.4 Target Properties

200 The review of ENGSGC100483 Rev A sampled the concrete properties and partial safety factors for the target structure used in the example calculations. These were found to be taken from Eurocode 2 (Ref. 21) which is consistent with the design code AFCEN ETC-C 2010 (Ref. 4) which also uses Eurocode 2. I am satisfied that these properties are applicable to dropped load scenarios, and although Eurocode 2 is not specifically written for nuclear power plants, it is applicable in this case.

4.6.2.3 Assessment Conclusions

201 ENGSGC100483 Rev B has been included as a reference to the UK Companion Document to the ETC-C, Rev E (Ref. 5) and to the new document "EPR Nuclear Island Civil Engineering Design Process" (Ref. 60) which is a deliverable under **GI-UKEPR-CE-01** (Ref. 7) as well as **GI-UKEPR-CE-02.A2 to A4**. This document is known as the Design Process Note and is an overarching document for the civil works design and sets

out the hierarchy of the civil design specification documents, called hypothesis notes, which are produced for each civil structure. The exact dropped load scenarios, loads and assessment methods will be agreed between the licensee and civil works designer at the start of design, and documented in the hypothesis notes.

202 The revised dropped load methodology document does provide additional detail guidance to the designer and is now a major reference to the UK CD. The Design Process Note provides the context within which the methodology will be used. There are, however, two shortfalls in the techniques within the methodology and I have raised Assessment Findings **AF-UKEPR-CE-81** and **AF-UKEPR-CE-82** to capture these.

4.6.3 Impacts on Civil Structures from Internal Missiles - ECEIG091634 Rev B1

203 EDF and AREVA submitted document ECEIG091634 Rev B1 (Ref. 117), "EPR™ – Internal missiles – Risk assessment report on building structure and layout" to demonstrate and justify its methods for assessing damage from internal missiles. This was submitted in June 2011 as a deliverable under **GI-UKEPR-IH-04**. My assessment work undertaken in support of the Internal Hazards Inspector was to review this document and in particular the calculations included in the appendices. This document details the potential internal missiles identified for the Nuclear Island on the Flamanville 3 (FA3) nuclear power plant, and is given as an example of the approach proposed for UK EPR™ My assessment has sampled the methods for calculating perforation to concrete structures from missiles generated by valves.

4.6.3.1 Overview

204 ECEIG091634 Rev B1 identifies two sources of missiles which are able to generate internal missiles potentially threatening to plant safety. These are shown below with the claims made in the document for each:

- Missiles coming from failure of rotating equipment
  - Most ruled out due to design measures to the plant.
  - Disintegration of reactor coolant pump flywheels – ruled out on material specs/ design, manufacture and inspection.
  - Missiles projected by the turbine - ruled out on probabilistic basis.
- Missiles coming from failure of high energy components
  - Ejection of control rods.
  - High energy valves of quality Q1/Q2/Q3 with wall separation.
  - High energy valves of quality Q1/Q2/Q3 not physically separated.
  - High energy valves of quality <Q3 – calculation given in Appendix 1.
  - Unclassified high energy tanks – none in C1 buildings.
  - Potential missiles on the large debris baskets of the IRWST.

205 The methodology for calculating the perforation to civil concrete structures from internal missiles is given in Appendix 1 of Ref. 117. The results of the calculations to check perforation of missiles generated by valves are given in Appendix 2, and those generated by tanks are given in Appendix 3.

4.6.3.2 Assessment of Methods

206 Appendix 1 uses first principles from physics to work out the impact velocity of the missiles. This can be used for both missiles or dropped loads since it is based on initial

velocity and acceleration, which would be zero and gravity in the case of a dropped load. I am satisfied that the equations used are appropriate and have been correctly applied.

207 Appendix 1 then gives two methods for checking whether a concrete wall or slab would be perforated by the missile.

- ETC-C 2006 (Ref. 30) Appendix 1.D, "Penetrations of Reinforced and Prestressed Concrete Slabs by Hard Missiles"
- LI Criterion – based on a method from the International Journal of Impact Engineering.

208 Both of the above methods are included in the dropped load methodology document ENGSGC100483 Rev B (Ref. 58). Therefore, the impact damage to concrete walls resulting from either dropped loads or internal missiles is treated in the same way. This is appropriate since the methods rely on the velocity at impact and not the direction of impact. However, the nature of the dropped load or missile i.e. pointed or blunt has not been considered. This shortfall will need to be justified by the licensee as required already by **AF-UKEPR-CE-82**.

209 ECEIG091634 Rev B1 states that there is a separate internal missile methodology but it is not clear how this interfaces with the dropped load methodology. Technical query TQ-EPR-1606 was raised to query this. The response from EDF and AREVA (Ref. 118) stated that "*ECEIG091634 B1 is a safety analysis associated with EPR™ FA3. A dedicated safety analysis for the "missiles" hazard will be carried for the* UK EPR™ *at detailed design stage. EDF and AREVA confirm that a review will be carried out to ensure that this dedicated study is consistent with the methodology ENGSGC100483*". The response also confirms that for FA3 a separate internal missile methodology document (referred to in ECEIG091634 Rev B1) was produced which "*sets the rules of study for the "missiles" hazard for the EPR™ FA3, it recalls: safety objectives, establishes the rules to identify aggressors and targets and refers to Appendix 1.D from ETC-C for civil engineering calculations*". This internal missile methodology will be updated at detailed design phase for UK EPR™.

210 Therefore, I am satisfied that the validity of the calculation methods within both ECEIG091634 Rev B1 and ENGSGC100483 Rev B will be independently confirmed by the separate internal missile methodology document. However, since the internal missile methodology document will not be available until site specific phase I raise the following assessment finding:

> ***AF-UKEPR-CE-83:*** *The licensee shall develop an internal missile methodology document for the site specific design, and clarify how it interfaces with the dropped load methodology document. The licensee shall also, having indentified the range of potential missile impacts for a particular civil structure, justify that the calculation methods used to assess the impact on civil structures from internal missiles are applicable.*
>
> ***Required Timescale:*** *Nuclear Island Safety-Related Concrete.*

211 The ETC-C 2006 referred to is now superseded by AFCEN ETC-C 2010 (Ref. 4). The equation given in Appendix 1 is the same as Equation 1.D-2 in Ref. 4 albeit rearranged. The validity range in Appendix 1 is not the same as Ref. 4 in that it is missing two out of the five validity criteria namely, compressive strength of concrete and symmetry of reinforcement. TQ-EPR-1606 also queried these differences. The response from EDF and AREVA (Ref. 118) was that ECEIG091634 Rev B1 is specific to FA3 and so used the

ETC-C current at that time, however "*we have checked that the formula presented in report ECEIG091364 rev. B1 Appendix 1 §2.2 is the same as in version 2010 of ETC-C*".

212 The licensee will need to justify the calculations carried out at site specific phase are in accordance with AFCEN ETC-C 2010. This is already captured by the Step 4 Assessment Finding **AF-UKEPR-CE-07** (Ref. 2).

4.6.3.3 Assessment of Calculations

213 The calculations presented in Appendix 2 of ECEIG091634 Rev B1 were sampled in terms of whether the methodologies had been applied correctly.

214 The selection of which of the two methods to use for the missile perforation calculations is clearly laid out and is based on the validity parameters. Therefore, if the ETC-C equation is not valid the LI Criterion is used. No examples are given where neither method is applicable. The ETC-C method calculates the minimum thickness of concrete wall or slab which will just be perforated. All examples given demonstrate the actual wall thicknesses are much greater than the just perforated thickness. The LI Criterion calculates the energy of the missile that is required to perforate a wall of a certain thickness. Provided the missile kinetic energy is less than the energy of just perforation, the wall is not breached by the missile. Again, the examples given have considerable margin, i.e. the walls are much thicker than the depth of penetration.

215 I raised specific queries via TQ-EPR-1606 on how certain calculations had been carried out. The parameters used to justify the validity of the methods in some cases were not clearly defined. The response from EDF and AREVA (Ref. 118) satisfactorily clarified these queries and confirmed that design criteria will be reviewed at detailed design stage as discussed in Section 4.6.3.2.

4.6.3.4 Assessment Conclusions

216 I am satisfied that the calculations for impact damage from internal missiles sampled from ECEIG091634 Rev B1 have been carried out correctly in accordance with Appendix 1.D of the ETC-C. The selection of which of the two methods to use was also carried out correctly for these examples.

217 ECEIG091634 Rev B1 refers to a separate internal missile methodology, which is additional to the UK CD Rev E, Clause 1.4.7 bis "Internal Projectiles and Dropped Loads". This will be a site specific document and so I have raised **AF-UKEPR-CE-83** to require the licensee to submit and justify this in relation to the dropped load methodology ENGSGC100483 Rev B.

218 My conclusions have been fed into the Internal Hazards assessment of GI-UKEPR-IH-04 (Ref. 119).

4.7 ASSESSMENT OF RESPONSE TO ACTION 2

4.7.1 Introduction

219 Action 2 of **GI-UKEPR-CE-02** required EDF and AREVA to update the UK Companion Document to address the ONR comments made on AFCEN ETC-C 2010 Part 0: General. These comments were given in ONR letter EPR70304N (Ref. 33) which had been in respect of the UK CD Rev A (Ref. 31). The key points were:

- There is limited evidence of the independent review of the AFCEN ETC-C 2010 provided in Part 0.
- There are a large number of references to French standards, with translations not provided.
- Loose references to “equivalent standards” and a lack of clarity of revision/version of referenced codes and standards to be used.
- There are no references to national annexes to some standards such as EN13670. This raises a question over the control of using French standards within the UK construction industry.

220 The UK CD underwent four iterations until the final version submitted for GDA, Rev E (Ref. 5) met Regulator expectations as a response to the above. The five detailed comments made on Part 0 were consolidated in the “ETC-C Tracking Spreadsheet” the final version of which is ENGSGC110269 Rev E (Ref. 13). This recorded EDF and AREVA’s staged responses to each question, any further comments by ONR and responses, thus iterating to a conclusion.

221 EDF and AREVA also produced an “Assessment File of the UK Companion Document to AFCEN ETC-C” ENGSGC110033 Rev C (Ref. 59) which gives further background to the justification for the revisions to each clause in the UK CD. This is because it is inappropriate to put the full justification into a technical clause. This document was named as a deliverable in the Resolution Plan. The mapping document requested in the **GI-UKEPR-CE-02.A2** is therefore provided by the Assessment File (Ref. 59) and by the ETC-C Tracking Spreadsheet (Ref. 13).

4.7.2 Assessment

222 The development of the ETC-C is described in Section 3.1 of this report. The 2006 version was written by EDF. However the 2010 version 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 Alternative Energies and Atomic Energy Commission (CEA) and experts from the French nuclear industry. AFCEN produces various design codes for use in the French nuclear industry. AFCEN works in a similar way to international code committees for instance technical experts sit on the AFCEN ETC-C subcommittee which may also have smaller task groups for specific technical topics.

223 EDF and AREVA submitted the description of how the AFCEN ETC-C 2010 had been written and independently reviewed to ensure its adequacy as a design code for nuclear safety related, civil structures. This is given in the Assessment File (Ref. 59) as the underlying justification to the UK CD new section “Background and Introduction”. This

states that the ETC-C was updated from the 2006 version by taking into account the following:

- "The assessment carried out by ASN and IRSN (French regulators) as part of the Flamanville 3 licensing process….
- Improvements recommended by AFCEN experts….
- Operating experience feedback from the design studies and initial construction work on Flamanville 3 and Olkiluoto 3 (Finland)….
- To conclude, another first level review of the ETC-C was performed by the experts from EDF/AREVA taking into account an assessment carried out by the French Safety Authorities."

224 The UK CD describes the process of how the AFCEN ETC-C 2010 is adapted by the UK CD and how any subsequent updates to the ETC-C are reviewed and incorporated in the UK CD if required. Future updates to the ETC-C will be instigated by feedback from the AFCEN experts, EPR™ design teams, constructors and operators and also any assessments by Regulators. The AFCEN code committee for ETC-C also review revisions of Eurocodes and international codes and standards as and when they occur. These additional descriptions are satisfactory justification that the UK CD and the ETC-C are independently reviewed in an equivalent manner to recognised standards.

225 The lists of codes and standards given in Tables 0.1.3-1 bis to 0.1.3-13 bis of the UK CD Rev E has been revised to remove French standards and to include either UK or Internationally recognised standards for use. The UK National Annexes to standards have also been added. One comment from Step 4 was that the removal of the reference to BS EN 1998-1 and lack of reference to good practice seismic detailing was considered a serious shortfall. This comment has been resolved by the submission of the specific detailing rules (see Section 4.4) and the seismic design methodology under **GI-UKEPR-CE-04** (Ref. 8). The previous omission of Eurocode 1, BS EN 1991 Part 1-7 (Ref. 20) which deals with robustness has been corrected, and further description of how robustness is considered has been included in the "EPR Nuclear Island Civil Engineering Design Process Note" (Ref. 60).

4.7.3 Conclusions for Action 2

226 I consider that the responses described above satisfy Regulator expectations with respect to **GI-UKEPR-CE-02.A2**. The mapping document requested in the action is provided by the ETC-C Tracking Spreadsheet (Ref. 13) and the justification of revisions to the UK CD are given in the Assessment File (Ref. 59), particularly where it would not be appropriate to include the background justification in a technical clause. No assessment findings have been raised for this action.

227 I am satisfied that **GI-UKEPR-CE-02.A2** can be closed.

4.8 ASSESSMENT OF RESPONSE TO ACTION 3

4.8.1 Introduction

228 Action 3 of **GI-UKEPR-CE-02** required EDF and AREVA to update the UK Companion Document to address the ONR comments made on AFCEN ETC-C 2010 Part 1: Design. These comments were given in ONR letter EPR70304N (Ref. 33) which had been in respect of the UK CD Rev A (Ref. 31). The key points were:

1) Errors in Formulas
2) Lack of Clarity/ ambiguity in text
3) Inconsistency with other sections of the code
4) Inconsistency with UK National Annex
5) Lack of guidance to designers on seismic design
6) Revisions of supporting documents unclear
7) Lack of guidance on choice of Eurocode value when no recommended value is available
8) Justification lacking for some revised liner stress limits

229 There were a considerable number of comments made for Part 1 and its appendices. The comments ranged from queries on fundamental technical philosophies to minor editorial comments. As for Action A2, the detailed comments made on Part 1 were consolidated in the "ETC-C Tracking Spreadsheet" ENGSGC110269 (Ref. 13) which recorded EDF and AREVA's responses to each question, any further comments by ONR and responses, thus iterating to a conclusion.

230 Resolution of the various comments was carried out in a staged manner, following a workshop in July 2011 and proceeded through to March 2012. Comments were progressed separately and individual clauses of the UK CD updated on a case by case basis as detailed in the ETC-C Tracking Spreadsheet (Ref. 13). Therefore, although each clause was reviewed by ONR there was a need to carry out a review of the whole document once completed in order to check that point 3 above "Inconsistency with other sections of the code" had been resolved. This consolidated review was commissioned by ONR with Arup and is documented in Arup report 209364-10-10 (Ref. 85)

4.8.2 Assessment

231 The final submission of the UK CD, Rev E (Ref. 5) has addressed points 1) to 8) listed in Action A3 as detailed below.

232 For point 1), typographical errors in the AFCEN ETC-C 2010 have been corrected by the UK CD. The corrections have been issued to the AFCEN code committee for them to include in the next revision of the ETC-C.

233 For point 2), technical clauses which were unclear or ambiguous have been updated satisfactorily. In addition, ONR has sought evidence that EDF and AREVA have suitable arrangements to safeguard against misinterpretation by the designers. This has been submitted via the "EPR Nuclear Island Civil Engineering Design Process Note" (Ref. 60) under **GI-UKEPR-CE-01** which sets out the process. Hypothesis notes are produced by the licensee's Design Authority for each structure and these are used as a specification to the designer. The designer then produces a detailed design hypothesis note which confirms the basis of design back to the Design Authority, both prior to start and upon

completion of the detailed design. Assessment of this process is discussed in more detail in my assessment report for **GI-UKEPR-CE-01** (Ref. 7), however my conclusions are that the arrangements proposed by EDF and AREVA for site specific design phase are satisfactory.

234 For point 3), the comprehensive review of the complete UK CD (Ref. 85) sampled the consistency in technical specification across the whole document. Where text did not meet the expected standard that had already been agreed, ONR issued further comments via the tracking sheet (Ref. 13). These comments were included in the final Rev E of the UK CD. In addition to the assessment file ENGSGC110033 Rev C (Ref. 59) EDF and AREVA also produced a further assessment file, ENGSGC120228 Rev A (Ref. 75) which recorded the additional revisions required from Rev D to Rev E of the UK CD.

235 For point 4) the technical adequacy of the proposed revised clauses in the UK CD were assessed against current good practice and recognised standards such as Eurocodes and their UK National Annexes. The assessment also reviewed the values chosen by EDF and AREVA within the UK CD for technical parameters. The detailed review of each comment is documented in the tracking sheet and the modification file (Refs. 13 and 14) and so will not be repeated here. The most notable technical issues raised at the workshop in July 2011 are shown below and the assessment of these has been already described under Action 1 in Section 4.3 of this report.

- Justification for the load combinations in ETC-C which do not cover standard combinations of static live + dead loads. Also the minimum imposed live load has been removed from the AFCEN ETC-C 2010 version. (Refer to Section 4.3.2.2.)
- Justification of the concrete maximum compressive stress under bi-axial / tri-axial behaviour accidental thermal conditions for the inner containment (Refer to Section 4.3.2.3).
- Design and provision of shear reinforcement in slabs and walls were not in accordance with UK National Annex to Eurocode 2. (Refer to Section 4.3.2.4)
- Justification of the effective diameter of prestressing cables assumed for reinforcement in ETC-C being different from the formulation in Eurocode 2 (refer to Section 4.3.2.6)
- Crack control - ONR were concerned that autogenous shrinkage is ignored in current ETC-C method for crack width assessment. Also the k2=0.5 value assumed in the cracking assessment was considered non-conservative. (Refer to Section 4.3.2.7.)
- Justification of the consequences of concrete cracking on liner leak-tightness. (Refer to Section 4.5.3)
- Construction Joints - ONR were concerned that design method for construction joints proposed in AFCEN ETC-C 2010 Part 1 deviated from the Eurocode 2 method used previously in ETC-C (2006). The new method was not seen as adequately justified. (Refer to Section 4.4.3.)

236 For point 5), additional guidance has been submitted by EDF and AREVA for the seismic design methodology in response to **GI-UKEPR-CE-06**. My assessment report for that GDA Issue (Ref. 10) concluded that the technical documents submitted were satisfactory for the generic phase. The UK CD Rev E now includes references to these methodology documents and technical clauses have been updated where specification was required.

237 For point 6) the reference list has been updated and it now includes the revisions of each document.

238 For point 7) the final version of the UK CD now specifies values for parameters which are required by Eurocodes. The AFCEN ETC-C 2010 is based on the French National Annexes and so values were either not given or did not match the UK National Annexes. The UK CD Rev E now includes parameters which agree with the UK National Annexes if appropriate or with recognised international standard, UK standards or current good practice.

239 For point 8) the revised liner stress limit refers to the justification of changing from the ETC-C 2006 limits to those of ASME Section III, Division 2 (Ref. 26) in the updated AFCEN ETC-C 2010. The assessment of this is detailed in Section 4.5.3 of this report and my conclusion was that the ASME II limits had been justified to be appropriate for the UK EPR™ design.

4.8.3 Conclusions for Action 3

240 I consider that the updated Part 1 of the UK CD Rev E, as supported by technical documents submitted satisfies Regulator expectations with respect to **GI-UKEPR-CE-02.A3**. The mapping document requested in the action is provided, as before, by the ETC-C Tracking Spreadsheet (Ref. 13) and in the Assessment Files (Ref. 59 and Ref. 75). No assessment findings have been raised for this action.

241 I am satisfied that **GI-UKEPR-CE-02.A3** can be closed.

4.9 ASSESSMENT OF RESPONSE TO ACTION 4

4.9.1 Introduction

242 Action 4 of **GI-UKEPR-CE-02** required EDF and AREVA to update the UK Companion Document to address the ONR comments made on AFCEN ETC-C 2010 Part 2: Construction. These comments were given in ONR letter EPR70767R (Ref. 34) which had been in respect of the UK CD Rev A (Ref. 31). The key points were:

1) Insufficient information to be the basis of a clear construction specification
2) Links to French ministerial standards are of no relevance to the UK
3) Clarification of the intention to demonstrate the equivalence of French standards to other national standards
4) Provide clarity over the approval of modifications or adaptations to the specification
5) Provide clarity over how demonstration of equivalence would be achieved

243 The ETC-C Tracking Spreadsheet ENGSGC110269 (Ref. 13) contains the comments from Ref. 34. These comments varied from queries on the technical specification to minor editorial comments. As before, the individual comments were resolved between July 2011 and March 2012 on a case by case basis, the details of which are recorded in ETC-C Tracking Spreadsheet (Ref. 13) and the Assessment Files (Refs. 59, 75 and 76).

4.9.2 Assessment

244 The final submission of the UK CD, Rev E (Ref. 5) has addressed the points within **GI-UKEPR-CE-02.A4** as described below**.**

245 For point 1), Part 2 of the ETC-C comprises the construction rules for the UK EPR™ required by the ETC-C detailed design. However, it forms part but not the complete construction specification for C1 civil structures. EDF and AREVA has confirmed that the construction specifications are site specific and will not be available until the site specific phase and so cannot be assessed at GDA stage. This is in accordance with the agreed scope of GDA as stated in Section 2.5 of the Step 4 Assessment Report (Ref. 2).

246 For points 2) and 3), the AFCEN ETC-C 2010 clauses that are amended by the UK CD now reflect the codes and standards used in the UK or that are internationally recognised. References to French standards have been removed and the equivalent standards used.

247 For point 4), the process for the approval of future modifications to the ETC-C and the UK CD has been detailed in response to Action A2 and in the “EPR Nuclear Island Civil Engineering Design Process Note”. Since this action, A4, is specifically for construction clauses in the ETC-C and the construction specifications are outside the scope of GDA any future modifications to these will be subject to Regulator scrutiny at site specific stage.

248 For point 5), equivalence in terms of compliance to UK standards, good practice or international standards has been provided by the updated codes and standards referenced in the UK CD Rev E. Future construction specifications will need to justify the quality of construction is in accordance with these standards.

4.9.3 Conclusions for Action 4

249 I am satisfied that sufficient justification has been provided for the resulting technical clauses within Part 2 of the UK CD Rev E within the scope of GDA. The mapping of the

revised technical clauses in the UK CD is provided by the Assessment Files (Refs. 59, 75 and 76).

250 I am therefore satisfied that **GI-UKEPR-CE-02.A4** can be closed.

5 INTERFACE OF GI-UKEPR-CE-02 WITH KEY DOCUMENTS

5.1 REVIEW OF THE PCSR

251 The EDF and AREVA resolution plan identified that resolution of **GI-UKEPR-CE-02** may require revisions to the following two sub-chapters of the March 2011 PCSR (Ref. 4).

- "Sub-chapter 3.3 – Design of Category 1 Civil Structures".
- "Sub-chapter 3.8 – Codes and standards used in the EPR™ design".

252 Sub-chapter 3.3 has been revised to Issue 05 (Ref. 113) and required only minimal changes to reflect EDF and AREVA's response to **GI-UKEPR-CE-02**. This is because the detailed information is contained within the finalised supporting documents assessed in this report. The revisions are as follows.

- The reference to the ETC-C 2006 has been replaced by the AFCEN ETC-C 2010.
- The "EPR Nuclear Island Civil Engineering Design Process Note" (Ref. 60) has been added as a major reference.
- Update of references, particularly those which are referenced in Ref. 60 or the UK CD which have been removed from the PCSR.
- Section 1.1 introduces the dedicated rules for C2 classified structures – this has been assessed under GI-UKEPR-CC-01.A2 (Ref. 120).
- Minor editorial corrections.

253 Sub-chapter 3.8 has been revised to Issue 05 (Ref. 114) as follows as a result of the resolution of **GI-UKEPR-CE-02.**

- The reference to the ETC-C 2006 has been replaced by the AFCEN ETC-C 2010.
- The reference to the UK CD has been updated to Rev E.
- Section 4.1 now has a clear statement that the UK CD governs the AFCEN ETC-C 2010.
- Section 4.2 now confirms the UKCD uses internationally accepted standards, UK standards or current UK good practice rather than French standards.
- The description of the AFCEN organisation has been expanded to include the ETC-C sub-committee.
- Minor editorial corrections.

254 Sub-chapter 13.2 Internal hazards has been revised to Issue 05 (Ref. 115) with respect to impacts from dropped loads and internal missiles, as described in paragraph 198 of this report. The only change required for **GI-UKEPR-CE-02** was to update the reference to the dropped load methodology to ENGSGC100483 Rev B.

255 I am satisfied that the updates made to the PCSR are sufficient to describe the safety case for C1 civil structures which are to be designed and constructed in accordance with the UK CD and the ETC-C. The PCSR also now includes the "EPR Nuclear Island Civil Engineering Design Process Note" as a major underpinning document, and this signposts the technical supporting documents.

5.2 INTERFACE WITH OTHER GDA ISSUES

256 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 Note" (Ref. 60) submitted under GI-UKEPR-CE-01.
- GI-UKEPR-CE-04 has required updates to the UK CD in respect of the technical clauses for FE modeling of C1 structures. The relevant clauses are within Appendix 1.A Seismic Analysis and the required amendments are detailed within the assessment files (Ref. 59 and Ref. 75).
- Seismic Analysis of Foundation Raft, ENGSDS100268 Rev B (Ref. 62) and Methodology for Seismic Analysis of NI Buildings ENGSDS100269 Rev B (Ref. 63) were submitted under GI-UKEPR-CE-06. These two documents are referenced within Appendix 1.A Seismic Analysis of the UK CD. My assessment report for closure of this issue (Ref. 10) describes the revisions required to the documents and that both were accepted as part of the satisfactory response to the issue. Certain clauses within the UK CD Appendix 1.A have needed updating in response to GI-UKEPR-CE-06 and these are detailed within the assessment files (Ref. 59 and Ref. 75).
- The dropped load methodology has been assessed and found to be satisfactory subject to three assessment findings. This has been fed into the Internal Hazards assessment of GI-UKEPR-IH-01 (Ref. 116) and GI-UKEPR-IH-04 (Ref. 119).
- The dedicated rules for C2 structures, which are based on the ETC-C, have been assessed under GI-UKEPR-CC-01.A2 (Ref. 120).

257 The specifics of my assessment of these deliverables with respect to each GDA issue are given in the relevant ONR assessment report which should be read in conjunction with this report.

6 ASSESSMENT FINDINGS

6.1 ADDITIONAL ASSESSMENT FINDINGS

258 I conclude that the following assessment findings, also listed in Annex 1, should be taken forwards during the site specific phase in addition to those identified in the Step 4 Civil Engineering Assessment Report (Ref. 2).

AF-UKEPR-CE-76: *The licensee shall confirm that the enhanced concrete compressive strength used for the design of the inner containment structure accounts for the final concrete mix design specified, and in particular the thermal expansion coefficient for the type(s) of aggregates to be used.*

Required timescale: *Nuclear Island Safety-Related Concrete.*

AF-UKEPR-CE-77: *The licensee shall confirm that design shear strength used for reinforced concrete structures accounts for the final type(s) of aggregates used in the concrete mix design in accordance with the UK National Annex to Eurocode 2, BS EN 1992-1-1.*

Required timescale: *First structural concrete.*

AF-UKEPR-CE-78: *The licensee shall provide a list of the safety critical reinforced concrete structural elements whose behaviour under shrinkage is dominated by end restraint. The licensee shall provide justification of the shrinkage control methods and reinforcement provided for such elements.*

Required timescale: *Nuclear Island Safety-Related Concrete.*

AF-UKEPR-CE-79: *The licensee shall confirm that there is adequate margin beyond design basis for safety critical non-massive structural elements, e.g. concrete columns or steel frames, such that if plasticity occurs in any part of those elements for the event considered, this will not lead to sudden failure.*

Required Timescale: *Nuclear Island Safety-Related Concrete.*

AF-UKEPR-CE-80: *The licensee shall provide the final construction specification and details for the joints within the concrete dome roof to the inner containment, and justify that the finished structure will fulfil the nuclear safety requirements.*

Required Timescale: *Install Polar Crane.*

AF-UKEPR-CE-81: *Where separate methods are used to check the punching shear and the bending stresses in concrete civil structures induced by potential dropped loads or internal missiles, the licensee shall justify that the methods are compatible with one another.*

Required timescale: *Nuclear Island Safety-Related Concrete.*

AF-UKEPR-CE-82: *The licensee shall justify that the calculation methods used to assess the damage to civil structures due to impact from potential dropped loads or internal missiles, are applicable to the range of dropped loads or missiles identified by the safety assessment for that structure.*

Required timescale: *Nuclear Island Safety-Related Concrete.*

AF-UKEPR-CE-83: *The licensee shall develop an internal missile methodology document for the site specific design, and clarify how it* *interfaces with the dropped load methodology document. The licensee shall also, having indentified the range of potential missile impacts for a particular civil structure, justify that the calculation methods used to assess the impact on civil structures from internal missiles are applicable*

Required timescale: *Nuclear Island Safety-Related Concrete.*

6.2 IMPACTED STEP 4 ASSESSMENT FINDINGS

259 There are no impacted Step 4 assessment findings.

7 ASSESSMENT CONCLUSIONS

260 I am satisfied that the latest version of the UK Companion Document, Rev E (Ref. 5) has adequately addressed the ONR technical comments raised during GDA Step 4 on Parts 0, 1 and 2 of the AFCEN ETC-C 2010 design code which is to be used for the UK EPR™. Sufficient justification has been given for the updated clauses in the UK CD and evidence provided that they are in accordance with internationally recognised codes and standards and UK current good practice. Omissions noted by ONR have also been corrected.

261 Section 4.3 presents my assessment of the supporting technical documents submitted as responses to the nine technical areas listed in **GI-UKEPR-CE-02.A1**. Sections 4.4 to 4.6 present my assessment of the three methodologies also required by A1: detailing provisions, pool liner design and dropped loads analysis. These documents have been assessed and I consider that they satisfy Regulator expectations with respect to the generic information required for **GI-UKEPR-CE-02.A1**. The documents also clarify what design information is included in the generic submission and what will be developed further during the site specific phase.

262 I am satisfied that **GI-UKEPR-CE-02.A1** can be closed.

263 Sections 4.7, 4.8 and 4.9 present my assessment of the updated clauses within the UK CD Rev E which have been modified in response to **GI-UKEPR-CE-02.A2, A3** and **A4.** The technical detail to these updates has been documented by EDF and AREVA in documents called Assessment Files. These describe the rationale for any updates to clauses within the UK CD, and also record additional justification of clauses which were questioned by ONR but have subsequently been agreed as adequate. The relevant Assessment Files are Refs. 59, 75 and 76.

264 I am satisfied that actions **GI-UKEPR-CE-02.A2, A3** and **A4** can be closed.

265 Resolution of **GI-UKEPR-CE-02** has also benefitted from the introduction of the "EPR Nuclear Island Civil Engineering Design Process Note" (Ref. 60) submitted under **GI-UKEPR-CE-01**. This document is an overarching description of the civil engineering design process and confirms the hierarchy of design documentation, including the UK CD and the AFCEN ETC-C 2010. My assessment of Ref. 60 is given in ONR report ONR-GDA-AR-12-006 (Ref. 7).

266 I have raised eight assessment findings (**AF-UKEPR-CE-76** to **AF-UKEPR-CE-83**) to help ensure compliance with the outcomes from **GI-UKEPR-CE-02**. I also note that the assessment of the complete construction specifications for civil structures is outside of the GDA scope and this will be subject to regulatory scrutiny at site specific stage.

267 Relevant sub-chapters 3.3 and 3.8 of the March 2011 PCSR have been revised such that I am satisfied the safety case is based on the current submission.

268 I therefore conclude that **GI-UKEPR-CE-02** can be closed.

8 REFERENCES

Ref.	Document
1	*GDA Issue GI-UKEPR-CE-02 Revision 1. Use of ETC-C for the Design and Construction of the UK EPR™*. July 2011. TRIM Ref. 2011/385289 (TRIM folder 5.1.3.6348.)
2	*Step 4 Civil Engineering and External Hazards Assessment of the EDF and AREVA UK EPR™ Reactor*. ONR Assessment Report ONR-GDA-AR-11-018 Rev 0, December 2011. TRIM Ref. 2010/581513. (TRIM folder 4.4.1.1827.).
3	*Resolution Plan for GI-UKEPR-CE-02.* EDF and AREVA. Rev 0, 29/06/2011. TRIM Ref. 2011/345898.
4	*AFCEN ETC-C 2010 Edition*: *ETC-C EPR Technical Code for Civil Works*. AFCEN. 23 December 2010. TRIM Ref. 2011/430452.
5	*UK Companion Document to AFCEN ETC-C,* ENGSGC110015 Rev E, EDF and AREVA, Sept 2012. TRIM Ref. 2012/350151.
6	*UK EPR™ GDA Step 4 Consolidated Pre-construction Safety Report – March 2011.* EDF and AREVA. Detailed in EDF and AREVA letter UN REG EPR00997N. 18 November 2011. TRIM Ref. 2011/552663.
7	*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 Rev. 0. January 2013. TRIM Ref. 2012/6.
8	*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 UKEPR-CE-04 Revision 1 - Analysis of the Containment.* ONR assessment report ONR-GDA-AR-12-003, Rev 0, January 2013. TRIM Ref: 2012/3.
9	*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 Rev. 1, May 2012. TRIM Ref. 2012/214232.
10	*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 Rev. 0, December 2012. TRIM Ref. 2012/2.
11	*ONR HOW2 Business Management System. Document PI/FWD "Permissioning - Purpose and Scope of Permissioning", Issue 3.*
12	*Assessment Plan for Civil Engineering and External Hazards, Closure of GDA for the EPR™*, ONR Assessment Plan ONR-GDA-AP-11-001, Rev 0, Nov 2011. TRIM Ref. 2011/650014
13	*ETC-C Tracking Sheet for resolution of GI-UKEPR-CE-02,* ENGSGC110269.xls, EDF and AREVA, Rev E ONR 107, 25 June 2012. TRIM Ref. 2012/257921.
14	*Additional Modifications to ENGSGC110015.doc,* ENGSGC110269.doc Appendix 1, EDF and AREVA, Rev E, April 2012. TRIM Ref. 2012/455130.
15	*Safety Assessment Principles for Nuclear Facilities.* 2006 Edition Rev 1. HSE. January 2008. www.hse.gov.uk/nuclear/SAP/SAP2006.pdf.

Ref.	Document
16	ONR 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 Rev 1, Jan 2009. *Fundamental Principles*, T/AST/004, Issue 3, March 2010 www.hse.gov.uk/nuclear/operational/tech_asst_guides/index.htm.
17	*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.
18	*Western European Nuclear Regulators' Association. Reactor Harmonization Group. WENRA Reactor Reference Safety Levels.* WENRA. January 2008. www.wenra.org.
19	*BS EN 1990:2002. Basis of Structural Design*. British Standards Institution, CEN Comite European de Normalisation. July 2002, *Amendment 1:2005*, 15 December 2004. *UK National Annex to BS EN 1990:2002*
20	*BS EN 1991 – Eurocode 1 – Actions on Structures,* British Standards Institution, CEN Comite European de Normalisation. • *BS EN 1991-1-1:2002. Part 1-1: General actions – Densities, self weight, imposed loads for buildings. 2002 and AC:2009.* • *BS EN 1991-1-7:2006. Part 1-7: General actions - Accidental actions. 2006 and AC 2010* *UK National Annex to Eurocode 1: Actions on Structures. General Actions* • *NA to BS EN 1991-1-1. – Densities, self weight, imposed loads for buildings. 2005.* • *NA to BS EN 1991-1-7:2006 – Accidental Actions*
21	*BS EN 1992, Eurocode 2: Design of concrete structures.* British Standards Institution, CEN Comite European de Normalisation. • *BS EN 1992-1-1: 2004. Part 1-1: General rules and rules for buildings. 23*/12/2004*.* • *BS EN 1992-1-2: 2004. Part 1.2: Structural fire design.* 09/02/2005. • *BS EN 1992-2: 2005. Part 2: Concrete bridges. Design and detailing rules.* 02/12/2005*.* • *BS EN 1992-3: 2006. Part 3: Liquid retaining and containing structures.* 31/07/2006*.* *UK National Annexes to Eurocode 2: Design of concrete structures.* • *NA to BS EN 1992-1-1:2004. Part 1-1: General rules and rules for buildings. 08/12/2005.* • *NA to BS EN 1992-1-2: 2004. Part 1.2: Structural fire design 08/12/2005* • *NA to BS EN 1992-2: 2005. Part 2: Concrete bridges. Design and detailing rules. 31/12/2007* • *NA to BS EN 1992-3: 2006. Part 3: Liquid retaining and containing structures. 31/10/2007*
22	*BS EN 1993. Eurocode 3: Design of steel structures.* • *BS EN 1993-1-1:2005. general rules and rules for buildings.* • *BS EN 1993-2:2006, Design of Steel Structures. Steel bridges. 30/11/2006.* • *BS EN 1993-4-2:2007 Design of Steel Structures. Tanks. 31/05/2007* *UK National Annexes to Eurocode 3: Design of steel structures.* *NA to BS EN 1993-1-1:2005. general rules and rules for buildings*

Ref.	Document
23	*BS EN 1998, Eurocode 8, Design of Structures for Earthquake Resistance.* • *BS EN 1998-1:2004. General Rules, seismic actions and rules for buildings. 08/04/2005.* • *UK National Annexe to BS EN 1998-1:2004. General Rules, seismic actions and rules for buildings. 29/08/2008*
24	*Code Requirements for Nuclear Safety Related Concrete Structures and Commentary.* ACI 349-06. American Concrete Institute. 1st September 2007.
25	*Building Code Requirements for Structural Concrete and Commentary*. ACI 318-11. American Concrete Institute. 2011. ISBN: 9780870317446.
26	*Section III, Division 2, ASME Boiler and Pressure Vessel Code. Code for Concrete Containments – Rules for Construction of Nuclear Facility Components.* ACI 359M-07 ASME. 2007
27	Fastenings to Concrete and Masonry Structures, CEB Bulletin No 216, 1994. ISBN 978-0-7277-1937-9 The International Federation for Structural Concrete (FIB - fédération internationale du béton), www.fib-international.org. Formerly the Euro-International Concrete Committee (CEB - Comité Euro-International du Béton).
28	*Early-age thermal crack control in concrete*, CIRIA Guide C660. Construction Industry Research and Information Association, London. February 2007. ISBN: 978-0-86017-660-2
29	*Design of fastenings for use in concrete.* Eurocode 2 Part 4 Document in Development DD CEN/TS 1992-4:2009, BSi, 30 June 2009, ISBN 978 0 580 62635 7
30	*ETC-C EPR Technical Code for Civil Works*. Rev B, 2006. EDF. TRIM Ref. 1710/404165.
31	UK Companion Document to AFCEN ETC-C – Part 1. ENGSGC110015 Rev A. 11 February 2011. EDF. TRIM Ref. 2011/128959.
32	*Various Submissions on ETC-C*. Letter from ND to UK EPR™ Project Front Office. Unique Number EPR70291R. 3 February 2011. TRIM Ref. 2011/70303.
33	*AFCEN ETC-C April 2010*. Letter from ND to UK EPR™ Project Front Office with comments on Part 0 and Part 1 and provisional comments on Part 2 and Part 3. Unique Number EPR70304N. 19 April 2011. TRIM Ref. 2011/235790.
34	*AFCEN ETC-C Part 2*. Letter from ONR to UK EPR™ Project Front Office. Unique Number EPR70367R. 07 October 2011. TRIM Ref. 2011/514252.
35	*Determination of the α_{cc} coefficient used in the formula for the design value of the compressive strength in Eurocode 2*. ENGSGC100384 Rev B. EDF. TRIM Ref. 2011/306266.
36	*GDA – Presentation and justification of ψi factors of ETC-C for variable actions in accidental and non-accidental situations.* ENGSGC100394 Rev B. EDF. 2 March 2011. TRIM Ref. 2011/132210.
37	*Justification of the concrete maximum compressive stress under bi axial/triaxial behaviour (accidental thermal conditions for the inner containment).* ENGSGC100415 Rev B. EDF. 17 March 2011. TRIM Ref. 2011/159534.

Ref.	Document
38	*EPR UK – Shear design proposal.* ENGSGC100410 Rev C. EDF, March 2011, TRIM Ref. 2012/81186 (Issued under EPR00824N. 8 March 2011. TRIM Ref. 2011/139617.)
39	*Steel and concrete partial safety factors for EPR™ fastening systems.* ENGSGC100395 Rev B. EDF. 11 November 2010. TRIM Ref. 2011/237385.
40	*UK EPR™ – GDA – Prestressing tendons participation in reinforced concrete calculations for the inner containment.* ENGSGC 100416 Rev B. EDF. 18 February 2011. TRIM Ref. 2011/128599.
41	*UK EPR™ – GDA – Methodology for consideration of shrinkage for EPR™ concrete structures.* ENGSGC100426 Rev B. EDF. 31 January 2011. TRIM Ref. 2011/128924.
42	*UK EPR™ – GDA – Verification of crack width for EPR™ concrete structures for durability requirement.* ENGSGC100428 Rev B. EDF. 31 January 2011. TRIM Ref. 2011/128922.
43	*Global approach about methodology for consideration of shrinkage and crack limitation.* ENGSGC110025 Rev A, EDF, February 2011. TRIM Ref. 2011/128920.
44	*Justification of the partial factor for prestressing actions γ_P.* ENGSGC100402 Rev A. EDF. 14 December 2010. TRIM Ref. 2011/85932.
45	*EPR™ Safety Category 1 (C1) Structures – Good Practice Detailing Rules for Reinforced Concrete and Steel Structures.* ENGSGC110157 Rev A EDF, TRIM Ref 2011/376079
46	*Pool Liner Design Requirements and Methodology,* ENGSGC110243 Rev A. EDF August 2011. TRIM Ref 2011/415254
47	*Methods with regard to the risk of dropped loads for EPR™ UK for concrete structures,* ENGSGC100483 Rev A, EDF and AREVA. April 2011. TRIM Ref. 2011/326141
48	*UK Companion Document to AFCEN ETC-C – Part 1*. ENGSGC110015 Rev B. April 2011. EDF. TRIM Ref. 2011/227961.
49	*Assessment File of the UK Companion Document to AFCEN ETC-C*, ENGSGC110033, Rev B, April 2011, EDF SEPTEN. TRIM Ref. 2011/227964.
50	*EPR Nuclear Island Civil Engineering Design Process*, ECEIG111110 Rev A, EDF and AREVA, August 2011, TRIM Ref. 2011/425958
51	*ETC-C Part 2.10 – Mapping of Changes from ETC-C Revision B to AFCEN ETC-C 2010* , ETDOIG110305, Rev A, EDF, June 2011. TRIM Ref. 2011/319054
52	*ETC-C Part 2: Construction Update – Mapping of Changes from ETC-C Revision B to AFCEN 2010 ETC-C (Sections 2.2 to 2.5, 2.11, and 2.12)* EDTGC110381 Rev A, EDF, June 2011, TRIM Ref. 2011/321789
53	*GDA – Presentation and justification of ψi factors of ETC-C for variable actions in accidental and non-accidental situations.* ENGSGC100394 Rev C. EDF. Aug 2011. TRIM Ref. 2011/450247.
54	*EP™R UK – Shear design proposal.* ENGSGC100410 Rev D. EDF, February 2012, TRIM Ref. 2012/81186
55	*EPR™ UK – GDA – Prestressing tendons participation in reinforced concrete calculations for the inner containment.* ENGSGC100416 Rev C. EDF. September 2011. TRIM Ref. 2011/493146

Ref.	Document
56	*EPR™ Safety Category 1 (C1) Structures – Good Practice Detailing Rules for Reinforced Concrete and Steel Structures.* ENGSGC110157 Rev B. EDF. TRIM Ref. 2011/620177
57	*Pool Liner Design Requirements and Methodology.* ENGSGC110243 Rev B. EDF. TRIM Ref. 2012/112052
58	*Methods with regard to the risk of dropped loads for EPR™ UK for civil works structures,* ENGSGC100483 Rev B, EDF and AREVA. March 2012. TRIM Ref. 2012/116384.
59	*Assessment File of the UK Companion Document to AFCEN ETC-C,* ENGSGC110033 Rev C, EDF, May 2012. TRIM Ref. 2012/227355.
60	*EPR Nuclear Island Civil Engineering Design Process*, ECEIG111110 Rev C, EDF and AREVA, September 2012, TRIM Ref. 2012/422394.
61	Not Used.
62	*UK EPR™* - Seismic Analysis of Foundation Raft. ENGSDS100268 Rev B. EDF and AREVA. April 2012. TRIM Ref. 2012/154518.
63	*UK EPR™* - Methodology for Seismic Analysis of NI Buildings. ENGSDS100269 Rev B. EDF and AREVA. May 2012. TRIM Ref. 2012/184476.
64	*GDA Issue GI-UKEPR-CE-01 Revision 1. Hypothesis and Methodology Notes for Class 1 Structures*. July 2011. Office for Nuclear Regulation, TRIM Ref. 2011/385288
65	*GDA Issue GI-UKEPR-CE-03 Revision 1. Beyond Design Basis Behaviour Of The Containment*. July 2011. Office for Nuclear Regulation TRIM Ref. 2011/385290
66	*GDA Issue GI-UKEPR-CE-04 Revision 1. Containment Analysis,* July 2011. Office for Nuclear Regulation. TRIM Ref. 2011/385291
67	*GDA Issue GI-UKEPR-CE-05 Revision 1. Reliability Of The ETC-C,* July 2011. Office for Nuclear Regulation, TRIM Ref. 2011/385292
68	*GDA Issue GI-UKEPR-CE-06 Revision 1. Seismic Analysis Methodology.* July 2011. Office for Nuclear Regulation. TRIM Ref. 2011/385293
69	*GDA Issue GI-UKEPR-IH-01 Revision 2. Substantiation And Analysis Of The Consequences Of Dropped Loads And Impact From Lifting Equipment Included Within The EPR™ Design* ONR, July 2011. TRIM Ref. 2011/385308 (TRIM folder 5.1.3.6348.)
70	*GDA Issue GI-UKEPR-IH-04 Revision 2. Consequences of Missile Generation Arising From Failure of RCC-M Components,* ONR July 2011. TRIM Ref. 2011/385311
71	*GDA Issue GI-UKEPR-CC-01.A2, Classification of structures systems and components,* ONR July 2011. TRIM Ref. 2011/385286
72	*Classification of Structures Systems and Components*, NEPS-F DC 557 Rev D Fin_2, AREVA, 10 October 2012. TRIM Ref. 2012/595982.
73	*UK Companion Document to AFCEN ETC-C,* ENGSGC110015 Rev D Preliminary, EDF and AREVA, March 2012. TRIM Ref. 2012/103915.
74	*UK Companion Document to AFCEN ETC-C,* ENGSGC110015 Rev D, EDF and AREVA, May 2012. TRIM Ref. 2012/184807.

Ref.	Document
75	*Assessment File of Revision E of UK Companion Document to the AFCEN ETC-C 2010*, ENGSGC120228 Rev A. EDF, September 2012. TRIM Ref. 2012/350152.
76	*Assessment File of the UK Companion Document to AFCEN ETC-C, (Section 2.2 to 2.5 of ENGSGC110015 D),* EDTGC120392 Rev A, EDF CEIDRE, May 2012. TRIM Ref. 2012/227353.
77	*Post Step 4 Review of the GDA Issue on ETC-C for the UK EPR™ - Review of revised supporting documents*. Report 209364-10-01 Issue, Nov 2011, Ove Arup & Partners. TRIM Ref. 2012/288747.
78	*Review of Document ENGSGC110222 Rev A, "Justification of the AFCEN ETC-C Construction Joint Design Method"* Report 209364-10-02 Issue, Nov 2011, Ove Arup & Partners. TRIM Ref. 2012/288756
79	*Post Step 4 Review of the GDA Issue on ETC-C for the UK EPR™ - Control of cracking due to Thermal and Shrinkage Effects,* Report 209364-10-03 Issue, Nov 2011, Ove Arup & Partners. TRIM Ref. 2012/288761
80	*Review of EDF/AREVA Document ENGS110046 Rev A - Presentation and justification of the consequences of concrete cracking on liner leaktightness.* Report 209364-10-04 Issue, Nov 2011, Ove Arup & Partners. TRIM Ref. 2012/288771
81	*Post Step 4 Review of the GDA Issue on ETC-C for the UK EPR™ - Review of document ENGSGC110157 Rev A,* Report 209364-10-05, Issue, Nov 2011, Ove Arup & Partners. TRIM Ref. 2012/288777
82	*Review of Document ENGSGC110345 Rev A, "Justification of ETC-C Shrinkage rules"* Report 209364-10-06 Issue, April 2012, Ove Arup & Partners. TRIM Ref. 2012/288845
83	*Review of Document EPR01031N, "GDA Issue GI-UKEPR-CE02: Revised proposal for out-of-plane shear reinforcement in structures designed according to AFCEN ETC-C 2010 (UK Companion Document)"* Report 209364-10-07 Issue, April 2012, Ove Arup & Partners. TRIM Ref. 2012/288849
84	*Review of document ENGSGC100410 Rev D - EPR-UK shear design proposal* Report 209364-10-08 Issue, June 2012, Ove Arup & Partners. TRIM Ref. 2012/288853
85	*Use of ETC–C in the design of nuclear structure. Review of ETC–C 2010 AFCEN and UK Companion Document Rev D PREL,* Report 209364-10-10 Issue, June 2012, Ove Arup & Partners. TRIM Ref. 2012/288859
86	*Review of ENGSGC110243 Rev A, "Pool Liner Design Requirements and Methodology",* Report 209364-10-11 Issue, September 2011, Ove Arup & Partners. TRIM Ref. 2011/415254.
87	*GDA Issue GI-UKEPR-CE02: Revised proposal for out-of-plane shear reinforcement in structures designed according to AFCEN ETC-C 2010*. EDF and AREVA Letter EPR01031N, December 2011, TRIM Ref 2011/635109.
88	*Comments on EDF and AREVA Letter EPR01031N, "GDA Issue GI-UKEPR-CE02: Revised proposal for out-of-plane shear reinforcement in structures designed according to AFCEN ETC-C 2010.* Email from ONR to EDF, TRIM Ref 2012/0059085.
89	*New proposal for out of plane shear reinforcement*, ENGSGC110375 Rev B, EDF, March 2012. TRIM Ref. 2012/59106.

Ref.	Document
90	*Comments on ENGSGC110375 B Out of Plane Shear Reinforcement,* Email from ONR to EDF. Jan 2012. TRIM Ref. 2012/0059104.
91	*PD6687-1:2010. Background paper to the National Annexes to BS EN 1992-1 and BS EN 1992-3.* BSi 13 December 2010. ISBN: 978 0 580 58685 9.
92	*Justification of the AFCEN ETC-C Construction Joint Design Method*. ENGSGC110222 Rev A, EDF, September 2011. TRIM Ref. 2011/476860.
93	*EDF and AREVA UK EPR™ - Schedule of Technical Queries Raised during GDA Step 1 to Step 4.* HSE-ND. TRIM Ref. 1710/600726.
94	*GDA Issue CE-02- ETC-C*, ONR Letter EPR70370N, dated 12/10/2011. TRIM Ref. 2011/524780 and 2011/524830
95	*Justification of ETC-C Shrinkage rules*, ENGSGC110345 Rev A. EDF January 2012. Submitted under cover of letter EPR01056N. TRIM Ref 2012/9844.
96	*Email from AREVA to ONR. ENGSGC110157 Rev B Prel Good Practice Guide for Detailing Provisions November 2011 TRIM Ref 2012/0058842*
97	*Seismic rules for EPR™ Civil Works - Justification of ETC-C seismic design rules*. Report by Philipe Bisch in support of ENGSGC110157 Rev B Prel. Sent via Email from AREVA to ONR, TRIM Ref 2012/0058854
98	*Detailing Rules for C1 Steel Structures.* Letter from *UK EPR*™ Project Front Office to ONR, Unique Number EPR01108N. 8th March 2012. TRIM Ref. 2012/107410
99	*Structural Steel Design – Expert Opinion*. 8 March 2012, Authors Pierre-Olivier Martin and Patrick Le Chaffotec, CTICM (Centre Technique Industriel de la Construction Metallique) TRIM Ref. 2012/107430
100	*GDA Issue GI-UKEPR-CE02 TATS Action #47.1: Constructions Joints (CJs).* Letter from *UK EPR*™ Project Front Office to ONR Unique Number EPR01060N, 19/01/12. TRIM Ref. 2012/32989.
101	*UK EPR™ – GDA – Presentation and Justification of the Consequences of Concrete Cracking on Liner Leak-tightness*, ENGSC110046 Rev A, EDF, September 2011. TRIM Ref. 2011/497144.
102	*ONR comments on ENGSGC110243 Rev A*. Letter from ONR to UK EPR™ Project Front Office. Unique Number EPR70366R. 5th October 2011. TRIM Ref. 2011/510996 (letter) and 2011/511017 (comments)
103	*GDA of EPR™ Pools and Liners methodology report, ENGSGC110243 Rev B Prel, EDF, January 2012.* Sent via email from AREVA to ONR. TRIM Ref 2012/057187.
104	*GDA of EPR™ TA comments on ENGSGC 110243 Rev B Prel Pools and Tanks Liner Design Requirements*, Email from ONR to EDF, Feb 2012, TRIM Ref 2012/0057162
105	*GDA Issue GI-UKEPR-CE02.A2: Methodology and Justification Reports for Design of Pool and Containment Liners*. Letter from UK EPR™ Project Front Office to ONR. Unique Number EPR01114N. 12th March 2012. TRIM Ref. 2012/111987
106	*UK EPR™ – GDA – Presentation and Justification of the Consequences of Concrete Cracking on Liner Leak-tightness*, ENGSC110046 Rev B, EDF, February 2012. TRIM Ref. 2012/112026

Ref.	Document
107	*ONR comments on ENGSGC110046 Rev A*. Email from ONR to EDF, 18 November 2011 TRIM Ref 2012/350324.
108	*Step 4 Internal Hazards Assessment of the EDF and AREVA UK EPR™ Reactor*. ONR Assessment Report ONR-GDA-AR-11-017 Rev 0, December 2011. TRIM Ref. 2010581514. (TRIM folder 4.4.1.1827.).
109	*GDA - UK EPR™ Review of GDA Issue on Dropped Loads report ENGSGC100483 Rev A*, 2120812-R-07 Issue 2, ABS Consulting Ltd, March 2012. TRIM 2012/301272.
110	*ONR Comments on ENGSGC100483 Rev.A*, ONR, 26 August 2011, TRIM Ref. 2011/0448467.
111	Letter EPR01098N, *GDA Issue GI-UKEPR-IH-01.A2: Approach taken to treat Dropped Loads on Civil Structures,* EDF and AREVA, 13 March 2012, TRIM Ref. 2012/116374.
112	*R3 Impact Assessment Procedure,* Magnox Electric plc British Energy Generation Ltd 2003.
113	*UK EPR™ PCSR Sub-chapter 3.3 – Design of Safety Classified Civil Structure.* EDF and AREVA, UKEPR-0002-035 Issue 05, October 2012. TRIM Ref. 2012/422397.
114	*UK EPR™ PCSR Sub-chapter 3.8 - Codes and standards used in the EPR™ design*. EDF and AREVA. UKEPR-0002-038 Issue 05, September 2012. TRIM Ref. 2012/226767
115	*UK EPR™ PCSR Sub-Chapter 13.2 – Internal Hazards Protection.* EDF and AREVA. UKEPR-0002-132 Issue 05, 31 October 2012. TRIM Ref. 2012/425734
116	*GDA Close-out for the EDF and AREVA UK EPR™ Reactor, GDA Issue GI-UKEPR-IH-01 Rev 2 - Internal* Hazards Assessment Report ONR-GDA-AR-12-016, Rev 0, December 2012, TRIM Ref. 2011/0016.
117	*EPR™ – Internal missiles – Risk assessment report on building structure and layout*, ECEIG091634 Rev B1, EDF, April 2011. TRIM Ref. 2011/324014. Received via letter EPR00875N 15 June 2011.
118	*TQ-EPR-1606 Full Response,* EDF and AREVA, 31 May 2012. TRIM Ref 2012/225343.
119	*GDA Close-out for the EDF and AREVA UK EPR™ Reactor, GDA Issue GI-UKEPR-IH-04 Rev 2 -* Internal Hazards Assessment Report ONR-GDA-AR-12-015, Rev 0, December 2012, TRIM Ref. 2011/0015.
120	*ONR Assessment Note UKEPR™ - Civil Engineering Review of GI-UKEPR-CC-01.A2, Classification of Civil Structures,* ONR, to be published. TRIM Ref. 2012/455299

Table 1: Relevant SAPs Considered for Close-out of GI-UKEPR-CE-02

SAP No.	SAP Title	Description
ECS.3	Engineering principles: Safety classification and standards Standards	Structures, systems and components that are important to safety should be designed, manufactured, constructed, installed, commissioned, quality assured, maintained, tested and inspected to the appropriate standards.
ECS.4	Engineering principles: Safety classification and standards Codes and standards	For structures, systems and components that are important to safety, for which there are no appropriate established codes or standards, an approach derived from existing codes or standards for similar equipment, in applications with similar safety significance, may be applied.
ECS.5	Safety classification and standards Use of experience, tests or analysis	In the absence of applicable or relevant codes and standards, the results of experience, tests, analysis, or a combination thereof, should be applied to demonstrate that the item will perform its safety function(s) to a level commensurate with its classification.
ECE.6	Engineering principles: civil engineering Design Loadings	For safety-related structures, load development and a schedule of load combinations within the design basis together with their frequency should be used as the basis for the design against operating, testing and fault conditions.

Table 1: Relevant SAPs Considered for Close-out of GI-UKEPR-CE-02

SAP No.	SAP Title	Description
EHA.14	Engineering principles: External and internal hazards Fire, explosion, missiles, toxic gases etc – sources of harm	Sources that could give rise to fire, explosion, missiles, toxic gas release, collapsing or falling loads, pipe failure effects, or internal and external flooding should be identified, specified quantitatively and their potential as a source of harm to the nuclear facility assessed.
ECE.12	Engineering principles: civil engineering 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.
ECE.13	Engineering principles: civil engineering structural analysis and model testing Use of data	The data used in any analysis should be such that the analysis is demonstrably conservative.
ECE.14	Engineering principles: civil engineering structural analysis and model testing 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	Engineering principles: civil engineering: structural analysis and model testing 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.

Annex 1

GDA Assessment Findings Arising from GDA Close-out for GI-UKEPR-CE-02 Rev 1

Finding No.	Assessment Finding	MILESTONE (by which this item should be addressed)
AF-UKEPR-CE-76	*The licensee shall confirm that the enhanced concrete compressive strength used for the design of the inner containment structure accounts for the final concrete mix design specified, and in particular the thermal expansion coefficient for the type(s) of aggregates to be used.*	*Nuclear Island Safety-Related Concrete*
AF-UKEPR-CE-77	*The licensee shall confirm that design shear strength used for reinforced concrete structures accounts for the final type(s) of aggregates used in the concrete mix design in accordance with the UK National Annex to Eurocode 2, BS EN 1992-1-1.*	*First Structural Concrete*
AF-UKEPR-CE-78	*The licensee shall provide a list of the safety critical reinforced concrete structural elements whose behaviour under shrinkage is dominated by end restraint. The licensee shall provide justification of the shrinkage control methods and reinforcement provided for such elements.*	*Nuclear Island Safety-Related Concrete*
AF-UKEPR-CE-79	*The licensee shall confirm that there is adequate margin beyond design basis for safety critical non-massive structural elements, e.g. concrete columns or steel frames, such that if plasticity occurs in any part of those elements for the event considered, this will not lead to sudden failure.*	*Nuclear Island Safety-Related Concrete*
AF-UKEPR-CE-80	*The licensee shall provide the final construction specification and details for the joints within the concrete dome roof to the inner containment, and justify that the finished structure will fulfil the nuclear safety requirements.*	*Install Polar Crane*

Annex 1

GDA Assessment Findings Arising from GDA Close-out for GI-UKEPR-CE-02 Rev 1

Finding No.	Assessment Finding	MILESTONE (by which this item should be addressed)
AF-UKEPR-CE-81	*Where separate methods are used to check the punching shear and the bending stresses in concrete civil structures induced by potential dropped loads or internal missiles, the licensee shall justify that the methods are compatible with one another.*	*Nuclear Island Safety-Related Concrete*
AF-UKEPR-CE-82	*The licensee shall justify that the calculation methods used to assess the damage to civil structures due to impact from potential dropped loads or internal missiles, are applicable to the range of dropped loads or missiles identified by the safety assessment for that structure.*	*Nuclear Island Safety-Related Concrete*
AF-UKEPR-CE-83	*The licensee shall develop an internal missile methodology document for the site specific design, and clarify how it interfaces with the dropped load methodology document. The licensee shall also, having indentified the range of potential missile impacts for a particular civil structure, justify that the calculation methods used to assess the impact on civil structures from internal missiles are applicable.*	*Nuclear Island Safety-Related 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

GDA ISSUE

USE OF ETC-C FOR THE DESIGN AND CONSTRUCTION OF THE UK EPR™

GI-UKEPR-CE-02 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">None</td></tr>
<tr><td>GDA Issue Reference</td><td colspan="2">GI-UKEPR-CE-02</td><td>GDA Issue Action Reference</td><td>GI-UKEPR-CE-02.A1</td></tr>
<tr><td>GDA Issue</td><td colspan="4">There is not yet sufficient justification of the AFCEN ETC-C 2010 version and UK Companion Document to confirm these can be used for the design, construction and testing of the UK EPR™ civil works structures.</td></tr>
<tr><td>GDA Issue Action</td><td colspan="4">Support assessment within the following areas by providing adequate responses to any questions arising from assessment by ONR of documents submitted during GDA Step 4 but not reviewed in detail at that time:
a_{cc} Coefficient
Load Combination Factors
Biaxial Stress Limits
Shear
Fastenings
Pre-stressing Participation
Shrinkage
Crack Width Control
Pre-stressing Partial Factor
Provide additional supporting documents on the following areas
Detailing provisions
Pool Liner Design
Drop Load Analysis
With agreement from the Regulator this action may be completed by alternative means.</td></tr>
</table>

Annex 2

EDF AND AREVA UK EPR™ GENERIC DESIGN ASSESSMENT

GDA ISSUE

USE OF ETC-C FOR THE DESIGN AND CONSTRUCTION OF THE UK EPR™

GI-UKEPR-CE-02 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-02</td><td>GDA Issue Action Reference</td><td>GI-UKEPR-CE-02.A2</td></tr>
<tr><td>GDA Issue Action</td><td colspan="3">Provide a revision of the UK companion document which addresses the observations raised on AFCEN ETC-C Part 0 as a result of our assessment, the key points being:
• Lack of independent review of the code.
• References to French standards, with translations not provided
• Loose references to “equivalent standards”
• There are no references to national annexes to some standards such as EN13670
In addition, please provide a mapping document (i.e. updated ETC-C assessment file) which identifies how these points have been dealt with.

With agreement from the Regulator this action may be completed by alternative means.</td></tr>
</table>

Annex 2

GDA ISSUE

USE OF ETC-C FOR THE DESIGN AND CONSTRUCTION OF THE UK EPR™

GI-UKEPR-CE-02 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">None</td></tr>
<tr><td>GDA Issue Reference</td><td>GI-UKEPR-CE-02</td><td colspan="2">GDA Issue Action Reference</td><td>GI-UKEPR-CE-02.A3</td></tr>
<tr><td>GDA Issue Action</td><td colspan="4">Provide a revision of the UK companion document which addresses the observations raised on AFCEN ETC-C Part 1 as a result of our assessment, the key points being:

• Errors in Formulas
• Lack of Clarity/ ambiguity in text
• Inconsistency with other sections of the code
• Inconsistency with UK National Annex
• Lack of guidance to designers on seismic design
• Revisions of supporting documents unclear
• Lack of guidance on choice of Eurocode value when no recommended value is available
• Justification lacking for some revised liner stress limits

In addition, please provide a mapping document (i.e. updated ETC-C assessment file) which identifies how these points have been dealt with.

With agreement from the Regulator this action may be completed by alternative means.</td></tr>
</table>

Annex 2

GDA ISSUE

USE OF ETC-C FOR THE DESIGN AND CONSTRUCTION OF THE UK EPR™

GI-UKEPR-CE-02 REV 1

<table>
<tr><td>Technical Area</td><td colspan="3">CIVIL ENGINEERING</td></tr>
<tr><td>Related Technical Areas</td><td colspan="3">None</td></tr>
<tr><td>GDA Issue Reference</td><td>GI-UKEPR-CE-02</td><td>GDA Issue Action Reference</td><td>GI-UKEPR-CE-02.A4</td></tr>
<tr><td>GDA Issue Action</td><td colspan="3">Provide a revision of the UK companion document which addresses the observations raised AFCEN ETC-C Part 2 as a result of our assessment, the key points being:
• Insufficient information to be the basis of a clear construction specification
• Links to French ministerial standards are of no relevance to the UK
• Clarification of the intention to demonstrate the equivalence of French standards to other national standards
• Provide clarity over the approval of modifications or adaptations to the specification
• Provide clarity over how demonstration of equivalence would be achieved

In addition, please provide a mapping document (i.e. updated ETC-C assessment file) which identifies how these points have been dealt with.

With agreement from the Regulator this action may be completed by alternative means.</td></tr>
</table>