Office for Nuclear Regulation
An agency of HSE

Generic Design Assessment – New Civil Reactor Build

GDA Closeout for the EDF and AREVA UK EPR™ Reactor

GDA Issue GI-UKEPR-RC-02 Revision 0 – Control and Minimisation of Ex-core Radioactivity

Assessment Report: ONR-GDA-AR-12-020
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EXECUTIVE SUMMARY

This report presents the close-out of part of the Office for Nuclear Regulation's (an agency of HSE) Generic Design Assessment (GDA) within the area of Reactor Chemistry. The report specifically addresses the GDA Issue **GI-UKEPR-RC-02 Revision 0** generated as a result of the GDA Step 4 Reactor Chemistry Assessment of the UK EPR™. The Step 4 Reactor Chemistry assessment concluded that the UK EPR™ reactor was suitable for construction in the UK subject to satisfactory resolution of a number of GDA Issues. On the basis of the claims, arguments and evidence presented to the end of Step 4, I considered that, overall, EDF and AREVA had not yet made an adequate and complete case to support the claim that radioactivity could be controlled in the Nuclear Island systems in UK EPR™. I was content this could be done, but as it was not completed in the Step 4 assessment timescale I carried this forward as a GDA Issue.

To address this GDA Issue EDF and AREVA provided additional information, through a series of reports and through technical meetings. The main deliverables provided in response to this GDA Issue included:

- A report which discusses the source term selection and quantification in the primary circuit of the UK EPR™. This report is based upon a mixture of plant operation feedback and calculations. Overall, this report provides evidence to support the UK EPR™ source term as specified in the Pre-Construction Safety Report (PCSR) and justifies the selection of criteria and monitoring and measurement equipment for the UK EPR™.
- A report which analyses the management of activity in the UK EPR™ auxiliary systems. The roles of the different auxiliary systems which relate to activity management are detailed, along with important equipment and the associated operating conditions. The principles and main criteria associated with activity management during normal power operation and transients are described. In addition, the report presents the results of a study of activity deposition in a number of important pipes, fittings and pools in EPR™. Overall, this report aims to confirm that the expected plant limits and conditions are consistent with the management of radioactivity.
- A summary report which contains the claims-argument-evidence trail for this GDA Issue and highlights the key supporting information and conclusions.

From my assessment, I have concluded that:

- EDF and AREVA have provided sufficient evidence to demonstrate that UK EPR™ should be capable of controlling and minimising radioactivity levels in the primary and primary auxiliary systems. UK EPR™ should be capable of managing radioactivity at least as well as, if not better than, comparable plants. This should be achieved through improvements to the coolant treatment, storage and monitoring systems in the auxiliary systems as well as by optimisation of the materials and operating chemistry of the primary circuit.
- As part of this GDA Issue EDF and AREVA have also confirmed the bounding nature of the PCSR source terms.
- EDF and AREVA's estimations indicate that the activity levels in UK EPR™ are likely to be similar to the latest French (N4) plants. There is some uncertainty inherent in these values but I remain content that it should be possible to operate UK EPR™ at lower levels than this if adequate controls over all operations are maintained by the licensee. It is for this reason that I have identified an Assessment

Finding for a future licensee to refine the bounding estimates provided for GDA during the site specific phase. This will help to define and justify limits, conditions, criteria and operating procedures and take advantage of developments and EPR™ operating experience before any UK EPR™ is operated in the UK.

- In response to this GDA Issue, EDF and AREVA updated the PCSR. I have reviewed these updates and am content that they accurately reflect the responses to the Issue Actions.

Overall, based on my assessment undertaken in accordance with ONR procedures, I consider the responses to be satisfactory and sufficient for closing the GDA Issue. This assessment has resulted in one new Assessment Findings which will need to be resolved by a future UK EPR™ licensee on a site specific basis.

LIST OF ABBREVIATIONS

ALARP	As Low as Reasonably Practicable (see also SFAIRP)
AREVA	AREVA NP SAS
BOA	Boron-induced Offset Anomaly code
CCWS	Component Cooling Water System [EDF coding system – RRI]
CDS	Coolant Degasification System [EDF coding system – TEP4]
CEA	Commissariat à l'énergie atomique et aux énergies alternatives (French Alternative Energies and Atomic Energy Commission)
CFD	Computational Fluid Dynamics
CILC	Crud-Induced Localised Corrosion
CIPS	Crud-Induced Power Shift
CPS	Coolant Purification System [EDF coding system – TEP2]
CSS	Coolant Storage and Supply system [EDF coding system – TEP1]
CSTS	Condensate Storage and Treatment System [EDF coding system – TEP] (see also CPS, CSS and CTS)
CTS	Coolant Treatment System [EDF coding system – TEP3]
CVCS	Chemical and Volume Control System [EDF coding system – RCV]
DF	Decontamination Factor
DSRC	Design Safety Review Committee
EA	Environment Agency
EBS	Extra Borating System [EDF coding system – RBS]
EDF	Groupe Electricité de France
EPR™	AREVA pressurised water reactor design
FA3	Flamanville 3
FPPS	Fuel Pool Purification System
FPCS	Fuel Pool Cooling System
GDA	Generic Design Assessment
GWPS	Gaseous Waste Processing System [EDF coding system – TEG]
HFT	Hot Functional Testing
HSE	(The) Health and Safety Executive
HVAC	Heating, Ventilation and Air Conditioning
IAEA	International Atomic Energy Authority
IRWST	In-containment Reactor Water Storage Tank
LWPS	Liquid Waste Processing System [EDF coding system – TEU]
mdm	mg dm^{-2} $month^{-1}$
NAB	Nuclear Auxiliary Building
NPP	Nuclear Power Plant

NSS	Nuclear Sampling System [EDF coding system – REN]
NVDS	Nuclear Vents and Drains System [EDF coding system – RPE]
OEF	Operator Experience Feedback
ONR	Office for Nuclear Regulation
ORE	Operator Radiation Exposure
PCER	Pre-Construction Environmental Report
PCSR	Pre-Construction Safety Report
PWR	Pressurised Water Reactor
RBWMS	Reactor Borated Water Make-up System [EDF coding system – REA]
RCS	Reactor Coolant System [EDF coding system – RCP]
RHRS	Residual Heat Removal System [EDF coding system – RRA]
RO	Regulatory Observation
SAP	Safety Assessment Principle
SDM	System Design Manual
SFAIRP	So Far as is Reasonably Practicable (see also ALARP)
SIS	Safety Injection System [EDF coding system – RIS]
SSC	Systems, Structures and Components
TSC	Technical Support Contractor
UK	United Kingdom
UK EPR™	EDF and AREVA UK specific pressurised water reactor design
VCT	Volume Control Tank
WENRA	Western European Nuclear Regulators Associated

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1 INTRODUCTION

1.1 Background

1 This report presents the assessment conducted as part of the close-out of the Office for Nuclear Regulation (ONR), an agency of the Health and Safety Executive (HSE), Generic Design Assessment (GDA) within the area of Reactor Chemistry. The report specifically addresses the GDA Issue **GI-UKEPR-RC-02** Revision 0 and associated GDA Issue Action (Ref. 1) generated as a result of the GDA step 4 Reactor Chemistry assessment of the UK EPR™ (Ref. 2), related to the control and minimisation of radioactivity outside of the reactor core. The assessment has focussed on the deliverables identified within the EDF and AREVA resolution plans (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 the EDF and AREVA were examined and in Step 3 the arguments that underpin those claims were examined. The Step 4 assessment reviewed the safety aspects of the UK EPR™ reactor in greater detail, by examining the evidence, supporting the claims and arguments made in the safety documentation.

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

4 The Step 4 assessment concluded that the UK EPR™ reactor was suitable for construction in the UK subject to resolution of 31 GDA Issues. The purpose of this report is to provide the assessment which underpins the judgement made in closing GDA Issue **GI-UKEPR-RC-02**.

1.2 Methodology

5 This assessment has been undertaken in line with the requirements of the Office for Nuclear Regulation (ONR) HOW2 PI/FWD – Issue 3 (Ref. 4) which sets down the process of assessment within ONR. The Safety Assessment Principles (SAPs) (Ref. 5) have been used as the basis for this assessment. Ultimately, the goal of assessment is to reach an independent and informed judgment on the adequacy of a nuclear safety case.

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

7 The assessment allows ONR to judge whether the submissions provided in response to the GDA Issue are sufficient to allow it 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.

1.3 Structure

8 The assessment report structure differs slightly from the structure adopted for the previous reports produced within GDA, most notably from the Step 4 Reactor Chemistry assessment (Ref. 2). While previous reports have made extensive use of sampling, this present report builds on the previous work during GDA and focuses on the resolution of the GDA issue. As such this report is structured around the assessment of **GI-UKEPR-RC-02** rather than a report detailing close out of all GDA Issues associated with this technical area.

9 The reasoning behind adopting this reporting approach is to allow closure of GDA Issues as the work is completed rather than waiting for the completion of all the GDA work in the Reactor Chemistry technical area.

2 ONR'S ASSESSMENT STRATEGY FOR REACTOR CHEMISTRY

10 The intended assessment strategy for closeout of GDA for the Reactor Chemistry topic area was set out in an assessment plan (Ref. 6) that identified the intended scope of the assessment and the standards and criteria that would be applied. This is summarised below:

2.1 Assessment Scope

11 This report presents only the assessment undertaken for resolution of Reactor Chemistry GDA Issue **GI-UKEPR-RC-02**, related to the control and minimisation of radioactivity outside of the reactor core (Ref. 1).

12 This report does not represent the complete assessment of UK EPR™ in the Reactor Chemistry topic area for GDA, or even a complete assessment of the UK EPR™ safety case for controlling and minimising radioactivity in UK EPR™. It is recommended that this report be read in conjunction with the Step 3 and Step 4 Reactor Chemistry assessments of the EDF and AREVA UK EPR™ (Refs 7 and 2) in order to appreciate the totality of the assessment undertaken as part of the GDA process. Section 3 of this report does provide a brief overview of the background to **GI-UKEPR-RC-02**.

13 Similarly, this assessment report does not revisit aspects of assessment already undertaken and accepted as being adequate during previous stages of GDA. However, should the assessment of EDF and AREVA's responses to the GDA Issues highlight shortfalls not previously identified during Step 4 or cast doubt on previously accepted arguments, there will be a need for these aspects of the assessment to be highlighted and addressed as part of the closeout phase or be identified as Assessment Findings to be taken forward to the site specific phase. As such the possibility of further Assessment Findings being generated as a result of this present assessment is not precluded.

14 Table 1 summarises **GI-UKEPR-RC-02** and its associated GDA Issue Actions generated as a result of the Step 4 Reactor Chemistry assessment. Annex 2 of this report contains the full text of the GDA Issue and Actions. Ref. 8 provides further background and explanatory information on the GDA Issue and Actions. EDF and AREVA have produced individual resolution plans for each of the GDA Issues which detail the methods by which they intended to resolve the Issues through identified timescales and deliverables; see Ref. 3.

GDA Issue Number	GDA Issue Description	Summary of GDA Issue Action	GDA Issue Resolution Plan and Reference
GI-UKEPR-RC-02	Control and Minimisation of Ex-core Radiation	Action 1 – EDF and AREVA to provide calculations, or alternative evidence agreed by the regulator, which demonstrate that the control of corrosion products (fuel crud) and other radioactivity (excluding tritium) in safety systems in the UK EPR™ and outside of the primary reactor cooling circuit are minimised so far as is reasonable practicable and are controlled.	Resolution Plan for GI-UKEPR-RC02, GI-UKEPR-RC02-RP, Rev 1, 01.07.2011. Ref. 3

Table 1: GI-UKEPR-RC-02, associated actions and resolution plans

15 Due to the nature of the GDA process, it was not considered feasible or realistic for EDF and AREVA to be able to fully define the chemistry that may be used at this stage as there will also be the need for licensee input for each specific site. In fact, it was considered beneficial not to compel EDF and AREVA to precisely define every aspect of UK EPR™ chemistry at this stage due to the likely changes in relevant good practice that may occur between GDA and operation of any reactor. The Step 4 assessment was based on the "expected" UK EPR™ chemistry regime (i.e. a baseline case), with further licensee specific development required during the site specific phase. The assessment conducted for resolution of **GI-UKEPR-RC-02** is consistent with this approach.

2.2 Assessment Methodology

16 This report has been prepared in accordance with relevant ONR guidance (Refs 4 and 9), and the scope defined in the assessment plan (Ref. 6).

17 The assessment process consists of examining the evidence provided by EDF and AREVA in responding to the GDA Issue action. This is then assessed against the expectations and requirements of the SAPs and other guidance considered appropriate. Further details on the information that supported this assessment are given in Section 2.4 of this report.

18 The basis of the assessment undertaken to prepare this report is therefore the Reactor Chemistry elements of:

- Submissions made to ONR in accordance with the resolution plans.
- Updates to the submission / Pre-Construction Safety Report (PCSR) / supporting documentation.
- The Design Reference that relates to the submission / PCSR as set out in UK EPR™ GDA Project Instruction UKEPR-I-002 (Ref. 10).
- Consideration of internal and international standards and guidance, international experience, operational feedback and expertise and assessments performed by other regulators, especially their findings.
- Interaction with other relevant technical areas (where appropriate).
- Holding necessary technical meetings to progress the identified lines of enquiry.

19 Consistent with the GDA deadlines and to provide ONR with information for use in my assessment of **GI-UKEPR-RC-02**, I procured Technical Support Contractor (TSC) support. Further details of this work, and its relevance to the assessment conducted is given in Section 2.5 of this report.

2.3 Assessment Approach

20 The approach to the closure of GDA for the UK EPR™ is described in greater detail in the Reactor Chemistry assessment plan (Ref. 6) and is based upon the assessment methodology described above. The closure of the GDA Issues will be reflected in a standalone Reactor Chemistry assessment report, which will describe the closure of the GDA Issue from the position established at the end of Step 4 (this report).

21 The overall strategy for closure of GDA is to build upon the assessment conducted during Step 4 and earlier, focussing on the detailed examination of the evidence presented by EDF and AREVA to support the satisfactory resolution of the GDA Issue Actions.

22 The following subsections provide an overview of the outcome from each of the information exchange mechanisms in further detail.

2.3.1 Technical Queries

23 No Technical Queries (TQs) were raised with EDF and AREVA for the Reactor Chemistry assessment during closeout of **GI-UKEPR-RC-02** for UK EPR™.

2.3.2 Technical Meetings

24 Provision was made for a series of technical meetings with EDF and AREVA during assessment of the **GI-UKEPR-RC-02** responses. These meetings occurred at appropriate points during 2011 and 2012 when most of the assessment took place. Approximately 3 days of main technical exchange meetings were undertaken, in addition to numerous teleconferences and smaller meetings, as necessary.

25 The principal focus of the meetings was to discuss progress and responses, to facilitate technical exchanges and to hold discussions with EDF and AREVA technical experts on emergent issues. A further key output was the direct interaction between EDF, AREVA and TSC experts to allow for dialogue and the ready exchange of information to enable TSC contracts to be fulfilled.

2.3.3 TSC Outputs

26 As detailed in Section 2.5, a technical support contract was placed to review aspects of the EDF and AREVA responses to the GDA Issue action. The output from this contract was a report summarising the review work undertaken by the TSC in completing the task and containing expert conclusions and recommendations (Ref. 11). Outputs from this contract were used as an input into the assessment of UK EPR™ undertaken by ONR and are an input into the conclusions of this report.

2.4 Standards and Criteria

27 The following section outlines the relevant standards and criteria that have informed the Reactor Chemistry assessment during closeout of **GI-UKEPR-RC-02** for UK EPR™.

2.4.1 Safety Assessment Principles

28 Of all of the standards and criteria that inform the assessment, it is the selection of the relevant SAPs (Ref. 5) that plays a key role in determining the scope of assessments in ONR. The SAPs considered relevant to the closeout assessment are listed in Table 8. These SAPs are a sub-set of those considered throughout the Step 4 assessment, as relevant to **GI-UKEPR-RC-02**.

2.4.2 Other ONR Guidance

29 Assessment was conducted to relevant ONR internal standards and guidance (Refs 4 and 9 and Table 9).

2.4.3 External Standards and Guidance

30 Generally, external standards and guidance specific to Reactor Chemistry are very limited in number.

31 The International Atomic Energy Authority (IAEA) has prepared a standard on Reactor Chemistry (Ref. 12). This document is authoritative, wide-reaching and consistent with the assessment, but concentrates on operational chemistry matters so is not expected to contribute significantly to the assessment of **GI-UKEPR-RC-02**.

32 A review of WENRA (Western European Nuclear Regulators' Association) levels (Ref. 13) found none specific to Reactor Chemistry, although resolution of this GDA Issue may contribute towards Issue H: Operational Limits and Conditions.

2.5 Use of Technical Support Contractors

33 Technical Support Contractors (TSCs) were engaged to assist with the Reactor Chemistry assessment work during Step 4 and this process continued during the GDA closeout stage, although only one contract was let in relation to **GI-UKEPR-RC-02**.

34 Whilst the TSC undertook a detailed technical review, this was under close direction and supervision by ONR and the regulatory judgment on the adequacy or otherwise of the UK EPR™ safety submissions are made exclusively by ONR. The TSC outputs were used as an input to this decision making process. The TSC report is referenced in this report under the relevant assessment sections, as appropriate.

35 Visibility of TSC work and feedback on progress and outcomes of TSC work was provided to EDF and AREVA throughout the process, including copies of the TSC outputs and reports.

2.6 Out of Scope Items

36 EDF and AREVA have identified no additional items as out of scope other than those identified during the Step 4 assessment.

2.7 Support from Other Assessment Areas

37 No support work has been required from other ONR assessment areas to complete the assessment documented in this report.

2.8 Working with Other Regulators

38 I have worked appropriately with the Environment Agency (EA) as part of my assessment. As this GDA Issue relates to source terms, waste generation and discharge treatment systems the responses to this GDA Issue are therefore of relevance to both ONR and EA.

3 BACKGROUND TO THE GDA ISSUE AND EDF AND AREVA'S RESPONSES

3.1 Overview of the EDF and AREVA Safety Case for Control and Minimisation of Radioactivity

39 Radioactivity carried by the primary coolant of a Pressurised Water Reactor (PWR) is an important contributor to Operator Radiation Exposure (ORE) and routine radioactive wastes as well as a potential source term in accidents. Roughly 90% of the ORE in a PWR can arise from activated corrosion products, and the major source of this is fuel crud, which is formed when corrosion products carried by the coolant deposit on the heat transfer surfaces of the fuel and become activated in the high radiation environment of the core. Other sources of radioactivity arise from activation of the coolant additives or impurities and releases of fission products from the fuel cladding, either through diffusion or more directly, but unlikely, in the case of cladding defects. Unlike many other source terms in a PWR (core radiation, ^{16}N, spent fuel etc.), the designers and operator of a PWR can influence the amount of crud produced, the concentration of activation products or the rate of fuel cladding defects by exercising adequate control over the operating chemistry, minimising impurity levels and by choices made during plant design and operations.

40 Decreasing personnel doses and controlling radioactive wastes were important objectives for EDF and AREVA in the design of UK EPR™. In common with all nuclear reactors there is no single factor which can be used to ensure radioactivity is minimised and controlled so far as is reasonably practicable, but there are many interrelated elements which when taken together can affect this control. EDF and AREVA describe how this has been approached for UK EPR™ in many parts of the safety case, including:

- Section 2.1 of sub-chapter 12.4 of the PCSR (Ref. 14) presented their claims for GDA that this goal had been achieved.
- The Pre-Construction Environmental Report (PCER), particularly chapter 8, provides a summary of the optimisations in the design which have been included to affect this (Ref. 15).
- Sub-chapter 5.5 of the PCSR (Ref. 16), in particular, provides the rationale for optimisation of the primary coolant chemistry to minimise radiation fields, in balance with the other safety aims for chemistry.

41 To summarise, EDF and AREVA claim that radioactivity has been controlled and minimised in UK EPR™ by a combination of:

- Material choices and conditioning techniques (including high cobalt alloy (e.g. Stellite™) reduction, reduction of residual trace cobalt levels in materials, steam generator tube manufacturing improvements and Hot Functional Testing (HFT) procedures).
- Chemistry optimisation, including the choice of pH, dissolved hydrogen concentration and zinc addition during normal operations and the careful management of start-up and shutdown transient periods.
- Treatment, purification, sampling and make-up systems which have considered the control and minimisation of radioactivity as part of their design.

3.2 Assessment during GDA Step 4

42 A fundamental part of any nuclear safety case is the derivation of the source term (Ref. 17) and demonstration that this level of radioactivity has been minimised so far as is reasonably practicable and can be controlled. Both the SAPs (Ref. 5) and the IAEA

chemistry safety guide (Ref. 12) contain many paragraphs and principles related to the control and minimisation of radioactivity, including corrosion products, both at source and within connected systems. The fundamental expectation in both of these is that radioactivity should be minimised. The specific UK expectation is that it should be reduced So Far As Is Reasonably Practicable (SFAIRP).

43 My assessment of the UK EPR™ safety case for control and minimisation of radioactivity is reported in Ref. 2. As described above (para. 41), there are many considerations when attempting to ensure that radioactivity is controlled to levels which can be considered reduced SFAIRP. Thus radioactivity was a major theme of my Step 4 assessment and is reported throughout my report. I sampled many aspects as part of my Step 4 assessment, including:

- Material choices, both for bulk materials, minor components and for trace elements, and their conditioning, manufacturing, surface finishing and surface cleanliness.
- Chemistry control requirements to limit the production and maximise the removal of radioactivity.
- The capability of those systems which minimise or remove radioactivity or allow sampling and control.
- The capability of the design to support operations which would minimise the generation or spread of radioactivity, particularly during transients such as plant shutdowns.

44 Hence it is difficult to provide a comprehensive and concise summary of all aspects here, instead only the most relevant and important considerations in relation to the current GDA issue are summarised below.

45 A weakness in the Step 3 safety case carried forward to the Step 4 assessment was relevant to my assessment of radioactivity in UK EPR™. I noted that the safety case was heavily biased towards ‘evidence’ derived from operations with other reactors. While I agree that operating experience is a valuable input, the Step 4 assessment report (Ref. 2) noted that *“…It is apparent that the ‘evidence’ that is currently presented is very much biased towards operational experience with other reactors. This is a valid input to an evidence based argument, but should be balanced with other evidence, such as calculations or modelling, where appropriate. The lack of theoretical or quantitative analyses weakens some arguments, especially where UK EPR™ differs and this balance will need to be addressed as part of the safety case development“.* This approach also made it difficult to assess if EDF and AREVA had truly reduced radioactivity SFAIRP in the design of UK EPR™ or were content to achieve performance comparable with current plants.

46 Since this approach appeared to take little account of the specifics of the UK EPR™ design, I raised a number of TQs and Regulatory Observations (ROs) during Step 4 which required EDF and AREVA to justify that the materials and chemistry specified for UK EPR™ would achieve the low levels of radioactivity claimed, based on both the material and chemistry choices:

- **RO-UKEPR-46** (Ref. 18) requested EDF and AREVA to provide a justification and evidence that radioactivity within the primary coolant of UK EPR™ had been reduced so far as reasonably practicable, based upon both chemistry (Action 1) and material choices (Action 2). EDF and AREVA’s responses outlined the main material choices and the chemistry needed to minimise the concentration of corrosion products in the coolant and minimise their deposition on fuel cladding and limit accumulation on out-of-core surfaces. The responses to these Regulatory

Observation (RO) actions provided reasonable arguments and evidence to suggest this had been achieved for UK EPR™.

- **RO-UKEPR-73** (Ref. 18) requested EDF and AREVA to define and justify the source term for UK EPR™, including how it had been used and applied across many of the GDA technical areas, including Reactor Chemistry. In the response to **RO-UKEPR-73** EDF and AREVA provided estimates for the radioactivity within the reactor building and In-Containment Refuelling Water Storage Tank (IRWST) pools, amongst other systems.

47 The information supplied in the RO responses was later included in the consolidated PCSR for GDA (for example in Ref. 16), which I considered to be much improved and to have largely resolved the imbalance in evidence described above.

48 However, EDF and AREVA did not complete their responses to **RO-UKEPR-74** (Ref. 18) in time for Step 4. This RO requested EDF and AREVA to provide sufficient and suitable evidence to demonstrate that radioactivity and its accumulation in the Nuclear Island, to be as low as reasonably practicable. This RO requested evidence particularly for tritium (Action 1), fuel crud (Action 2) and other radioactivity (Action 3) respectively. A brief summary of the position regarding this RO at the end of Step 4 is:

- All of the responses to **RO-UKEPR-74.A1**, covering tritium, were provided and assessed during Step 4 and when taken together they provided sufficient confidence that tritium could be adequately controlled in UK EPR™ but this will be highly dependant upon operating procedures and will therefore be taken forward with any future UK EPR™ licensee as Assessment Findings.
- **RO-UKEPR-74.A2** requested evidence that the UK EPR™ design could adequately control fuel crud throughout the Nuclear Island systems. Similarly, **RO-UKEPR-74.A3** requested evidence for the control of other radioactive materials throughout the Nuclear Island. EDF and AREVA chose to combine the response to these latter two actions. At the time of preparing the Step 4 assessment report EDF and AREVA had not completed their response to these ROAs, having provided only the first half of a three stage response (i.e. two reports out of four).

49 At the end of Step 4 I concluded that, overall, EDF and AREVA had not yet made an adequate and complete case to support the claim that radioactivity could be controlled in the Nuclear Island systems in UK EPR™. I was content this could be done, but was not completed in the Step 4 assessment timescale. Overall, while I was content with the majority of the UK EPR™ safety case related to radioactivity, this assessment resulted in nine related Assessment Findings and a single GDA Issue, partly in response to EDF and AREVA's request to include this information as part of the generic UK EPR™ design. Full details of the conclusions of this assessment are reported in Ref. 2, so are not repeated in detail here.

3.3 Summary of the GDA Issue and Actions

50 GDA Issue **GI-UKEPR-RC-02** and its associated one action are given in Ref. 1. Further explanatory information on this issue and action is provided in Ref. 8. This action required EDF and AREVA to provide evidence, via calculation or other alternate means, to prove that the radioactivity within UK EPR™ systems outside of the main primary circuit (i.e. in the spent fuel pool, in-containment reactor water storage tank, residual heat removal system etc.) can be controlled at levels that are reduced SFAIRP. Essentially this required completion of the scope originally defined for **RO-UKEPR-74.A2 and A3**.

3.4 EDF and AREVA Deliverables in Response to the GDA Issue

51 The EDF and AREVA resolution plan for this Issue is given in Ref. 3. This provides details of the deliverables EDF and AREVA intended to provide to respond to this action.

3.4.1 Action 1 – Demonstration that Ex-core Radiation Levels in UK EPR™ are minimised SFAIRP and can be controlled

52 As described in Section 3.2 above, EDF and AREVA provided some of the relevant material to respond to **GI-UKEPR-RC-02** at the end of Step 4 of GDA as the resolution plan involves completion of the **RO-UKEPR-74** responses, as defined in letter EPR00546N (Ref. 19). Two reports were provided during Step 4:

- The first report in the response (Ref. 20) is an overview document providing information on how EDF and AREVA have approached the management of activity in UK EPR™. Various steps are described including identification, quantification and characterisation of the source terms, followed by analysis of the performance of the various UK EPR™ treatment systems. In particular, this report provides details of the alternative means (modelling, hypothesis, codes) proposed by EDF and AREVA for estimating the source term for corrosion and fission products taking into account the specific design and operating conditions of UK EPR™. Much of the information is linked to other previously supplied documentation, particularly the responses to **RO-UKEPR-73** and **RO-UKEPR-74.A1**.
- The second report of the response (Ref. 21) provides the EDF and AREVA estimates for fuel crud in UK EPR™. This report is discussed in detail in the Step 4 assessment report, so is not repeated here, except to acknowledge that it appears to provide a bounding estimate for fuel crud production in UK EPR™. This analysis is an input to the fuel crud radioactivity likely to be transported to ex-core Systems, Structures and Components (SSC's) during normal operations (mainly during shutdown transients).

53 The remaining deliverables, specifically assessed as part of the resolution for this GDA Issue are:

ECEF110448 - Analysis of UK EPR™ source term: Identification, Quantification and Characterisation

54 This report (Ref. 22) discusses the source term selection and quantification for the Reactor Coolant System (RCS) of the UK EPR™. This report is supported by a specific reference report which describes the characterisation of corrosion products (Ref. 23). A description of the nuclides taken into account for the primary coolant in order to manage and control the radioactivity in the Nuclear Island is described. Quantification of the RCS source term, based on plant Operational Experience Feedback (OEF), empirical calculations and thermodynamic evaluations, is provided in order to show the applicability of the nuclide source term specified by EDF and AREVA in the PCSR. The specific materials and chemistry conditions of UK EPR™ are discussed as part of this quantification. The speciation and characterisation of the radionuclides is described, as are the radioactivity control parameters that are monitored during normal power operation and transients. Overall, this report aims to provide evidence which justifies the selection of criteria and monitoring and measurement equipment for the UK EPR™.

ECECF110449 - Activity Management at UK EPR™ Auxiliary Systems: System Performance and Control Actions

55 This report (Ref. 24) discusses the management of activity in the UK EPR™ auxiliary systems. It provides a description of the activity pathway through the main auxiliary systems and presents the results of a parametrical study of source term estimates and activity deposition in the circuits. For UK EPR™ the activity management process is based on the performance of the purification devices used in the auxiliary systems (i.e., filters, resins, flowrates, etc.), the design of the plant (e.g. valve choice, pipework design, flowrates etc) and the monitoring arrangements (e.g. instrumentation, criteria etc.). The report describes the roles of the different auxiliary systems which contribute to the management of activity, along with important equipment and their associated operating conditions. The principles and main criteria associated with activity management during normal power operation and transients are described. Overall, this report aims to demonstrate that the design and expected plant limits and conditions are consistent with an As Low As Reasonably Practicable (ALARP) activity management strategy.

ECECS121408 – Ex-core Radiation Minimisation and Control in UK-EPR™ Reactor

56 This report (Ref. 25), provided in response to my assessment, summarises the claims, arguments and evidence developed by EDF and AREVA in the more detailed Refs 22 and 24. This report aims to underline this links and summarise the main insights provided by the overall response to this GDA Issue.

4 ONR'S ASSESSMENT

57 The following sections detail the specific assessment undertaken for GDA Issue GI-UKEPR-RC-02 as identified by the Reactor Chemistry assessment in Step 4.

58 As described earlier, this report does not represent the entirety of assessment conducted on these topics, with the Step 4 report (Ref. 2) providing further detailed assessment. The sections follow the following outline structure:

- The main part of the section describes my assessment, detailing the work undertaken, external inputs into this assessment (e.g. TSC reports), the principal RP deliverables reviewed and the conclusions of the assessment.
- EDF and AREVA have updated the PCSR to reflect the outcomes of the GDA Issue Actions, and I briefly review this.
- Finally, a summary is provided, including my judgement on whether the Action has been adequately resolved, together with any areas where further work has been highlighted as necessary following GDA as Assessment Findings.

59 I commissioned TSC support to review the responses provided to this GDA Issue, see Ref. 11. The assessment that follows is consistent with the conclusions of this review, as appropriate.

4.1 Action 1 - Demonstration that Ex-core Radiation Levels in UK EPR™ are minimised SFAIRP and can be controlled

4.1.1 Overview of the EDF and AREVA response

60 ONR recognise that EPR™ is a new reactor design with no directly equivalent plants in operation. This means that attempts to quantify the behaviour of the plant regarding radioactivity generation, accumulation and transfer between the various systems is likely to be difficult with a high degree of certainty. However, EDF and AREVA have over 1300 reactor years of operating experience gained from the French and German PWR fleets (Ref. 15), in addition to published operating feedback from other plants on which more semi-quantitative or empirical estimates could be based. One of the main aims for this GDA Issue was therefore to use this wealth of experience, in combination with suitable modelling and calculations, to derive the likely behaviour of UK EPR™, particularly in those areas where the design differs from other plants.

61 The EDF and AREVA approach to resolution of **GI-UKEPR-RC-02** is based around the activity management philosophy described in Ref. 20. EDF and AREVA recognise that, although the radiochemical spectra of the primary coolant of PWRs is well known, there remains uncertainty in the chemical speciation of these nuclides which could have effects on the control and transfer of radioactivity between connected systems. To counter this uncertainty EDF and AREVA consider multiple inputs, including extrapolated OEF data and theoretical models, to attempt to obtain a balanced view.

62 Overall, EDF and AREVA provided a large number of detailed responses for this GDA Issue. Figure 1 below shows the interrelationships between the various documents submitted in response to **GI-UKEPR-RC-02**. ECECS121408, "*Ex-Core Radiation Minimisation and Control in UK EPR™ reactor*", (Ref. 25) is the high level summary document for this GDA Issue, containing the claims-arguments-evidence trail and heavily referencing the main supporting documents ECEF110448 (Ref. 22) and ECEF110449 (Ref. 24). These latter two documents contain much of the detailed evidence as calculations, operating experience or relevant research results. Similarly these reports rely on several key technical references (e.g. Refs. 21 which contains the Boron-induced Offset Anomaly (BOA) analysis for UK EPR™) and the overall EPR™ source term documents (e.g. Ref. 17 for the primary coolant source terms and Refs 26, 27 and 28 for the various auxiliary systems).

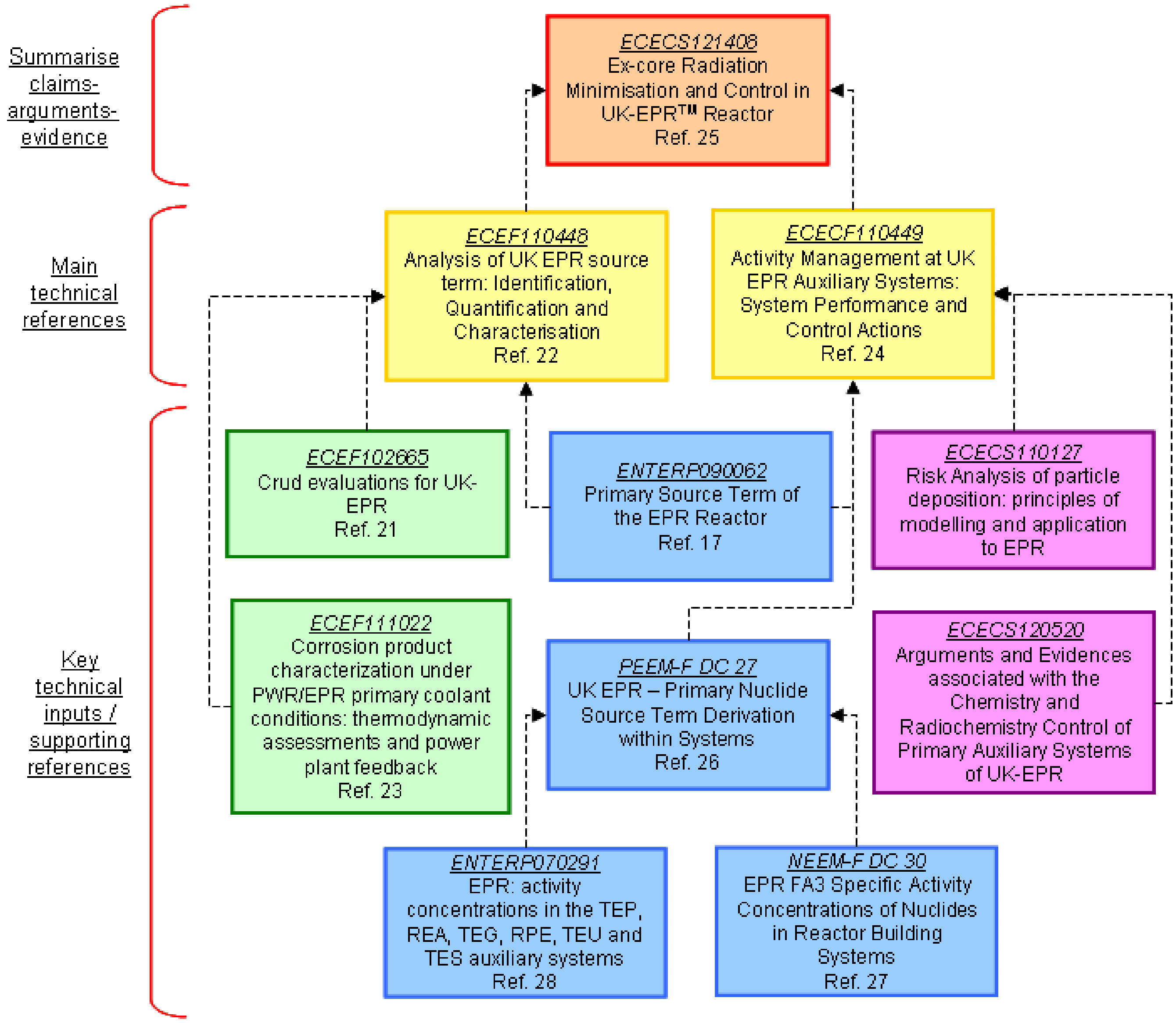

Figure 1: Relationship between EDF and AREVA **GI-UKEPR-RC-02** responses

63 The structure of my assessment report more closely resembles the content of Ref. 25 which is built around a claims-arguments-evidence structure. EDF and AREVA produced Ref. 25, in response to my assessment of Refs 22 and 24. The two references were originally identified by EDF and AREVA as sufficient to resolve this GDA Issue. The technical content of Refs 22 and 24 are described and assessed in greater detail in the subsequent sections that follow, however it became apparent during my reviews of these detailed reports that the evidence trail in these documents was complex and often difficult to follow and as such I requested EDF and AREVA to provide a more concise and transparent "*roadmap*" document, which resulted in the production of Ref. 25.

64 In Ref. 25 EDF and AREVA identify five “*sub-claims*” which support the overall claim made for UK EPR™ that “*ex-core radiation is minimised and controlled in UK EPR*™”, namely;

- The source terms are minimised
- The auxiliary systems have been designed to meet their respective chemistry and radiochemistry requirements
- The purification systems are optimised
- The potential deposition mechanisms have been evaluated (and considered in the design)
- The chemistry and radiochemistry monitoring and control arrangements are ALARP

65 For each of these identified “*sub-claims*”, EDF and AREVA identify the corresponding arguments and evidence which support this claim, mainly referencing the more detailed studies found within Refs 22 and 24. I consider that these are reasonable “*sub-claims*” to support the overall claim and consider the arguments and evidence provided under each further below. This approach is shown below:

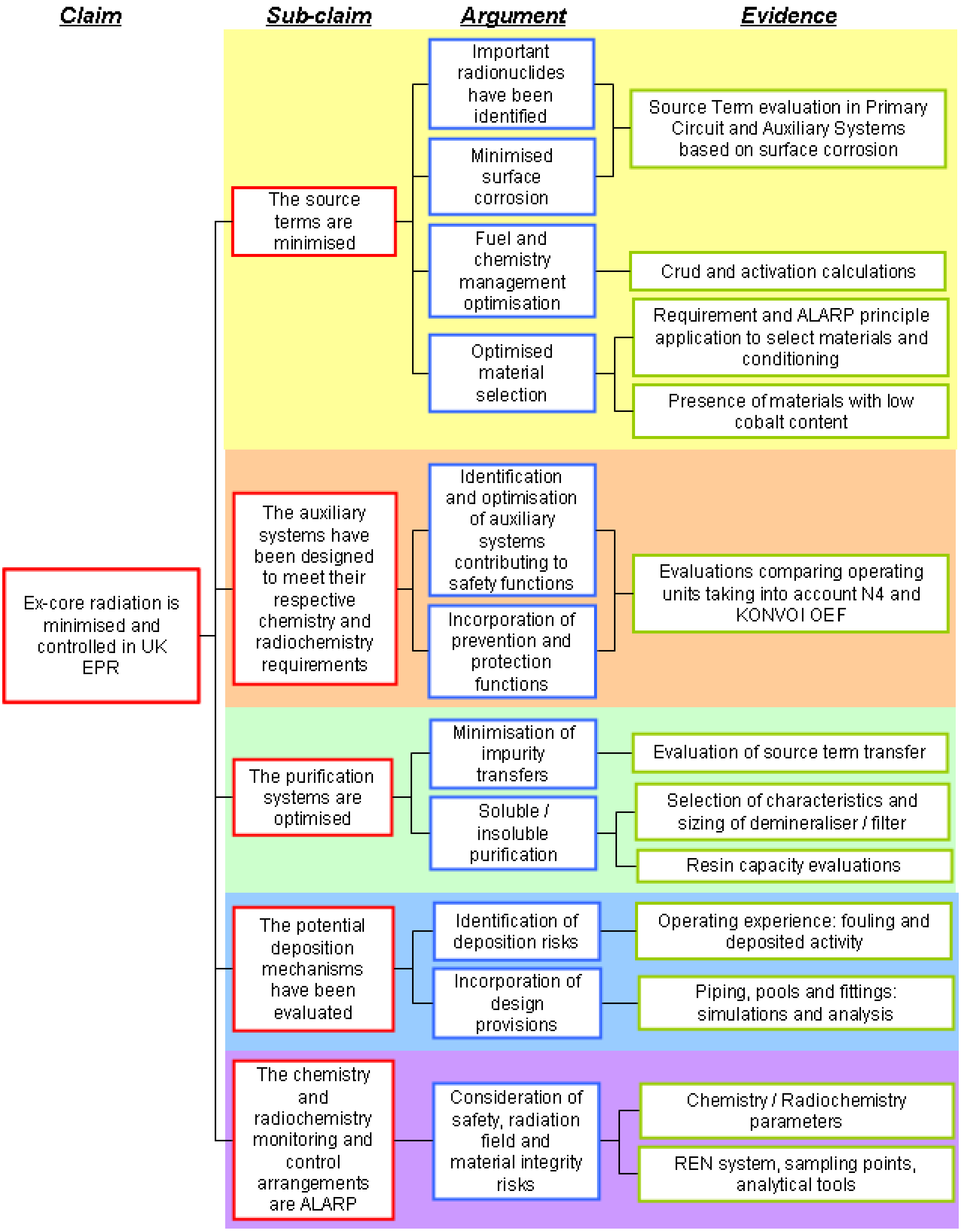

Figure 2: Claims, arguments and evidence flowchart for minimisation and control of ex-core radiation in UK EPR™ (from Ref. 25)

66 I assess the evidence provided to support each of these sub-claims in the sections that follow below.

4.1.2 Sub-claim 1: The Source Terms are Minimised

67 This sub-claim represents the bulk of the evidence provided by EDF and AREVA in response to this GDA Issue. EDF and AREVA consider both the primary circuit and the main auxiliary systems in UK EPR™. The approach taken and evidence provided for each of these is different, hence I consider each separately below.

4.1.2.1 Minimisation of the Source terms in the Primary Circuit

68 EDF and AREVA recognise the importance of applying an ALARP approach to reducing the radioactivity levels within UK EPR™. Ref. 25 provides a high-level summary of their approach to source term minimisation in UK EPR™ which includes identifying those nuclides which have the greatest safety impact (e.g. ^{58}Co and ^{60}Co during shutdowns) and their potential consequences (for example, control over nickel is important for both ^{58}Co production but also for fuel crud formation). Based on this identification, EDF and AREVA argue that the source term in the UK EPR™ primary circuit has been minimised by the appropriate choice of materials in the primary circuit, the fuel management strategy and the operating chemistry in the primary circuit.

69 These arguments are supported by a range of evidence, including calculations, estimations, and plant feedback, as shown in Figure 2 previously.

70 As described in Section 3, I considered many of these aspects for the primary circuit in detail as part of my Step 4 assessment of UK EPR™ (Ref. 2), in particular the material inventories of the primary circuit and the impact of the plant operating chemistry parameters. These are assessed in detail in Section 4.2.3 of my Step 4 assessment report, which concluded that "*Overall, UK EPR™ follows the well established and developed approach of restricting the material in contact with the primary coolant to mainly austenitic stainless steels (or cladding) or Ni-Cr-Fe alloys. EDF and AREVA have specified restrictive levels for impurities in these alloys and have described how the important factors such as conditioning and surface treatments will be specified to ensure releases are effectively controlled. I am content with the material choices for UK EPR™ and am content that EDF and AREVA have made an adequate ALARP argument for UK EPR™*". My assessment that follows therefore concentrates on those aspects or evidence which I have not assessed previously, although my conclusions are based on the overall EDF and AREVA safety case for the management and control of radioactivity.

71 The first deliverable provided by EDF and AREVA in response to **GI-UKEPR-RC-02**, "*Analysis of UK EPR™ source term: Identification, Quantification and Characterisation*" (Ref. 22), presents the arguments and evidence from EDF and AREVA to demonstrate the claim that activity has been minimised and is controllable in the UK EPR™ primary circuit. In terms of minimisation of the source term the arguments and the evidences are based on the identification, quantification and characterisation of the source term according to the specifics of the UK EPR™ design (i.e. core design, material, operating conditions, chemistry program).

4.1.2.1.1 Primary Circuit – Identification of Relevant Nuclides

72 The first part of Ref. 22 describes the background to which nuclides have been included in the UK EPR™ source term. EDF and AREVA rationalise this selection based upon the origin (from fuel, structural material corrosion or coolant activation), properties (solubility, volatility, tendency to precipitate or absorb on surfaces etc.) and ability to monitor. The nuclides are “grouped” according to the safety concern they are linked to; fuel failure, material degradation or fuel crud accumulation.

73 While it is useful to present this more detailed rationale for the source term selection, the scope and content of the UK EPR™ source term was assessed during Step 4 in numerous technical areas in relation to their own specific assessments (e.g. reactor chemistry, radiation protection, radwaste etc.). None of the radionuclides identified are unique to UK EPR™, no significant deficiencies were identified and no new information is presented in Ref. 22 to dispute this approach.

4.1.2.1.2 Primary Circuit – Quantification of Relevant Nuclides

74 The second and main part of Ref. 22 provides quantifications for the various identified nuclides. An important distinction that needs to be made here is that EDF and AREVA use this section of the report to provide a demonstration that the source term specified for UK EPR™ in the PCSR (from Ref. 17) is appropriate and bounding, including during identified fault scenarios such as fuel failures. The aim of this part of Ref. 22 is stated as “*to justify by a semi-quantitative approach the as defined UK EPR™ source term*”. These calculations do however take credit for the ALARP improvements already identified for the primary circuit, namely operating chemistry choices and material inventories. The purpose of this quantification for **GI-UKEPR-RC-02** is therefore to justify EDF and AREVA using the PCSR source term for subsequent calculations and estimations, as well as contributing towards rebalancing the experience versus estimation balance in the UK EPR™ safety case (see Para. 45).

75 Rather than attempting to quantify all the (sometimes minor) nuclides, EDF and AREVA concentrate on those which are directly relevant to detecting “problems” and hence are part of the plant limits and conditions.

76 As described earlier, the UK EPR™ source term is primarily based upon EDF operating experience (N4 and 1300 MW_e plants) which is adapted for UK EPR™ based upon the methodology described in the source term report (Ref. 17). For nuclides where there was no feedback available, calculations based upon simple production and decay were used. For the assessment that follows it is worthwhile noting that the UK EPR™ source term is defined by three distinct levels:

- “*Realistic*” – the mean specific activity assumed during normal steady operations and transient periods
- “*Biological Shield Design*” (DPB) – used for sizing of biological shielding, ventilation systems and screens
- “*Radiological consequences*” (DSE) – the most penalising source term used in the evaluation of radiological consequences of accidents

4.1.2.1.2.1 Activation products

77 Ref. 22 contains no discussion on the quantification of the relevant activation products in UK EPR™. The source term report (Ref. 17) provides this information for ^{16}N, ^{17}N, ^{41}Ar, ^{3}H and ^{14}C. The values used are based upon calculations for ^{16}N and ^{17}N, plant feedback

for ^{41}Ar and ^{14}C and an assumed bounding value is taken for ^{3}H (note that ^{3}H is outside the scope of **GI-UKEPR-RC-02** and was considered during the Step 4 assessment (Ref. 2)).

4.1.2.1.2.2 Fission Products and Actinides

78 EDF and AREVA consider fission product and actinide production from both tramp uranium contamination and fuel cladding defects. The methodology for calculating the estimated activity is described in Ref. 22 and is based upon the Bateman equations for determining the actinide and fission product formation. The input data is based upon UK EPR™ data such as neutron flux, coolant temperatures etc.

79 For cycles which have no fuel cladding defects, fission product and actinide activity arises due to traces of uranium which dissolve in the coolant and subsequently become activated. EDF and AREVA consider both residual uranium left on the outside of fuel rods during manufacture and trace uranium impurities within the zirconium cladding that are within the recoil range and hence susceptible to allowing direct release of fission products to the coolant. While the calculated uranium mass in the UK EPR™ core from these means is larger than N4 units (due to the larger core size) the overall mass is still negligible on the assumption that tight impurity limits are specified and met and cleaning of the rod external surfaces is highly efficient. Using the data supplied in this report it can be shown that around 1 g of uranium is needed to meet the "*realistic*" source term for ^{134}I, with more than 30 g needed to meet the ^{133}Xe level based on 30 MWd kg^{-1} burn-up. Even 1g uranium is approximately 750 times the mass EDF and AREVA's estimate to be present in UK EPR™. EDF and AREVA therefore assume a conservative mass of 0.5 g uranium which results in ^{133}Xe and ^{134}I concentrations below the "*realistic*" source term defined in Ref. 17. There is therefore considerable margin in the "*realistic*" source term when considering tramp uranium sources alone.

80 The level of fission product and actinide contamination would increase significantly in the event of fuel failures. EDF and AREVA therefore also calculate the activity releases due to defective fuel rods. This aspect is much more uncertain than the simple analytical relationships used for tramp uranium as the analysis is based upon estimations using diffusion-kinetic models, which are often empirically adjusted to fit plant data. Despite these limitations, this model can be used to show the effect of various plant parameters on the activity transferred to the primary coolant as a result of such defects, including the effects of escape rate (i.e. defect 'size') and rod power. Using these relationships EDF and AREVA show that:

- The "*realistic*" ^{133}Xe source term corresponds to a single medium or several small defects with the higher "*biological*" (DPB) source term equivalent to large multiple defects in high powered rods. This source term is based on 1300 MW$_e$ and N4 OEF.
- While the ^{131}I source terms ("*realistic*" and "*biological*") are much lower than the corresponding ^{133}Xe term, EDF and AREVA argue that this is due to the behaviour of iodine under normal operating conditions where it is not released from fuel rods in such large fractions as ^{133}Xe. This is a reasonable argument, consistent with plant experience and the known behaviour of iodine.
- As described earlier the ^{134}I "*realistic*" source term equates to a tramp uranium mass of around 1 g based on 30 MWd kg^{-1} burn-up. This represents a low level of potential actinide contamination of the coolant. The higher "*biological*" (DPB) source term can be produced from up to 30 g of uranium, depending upon the irradiation history of the material and indicates a much larger risk of contamination. In such

circumstances EDF and AREVA indicate that appropriate countermeasures would be undertaken (to be confirmed by the future licensee for UK EPR™ dependant upon the plant operating limits and conditions).

81 Transient periods, such as power changes, are important to the potential activity released from fuel defects. It has been shown from plant feedback that activity during such periods can increase significantly dependant upon several factors. EDF and AREVA do not attempt to calculate such periods in Ref. 22 due to the large uncertainties involved, particularly the detailed burn-up history of the failed rod. EDF and AREVA do indicate that the current specifications on EDF plants require a shutdown at activity levels close to the "*biological*" source term, limiting the potential for excessive increases during power changes. ONR consider it reasonable for a future UK EPR™ licensee to define such limits and conditions, as required by Assessment Finding **AF-UKEPR-RC-02**, identified at the end of Step 4.

82 The analysis shows that the calculated fission product and actinide activities compare favourably with the values used within the UK EPR™ source term. This is not surprising given that the fuel cladding materials are very similar and should perform better, meaning that similar levels of defects or contamination can be expected. Overall the quantity of fission products and actinides in UK EPR™ will be more a function of the fuel quality and type of failure observed, rather than the plant design or chemistry control (provided it is maintained within normal limits).

4.1.2.1.2.3 Corrosion Products

83 The calculation of detailed estimates of corrosion product inventories is not a simple matter as no single model exists which is able to accurately predict the resultant activities for a given reactor design. Those models that do exist are able to provide reasonable estimates, usually after the model has been benchmarked against previous operating cycles of that specific plant. The other alternative, often adopted, is to "benchmark" the design against current operating plants using judgements on the applicability and appropriate scaling of plant operating feedback.

84 The corrosion product source terms defined in the PCSR for UK EPR™ use this latter approach and are therefore based on a statistical analysis of EDF N4 plant measurements (see Ref. 17); the "*realistic*" and "*Biological Shield Design*" (DPB) values correspond to the mean and maximum values respectively. EDF and AREVA consider the N4 plants to be the most appropriate comparisons, being the closest progenitor of UK EPR™ in terms of design and materials. A comparison to these values compared to other data sources provided by my TSC as part of their review is given in Table 2 below;

Data Source	^{58}Co / MBq t^{-1}		^{60}Co / MBq t^{-1}	
	Normal Operational Values	**Shutdown Peak Values**	**Normal Operational Values**	**Shutdown Peak Values**
"*Realistic*" reference source term (Ref. 17) – Mean of N4 data	[redacted]	[redacted]	[redacted]	[redacted]
"*Biological Shield Design*" (DPB) reference source term (Ref. 17) – Maximum of N4 data	[redacted]	[redacted]	[redacted]	[redacted]
Median values for a range of plants (1) (Ref. 11)	[redacted]	[redacted]	[redacted]	[redacted]
Sizewell B Cycle 1 (Ref. 11)	[redacted]	[redacted]	[redacted]	[redacted]

Note: (1) Values are taken from a range of plants with different parameters (number of loops, steam generator tube material, power, operating chemistry etc.)

Table 2: Comparison of ^{58}Co and ^{60}Co corrosion product source terms

85 As can be seen from Table 2 above, the operational concentrations specified by EDF and AREVA appear conservative compared to plant data, while the shutdown peak values remain lower, but closer to the OEF. Such differences are to be expected given the large scatter in plant data observed, however it does suggest that the values used by EDF and AREVA, at least empirically, appear reasonable.

86 In Ref. 22 EDF and AREVA detail their "*semi-quantitative*" estimates for corrosion product activity in UK EPR™ which is based upon a simple methodology which uses estimations of the corrosion or wear rate, mass and activation in the primary circuit. The calculation steps are based upon:

- *Estimation of Material Corrosion Rates* - The main input data used by EDF and AREVA in their calculations are the material release rates. EDF and AREVA derive these from laboratory data on Inconel 690, stainless steels and Stellite™ tests under primary coolant conditions. These tests span a range of test conditions and were conducted by many different organisations over a number of years thus there is a significant scatter in the measured release rates. The analysis shows there is a trend towards decreased rates at increased exposure and the results tend to follow the expected parabolic kinetic law. Results are presented for the maximum, average and minimum rates, in addition to the "*fit value*" used by EDF and AREVA in their calculations. The "*fit value*" represents the release rate after 2000 hours of exposure based upon a mathematical fitting of the data to a parabolic curve. EDF and AREVA argue that the "*fit value*" is conservative due to the various deficiencies in the input data (e.g. duration of test, decrease in rates over time, improvements in material fabrication processes for UK EPR™ etc.), whereas the minimum values are most likely to be representative of UK EPR™ due to the material and chemistry improvements implemented. I did note that EDF and AREVA have not included some data in order to obtain a representative dataset (for example maximum and average rates are different between those calculated using the full data set and those used in the calculations), however given the other uncertainties inherent in this approach I do not consider this to be a significant assumption. I queried how these release rate values compare to the input data used for the BOA calculations in Ref. 21. EDF and AREVA stated that the BOA calculations would use values most similar to the average derived from this analysis. These are higher than the "*fit values*" derived by EDF and AREVA and hence are likely to result in conservative inputs to the BOA analysis.

- *Estimation of Mass Releases to the Coolant* – In order to calculate the total release rate for each individual element to the primary coolant of UK EPR™, EDF and AREVA multiply the material release rate, the surface area of each material in contact with the coolant and the (average) percentage element content of that material.
- *Estimation of Activation in the Coolant* - The next stage in the calculation is where greatest uncertainty lies as in order to calculate the concentration of activated corrosion products it is necessary to know what fraction of the released material is subjected to activation. This fraction is the product of many complex interactions dependant on the relative effects of the various deposition, solubilisation and transport phenomena. To overcome these uncertainties EDF and AREVA make a number of assumptions and simplifications in their treatment which should produce conservative estimations (e.g. the purification rate during normal operations is taken as negligible, residence time of material in the core is taken as equal to the entire cycle duration etc.). The activated products produced by each gram of parent element in the primary coolant are calculated by EDF and AREVA using their DARWIN code. EDF and AREVA also make similarly bounding assumptions when calculating the amount of clean-up expected during a shutdown, when the corrosion product solubility increases significantly (which has been estimated in Ref. 23 and compared with International data).

87 EDF and AREVA estimate the activities during both normal operations and shutdown periods using this approach:

- For the normal operational period activities, EDF and AREVA use the typical measured plant coolant soluble metal concentrations to estimate the activity that could result in UK EPR™. For each of the species considered the activity in the primary coolant, based upon either the suggested limits for UK EPR™ or OEF feedback, are calculated to be above the "*realistic*" source term, but below the "*biological*" (DPB) term. EDF and AREVA consider that the concentrations expected during normal operations would correspond more closely with the "*realistic*" source term:

Radionuclide	Basis of Estimate	Normal Operational Values / MBq t^{-1}		
		Estimated UK EPR™ Activity (Ref. 22)	“*Realistic*” Reference Source Term (Ref. 17)	“*Biological Shield Design*” (DPB) Reference Source Term (Ref. 17)
^{58}Co	Soluble Ni limit	[redacted]	[redacted]	[redacted]
^{60}Co	Measured soluble Co	[redacted]	[redacted]	[redacted]
^{59}Fe	Measured soluble Fe	[redacted]	[redacted]	[redacted]

Table 3: Comparison of the normal operational PCSR corrosion product source terms (Ref. 17) with those estimated by EDF and AREVA in Ref. 22

- Similarly EDF and AREVA estimate activities during a shutdown concentrating on the ^{58}Co and ^{60}Co oxygenation peak activities, due to their contribution to radiological doses, increases during oxygenation and use as a general measure of the level of contamination within the plant. There is more uncertainty in these estimations, due to the assumptions used. For this reason EDF and AREVA present a range of values which vary depending upon which material release rate is considered (the “*fit value*” or the minimum), if credit is given to various UK EPR™ chemistry and purification modifications (e.g. EDF and AREVA credit a 40 to 50% reduction in material release rate due to zinc addition) and whether the minimum or maximum assumed purification is credited. This range of values can be taken to cover both potential bounding and best estimates. Generally the results show that it is necessary to credit some combination of UK EPR™ chemistry/material modifications or to use the minimum corrosion rates in order to produce estimates which are consistent with the UK EPR™ PCSR source terms. These are compared to the reference source terms below. Note that values highlighted orange are below the “*biological*” (DPB) term, blue are below the “*realistic*” term:

Methodology			**^{58}Co Oxygenation Peak / MBq t^{-1}**	**^{60}Co Oxygenation Peak / MBq t^{-1}**
"*Realistic*" reference source term (Ref. 17)			[redacted]	[redacted]
"*Biological Shield Design*" (DPB) reference source term (Ref. 17)			[redacted]	[redacted]
Corrosion Rate	**UK EPR™ Modifications Considered**	**Purification Considered**	**^{58}Co Oxygenation Peak / MBq t^{-1}**	**^{60}Co Oxygenation Peak / MBq t^{-1}**
"*fit value*"	No	None	[redacted]	[redacted]
	Yes	None	[redacted]	[redacted]
	Yes	Minimum	[redacted]	[redacted]
	Yes	Maximum	[redacted]	[redacted]
Minimum	No	None	[redacted]	[redacted]
	Yes	None	[redacted]	[redacted]
	Yes	Minimum	[redacted]	[redacted]
	Yes	Maximum	[redacted]	[redacted]

Table 4: Comparison of the oxygenation peak PCSR corrosion product source terms with those estimated by EDF and AREVA in Ref. 22

- In addition to such corrosion products EDF and AREVA also consider both antimony and silver sources:
    1. The only potential source of antimony isotopes in the UK EPR™ primary circuit is due to failure of a secondary neutron source. EDF and AREVA consider such failure as very unlikely given the design improvements implemented for UK EPR™. Nonetheless they estimate the activity levels likely in the case of failure of a single rod exposed for 15 years. While this results in activities much larger than the source terms specified for UK EPR™ the calculation is very conservative (unrealistically so in my opinion) and any detectable increase in ^{125}Sb would instigate an investigation.
    2. Silver could come from either the SINCAD (SIlver-INdium-CADmium alloy) control rods or from silver coated seals used in the RPV or RCPs. EDF and AREVA discount gross failure of the control rods, with any small increase in ^{110m}Ag leading to an investigation of the source. It is possible that some small amounts of silver could be transferred to the coolant due to maintenance or other activities on the pumps. The behaviour of this material is uncertain, due to a lack of measurements of silver solubility under primary coolant conditions. Nonetheless assuming all of the potential silver release from a single pump is solubilised during a shutdown results in a source term below the "*realistic*" level (in fact all four pumps could be considered and still meet this value).

88 Overall, the estimated activities calculated by EDF and AREVA are comparable with the values used within the UK EPR™ source term, given the limitations of such calculations. They do indicate the importance of ensuring adequate chemistry control, material conditioning and shutdown procedures; aspects which I assessed in detail during GDA Step 4 and which are the subjects of Assessment Findings in many cases. Hence in the context of **GI-UKEPR-RC-02**, and the aim of Ref. 22 (semi-quantification of the source term), the response is adequate and demonstrates that the use of the PCSR corrosion product source terms for subsequent estimations is appropriate.

89 The alternative approach for estimating corrosion product source terms in PWRs described in Para. 83, namely computer code modelling, is discounted by EDF and AREVA in Ref. 22 on the basis that such codes need some tuning in order to provide realistic quantifiable results. In the context of **GI-UKEPR-RC-02**, I am content that the “semi-quantitative” estimates that have been provided are sufficient to fulfil the intent of the GDA Issue (i.e. they are sufficient to indicate if a particular aspect is better or worse and the potential importance of improvements). The estimates are adequate for this stage in the development of the safety case for UK EPR™.

90 However, I do believe that further work will be required by a future licensee in this important area, such that the licensee has a clear expectation of what the activity levels will be in UK EPR™ before the plant is operated. This also means that advantage can be taken of experience and feedback from other EPR™ plants around the world which come into operation before any UK EPR™. I would expect the UK EPR™ source term estimations to be further refined as the safety case is developed by the future licensee, moving the estimates from “semi-quantitative” towards “quantitative” (for example, changing the baseline data from operating PWR plants to operating EPR™ plants), and hence I consider this to be an Assessment Finding, **AF-UKEPR-RC-69**, as below.

> ***AF-UKEPR-RC-69*** *- The licensee shall continue to refine the estimated performance of UK EPR™, in terms of the production, transport and accumulation of radioactivity in the primary circuit and connected systems, during the site specific phase. This should include taking account of operating experience feedback from other EPR™ plants, the aim being to move towards quantitative estimates so far as is reasonably practicable. This Assessment Finding should be completed before nuclear operations, as this is when radioactivity is generated in the plant.*
>
> ***Required timescale:*** *Initial criticality.*

91 The benefit in further refining these estimates is in helping the licensee to justify related limits, conditions and criteria and to define operating practices to ensure that radioactivity is controlled and minimised at all times. For example, if UK EPR™ was estimated to be at the upper end of the bounding PCSR source terms this would require much tighter and stringent controls by the licensee to ensure radioactivity was ALARP, as opposed to estimates suggesting levels much lower than the bounding PCSR assumptions. The safety case should make use of relevant good practice related to the modelling and calculation of radioactivity generation, accumulation and transfer processes and I believe that the understanding of such processes has developed sufficiently in recent years to merit this. I note that EDF and AREVA have access and experience in using the OSCAR (PACTOLE) material transport code (Ref. 29) which is an example of the type of code which could be used for this purpose.

4.1.2.1.2.4 Fuel Crud

92 Control of fuel crud, in addition to its safety impacts during operations (for example Crud Induced Power Shifts (CIPS) and Crud Induced Localised Corrosion (CILC)), is an important parameter to control in relation to the transfer of radioactivity outside of the primary circuit. For example, two plants which have the same corrosion product levels would not necessarily generate the same quantities of fuel crud. As all fuel is eventually removed from the core, so all fuel crud adhered to that fuel is also removed and hence becomes a potential source for transfer to the auxiliary system, either as particulate or as re-dissolved species.

93 The methodology described previously (i.e. using corrosion rates) is one approach to estimating the amount of fuel crud likely to be produced in UK EPR™. This method is based on using the material release rate for nickel described above and the assumption that 80% of this is retained in the core as fuel crud. This method is only suitable to approximate the potential crud inventory as it takes no account of the different mechanisms involved or their inter-relationships. EDF and AREVA also describe two additional methods, which they have undertaken, for calculating this parameter in Ref. 22:

- Estimations relating the oxygenation peak values for ^{58}Co, using the UK EPR™ source terms.
- Detailed thermohydralic-neutronic-chemistry modelling using the BOA code (Ref. 21).

94 It is very difficult to compare results from each of these estimations directly as there are many different assumptions and simplifications used in each method and in fact, EDF and AREVA acknowledge this and do not attempt to do so in their own report (Ref. 22). However, as shown in the table below, there is a general agreement on the order of magnitude of fuel crud estimated by each of the EDF and AREVA methods. It could be argued that, even despite the lack of OEF to help with applying the BOA code to UK EPR™, this should still provide the most reliable data.

Methodology	**Input data**	**Estimated Ni release (kg)**	**Estimated Ni crud deposit (kg)**
Material release rates	"*fit value*" release rates, 80% Ni release assumed to be retained in fuel crud	[redacted]	[redacted]
	minimum release rates, 80% Ni release assumed to be retained in fuel crud	[redacted]	[redacted]
^{58}Co oxygenation peak release	"*realistic*" source term (Ref. 17)	-	[redacted]
	"*biological*" (DPB) source term (Ref. 17)	-	[redacted]
BOA calculations (Refs 21 and 22)	1st cycle	[redacted]	-
	4th (equilibrium) cycle	[redacted]	[redacted]

Table 5: Comparison of the fuel crud source terms estimated by EDF and AREVA

95 It is notable that the deposited nickel mass derived using the ^{58}Co oxygenation peak releases (i.e using the PCSR reference source terms) appear low when compared with the results from the other methods. As explained in Ref. 22, this discrepancy is a result of:

- The fact that the ^{58}Co oxygenation peak release does not represent the entire fuel crud inventory, with some fraction remaining on the fuel following shutdown. It is not currently possible to estimate the fraction remaining on the fuel, due to the multiplicity of parameters involved and the plant to plant variations observed..
- This method takes no account of material already present on the fuel from previous cycles. As exemplified by the BOA results above, this carry-over can be significant.

96 This means that this method underestimates the deposited nickel mass. While this is an anomaly with trying to compare the results in this manner it does not suggest that the reference source terms are similarly underestimated. On the contrary, if the same method is applied to the ^{58}Co oxygenation peak releases derived from the material release rate calculations, this gives "*fit value*" and minimum nickel crud deposits of [redacted] and [redacted] kg respectively (compared to [redacted] and [redacted] in Table 5 above). Comparisons on this latter basis show that the nickel crud deposits calculated using the ^{58}Co oxygenation peak release are in fact less than the "*biological*" (DPB) reference source term (i.e. up to [redacted] kg compared to [redacted] kg)

97 As part of my Step 4 assessment, I also procured an independent review of likely core crud levels in UK EPR™. This review, using input data supplied by EDF and AREVA for UK EPR™ but with a simplified model, estimated that the total core crud mass (Ni + NiO + $NiFe_2O_4$ + Fe_3O_4) would be 20.3 kg for UK EPR™ for cycle 1, larger than for a "standard" 4-loop non-boiling PWR using the same method (12.4 kg), see Ref. 2. These values are within the range suggested by the EDF and AREVA methods above.

98 Importantly, EDF and AREVA also note that the BOA analysis for UK EPR™ indicates that the predicted crud thicknesses are such that CIPS or CILC are unlikely. This is mainly due to the fact that the fuel management spreads the formed fuel crud throughout the core, despite the increase in fuel duty and corrosion source term derived from the large UK EPR™ steam generators. This is supported by their analysis for cycle 1, but it does emphasise the importance of ensuring adequate clean-up and procedures during shutdowns to ensure only the minimum amount of fuel crud is carried forward to subsequent cycles.

99 Overall, the EDF and AREVA fuel crud calculations do contribute to the valuable understanding on the likely scale of fuel crud in UK EPR™ and some of the more relevant parameters to target to achieve control. They do indicate that it would be possible for UK EPR™ to generate relatively large amounts of fuel crud, although conversely this is not predicted to be sufficient for CIPS or CILC due to the large areas affected, as I concluded at the end of Step 4. This resulted in Assessment Finding **AF-UKEPR-RC-13**, which requires a future UK EPR™ licensee to conduct sensitivity analysis for fuel crud formation in UK EPR™ to demonstrate that levels of crud can be controlled and reduced SFAIRP. I remain content that this Assessment Finding is the appropriate way to progress this area of the safety case.

4.1.2.1.2.5 Primary Circuit Quantification - Summary

100 Based on my assessment of the quantification of the primary circuit radionuclides in UK EPR™, I conclude that:

- EDF and AREVA have identified the key radionuclides to be considered in order to ensure that the primary coolant radioactivity risks are reduced. Without significant fuel failures the main contributors are expected to be ^{60}Co and ^{58}Co, mainly produced from activation of cobalt and nickel respectively.
- I considered the impact of operating chemistry and material selections on the primary circuit of UK EPR™ extensively during my Step 4 assessment, which is reported elsewhere (Ref. 2). The general conclusion was that I was content that EDF and AREVA had made an adequate ALARP argument for UK EPR™ for this stage of the new build project where detailed operating procedures have yet to be finalised, notwithstanding the specific comments highlighted in that report and the related Assessment Findings that resulted. The information presented in response to GI-UKEPR-RC02 does not change this conclusion.
- The additional calculations of the radioactivity likely to be present within the primary circuit support the use of the UK EPR™ source term, as given in the PCSR. This suggests such a methodology is appropriate for producing source terms for use in safety assessments.
- For the corrosion products estimates, the results presented suggest that UK EPR™ will be similar to the average of the French N4 plants, but this is a subjective statement and I remain content that it should be possible to operate the plant at lower levels than this if adequate controls over all operations are maintained by the licensee. It is for this reason that I have identified an Assessment Finding, **AF-UKEPR-RC-69**, for a future licensee to continue to refine the bounding estimates provided to help define limits, conditions, criteria and operating procedures. This Assessment Finding is complementary to **AF-UKEPR-RC-13**, raised during Step 4, but deals with aspects other than fuel crud formation.
- The fuel crud estimations carried out by several methodologies do show that:
    1. The overall amount of fuel crud expected is reasonably consistent between the results obtained from the neutron/thermodynamic calculations, the estimation from the ^{58}Co activity released during shutdowns and the evaluation of corrosion rates when the limitations of each method are considered. These estimates suggest that UK EPR™ may produce upwards of 15 kg of fuel crud in a typical cycle.
    2. While it is likely that UK EPR™ will produce more fuel crud than the comparable N4 plants, this increased level of crud is mitigated to some extent by the expected fuel management and chemistry conditioning applied. These calculations suggest that the high surface area with boiling in the UK EPR™ core helps to distribute the crud and mitigate the potential consequences which can result from the formation of thicker crud. The crud thicknesses predicted are below the levels where CILC damage or boron accumulation resulting in CIPS is likely. The results demonstrate the importance of ensuring an efficient clean-up between cycles and further reinforce the importance of **AF-UKEPR-RC-13** and **AF-UKEPR-RC-69**.

4.1.2.1.3 Primary Circuit – Characterisation of Relevant Nuclides

101 As well as identifying the relevant nuclides for UK EPR™, EDF and AREVA also attempt to characterise them. These properties are relevant when the transfer of materials from the primary to auxiliary systems is considered.

4.1.2.1.3.1 Activation Products

102 As described previously, the EDF and AREVA response concentrates on the fission and corrosion products and hence does not provide information on the characterisation of the other activation products. I consider this reasonable given their relative safety importance.

4.1.2.1.3.2 Fission Products and Actinides

103 The most important fission products are the isotopes of iodine as these are potentially volatile and can have significant radiological consequences. EDF and AREVA summarise OEF from measurement campaigns during both normal power operations and shutdowns. This data shows that iodine is mainly (>90%) present in in-volatile forms during normal operations, but that some volatile forms can be created during oxidising conditions at shutdowns.

104 The behaviour of actinide contamination is more uncertain, with apparent discrepancies often reported in plant OEF. EDF and AREVA consider these differences to mainly be a function of the deposition mechanisms and kinetic limitations on the actinides (for example, adsorption of uranium onto iron oxides and the long-term persistence of uranium contamination following fuel failures). The important conclusion drawn by EDF and AREVA is that, irrespective of their speciation, the solubility of actinides is low under primary coolant conditions and as such they tend to have a long residence time within the primary circuit, if present. Regardless of these uncertainties EDF and AREVA acknowledge the importance of keeping actinide contamination in the primary circuit to effectively zero.

4.1.2.1.3.3 Corrosion Products and Fuel Crud

105 The characterisation of corrosion products is an on-going area of research for PWRs, with the aim of further understanding being to lead to improvements in operating practices. EDF and AREVA are active in this area and provide details of their latest experience, modelling work and understanding in Ref. 22 which is itself a summary of the more detailed Ref. 23. This report (Ref. 23) uses the CEA (Commissariat à l'énergie atomique et aux énergies alternatives)/EDF/AREVA database and considers:

- Determination of the solid phases on the steam generator surfaces and fuel cladding (i.e. ex-core and in-core) for each of the main corrosion product elements (Ni, Fe, Cr and Co), within the proposed boundaries of the UK EPR™ operating chemistry.
- Calculations of the solubility of each element from the phases determined above, under primary circuit conditions.
- Comparisons of the calculated data with Nuclear Power Plant (NPP) feedback.

106 This analysis is comprehensive and is not repeated in detail here. The main relevant conclusions in terms of the species predicted to be present by EDF and AREVA are:

- Nickel is mainly present as Ni/NiO on the out of core surfaces, with relatively little $NiCr_2O_4$. For in-core surfaces the nickel is mainly present as a mixture of $NiFe_2O_4$ and Ni/NiO. The transition between Ni and NiO depends on both the temperature and hydrogen concentration. EDF and AREVA predict this to occur at around 300 °C for 17 cc kg^{-1} hydrogen as specified for UK EPR™.

- Iron is present almost exclusively as $FeCr_2O_4$ on out of core surfaces independent of the temperature and hydrogen concentration, but as a mixture of $NiFe_2O_4$ and Fe_3O_4 on in-core surfaces with the proportion of Fe_3O_4 increasing with increased hydrogen levels and reduced temperature.
- Out of core chromium is present as a mixture of iron and nickel chromites ($FeCr_2O_4$ and $NiCr_2O_4$), with the nickel chromite decomposing to NiO and Cr_2O_3 at low temperatures and low hydrogen levels. In core the chromium is present as mainly iron chromite, with small amounts of cobalt and nickel chromite, the proportions of which are relatively insensitive to temperature and hydrogen levels.
- Cobalt is present as almost pure cobalt chromite ($CoCr_2O_4$) in out of core deposits, but a mixture of cobalt ferrite ($CoFe_2O_4$) and cobalt chromite in core. Cobalt chromite is more stable at increased temperatures and low hydrogen levels.

107 With the speciation predicted EDF and AREVA use the CEA/EDF/AREVA database to estimate the solubility of each element from those species. Calculations were performed for various temperature, pH and redox conditions. The results are again complex, consisting of a series of graphs which show the variations in solubility as the various parameters are changed. Using this data EDF and AREVA estimate the solubility of each element under both hot reducing full power and cold oxidising shutdown conditions and the transient in-between. The overall conclusions are that:

- Under the hot alkaline-reducing conditions of full power the stable thermodynamic phases predicted have very low solubilities, indicating that most of the corrosion products are expected to be deposited on the primary circuit surfaces during operations.
- The various phases are all affected by the change in environment during a shutdown, with all but one phase increasing its solubility. The range of increase varies, but is much larger for nickel particularly from NiO. The increase is much more modest for the other elements, if at all. EDF and AREVA suggest that this accounts for the relative stability of chromium rich phases during a shutdown.

108 The main limitations on such results are that the calculated solubilities are based upon that particular element from that particular phase considered in isolation (i.e. the actual solubility of nickel will depend on the interaction between all phases that release nickel, not just NiO). This is important when a phase may release more than one element. The calculations also do not consider kinetic effects, which may limit the rate of solubilisation. EDF and AREVA do provide some feedback on kinetic effects derived from laboratory and plant feedback, the main conclusions of which are that there is still a large degree of uncertainty in the results. Thus these calculations are only reliable as order of magnitude values and indicators for trends rather than specific numeric values.

109 The report also summarises plant OEF regarding corrosion product characterisation, including the observed soluble/insoluble activity ratio and the effects of pH, hydrogen and zinc on corrosion products. Based on this OEF and calculations EDF and AREVA draw a number of conclusions, some of which I do not consider to be fully supported by the information as presented in the report, namely;

- A constant pH_{300} 7.2 limits the transfer of corrosion products from ex-core surfaces to the fuel. This appears to be based purely on solubility arguments; however it remains uncertain whether the dominant form of corrosion product transfer to the core of any PWR is from particulate or soluble species. The effects of pH on particulate material (e,g, dissolution, precipitation, transfer etc.) are also unclear. However, as described more fully in my Step 4 assessment (Ref. 2), I am content that pH_{300} 7.2 represents a reasonable compromise between the various safety concerns for the primary coolant chemistry and should provide good control over corrosion and corrosion product transport whilst limiting harmful effects due to high lithium in terms of fuel cladding integrity or tritium production.

- A hydrogen concentration at the lower end of the normal PWR operating range results in lower fuel crud deposition, which was assessed further as part of Step 4 (Ref. 2), resulting in Assessment Finding **AF-UKEPR-RC-15**.

110 I am content that these points do not undermine the response in the context of **GI-UKEPR-RC-02** and that the Assessment Findings remain the most appropriate means to progress these areas as the safety case for UK EPR™ is developed by the future licensee. The calculations requested in **AF-UKEPR-RC-69** would help provide further evidence to support these claims.

4.1.2.1.3.4 Primary Circuit Characterisation - Summary

111 EDF and AREVA provide information on their latest theoretical work on characterisation of the radioactivity with the primary coolant of PWRs. Such work is for the most part theoretical but is helping to develop understanding of the main physico-chemical process which control radionuclide transport in a PWR.

112 It is not clear what impact these studies have on the UK EPR™ source term. EDF and AREVA do not attempt to link these to the source terms directly, rather to the primary chemistry parameters which in turn could impact on the source terms (e.g. pH, hydrogen or zinc levels). Conversely this analysis does not suggest that any changes to the UK EPR™ activity control philosophy are needed.

4.1.2.1.4 Minimisation of the Source terms in the Primary Circuit - Summary

113 EDF and AREVA have provided information on the identification, quantification and characterisation of the main radionuclides expected within the primary circuit of UK EPR™. This suggests ^{58}Co and ^{60}Co will be the most important nuclides to control.

114 A coordinated and consistent estimate for the concentrations of the various radionuclides in the primary coolant of a PWR is a difficult task because the number of variables is large, their impact and interrelationships are often poorly understood and there are large associated uncertainties. To address these difficulties EDF and AREVA have estimated the activities in UK EPR™ using simplified assumptions based upon the corrosion and subsequent activation of the circuit materials, often mitigated by an assumed extent by “UK EPR™ improvements” (such as zinc addition).

115 My assessment of these estimates has shown that:

- The calculations do suggest that the source terms used within the PCSR are reasonable, provided the expected UK EPR™ improvements are realised. In this sense the main result of Ref. 22 is to confirm that the PCSR source terms can be used for the subsequent parts of the EDF and AREVA response to **GI-UKEPR-RC-02**.
- Because of the simple approach adopted, EDF and AREVA’s estimates are only “*semi-quantitative*” in directly demonstrating that radioactivity has been minimised. They do show, in simple terms, that the chemistry and material modifications made to UK EPR™ have a large impact on the expected source terms. This confirms the main related conclusion from my Step 4 assessment that EDF and AREVA had

made an adequate ALARP argument for UK EPR™ for this stage in the development of the safety case.

- The analysis does suggests that levels of radioactivity in UK EPR™ may be similar to the latest French N4 plants and that stringent controls will be needed at all stages of manufacturing, commissioning and operation to ensure that an ALARP position is maintained.

116 EDF and AREVA provide information on their latest theoretical characterisation of activity in the primary circuit. This confirms that changes to the UK EPR™ activity management philosophy are unnecessary.

117 On this basis, I am content that sufficient information has been provided in the context of **GI-UKEPR-RC-02**. It has highlighted an area where further development of the safety case will be needed related to further refinements to the quantification of the expected UK EPR™ radiation levels. I have raised this as an Assessment Finding for a future licensee, **AF-UKEPR-RC-69**.

4.1.2.2 Minimisation of the Source terms in the Primary Auxiliary Systems

118 As with the primary circuit, EDF and AREVA base their arguments for the minimisation of radioactivity within the UK EPR™ auxiliary systems on a combination of design choices (e.g. material selection) and estimations.

119 The second main deliverable provided by EDF and AREVA in response to **GI-UKEPR-RC-02**, "*Activity Management at UK EPR™ Auxiliary Systems: System Performance and Control Actions*" (Ref. 24), provides the arguments and evidence cited by EDF and AREVA to support the claim that activity in the UK EPR™ nuclear island auxiliary systems is minimised SFAIRP and is controllable. In many aspects the overall response goes beyond the scope of the GDA Issue, including many aspects which are not related to Reactor Chemistry or the present GDA Issue (for example, the use of concrete as shielding or equipment classification). Many of the ALARP justifications provided by EDF and AREVA are not related to activity control and minimisation, for example a two train Extra Borating System (EBS) system. While such a comprehensive report may be considered useful, it does come at the detriment of making the specific activity control and minimisation aspects more opaque. For this reason, Ref. 25 is a useful "*roadmap*" to identifying the key arguments and evidence presented in Ref. 24 specifically in relation to this GDA Issue.

120 In Ref. 24 EDF and AREVA consider those systems within the Nuclear Auxiliary Building (NAB), the reactor building and the safeguard auxiliary systems which have a direct or indirect role in the management of activity within liquid or gaseous streams or are involved in the transfer of radioactive liquids between systems. EDF and AREVA exclude solid waste streams, secondary circuit activity management systems and decommissioning activities from their response. I consider these demarcations to be appropriate in the context of this GDA Issue. On this basis EDF and AREVA consider the following UK EPR™ systems in their response:

- CVCS (Chemical and Volume Control System)
- CSTS (Condensate Storage and Treatments System)
- RBWMS (Reactor Borated Water Make-up System)
- SIS / RHRS (Safety Injection System / Residual Heat Removal System)
- IRWST (In-containment Reactor Water Storage Tank)

- FPPS / FPCS (Fuel Pool Purification System / Fuel Pool Cooling System)
- NVDS (Nuclear Vents and Drains System)
- CCWS (Component Cooling Water System)
- EBS (Extra Borating System)
- NSS (Nuclear Sampling System)
- HVAC (Heating, Ventilation and Air Conditioning) systems
- GWPS (Gaseous Waste Processing System)

121 Not all of these systems work at all times, or interact with the RCS in the same way. The interactions between the most important of the various systems and the primary circuit of UK EPR™ is shown schematically in Figure 3 below, for normal operations:

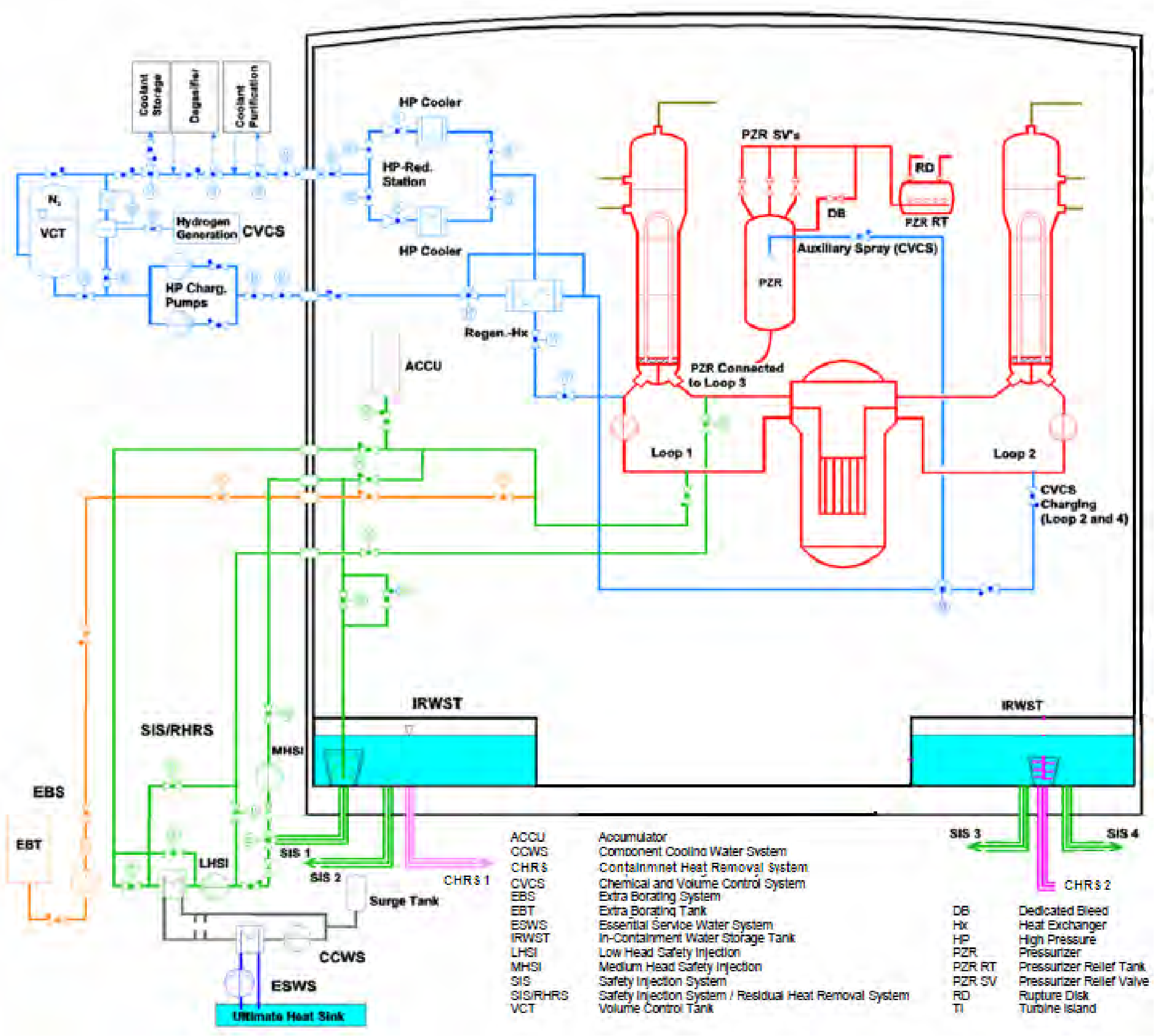

Figure 3: Main auxiliary liquid systems connected to the RCS in EPR™ (Ref. 30)

122 Due to the large number of systems considered, in my assessment that follows I refer to the CVCS as an exemplar for the other systems considered by EDF and AREVA, although I have assessed the whole of the response. The CVCS is a particularly useful example as it operates for the vast majority of the operating cycle, connects directly to the primary circuit and is a very important system for managing levels of liquid radioactivity in UK EPR™. This approach reduces the amount of repetition in the following sections. I discuss only specific notable points for those systems other than the CVCS, as appropriate.

4.1.2.2.1 Auxiliary Systems – Identification of Requirements and Roles in Activity Management

123 The first part of Ref. 24 is used by EDF and AREVA to identify those principles, standards or requirements which relate to activity management and to attempt to show that the design of UK EPR™ is in compliance with them. This considers the ONR SAPs (Ref. 5), relevant ONR technical assessment guides, IAEA standards and EDF safety standards as well as the safety functions ascribed to the various systems in their System Design Manuals (SDM). Unfortunately this section is somewhat confusing in places, as EDF and AREVA seem to attempt to try and link activity management into as many principles, standards and requirements as possible, sometimes only tenuously. Notwithstanding the above, EDF and AREVA do ultimately arrive at what I consider to be the main aspects that should be considered further in this context. On the basis of this review, EDF and AREVA consider the source term estimation and reduction, purification and deposition in more detail later in Ref. 24. I assess these aspects of their response further below.

124 In the next part of Ref. 24, EDF and AREVA also provide a description of the tasks fulfilled by the auxiliary systems in UK EPR™ that are related to the control and minimisation of radioactivity. They recognise that all the systems contribute to maintaining the containment of radioactive material but distinguish between those systems which directly contribute to activity management and those which provide a support function, as follows:

Direct contribution to controlling radioactivity:

- Via coolant purification - CVCS, CSTS and FPPS / FPCS
- Via gas/atmosphere purification - GWPS, HVAC
- Via monitoring of the operating chemistry - NSS
- Via activity transfer from the NAB systems to the waste treatment systems - NVDS

Indirect contribution to controlling radioactivity:

- Via boron control - RBWMS, EBS, IRWST, FPPS / FPCS and CSTS
- Via cooling of auxiliary systems - CCWS
- Via cooling of the primary circuit during shutdowns - SIS / RHRS

125 Of these, the only systems which I did not explicitly consider during Step 4 were the NVDS and HVAC systems, as neither has any main reactor chemistry related functions. The NVDS effluents are treated by the CSTS or Liquid Waste Processing System (LWPS), both of which were assessed during my Step 4 assessment, while the HVAC system was considered as part of the mechanical engineering assessment during Step 4 (Ref. 31). I consider that the descriptions given in Ref. 24 for these two systems are appropriate.

126 This part of the EDF and AREVA response provides a useful summary of the main tasks and design provisions within the auxiliary systems. I have considered the chemistry related functions provided by these auxiliary systems previously, as part of my step 4 assessment (Ref. 2). Further details can also be found in the relevant SDMs for the various systems (again refer to Ref. 2 for detailed references). As these are reported elsewhere, they are not repeated here and I did not identify any concerns in these areas, other than those related to the relevant Assessment Findings from Ref. 2.

4.1.2.2.2 Auxiliary Systems – Identification of Relevant Nuclides

127 In Ref. 24 EDF and AREVA identify which nuclides they consider within the primary auxiliary systems of UK EPR™ on the basis of two factors:

- *Origin of the nuclide* – As the auxiliary systems do not contain fuel or an irradiation source they are not themselves a source of fission products, actinides or activation products. The exception to this being the fuel route systems which could be a source due to the transfer and storage of damaged fuel elements in the spent fuel pool. On the contrary, the auxiliary system could potentially be considered as an additional source of metallic impurities produced by corrosion within those systems. These products are susceptible to be transferred into the primary circuit and consequently irradiated and activated.
- *Safety significance of the nuclide* – As described previously, and as identified from NPP OEF, ^{60}Co, ^{58}Co, ^{54}Mn, ^{59}Fe and ^{51}Cr are identified as the main isotopes likely to be present as deposits on all the components and pipes of the primary coolant circuit and the circuits that are connected to it. Of these ^{60}Co and ^{58}Co are the main contributors to doses during maintenance and repair of auxiliary circuits. In addition, EDF and AREVA identify ^{63}Ni because, in spite of its minor importance for dose rate considerations during operation, it can become of greater importance during decommissioning operations due to its long half life.

128 Based on the above factors, EDF and AREVA consider two sources for the nuclides:

- Transfer of contaminated coolant from the primary circuit to the auxiliary system.
- The "*source term*" generated by the corrosion of the auxiliary system surfaces considering Co, Ni, Cr, Fe and Mn as the sources for ^{60}Co, ^{58}Co, ^{54}Mn, ^{59}Fe, ^{51}Cr and ^{63}Ni.

4.1.2.2.3 Auxiliary Systems – Quantification of Relevant Nuclides

129 A significant part of Ref. 24 deals with the evaluation of the source terms in the various identified auxiliary systems. This approach relies heavily on a number of other responses sent as part of GDA Step 4, in particular those provided in response to **RO-UKEPR-73** (Ref. 18), namely Refs 26, 27 and 28, and the UK EPR™ primary coolant source term (Ref. 17).

130 For these calculations EDF and AREVA use the primary coolant source terms from the PCSR (Ref. 17). As detailed in Section 4.1.2.1.2., EDF and AREVA have demonstrated that these are suitably conservative for use in such estimations as they are based on pessimistic assumptions for the steady-state and transient primary coolant activity concentrations.

131 EDF and AREVA use the activity transfer mechanisms (i.e. primary circuit to auxiliary system), as set out in Refs 26, 27 and 28, which estimate the activity found within the

different auxiliary systems for the Flamanville 3 (FA3) EPR™ assuming that all the activity in the auxiliary system comes from the primary circuit and that the removal, accumulation or transfer of activity within that system is a function of the operations within that system (e.g. use of the evaporator in the CSTS).

132 For all of the systems which contain liquid activity EDF and AREVA follow the same basic approach for the source term evaluations in this response, which consists of:

- Determining the activity pathway, from the primary circuit to the auxiliary system. EDF and AREVA consider both the general primary circuit pathway, during normal operations, shutdown and start-up and also the specifics for each individual system taking account of the components within the particular pathway (for example, filters or ion exchange beds).
- Estimating the "*source term*" which originates within the auxiliary system due to corrosion of its surfaces. This is not a true source term as this represents only inactive corrosion products, but does allow comparisons to be made on the basis of metal releases for cobalt, chromium, nickel, manganese and iron. To calculate these values EDF and AREVA use a similar approach to that described for the primary circuit in Section 4.1.2.1.2. above, namely:
    1. Assume the corrosion rates described in Ref. 22 (i.e. the "*fit value*" and minimum).
    2. Modify these to account for the operating temperature.
    3. Multiply this rate by the surface area and composition of the specific materials within the system to determine the release rates for the particular metals.
- Comparison of the above two estimations in terms of:
    1. Mass transfer from the primary circuit compared to that produced from corrosion of the auxiliary system surfaces.
    2. Mass transfer from the auxiliary system corrosion compared to that within the primary coolant.
    3. Impact on purification capacities assuming additional mass transfer of corrosion products from the auxiliary system to the primary circuit.

133 There are several assumptions explicit in this approach. For example, EDF and AREVA assume a single corrosion rate irrespective of the particular type of steel used within the auxiliary systems. EDF and AREVA identify the steels in UK EPR™ in Ref. 24, which are exclusively from the 300 (austenitic) series stainless steels. The corrosion rate assumed is based on the review conducted as part of Ref. 22, which relates to various steels, under various (nominally primary coolant) conditions, for various durations. The surface finish and velocity of these tests is also unclear. This review produces corrosion rates of [redacted] and [redacted] mdm (mg dm^{-2} $month^{-1}$) for the "*fit value*" and minimum respectively. Values of around 1 mdm are typical for use in assessments of corrosion sources in PWR primary circuits (Ref. 32). Much comparable data comes from tests to study the effects of zinc addition, which give corrosion rates of around 3 mdm (see for example Refs. 33, 34 and 35). On this basis the use of the minimum value can be considered optimistic. Conversely, EDF and AREVA assume that all of the material released from the auxiliary system corrosion becomes activated, which is clearly very pessimistic.

134 Due to these assumptions, I do not believe that the results from this study should be interpreted in too much detail. They are useful in showing trends and supporting "generic"

conclusions (i.e. is something significant or negligible) but the actual values are only accurate within an order of magnitude, or potentially several.

4.1.2.2.3.1 Application to the CVCS

135 The operation of the RCS and main auxiliary systems in UK EPR™ is described in the Step 4 Assessment report (Ref. 2) and the PCSR (Ref. 16), so is not repeated here. Figure 4 below shows schematically the main activity pathways from the RCS during normal operations, mainly involving the CVCS and CSTS auxiliary systems.

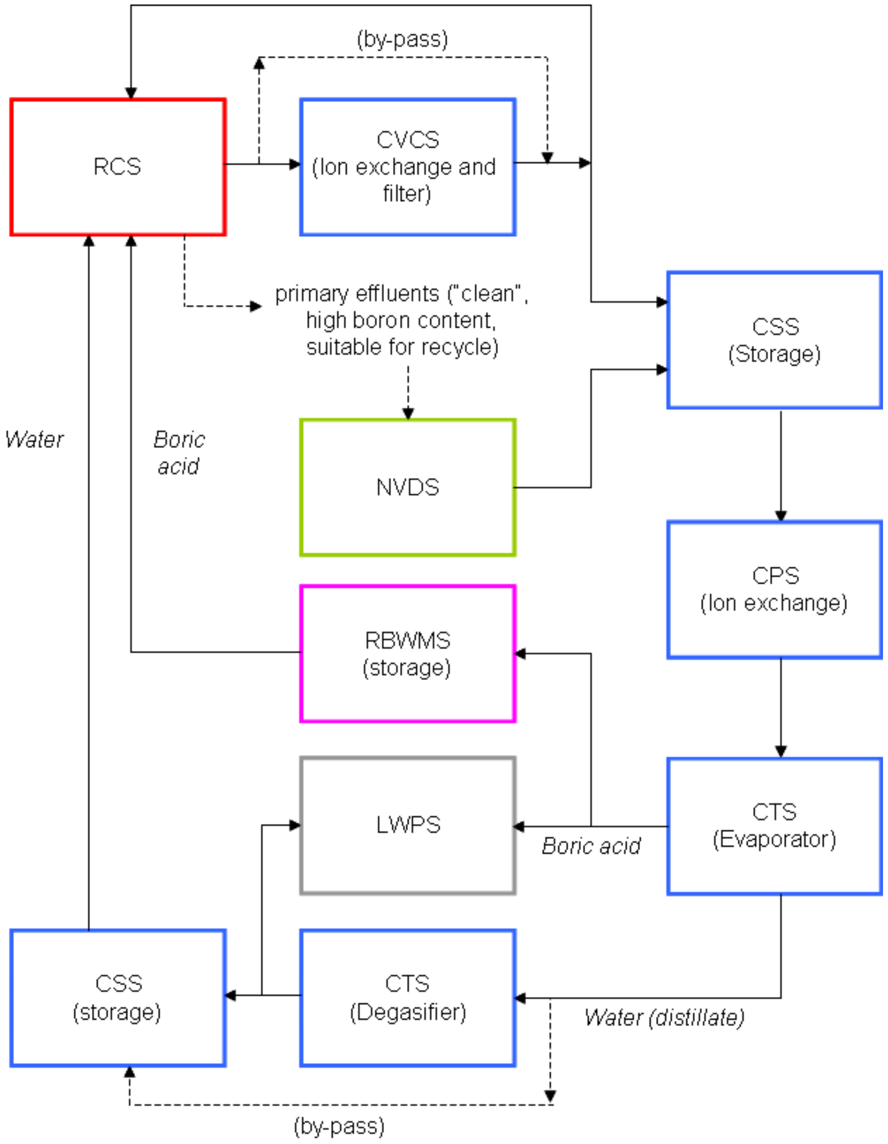

Figure 4: Activity pathway in the main auxiliary systems during normal operations

136 Ref. 27 sets out the activity pathway considered for the CVCS. EDF and AREVA consider both normal operations and shutdown and start-up, the difference being the doubling of

the flowrate and additional purification (by the Coolant Degasification System (CDS) degasifier) outside of normal operations. This arrangement is shown in Figure 5 below.

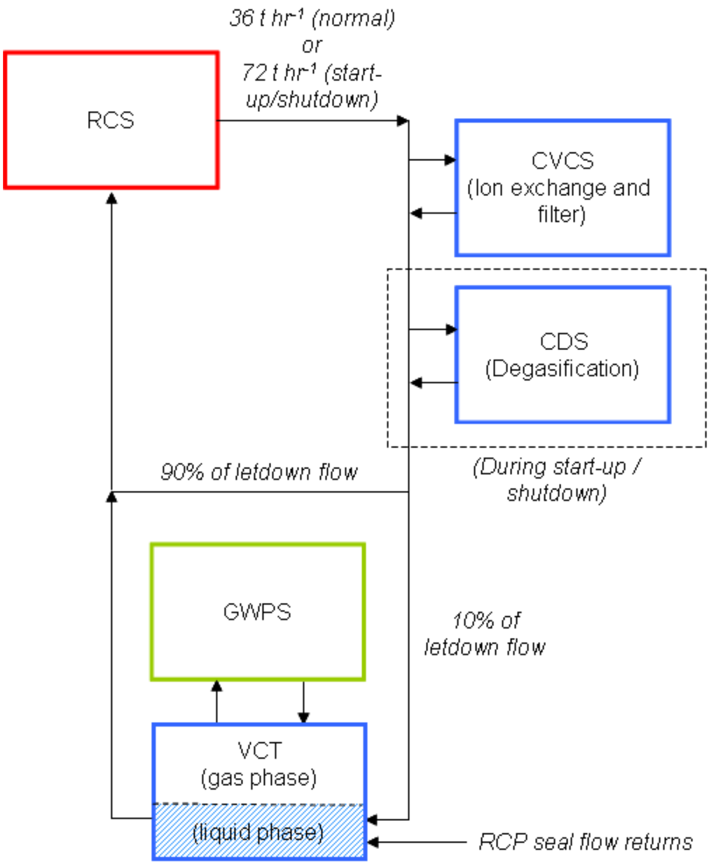

Figure 5: Activity pathway in the CVCS during normal operations

137 Under normal conditions, the reactor coolant purification part of the CVCS is permanently in operation. The purification loop of the CVCS is located within the Nuclear Auxiliary Building. More details on the purification loop can be found in the Step 4 Reactor Chemistry report (Ref. 2). Downstream of the CVCS purification system, the letdown flow can also be routed to the degasification system if necessary (prior to or during the outage).

138 EDF and AREVA assume that the activity upstream of the CVCS purification is equal to that within the RCS coolant. Downstream of the CVCS purification the coolant activity is abated by the Decontamination Factor (DF) for the ion exchange system. Similarly the CDS has an associated DF for volatile radionuclides. The DFs applied vary between 1.2 and 100, depending upon the species concerned, with corrosion products using a DF of 10. EDF and AREVA use their most pessimistic estimates for DFs, which would be monitored as part of normal operational practices. The small proportion of the letdown flow that enters the Volume Control Tank (VCT) is mixed with the return flow from the reactor coolant pump seal flow returns (at primary coolant activity levels), whereas the gas phase in the VCT is assumed to be equal to that found within the GWPS due to the constant gas purge applied.

139 EDF and AREVA compare the activity derived from the above to that within the CVCS in terms of:

- *Mass transfer from the primary circuit compared to that produced from corrosion of the auxiliary system surfaces* – for all the comparisons made for the CVCS the mass transfer rates of metals (cobalt, chromium, nickel, manganese and iron) transferred to the auxiliary system coolant from corrosion compared to that from activity transfer from the RCS are negligible. Typically the primary coolant is adding around five orders of magnitude more metal to the coolant than is released from "internal" corrosion of the auxiliary CVCS system.
- *Mass transfer from the auxiliary system corrosion compared to that within the primary coolant* – unsurprisingly, given the above differences, it is shown that the CVCS corrosion process leads to a negligible potential increase in fuel crud mass (< 0.12 to 0.06%). To do this EDF and AREVA assume that the mass of corrosion in the CVCS over a full 18 month cycle is added to that produced in the RCS over the same period. EDF and AREVA do not calculate the largest or smallest difference in their approach (i.e. largest is obtained by comparing the "*fit value*" CVCS corrosion with the minimum RCS corrosion; smallest compares the minimum CVCS corrosion with the "*fit value*" RCS corrosion). My own calculation of these differences gives a potential total metal increase of between 0.02% and 0.56%. These larger values are still not significant. However, the rates of release are different for each individual metal considered and a similar calculation for cobalt shows increases between 0.15 and 2.6%, which might have a noticeable, but not significant, impact on ^{60}Co levels if this upper maximum was actually achieved, although I consider this unlikely.
- *Impact on purification capacities assuming additional mass transfer of corrosion products from the auxiliary system to the primary circuit* – the final comparison is to assume that the entire mass of auxiliary system corrosion for the full cycle is accumulated and released into the primary circuit during the shutdown, adding to the purification requirements. Again, given the first comparison made it is not surprising that this shows that the impact is negligible, with the CVCS contributing less than 0.01% to the total purification demands.

140 Overall, these calculations confirm that the CVCS does not contribute significantly to the primary circuit activity within UK EPR™. However, this calculation does not consider material losses caused by wear. In the case of the CVCS this has been shown to be important, particularly for any hard-facing materials. For instance, Sizewell B removed some Stellite^{TM} hard-facings from their CVCS to reduce ^{60}Co. This, along with the careful commissioning and operations, is cited as one of the reasons for the low dose rates observed. Even though no estimate of wear is given, the areas of Stellite^{TM} are the same as those which I assessed during Step 4. My assessment of the CVCS material choices during Step 4 (Ref. 2, Section 4.2.3.2.5) confirmed that:

- There are no cobalt-based alloys in contact with primary coolant in the CVCS. There are two small valves which do contain cobalt-bearing Stellite^{TM}, not in contact with coolant. Their entire surface area is less that 0.003 m^2.
- Hard-facing valve components will be made from NOREM^{TM}, an alloy of iron, chromium and nickel containing less than 0.2 % cobalt, or from grade 4/5 hardfacing nickel alloy containing up to 1.5 % cobalt. NOREM^{TM} valves have a surface area of around 0.5 m^2, with the nickel hard facing at less than 0.1 m^2.
- Hard-facing pump components will be made of Colmonoy^{TM} 62, an alloy of nickel and chromium, containing less than 0.2 % cobalt. Their entire surface area is around 0.3 m^2.

141 Thus, while wear will still impact the results, the replacement of Stellite™ components will limit the increases in ^{60}Co this could have caused, although this will potentially increase other, less dose intensive isotopes such as ^{59}Fe.

4.1.2.2.3.2 Application to the other Auxiliary Systems

142 EDF and AREVA perform the same estimates for the other UK EPR™ auxiliary systems with the exceptions of the EBS and IRWST. Ref. 27 states that the EBS system is considered as non-contaminated during normal power operation and shutdown of the reactor, the EBS is isolated from the RCS and has no normal operational use. The IRWST is not considered because, similar to the EBS, it is isolated in normal operations and cleaned-up before storage following use during an outage. It is reasonable not to consider these systems due to their operational uses; I am content that inadvertent contamination of these systems could be dealt with by the currently available systems (e.g. the IRWST can be routed through the CVCS demineralisers for clean-up).

143 The results of these calculations are summarised in Table 6 below, which shows what percentage of the source term in each auxiliary system is derived from surface corrosion as opposed to transfer from the primary circuit. In all cases the latter effect dominates. The largest impact of corrosion is from the FPPS but this is still less than 1%.

Auxiliary System	**Percentage of Source Term derived from Surface Corrosion of the Auxiliary System Surfaces (highest estimate) compared to Activity Transferred from the RCS (lowest estimate) / %**	
	Ni	**Co**
CVCS	[redacted]	[redacted]
CSTS	[redacted]	[redacted]
RBWMS	[redacted]	[redacted]
SIS / RHRS	[redacted]	[redacted]
FPPS / FPCS	[redacted]	[redacted]
NVDS (combined floor, chemical and process drains)	[redacted]	[redacted]
NSS	[redacted]	[redacted]

Table 6: Comparison of the auxiliary system source term derived from surface corrosion and activity transfer

144 What limited plant OEF contained in Ref. 24 is not really used by EDF and AREVA in their analysis, as they conclude that the direct application to UK EPR™ is not possible due to differences in the functions and components of the UK EPR™ auxiliary systems. On this basis EDF and AREVA do not use OEF to quantify or estimate the auxiliary system activities, but instead rely on the estimations described above. I agree that direct use of such OEF is difficult, but it would have been useful to expand upon this aspect to

include consideration of whether the differences in UK EPR™ are actually improvements or not. I consider this later in my assessment (Section 4.1.3).

4.1.2.2.3.3 Auxiliary System Quantification - Summary

145 As for the primary circuit, EDF and AREVA again provide a set of "semi-quantitative" estimations for the auxiliary systems of UK EPR™. The results of all the calculations are that, as the surface areas and temperatures in the auxiliary systems are lower than the primary circuit, the material release rates are significantly less and hence their contribution to activity is minimal. EDF and AREVA conclude that the determining factor for the activity levels in the auxiliary system is the rate of transfer of primary coolant to those systems and the abatement provided within that system. In this respect the estimations do highlight where the various treatment systems are in the auxiliary circuits and how these have been arranged to ensure effective operations and to minimise transfers of activity from the primary coolant.

4.1.2.2.4 Auxiliary Systems – Characterisation of Relevant Nuclides

146 EDF and AREVA consider that the generic characterisation of radionuclides in the primary coolant, as described under Section 4.1.2.1.3, remain valid for the auxiliary systems.

4.1.2.2.5 Minimisation of the Source terms in the Primary Auxiliary Systems - Summary

147 EDF and AREVA have provided information on the identification, quantification and characterisation of the main radionuclides expected within the primary auxiliary systems of UK EPR™.

148 As with the primary coolant quantification estimates, these are ultimately based upon feedback from the French N4 plants, as the PCSR source terms are used. Due to the assumption described previously these are "*semi-quantitative*" estimates for the activities possible within the UK EPR™ auxiliary systems. Consequently, this results in analyses that do not quantify the likely auxiliary circuit source terms but do provide reasonable bounding estimates using pessimistic assumptions.

149 This analysis also demonstrates that:

- The primary coolant is the major source of the activity.
- There are systems installed to minimise the activity within the primary coolant as it is passed into the auxiliary systems (and vice versa where necessary).

150 In terms of demonstrating that the activity in the auxiliary systems has been minimised the EDF and AREVA argument is therefore based on the conclusions that transfer of primary coolant to the auxiliary systems, abated by the installed treatment equipment, determines their respective activities and that the primary coolant activity has been reduced to levels which are ALARP.

4.1.2.3 Sub-claim 1: The Source Terms are Minimised - Summary

151 The sub-claim "minimisation of source terms" is based around several arguments put forward by EDF and AREVA in their responses to **GI-UKEPR-RC-02** related to material selection, chemistry optimisation and fuel management. The supporting evidence is focused around a number of empirical arguments (such as reductions in Stellite^{TM}) and a

number of “semi-quantitative” estimations for the radioactivity in both the primary circuit and connected auxiliary systems.

152 The results of this analysis show that:

- The PCSR source terms are appropriate and bounding.
- The UK EPR™ activity management philosophy is appropriate.
- The chemistry and material modifications made to the primary circuit of UK EPR™ have a large impact on the expected source terms. This confirms the main related conclusion from my Step 4 assessment that EDF and AREVA had made an adequate ALARP argument for UK EPR™ for this stage in the development of the safety case.
- EDF and AREVA have considered and implemented systems in the auxiliary systems of UK EPR™ to minimise activity transferred from the primary coolant.
- The radioactivity in UK EPR™ may be similar to the latest French N4 plants and that stringent controls will be needed at all stages of manufacturing, commissioning and operation to ensure that an ALARP position is maintained.

153 On the basis of the evidence provided I am content that EDF and AREVA have made an adequate case to demonstrate that radioactivity in UK EPR™ has been minimised.

4.1.3 Sub-claim 2: The Auxiliary Systems have been designed to meet their respective Chemistry and Radiochemistry requirements

154 Ref. 24 contains details of the design of the UK EPR™ primary auxiliary systems. As with other sections of this report the level of detail is perhaps too high and repetitious of other documentation. In this regard Ref. 25 contains a more relevant description of the specific difference in UK EPR™ compared to the French N4 and German KONVOI plants as related to activity management and control. The most pertinent of the changes include:

- Installation of double filters upstream of the CVCS resins which improves particle retention and lowers resin damage rates. This change has been included as a modification to existing N4 plants.
- Reduction in the number of CVCS ion exchange vessel compared to N4 from five to three. EDF and AREVA cite the calculations described in Section 4.1.4 of my report as evidence to support the reduction without a comparable diminished performance.
- The design of the UK EPR™ VCT means that fission gas activity is reduced using the CSTS degasser and GWPS flushing rather than VCT flushing at shutdown. Irrespective of the means UK EPR™ will still have limits on coolant activity prior to primary circuit opening.
- UK EPR™ has specific design features for the injection of individual chemicals, as opposed to a single dosing tank.
- The RBWMS in UK EPR™ has an additional buffer tank in-between the effluent from the CSTS or the CVCS or RCS. This will minimise transfer and recontamination of the auxiliary systems.
- Modifications to the FPPS in UK EPR™ compared to N4, means that the system is able to treat other water volumes (such as the fuel building pools and IRWST) without the need for specific additional lines and with higher flowrates. In addition, it is possible to use the CVCS ion exchange system which doubles the possible treatment flowrate in UK EPR™ to three times that of N4.

- Changes to the CSTS design:
  1. A modified layout of the Coolant Storage System (CSS), closer to KONVOI design than N4, allows easier management of the discharged primary coolant and treated effluents.
  2. Simplification of the Coolant Purification System (CPS) demineraliser train without diminished performance.
  3. Installation of an evaporator and degasser in the Coolant Treatment System (CTS) to maximise coolant recycling.
- Change in abatement technology for the GWPS in UK EPR™ from delay tanks in N4 to the charcoal beds used in KONVOI.

155 In addition to the design changes, EDF and AREVA also describe the "*protection and control measures*" of each system. These are those features which will alert the operator to conditions which would indicate a deterioration or abnormal performance (e.g. flow, temperature, pressure sensors etc).

156 I assessed these systems in detail as part of my Step 4 assessment (Ref. 2), which by default included consideration of these differences to N4 and KONVOI. I noted no significant concerns regarding their functionality or performance for minimisation and control of radioactivity.

4.1.3.1 Sub-claim 2: The Auxiliary Systems have been designed to meet their respective Chemistry and Radiochemistry requirements - Summary

157 The overall tone of this part of the EDF and AREVA response is to emphasise that UK EPR™ should be capable of controlling radioactivity at least as well as, if not better than, those comparable plants. This is via changes to the coolant treatment, storage and monitoring systems. EDF and AREVA do not attempt to quantify the impact of any of these changes on the minimisation of radioactivity; rather they are seen as overall improvements. While there are no quantified estimates for the impact of these improvements I do consider that on an empirical basis these changes are reasonable changes in order to minimise the radioactivity outside of the primary circuit.

4.1.4 Sub-claim 3: The Purification Systems are Optimised

158 Ref. 24 also includes a description of the purification systems in UK EPR™, specifically:

- Purification principles
- Descriptions of the UK EPR™ purification systems
- Performance demonstrations for the auxiliary system purification components

159 Again, a large part of this section of the response repeats and summarises material already reviewed as part of GDA, as described in the Step 4 assessment report (Ref. 2) and the PCSR (Ref. 16), so is not repeated here. However, this section does provide a useful stand-alone summary, with EDF and AREVA identifying those auxiliary systems which have a dedicated function in terms of purifying (and hence controlling and minimising) the activity generated by the plant. These are the CVCS, CSTS, FPPS / FPCS and GWPS. While the other auxiliary systems do indeed have purification components in many cases, they do not contribute directly to the control of activity on a routine basis.

160 EDF and AREVA consider both soluble and insoluble purification (ion exchange and filtration) in their response.

161 The response highlights the differences in the UK EPR™ filtration systems compared to N4 plants, namely;

- The filtration efficiency has improved during the operation of the N4 plants, from 99 to 99.8%, which has carried through into the UK EPR™ design.
- EDF and AREVA recommend use of 1μm filtration, as they conclude there is insufficient evidence to support the adoption of sub-micron filtration.
- In contrast to N4, UK EPR™ does not have filters upstream of the CPS demineraliser; instead those systems which feed into the CPS (namely the CVCS and NVDS) include filtration stages to ensure that transferred coolant is pre-filtered.
- It is not possible to directly compare N4 and UK EPR™ filter capacity between the CVCS and FPPS due to differences in the design and operation of these systems. However, EDF and AREVA note the adoption of pool skimming technology as advantageous in removing particulate contamination from the spent fuel pool as part of the FPPS.
- Filter replacement criteria are based upon OEF.

162 As described previously in Sections 4.1.2.3., EDF and AREVA have provided evidence for the adequacy of the PCSR source term for the auxiliary systems and primary coolant source term for UK EPR™. For this reason, EDF and AREVA evaluate the performance of the UK EPR™ soluble purification systems using the PCSR source term and by considering conservative durations of operation. Thus EDF and AREVA use the larger "*Biological Shield Design*" (DPB) source term defined in Ref. 17.

4.1.4.1 Application to the CVCS

163 EDF and AREVA provide further details on the CVCS purification system, including particularly those aspects of the design which contribute towards ensuring that the transfer of radioactivity outside the primary circuit are minimised. These include:

- The ability to by-pass the CVCS ion exchange beds means that the filtration functions provided by the CVCS are maximised.
- The ion-exchange bed arrangement proposed (single Li+/borate form purification bed for normal operation, H+/borate form bed for delithiation during normal operations and a dedicated start-up and shutdown bed) allows for several process improvements in the context of radioactivity control, including:
    1. On-line lithium removal with ion-exchange purifies the coolant transferred to the CSTS before storage, minimising activity transfer outside of the CVCS.
    2. Optimised radionuclide removal during transient periods with the dedicated start-up and shutdown bed.
    3. The capability to deborate at the end of cycle, avoiding large water movements to the CSTS.
- Selection of a 2:1 cation to anion volumetric resin ratio is a compromise between the overall cation capacity of the bed and the capability to remove iodine in case of significant fuel failures.

164 While these arguments are purely qualitative, EDF and AREVA do go on to estimate the likely performance of the ion exchange beds, primarily to confirm that the capacity of the beds is sufficient to accommodate the highest levels of impurities in the primary coolant. To do this EDF and AREVA assume that the coolant has the "*Biological Shield Design*" (DPB) source term for the entire operating cycle (500 days at 36 t hr^{-1} flow), followed by the corresponding DPB shutdown oxygenation peak release (2 days at 72 t hr^{-1} flow). Similarly the concentrations of non-radioactive impurities in the coolant are taken to be either at the expected or limit value for the entire cycle. The values calculated for a single CVCS ion exchange bed are summarised below:

Parameter	Cation Resin	Anion Resin
Total theoretical demineraliser capacity / equivalents	[redacted]	[redacted]
Daily radioactivity retained by the demineraliser during normal operations / equivalents	[redacted]	[redacted]
Daily radioactivity retained by the demineraliser during a shutdown / equivalents	[redacted]	[redacted]
Daily non active species retained during normal operations (assuming limit values) / equivalents *[assuming expected values]*	[redacted]	[redacted]
Saturation time (assuming limit values) / days *[assuming expected values]*	[redacted]	[redacted]

Table 7: EDF and AREVA estimated CVCS demineraliser capacity from Ref. 24

165 As with many of the other calculations provided in Ref. 24, these estimates are simple and are based on many assumptions. For example, EDF and AREVA do not use this analysis to estimate the likely quantity of radioactivity that would be retained upon each bed. Assessment Finding **AF-UKEPR-RC-69** would contribute to such areas, such that purification system management options can be evaluated and incorporated into operating procedures. However, these calculations support that the design of the CVCS demineralisers is adequate to handle the quantities of impurities that could be expected within UK EPR™.

4.1.4.2 Application to the other Auxiliary Systems

166 In addition to the CVCS, EDF and AREVA perform similar calculations for both the FPPS and CSTS. The results are similar to those obtained for the CVCS, namely that the ion exchange systems have been suitably dimensioned to account for the likely levels of impurities.

4.1.4.3 Sub-claim 3: The Purification Systems are Optimised - Summary

167 The overall summary for this part of the EDF and AREVA response is that EDF and AREVA have considered, and adapted where appropriate, the design of the UK EPR™ purification systems to maximise the removal of radioactivity in balance with the other safety objectives of the plant. The estimates provided also indicate that, even assuming high impurity levels, the purification capacity is adequate.

4.1.5 Sub-claim 4: The Potential Deposition Mechanisms have been Evaluated

168 Following minimisation of the source term, the two complementary ways of minimising the effects of the source term present in the systems are via purification and deposition reduction. Purification was considered in the previous section of my report. In their response (Ref. 24) EDF and AREVA also consider the design of those components and pipes of the auxiliary systems which could be subject to deposition, in order to ensure that the residual source term and the possibility of deposits in the auxiliary systems is minimised. In this section of their response EDF and AREVA identify the main parameters they consider to have an impact on deposition risks and the design countermeasures applied in the auxiliary systems to mitigate these (piping slope, selection of valves and determination of optimal flow rate).

169 The overall arguments suggested in this section of Ref. 24 are somewhat contradictory. On one hand EDF and AREVA suggest that by controlling the flow rate they can minimise particle deposition and provide some empirical evidence to support this. Conversely they suggest that the thermodynamics of the system are such that particles will tend to dissolve. If particles do dissolve increasing the flow rate will increase mass transfer to surfaces and hence potentially increase the surface contamination. EDF and AREVA do not indicate which form (particle or soluble) they expect to dominate, although it is likely to be a mixture of the two (and in fact may not remain constant). As such it is unclear if the effect of increasing flow rates is a straightforward as EDF and AREVA suggest when the whole system is considered.

170 In support of this GDA Issue Action, EDF and AREVA have performed specific analyses in order to identify the key parameters playing a role in deposition. This analysis uses Computational Fluid Dynamics (CFD) simulations but is solely focussed on particulate species. The information presented in Ref. 24 is a summary of the more detailed work undertaken. EDF and AREVA use this analysis to show that the particulate fouling analysis carried out by EDF and AREVA is in reasonable agreement with previous theoretical and empirical works and demonstrate how the specific design of UK EPR™ limits such deposits, including by comparison to the predictions of fouling models from the literature and the experimental NPP feedback. While it is difficult to precisely quantify such effects this type of analysis is useful in determining the general trends and for identifying any particular areas where further attention is warranted.

171 In their calculations EDF and AREVA consider four specific cases:

- *Deposition risks in pipes* – based on CFD simulations, the report compares the flow conditions and velocities expected in various pipes in the primary and auxiliary systems of UK EPR™ (CVCS, RCS, FPPS and CSTS) compared to the limiting conditions which would lead to deposition. EDF and AREVA select these locations on the basis of an examination of plant OEF for doses incurred during maintenance activities on the later French PWRs, selecting the locations of highest dose. In all cases the comparisons reveal that the pipes considered have conditions up to several orders of magnitude different from conditions that would favour significant deposition. It is notable however that the pipes selected are all significant pipes which would be expected to see large amounts of flow. While it could be argued that it would have been more relevant to examine some smaller pipes with intermittent flow conditions or with larger quantities of particles (for example, those within the RHRS or used for water transfers from the spent fuel pool), I am content that that the choice has been made on the basis of dosimetry measurements from existing plants and hence even with a larger tendency to deposit these locations may still not be as relevant as those analysed by EDF and AREVA.

- *Deposition risks in valves (“singularities”)* – stagnant areas within valves and fittings, where flow conditions become disturbed are a potential location to accumulate deposits. In addition EDF and AREVA identify maintenance on primary circuit valves as a high dose activity in French PWRs. EDF and AREVA consider several types of valves commonly found within the auxiliary systems of UK EPR™ (e.g. globe, diaphragm or multi-stage valves). This identifies, in qualitative terms, the impact of valve type on likely deposit accumulation. The results obtained tend to support the engineering rules for valve selection used by EDF and AREVA in the design of EPR™. These rules suggest globe valves for lines which carry radioactive fluids (in balance with other requirements and functions).
- *Deposition risks in the Spent Fuel Pool* – the transfer of spent fuel, contaminated by adhered fuel crud represents a potential source for particle deposition. EDF and AREVA report on CFD simulations for the EPR™ fuel pond which show that: that:
    1. The behaviour predicted does not depend on whether one or two trains of FPPS are operating (i.e. operation of two trains does not change the trends, only the rate of clean-up etc.).
    2. Surprisingly, operation of two trains tends to slightly extend the residence time of a particle within the pond. EDF and AREVA suggest that this is due to the competing effect of two train running.
    3. The analysis predicts a tendency for particles to be transferred from the bottom area of the pond to the surface, where the water movements are lower and hence they tend to have a longer residence time. The size of particle considered does not significantly change this behaviour. This is in line with plant OEF.
    4. EDF and AREVA consider that the implementation of the spent fuel pool skimmer will counter any increased level of particulate contamination found near the pond surface.
- *Deposition risks in the NSS* – I assessed the NSS in some detail during Step 4, see Section 4.2.9 of Ref. 2. This considered the design of the NSS and whether it was capable of delivering all of the required samples in a representative and timely manner. EDF and AREVA repeat much of the relevant design information in Ref. 24. I raised Assessment Finding **AF-UKEPR-RC-17** which required the licensee to consider if isokinetic type sampling capabilities were needed for corrosion product sampling in UK EPR™. EDF and AREVA present results which suggest isokinetic sampling is not required in UK EPR™ on the basis that the calculated stokes number is lower than that required (10^{-4} compared to 10^{-2}). Irrespective of this, the fundamental requirement of **AF-UKEPR-RC-17**, namely to ensure corrosion product sampling is a representative as reasonably practicable whether sampling is truly isokinetic or not, should still be justified by the licensee as part of resolving this Assessment Finding.

4.1.5.1 Sub-claim 4: The Potential Deposition Mechanisms have been Evaluated - Summary

172 EDF and AREVA present their CFD analysis for deposition risks in pipes, fittings and pools in UK EPR™. This analysis is based entirely on the deposition of particulate

species, and is a summary of a much more detailed report. The results present tend to support the EDF and AREVA arguments regarding limiting the accumulation of particles within the nuclear island system of UK EPR™ and the previously identified systems for removing these (such as the spent fuel pool skimmers or FPPS).

4.1.6 Sub-claim 5: The Chemistry and Radiochemistry Monitoring and Control arrangements are ALARP

173 The final sub-claim, related to the monitoring and control arrangements, attempts to link the previously described responses to those limits and conditions which will ultimately be used to control the operating chemistry of UK EPR™.

4.1.6.1 Primary Circuit – Relationship to Control Parameters

174 Ref. 22 provides a description of how the control parameters specified for UK EPR™ relate to the source term and the considerations described above regarding speciation, quantification and characterisation. This considers normal operations as well as start-up and shutdowns.

175 A large proportion of the control parameter information presented in Ref. 22 is concerned with fission product activity in the coolant and the capability to detect fuel damage. The parameters described are "standard" across PWRs (e.g. ^{133}Xe/^{135}Xe ratio, ^{133}Xe activity etc.) and their application to UK EPR™ is straightforward. EDF and AREVA note that there are not expected to be any limits associated with corrosion product concentrations due to their very low concentrations during normal operations, however EDF and AREVA do indicate that the plant radiochemistry specifications will require routine analysis of the coolant, with increases in specific nuclides initiating an investigation into the causes.

176 The subject of Reactor Chemistry related Limits and Conditions was assessed as part of GDA Step 4, and is discussed further in Section 4.1.3 of Ref. 2. This resulted in Assessment Finding **AF-UKEPR-RC-02**. Both the Step 4 report and Ref. 22 make reference to the EDF and AREVA response to **RO-UKEPR-55** (Ref. 36), which is a main reference to the PCSR chemistry sub-chapter (Ref. 16), thus this part of the response to this GDA Issue Action is consistent with the other documents supplied as part of GDA for UK EPR™. The details provided can be considered as a more detailed description and justification for the main control parameters already described for UK EPR™, including more details on how these have been applied to the EDF fleet.

4.1.6.2 Auxiliary Systems – Relationship to Control Parameters

177 The final section of Ref. 24 contains information on the chemistry and radiochemical parameters which have been currently identified for the auxiliary systems. As with other parts of Ref. 24, this is a concise summary of a more detailed reference. The section discusses boron reactivity control, iodine mitigation and fission product activity control within or by the auxiliary systems. The section concludes by providing a detailed list of parameters which will be monitored within the various UK EPR™ systems.

178 As for the primary circuit, these are the subject of Assessment Finding **AF-UKEPR-RC-02**, raised at the end of Step 4.

4.1.6.3 Sub-claim 5: The Chemistry and Radiochemistry Monitoring and Control arrangements are ALARP - Summary

179 I am content that EDF and AREVA have described how the "preliminary" chemistry and radiochemistry limits and conditions for UK EPR™ are consistent with their previous arguments and evidence related to the identification, quantification and characterisation of radioactivity with the primary and primary auxiliary circuits. EDF and AREVA have also indicated how the likely value of some of these limits relates to the control and minimisation of radioactivity. While the definition of such limits and conditions is the subject of Assessment Finding **AF-UKEPR-RC-02** raised at the end of Step 4, I am content that the response is sufficient to support resolution of **GI-UKEPR-RC-02**.

4.1.7 PCSR Update

180 EDF and AREVA updated the consolidated Step 4 PCSR (Ref. 16) to account for the deliverables produced and assessment conducted for **GI-UKEPR-RC-02**. This was initially sent to ONR as an advanced version in letter EPR01212R (Ref. 37), which also included a roadmap for the changes. In addition to minor changes and updates, EDF and AREVA incorporated two more significant changes to the sub-chapter:

- Implementation of the Design Safety Review Committee (DSRC) recommendations.
- Addition of a new section presenting "Auxiliary Systems Water Chemistry".

181 The first of these, DSRC review, incorporated the recommendations raised as a result of the independent review of PCSR sub-chapter 5.5 (Ref. 38). These changes were not incorporated previously as PCSR sub-chapter 5.5 was a new addition to the consolidated PCSR at the end of Step 4. Implementation of the DSRC recommendations consists mostly of additional references and clarifications and I had previously discussed these changes with EDF and AREVA during one of my Technical Meetings. I am content that these changes have not impacted the intent of the PCSR, nor the claims, arguments or evidence contained therein.

182 The second significant change, addition of a new section essentially reflecting the additional information on the auxiliary systems as a result of **GI-UKEPR-RC-02**, was a more profound change to the chapter intended to extend the scope of the systems considered to also include the primary auxiliary systems such as the spent fuel pool and IRWST. While I considered this further information a valuable addition to the PCSR I felt its presentation could be improved and I provided EDF and AREVA with comments on this and other aspects. EDF and AREVA subsequently updated the sub-chapter to address my comments and this resulted in incorporation of the new information into the existing sections before transmittal to ONR under letter EPR01379N (Ref. 39). This version also included reference to the final response made under GI-UKEPR-RC-02, *ECECS121408 - Ex-core Radiation Minimisation and Control in UK EPR™ reactor*, Ref. 25.

183 It was also necessary to update PCSR sub-chapter 18.2 (limits and conditions) to be consistent with the updates to sub-chapter 5.5. In a similar way, EDF and AREVA supplied an advanced version which I returned comments on, mostly related to consistency with the latest version of sub-chapter 5.5. EDF and AREVA updated this chapter to satisfactorily address my comments regarding **GI-UKEPR-RC-02**. However, I note that the final version of sub-chapter 18.2 states that the "*pH is controlled in the RRI [CCWS] system to ensure the integrity of the third barrier*". While this is true, the CCWS chemistry also contributes to protecting the second barrier integrity via the various heat

exchangers which cool primary fluids. This should be resolved as part of Assessment Finding, **AF-UKEPR-RC-39**, raised during the Step 4 assessment (Ref. 2).

184 Overall, having reviewed the final versions of PCSR chapters 5.5 and 18.2 (Refs 40 and 41) I am content that the changes adequately reflect the responses provided to **GI-UKEPR-RC-02** and represent valuable additions to the safety case for UK EPR™.

4.1.8 Summary of the Assessment of the Responses

185 In response to **GI-UKEPR-RC-02**, EDF and AREVA provided a number of reports which contain their arguments and evidence to support the claim that radiation levels in UK EPR™ are minimised and controlled (Refs 22, 24 and 25). The first response (Ref. 22) deals with the activity levels within the primary circuit and provides ”semi-quantified” estimates for the possible activity levels in UK EPR™ during normal operations and shutdown. The main aim of this report in the context of this GDA Issue is in confirming the applicability of the primary coolant source terms used in the PCSR. The second deliverable (Ref. 24) deals with the activity in the auxiliary systems and the systems which minimise and control this and again provides “semi-quantitive” estimates for radioactivity within those systems. This report draws heavily on previously submitted documentation as well as additional supporting calculations. As a result it was necessary for EDF and AREVA to produce an additional “*roadmap*” document to clarify the claims-argument-evidence trail for this GDA Issue (Ref. 25). This roadmap identified five sub-claims, namely;

- The source terms are minimised
- The auxiliary systems have been designed to meet their respective chemistry and radiochemistry requirements
- The purification systems are optimised
- The potential deposition mechanisms have been evaluated
- The chemistry and radiochemistry monitoring and control arrangements are ALARP

186 I have assessed these sub-claims and the supporting evidence provided by EDF and AREVA and in conclusion I note that:

- Overall, EDF and AREVA claim that radioactivity has been controlled and minimised in UK EPR™ by a combination of the factors given below:
    1. Material choices and conditioning techniques (including Stellite^{TM} reduction, reduction of residual cobalt levels, steam generator tube manufacturing improvements and Hot Functional Testing (HFT) procedures).
    2. Chemistry optimisation, including the choice of operating pH, dissolved hydrogen concentration and zinc addition during normal operations and the careful management of start-up and shutdown transient periods.
    3. Treatment, purification, sampling and make-up systems which have considered the control and minimisation of radioactivity as part of their design.
- Many of the arguments presented by EDF and AREVA in response to this GDA Issue were purely qualitative, as above, and where estimations were undertaken they are ”semi-quantitative”. Plant feedback was not used or unsuitable to support many of the “semi-quantitative” estimates provided. Despite this, the responses do highlight those features which are available to control and minimise radioactivity, not

only in the primary circuit but also in the auxiliary systems and the relative effect of those on the plant. EDF and AREVA also show how the expected chemistry and radiochemistry limits and conditions are consistent with the minimisation of radioactivity.

- I consider there to be three main conclusions from my assessment, namely:
    1. The deliverables provide justifications for the primary coolant source term as it is defined in the PSCR for UK EPR™:
        a) The estimations undertaken by EDF and AREVA confirm the adequacy of the UK EPR™ source term for use in the PCSR.
        b) The chemistry role in the source term reduction has been highlighted and this underlines the importance of specifying and maintaining adequate controls on the primary coolant chemistry throughout the lifetime of the plant.
    2. I am content that EDF and AREVA have provided sufficient evidence to demonstrate that UK EPR™ should be capable of controlling and minimising radioactivity levels at least as well as, if not better than, those comparable plants. This is via improvements to the coolant treatment, storage and monitoring systems.
    3. The estimations provided by EDF and AREVA suggest that the activity levels in UK EPR™ are likely to be similar to the latest French (N4) plants. There is some inherent uncertainty in these estimates, as the bounding source terms were used, but this has highlighted that further refinement of the estimated radioactivity in UK EPR™ will be needed as the safety case develops. I am satisfied that this is best resolved by a future licensee, and as such I have raised this as an Assessment Finding.
- The update of the PCSR to account for this GDA Issue Action is appropriate, in particular I note that the further information provided on the auxiliary system chemistry requirements is an important addition.

187 On the basis of the evidence supplied by EDF and AREVA in response to **GI-UKEPR-RC-02**, I am content that an adequate safety case has been made and, in conjunction with the updated PCSR, I am content that this GDA Issue Action can be closed.

4.1.9 Assessment Findings

188 Based upon the assessment of the **GI-UKEPR-RC-02** responses described in Section 4.1 above, I have identified the following Assessment Finding which needs to be addressed, as normal regulatory business, by the licensee, during the design, procurement, construction or commissioning phase of the new build project;

AF-UKEPR-RC-69 *- The licensee shall continue to refine the estimated performance of UK EPR™, in terms of the production, transport and accumulation of radioactivity in the primary circuit and connected systems, during the site specific phase. This should include taking account of operating experience feedback from other EPR™ plants, the aim being to move towards quantitative estimates so far as is reasonably practicable. This Assessment Finding should be completed before nuclear operations, as this is when radioactivity is generated in the plant.*

Required timescale: *Initial criticality.*

5 ASSESSMENT FINDINGS

5.1 Additional Assessment Findings

189 As a consequence of my assessment for closeout of GDA for the UK EPR™ reactor design, I have identified one Assessment Finding that needs to be resolved, as appropriate. I conclude that the following Assessment Findings listed in Annex 1 should be programmed during the forward programme of this reactor as normal regulatory business.

5.2 Impacted Step 4 Assessment Findings

190 **AF-UKEPR-RC-39**, raised during Step 4, is impacted as a result of the assessment conducted for **GI-UKEPR-RC-02**. The scope of this Assessment Finding remains unchanged; however a specific expectation for resolution of this is described in Para.183 of this report.

191 In addition, Assessment Finding **AF-UKEPR-RC-69** raised as part of the close-out of **GI-UKEPR-RC-02** is closely related to **AF-UKEPR-RC-13**, raised as part of the Step 4 Assessment (Ref. 2). Both of these finding relate to provisions of quantified analysis on the performance of UK EPR™ for radioactivity and fuel crud respectively. As such a future licensee may wish to combine resolution of these related Assessment Findings.

6 CONCLUSIONS

192 This report presents the findings of the assessment for the close-out of **GI-UKEPR-RC-02** Revision 0 for the EDF and AREVA UK EPR™ reactor, related to the control and minimisation of ex-core radiation. The overall conclusions from my assessment, are presented below:

- EDF and AREVA have provided sufficient evidence to demonstrate that UK EPR™ should be capable of controlling and minimising radioactivity levels in the primary and primary auxiliary systems. UK EPR™ should be capable of controlling radioactivity at least as well as, if not better than, comparable plants. This is via improvements to the coolant treatment, storage and monitoring systems in the auxiliary systems as well as material and operating chemistry optimisation of the primary circuit.
- As part of this GDA Issue EDF and AREVA have also confirmed the bounding nature of the PCSR source terms.
- EDF and AREVA's estimations indicate that the activity levels in UK EPR™ are likely to be similar to the latest French (N4) plants. There is some uncertainty inherent in these values but I remain content that it should be possible to operate UK EPR™ at lower levels than this if tight controls over all operations are maintained by the licensee. It is for this reason that I have identified an Assessment Finding for a future licensee to refine the bounding estimates provided to help define and justify limits, conditions, criteria and operating procedures and take advantage of developments and EPR™ operating experience before any UK EPR™ is operated in the UK.
- In response to this GDA Issue, EDF and AREVA updated the PCSR. I have reviewed these updates and am content that they accurately reflect the responses to the Issue Actions.

193 Overall, based on my assessment undertaken in accordance with ONR procedures, I consider the responses to be satisfactory and sufficient for closing the GDA Issue. This assessment has resulted in one new Assessment Finding which will need to be resolved by a future UK EPR™ licensee on a site specific basis.

7 REFERENCES

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Table 8

Relevant Safety Assessment Principles considered for close-out of GI-UKEPR-RC-02 Revision 0

SAP No.	SAP Title	Description
The Regulatory Assessment of Safety Cases		
SC.4	Safety case characteristics	A safety case should be accurate, objective and demonstrably complete for its intended purpose.
Engineering principles: Key principles		
EKP.2	Fault tolerance	The underpinning safety aim for any nuclear facility should be an inherently safe design, consistent with the operational purposes of the facility.
Engineering principles: Control of nuclear matter		
ENM.1	Strategies for nuclear matter	A strategy (or strategies) should be made and implemented for the management of nuclear matter.
ENM.2	Provisions for nuclear matter brought onto, or generated on, the site	Nuclear matter should not be generated on the site, or brought onto the site, unless sufficient and suitable arrangements are available for its safe management.
ENM.3	Transfers and accumulation of nuclear matter	Unnecessary or unintended generation, transfer or accumulation of nuclear matter should be avoided.
ENM.4	Control and accountancy of nuclear matter	Nuclear matter should be appropriately controlled and accounted for at all times.
ENM.5	Characterisation and segregation	Nuclear matter should be characterised and segregated to facilitate its safe management.
ENM.6	Storage in a condition of passive safety	When nuclear matter is to be stored on site for a significant period of time it should be stored in a condition of passive safety and in accordance with good engineering practice.
ENM.7	Retrieval and inspection of stored nuclear matter	Storage of nuclear matter should be in a form and manner that allows it to be retrieved and, where appropriate, inspected.
Engineering principles: Containment and ventilation		
ECV.2	Minimisation of releases	Nuclear containment and associated systems should be designed to minimise radioactive releases to the environment in normal operation, fault and accident conditions.
ECV.3	Means of confinement	The primary means of confining radioactive substance should be by the provision of passive sealed containment systems and intrinsic safety features, in preference to the use of active dynamic systems and components.
Engineering principles: Heat transport systems		
EHT.5	Minimisation of radiological doses	The heat transport system should be designed to minimise radiological doses.

Table 9

Relevant Technical Assessment Guides considered for close-out of GI-UKEPR-RC-02 Revision 0

Reference	Issue	Title	Ref.
T/AST/051	01	Guidance on the purpose, scope and content of nuclear safety cases	42
T/AST/005	04	ND guidance on the demonstration of ALARP (as low as reasonably practicable)	43
T/AST/023	01	Control of processes involving nuclear matter	44

Annex 1

GDA Assessment Findings Arising from GDA Close-Out for Reactor Chemistry Issue GI-UKEPR-RC-02 Revision 0

Finding No.	Assessment Finding	MILESTONE (by which this item should be addressed)
AF-UKEPR-RC-69	The licensee shall continue to refine the estimated performance of UK EPR™, in terms of the production, transport and accumulation of radioactivity in the primary circuit and connected systems, during the site specific phase. This should include taking account of operating experience feedback from other EPR™ plants, the aim being to move towards quantitative estimates so far as is reasonably practicable.	This Assessment Finding should be completed before nuclear operations, as this is when radioactivity is generated in the plant. Required timescale: Initial criticality.

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, GI-UKEPR-RC-02 Revision 0 – Reactor Chemistry – UK EPR™

EDF AND AREVA UK EPR™ GENERIC DESIGN ASSESSMENT
GDA ISSUE
CONTROL AND MINIMISATION OF EX-CORE RADIATION
GI-UKEPR-RC-02 REVISION 0

Technical Area	**REACTOR CHEMISTRY**		
Related Technical Areas	Radiation Protection Fuel Design Waste and Decommissioning		
GDA Issue Reference	**GI-UKEPR-RC-02**	**GDA Issue Action Reference**	**GI-UKEPR-RC-02.A1**
GDA Issue	EDF and AREVA to demonstrate that ex-core radiation levels in UK EPR™ are minimised so far as is reasonably practicable and can be controlled.		
GDA Issue Action	EDF and AREVA to provide calculations, or alternative evidence agreed by the regulator, which demonstrate that the control of corrosion products (fuel crud) and other radioactivity (excluding tritium) in safety systems in the UK EPR™ and outside of the primary reactor cooling circuit are minimised so far as is reasonable practicable and are controlled. The safety systems considered should include all of those inside the Nuclear Island which are routinely expected to handle radioactive materials, including the Spent Fuel Pool, In-containment Refuelling Water Storage Tank and the Residual Heat Removal System. Activation of the reactor vessel itself need not be included in the response. Such evidence should be based upon the expected plant operating procedures, particularly relating to shutdown, head-lift criteria and operation of the boron recycle system and should be compatible with the expected plant limits and conditions. With agreement from the Regulator this action may be completed by alternative means.		

Further explanatory / background information on the GDA Issues for this topic area can be found at:	
GI-UKEPR-RC-02 Revision 0	Ref. 8.