Office for Nuclear Regulation

Civil Nuclear Reactor Build - Generic Design Assessment

Step 2 Assessment of the Reactor Chemistry of Hitachi GE's UK Advanced Boiling Water Reactor (UK ABWR)

Assessment Report ONR-GDA-AR-14-009
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EXECUTIVE SUMMARY

This report presents the results of my assessment of reactor chemistry for Hitachi-GE Nuclear Energy, Ltd's (Hitachi-GE) UK Advanced Boiling Water Reactor (UK ABWR), undertaken as part of Step 2 of the Office for Nuclear Regulation's (ONR) Generic Design Assessment (GDA).

The GDA process calls for a step-wise assessment of the Requesting Party's (RP) safety submission, with the assessments becoming increasingly detailed as the project progresses. Step 2 of GDA is an overview of the acceptability, in accordance with the regulatory regime of Great Britain, of the design fundamentals and key nuclear safety and security claims. The aim is to identify any safety or security shortfalls that could prevent the issue of a Design Acceptance Confirmation (DAC). During GDA Step 2 my work has focused on the assessment of the key safety claims in the area of reactor chemistry to judge whether they are complete and reasonable, given ONR's current understanding of reactor technology and the UK ABWR design.

For my assessment safety claims are interpreted as being:

- any requirement or constraint placed on the operating chemistry of the plant which must be met in order to allow the plant to be operated safely;
- any chemistry related functional requirement which must be met to ensure that the plant is operated within its design basis; and
- any effect or consequence of chemistry during operations, during faults or during severe accidents, which must be understood and controlled in order to ensure the safety of workers and the public.

The standards and guidance I have used to judge the adequacy of the claims in the area of reactor chemistry have been primarily ONR's Safety Assessment Principles (SAP) and Technical Assessment Guides (TAG). For my Step 2 assessment I have used the SAPs extensively, in particular those related to: the regulatory assessment of safety cases, ageing and degradation, integrity of metal components and structures, safety systems, control of nuclear matter, reactor core, heat transport systems, fault analysis and criticality safety. The main TAG considered was that on the chemistry of operating civil nuclear reactors.

My GDA Step 2 assessment work involved continuous engagement with the RP in the form of technical exchange workshops and progress meetings. In addition, my understanding of ABWR technology, and, therefore, my assessment, has benefited from visits to: ABWR units at the Kashiwazaki Kariwa Nuclear Power Plant (NPP), where I viewed the majority of the facility; Hitachi Works, where I saw many of the reactor internals and fuel assembly construction; Ohma NPP construction site, which is a partially built ABWR plant; and Japan Steel Works, where they manufacture large forgings for use as ABWR reactor pressure vessels.

My assessment has been based mainly on the RP's Preliminary Safety Report (PSR) for reactor chemistry, but has also included relevant aspects of other submissions. The RP's safety case for reactor chemistry, as presented in those documents, can be summarised as follows:

- The PSR for reactor chemistry describes the basis for chemistry management of the UK ABWR. It contains a description of the operational chemistry for a number of systems in UK ABWR where there is a requirement to maintain chemistry control for safety purposes. The systems considered do not represent all of those where such controls may be needed, but were selected by the RP on the basis of their safety

significance. These include the primary cooling water, spent fuel pool, component cooling water, suppression pool and standby liquid control systems.

- The main output from the PSR is a set of claims for reactor chemistry, which aim to link the operating chemistry with the safety related functions it provides. The claims vary by system, but relate to some or all of the aspects of the following, as appropriate: maintaining fuel integrity; maintaining structural material integrity; reducing dose rates; minimising radioactive waste; and minimising radioactive releases to the environment. The overriding claim is that the operating chemistry reduces risks to As Low As Reasonably Practicable (ALARP).

During my assessment I have identified the following areas of strength:

- Overall, the RP has identified the operating chemistry for most of the main safety related systems in the UK ABWR. They have linked this to the main safety related functions it provides and have identified a reasonable set of claims. While in some areas the claims are still at a high-level, and do not yet fully consider matters outside of the operating chemistry (for example the supporting engineering), I have no reason to suggest that they cannot be further developed as the GDA of UK ABWR progresses.
- The RP appears to be considering the impact and interactions that the reactor chemistry choices have on other aspects of the UK ABWR design in an appropriate manner.
- An important proposal made by the RP relates to the operating chemistry for the primary cooling system of the UK ABWR. If adopted, this would be the first time such an approach is taken for an ABWR (but not for a Boiling Water Reactor) and demonstrates that the RP is considering UK regulatory requirements as part of the development of their safety case.
- I am confident that the RP should be able to provide the arguments and evidence as necessary to adequately support the claims that have been made on reactor chemistry during Step 2.

In addition to the development of the safety case and additional claims on chemistry, during my assessment I have identified the following areas that require follow-up:

- Definition and justification of the radiological source terms for the UK ABWR during normal operations, including a demonstration that the risks are reduced ALARP. A Regulatory Observation has been issued during Step 2 to address this matter.
- Generation, accumulation, management and mitigation of radiolysis gas during normal operations and the safety justification for this in the safety case.
- Justification for the material choices for the UK ABWR and how this interacts with the operating chemistry and arguments which may be made regarding structural integrity and minimisation of radioactivity.
- Justification of the claim regarding pH control in the suppression pool, in particular whether it reduces risks ALARP.
- Development of the chemistry related aspects of the design basis and severe accident analysis for the UK ABWR.

In relation to my interactions with Hitachi GE's Subject Matter Experts (SME), I have found the RP to be responsive to my advice and open in our interactions. They have demonstrated a good level of technical knowledge and expertise and are committed to producing an adequate safety case which meets UK requirements, expectations and relevant good practice. I have noted some instances where there appeared to be a lack of communication between related technical disciplines in the RP, but this has improved throughout Step 2. My conclusion for Step 2 is that the level of SME resource in this area is suitable and sufficient at present.

Overall, I see no reason, on reactor chemistry grounds, why the UK ABWR should not proceed to Step 3 of the GDA process.

LIST OF ABBREVIATIONS

ABWR	Advanced Boiling Water Reactor
ALARP	As Low As Reasonably Practicable
ATWS	Anticipated Transient Without Scram
BAT	Best Available Technique
BMS	Business Management System
BWR	Boiling Water Reactor
CRUD	Chalk River Unidentified Deposit
CUW	Reactor Water Clean-up (system)
DAC	Design Acceptance Confirmation
DZO	Depleted Zinc Oxide
EA	Environment Agency
ECP	Electrochemical Corrosion Potential
EPRI	Electric Power Research Institute
FAC	Flow Accelerated Corrosion
GDA	Generic Design Assessment
GEP	Generic Environmental Permit
Hitachi-GE	Hitachi-GE Nuclear Energy, Ltd
HWC	Hydrogen Water Chemistry
IASCC	Irradiation Assisted Stress Corrosion Cracking
IGSCC	Inter-Granular Stress Corrosion Cracking
IAEA	International Atomic Energy Agency
LOCA	Loss of Coolant Accident
MAAP	Modular Accident Analysis Programme
MSLBA	Main Steam Line Break Accident
NPP	Nuclear Power Plant
NWC	Normal Water Chemistry
OLNC	On-Line NobleChem™

LIST OF ABBREVIATIONS

ONR	Office for Nuclear Regulation
ORE	Occupational Radiation Exposure
PCSR	Pre-construction Safety Report
PCV	Primary Containment Vessel
ppb	parts per billion
PSR	Preliminary Safety Report
RCCV	Reinforced Concrete Containment Vessel
RHR	Residual Heat Removal (system)
RO	Regulatory Observation
ROA	Regulatory Observation Action
RP	Requesting Party
RPV	Reactor Pressure Vessel
RQ	Regulatory Query
RCW	Reactor building Cooling Water (system)
RSW	Reactor building Service Water (system)
SAP	Safety Assessment Principle(s)
SCC	Stress Corrosion Cracking
SFP	Spent Fuel Pool
SJAE	Steam Jet Air Ejector
SLC	Standby Liquid Control (system)
SME	Subject Matter Expert
TAG	Technical Assessment Guide(s)
TGSCC	Trans-Granular Stress Corrosion Cracking
TSC	Technical Support Contractor
US NRC	United States Nuclear Regulatory Commission
WENRA	Western European Nuclear Regulators’ Association

TABLE OF CONTENTS

Table(s)

1 INTRODUCTION

1.1 Background

1. The Office for Nuclear Regulation's (ONR) Generic Design Assessment (GDA) process calls for a step-wise assessment of the Requesting Party's (RP) safety submission with the assessments becoming increasingly detailed as the project progresses. Hitachi-GE Nuclear Energy Ltd. (Hitachi-GE) is the RP for the GDA of the UK Advanced Boiling Water Reactor (UK ABWR).

2. Step 2 of GDA is an overview of the acceptability, in accordance with the regulatory regime of Great Britain, of the design fundamentals, including review of key nuclear safety and security claims with the aim of identifying any fundamental shortfalls that could prevent the issue of a Design Acceptance Confirmation (DAC).

3. This report presents the results of my assessment of reactor chemistry for Hitachi-GE's UK ABWR as presented in the safety submissions, mainly the Preliminary Safety Report (PSR) on reactor chemistry (Ref. 1) and other supporting documentation.

1.2 Methodology

4. My assessment has been undertaken in accordance with the requirements of the ONR How2 Business Management System (BMS) procedure PI/FWD, Purpose and Scope of Permissioning (Ref. 2), in relation to mechanics of assessment within ONR. Appendix 1 of Ref. 2 sets down the process of assessment within ONR while Appendix 2 explains the process of sampling safety case documentation. The ONR Safety Assessment Principles (SAP) (Ref. 3), together with supporting Technical Assessment Guides (TAG) (Ref. 4) have been used as the basis for this assessment, along with other relevant standards and guidance.

5. My assessment has followed the plan and strategy described in my Step 2 assessment plan for reactor chemistry (Ref. 5) prepared in December 2013 and shared with the RP to maximise the efficiency of our subsequent interactions. While the breadth and depth of my assessment in a number of areas has been restricted due to the RP's progress, I have been able to focus my assessment on the fundamental design aspects and main claims on reactor chemistry as required for Step 2.

2 ASSESSMENT STRATEGY

6. This section presents my strategy for the Step 2 assessment of reactor chemistry for the UK ABWR. It also includes the scope of the assessment and the standards and criteria I have applied.

2.1 Scope of the Step 2 Assessment

7. The objective of my assessment was to review and judge whether the claims made by the RP, related to reactor chemistry, that underpin the safety of the UK ABWR design are complete and reasonable, in the light of my current understanding of reactor technology and the UK ABWR design.

8. For reactor chemistry "safety claim" is interpreted as being:

- any requirement or constraint placed on the operating chemistry of the plant which must be met in order to allow the plant to be operated safely;
- any chemistry related functional requirement which must be met to ensure that the plant is operated within its design basis; and
- any effect or consequence of chemistry during operations, during faults or during severe accidents, which must be understood and controlled in order to ensure the safety of workers and the public.

9. During Step 2 I have also evaluated whether the claims related to reactor chemistry could be supported by a body of technical documentation sufficient to allow me to proceed with GDA work beyond Step 2.

10. Finally, during Step 2 I have undertaken preparatory work for my Step 3 assessment. I have therefore:

- become fully familiar with the fundamentals of the design and intended operations of the UK ABWR;
- identified any key claims or technical matters which may be difficult to resolve or may threaten completion of GDA on the anticipated timescales;
- identified the likely basis of the supporting arguments and evidence, and thus what will be included in the scope of my Step 3 (and Step 4) assessment work;
- considered lessons learned from the AP1000© and EPR™ GDAs and their relevance to future steps of GDA for the UK ABWR;
- agreed a programme of work with the RP for future submission requirements, including development of the PCSR;
- defined future Technical Support Contractor (TSC) work packages, including RP information requirements;
- identified further cross-cutting technical areas for assessment or areas for interaction with other ONR technical topics;
- identified whether any significant design or safety case changes may be needed, and communicate these to the RP as appropriate; and
- produced a detailed Step 3 assessment plan.

2.2 Standards and Criteria

11. The relevant standards and criteria adopted within my assessment are principally ONR's SAPs (Ref. 3) and TAGs (Ref. 4), relevant national and international standards and relevant good practice informed from existing practices adopted on nuclear licensed sites. The key SAPs and relevant TAGs are detailed within this section. National and international standards and guidance have been referenced where

appropriate within the assessment report. Relevant good practice, where applicable, has also been cited within the body of the assessment.

12. The SAPs (Ref. 3) were benchmarked against the IAEA safety standards at the time of their production (in 2004). Since then numerous other IAEA safety standards have been produced and these have been used, where appropriate, during the assessment.

13. Furthermore, ONR is a member of the Western Regulators Nuclear Association (WENRA). WENRA has developed Reference Levels, which represent good practices for existing nuclear power plants, and Safety Objectives for new reactors.

14. Therefore, the standards and criteria that have been used to judge the adequacy of the claims in the area of reactor chemistry for the UK ABWR are:

- ONR’s SAPs (Ref. 3);
- ONR’s TAGs (Ref. 4);
- Relevant IAEA safety standards (Ref. 6);
- WENRA references (Ref. 7); and
- Recognised chemistry guidelines for Boiling Water Reactors (BWR) (Refs 8 and 9).

15. These are described further below.

2.2.1 Safety Assessment Principles

16. The SAPs considered as part of my assessment are focussed on the functions and systems leading to the largest hazards or risk reduction and are similar to those considered throughout the previous GDA assessments. See also Table 1 for further details.

17. Reactor chemistry can have a role in helping to fulfil the Fundamental Principles (FP.1 to FP.8) although these were not the focus of this assessment. The key SAPs considered within the assessment were therefore:

- the regulatory assessment of safety cases (SC.1 – SC.6);
- ageing and degradation (EAD.1 – 4);
- integrity of metal components and structures (EMC.2, 3 and 21);
- safety systems (ESS.1 – 4);
- control of nuclear matter (ENM.2 – 4);
- reactor core (ERC.1);
- heat transport systems (EHT.5);
- fault analysis (FA.18); and
- criticality safety (ECR. 1).

2.2.2 Technical Assessment Guides

18. The TAGs (Ref. 4) listed in Table 2 have been used as part of my assessment. However NS-TAST-GD-088, Chemistry of Operating Civil Nuclear Reactors, was the main TAG considered.

2.2.3 National and International Standards and Guidance

19. The following national and international standards and guidance have also been used as part of this assessment:

- Relevant IAEA standards (Ref. 6):

  - The International Atomic Energy Agency (IAEA) has prepared a standard on reactor chemistry. This is authoritative, wide-reaching and consistent with the assessment scope for GDA and, as such, it is suitable as advisory guidance. Similar IAEA guidance is also available for the spent fuel pool, containment systems and for defining limits and conditions of operation and these have been similarly used as advisory during my assessment.

- WENRA references (Ref. 7):

  - A review of reference safety levels defined by WENRA found none specific to reactor chemistry. However, this assessment will contribute to meeting the following reference levels:
    - Issue E: Design Basis Envelope of Existing Reactors
    - Issue H: Operational limits and conditions
    - Issue I: Ageing Management
    - Issue K: Maintenance, in-service inspection and functional testing
  - The reactor chemistry assessment will also contribute towards the following safety objectives for new power reactors, defined by WENRA:
    - O2: Accidents without core melt (in particular "*reducing, so far as reasonably achievable, the release of radioactive material from all sources*")
    - O3: Accidents with core melt (in particular "*reducing potential releases to the environment from accidents with core melt*")
    - O6: Radiation protection and waste management

- Chemistry Specific Standards and Guidance:

  - A large number of operating BWRs worldwide base their chemical specifications on standards and guidance produced by industry bodies like the Electric Power Research Institute (EPRI) (Ref. 8) and the German Federation of Large Power Station Operators (VGB Powertech) (Ref. 9). Some of these documents are authoritative and contain detailed justifications for the recommendations made, whilst other simply list limits and action levels. As such they have been used as advisory guidance.

2.3 Use of Technical Support Contractors

20. During Step 2 I engaged a TSC to deliver a course on BWR chemistry and corrosion in support of reactor chemistry, and other related technical disciplines, becoming more familiar with BWR and ABWR technology. This informed my assessment.

2.4 Integration with Other Assessment Topics

21. Early in GDA I recognised that during the project there would be a need to consult with other assessors (including Environment Agency's assessors) as part of the reactor chemistry assessment process. Similarly, other assessors will seek input from my assessment. I consider these interactions to be important to ensure that assessment gaps and duplications are prevented, and, therefore, they are key to the success of the project. Thus, I made every effort to identify, up front, as many potential interactions as possible between the different technical areas, with the understanding that this position would evolve throughout the UK ABWR GDA process.

22. Also, it should be noted that the interactions between reactor chemistry and some technical areas need to be formalised since aspects of the assessment in those areas constitute formal inputs to the assessments, and vice versa. These are:

    - Reactor chemistry provides input to the integrity and corrosion aspects of the assessment. The effects of the operating chemistry (environment) on the susceptibility to material degradation mechanisms will be led by the reactor chemistry inspector. However, the overall judgement on the adequacy of the safety case for material degradation aspects will also need to be informed by material and stress factors, which will be led by the structural integrity inspector.
    - Reactor chemistry provides input to the cladding corrosion and CRUD (Chalk River Unidentified Deposit) aspects of the fuel design assessment. The effects of the operating chemistry on these aspects will be led by myself, as would the assessment of any chemistry related consequences (e.g. on radioactivity or deposition), but any non-chemistry related consequences will be led by the fuel design inspector.
    - Reactor chemistry provides a key input in the area of radiological source term(s) which will impact on radiation protection, radwaste and decommissioning and the Environment Agency’s areas of assessment. The impact of the operating chemistry on the normal operational source term(s) for UK ABWR will be led by the reactor chemistry discipline, but radiological source term(s) is a broad area requiring coordination between disciplines.
    - Reactor chemistry provides input into the fault studies and severe accidents areas, where chemistry effects are important in determining the consequences or effectiveness of mitigation measures. This area will be led by fault studies and severe accident inspectors, with input from reactor chemistry.

23. All of these interactions started during Step 2, and will continue as the GDA of the UK ABWR progresses.

24. In addition to the above, during Step 2 there have been interactions between reactor chemistry and the rest of the technical areas. Although these interactions, which are expected to continue through GDA, are mostly of an informal nature, they are essential to ensure consistency across the assessment.

3 REQUESTING PARTY'S SAFETY CASE

25. This section presents a summary of the RP's safety case in the area of reactor chemistry. It also identifies the documents submitted by the RP which have formed the basis of my assessment of the UK ABWR during Step 2.

3.1 Summary of the RP's Safety Case in the Area of Reactor Chemistry

26. The RP has taken a systematic approach to identifying the safety case for reactor chemistry of the UK ABWR. They have started with the most significant systems where chemistry controls are required. The safety case therefore covers the following systems at present:

- Primary Cooling Water System;
- Spent Fuel Pool;
- Component Cooling Water;
- Suppression Pool;
- Stand-by Liquid Control System.

27. These are the systems considered in the reactor chemistry Preliminary Safety Report (PSR). The chemistry aspects of other systems will be included in the safety case by the RP, during later steps of GDA.

28. At this stage of GDA the scope of the safety case has focussed on identifying the basis, purpose and therefore the safety claims made on operational chemistry controls for each identified system. The RP has identified a number of chemistry related claims for each of these systems. These are not reported in detail here, but are discussed in detail as part of my assessment that follows (Section 4). They relate to some or all of the aspects of the following, as appropriate:

- maintaining fuel integrity;
- maintaining structural material integrity;
- reducing dose rates;
- minimising radioactive waste; and
- minimising radioactive releases to the environment.

3.2 Basis of Assessment: RP's Documentation

29. Prior to and throughout Step 2 the RP made a number of submissions to ONR as part of the development of the safety case for the UK ABWR. Those of relevance prior to Step 2 were mainly design related documents, which describe the overall design (for example, Ref. 10). Similar to a number of technical areas there was no submission specifically in the reactor chemistry area prior to the start of Step 2. The main submission for my assessment was therefore the Preliminary Safety Report (PSR) for reactor chemistry (Ref. 1), submitted in April 2014, which forms the core of the operational chemistry safety case for the UK ABWR at this stage of GDA. A number of submissions in other technical areas also contained information of relevance to this chemistry assessment. These are in those areas where there is an interaction with chemistry and therefore it can influence the safety case, specifically the claims. This includes structural integrity, radiation protection, radwaste and decommissioning, fuel and core, fault studies and severe accidents. There is also some overlap with the Environment Agency submissions, particularly related to discharges and Best Available Technique (BAT) assessments. These submissions (as relevant to reactor chemistry), are described in greater detail below.

3.2.1 Design Documents

30. The RP provided a number of submissions which describe the overall UK ABWR design, the main of which are Refs 10 and 11. Hitachi GE describes the UK ABWR as a generation III+ light water reactor. The electrical power is approximately 1350 MWe. A number of design features have been included based upon the evolution of previous BWR designs including the use of internal coolant pumps, changes to the control rod design, containment structure and emergency core cooling systems. The reference design is based on the Kashiwazaki-Kariwa units 6 and 7, which began commercial operation in Japan in 1996 and 1997 respectively, plus other improvements and optimisation incorporated in the Ohma-1, Shimane-3 and Shika-2 Japanese ABWRs.

31. The main feature of the UK ABWR is the direct cycle nature of the plant whereby the water coolant is allowed to boil in the core and the steam produced drives the turbine before being cooled by a seawater fed main condenser, purified and returned to the reactor. This is different to other UK reactor plants. This has important impacts on the operating chemistry of the plant and the hazards and risks that must be mitigated. The design also features a number of cooling and safety systems where chemistry control must be maintained, either during normal operations or accidents. These features are described in greater detail as part of my assessment in Section 4.

3.2.2 Preliminary Safety Report for Reactor Chemistry

32. The PSR for reactor chemistry (Ref. 1) describes the basis for chemistry management of the UK ABWR. It contains a description of the operational chemistry for a number of systems in the UK ABWR where there is a requirement to maintain chemistry control for safety. The systems considered do not represent all of those where such controls may be needed, but were selected by the RP on the basis of their safety significance and include the primary cooling water, spent fuel pool, component cooling water, suppression pool and standby liquid control systems. The main output from the report is a set of claims for reactor chemistry, which aim to link the operating chemistry with the safety related functions it provides. An assessment of these specific claims is given in Section 4 of my report.

3.2.3 Other Submissions

33. A number of submissions made in other technical areas contained elements relevant to this chemistry assessment. These reports either included claims already made within the reactor chemistry PSR (Ref. 1), or identified new chemistry related claims. While the full scope of the safety case presented by these reports did not form part of my assessment, any chemistry related claims did and they are assessed in Section 4. The main documents included:

- The Structural Integrity PSR (Ref. 12);
- The PSR on Radiation Protection Section 1 Definition of Radioactive Sources (Ref. 13);
- The PSR on Radioactive Waste Management System (Ref. 14);
- The PSR on Reactor Core and Fuels (Ref. 15);
- Fault Studies to Discuss Deterministic Analysis, PSA and Fault Schedule Development (Ref. 16);
- The Topic Report on Severe Accident Phenomena and Severe Accident Analysis (Ref. 17).

3.2.4 Responses to Regulatory Queries

34. At the time of writing this report I had raised 13 Regulatory Queries (RQs) with the RP. In addition, other technical areas in ONR raised a further 4 RQs which are of relevance to my assessment. These are discussed under the relevant sections below.

3.2.5 Draft Pre-Construction Safety Report

35. In addition, in May 2014 the RP submitted to ONR, for information, an advance copy of the UK ABWR Pre-Construction Safety Report (PCSR). Chapter 29 (Ref. 18) addresses reactor chemistry. Although I have not formally assessed this report as part of Step 2, seeing it has been useful to start planning and preparing my Step 3 work and has given me confidence that in the area of reactor chemistry the RP is capable of proceeding beyond Step 2.

4 ONR ASSESSMENT

36. This assessment has been carried out in accordance with ONR How2 BMS document PI/FWD, “Purpose and Scope of Permissioning” (Ref. 2).

37. The scope of the assessment is as defined previously in Section 2.1 of this report and, as defined by my Step 2 assessment plan (Ref. 5). The fundamental objective for this assessment was to identify any fundamental safety shortfalls that could prevent the issue of a Design Acceptance Confirmation (DAC). Therefore, I have focussed my assessment on the key chemistry claims, to ensure they are complete and reasonable, and to satisfy myself that they could be supported by detailed evidence in subsequent GDA steps.

38. My Step 2 assessment work has involved regular engagement with the RP’s reactor chemistry Subject Matter Experts (SME). Three main technical exchange workshops (two in Japan and one in the UK) and four progress meetings (mostly video conferences) have been held. I have also visited:

- Kashiwazaki Kariwa Units 6&7 ABWRs, where I viewed the majority of the facility;
- Hitachi Works, where I saw many of the completed reactor internals (including core supports, shroud, steam dryers and separators) and fuel assembly construction;
- the Ohma construction site, which is a partially built ABWR plant; and
- Japan Steel Works, where they make large forgings to use for ABWR Reactor Pressure Vessels (RPV).

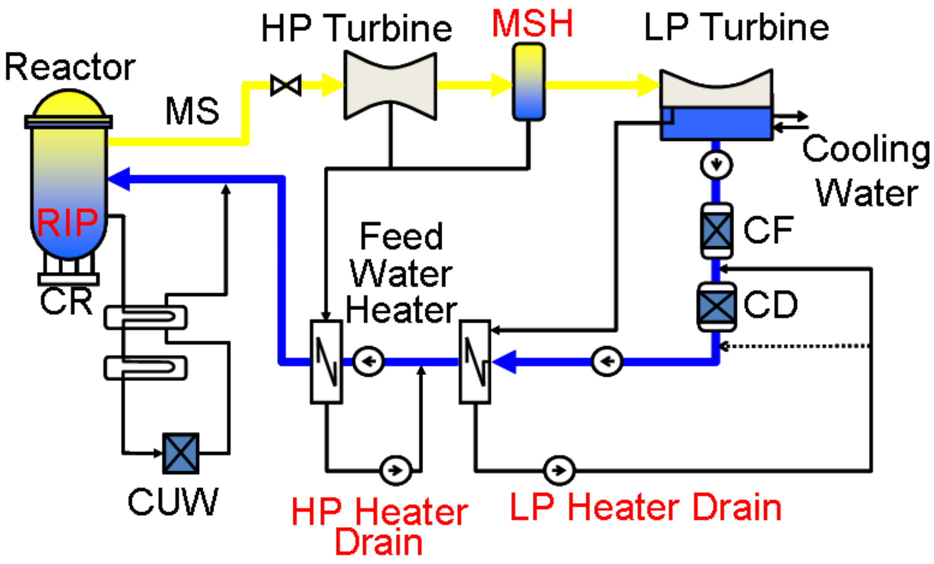
39. During my Step 2 assessment I have identified some shortfalls in documentation which have generally led to the issue of RQs; at the time of writing I have raised 13 RQs. Shortfalls in the safety case have generally led to the issue of ROs. I have raised 1 RO during Step 2.

40. Details of my Step 2 assessment of the UK ABWR safety case including the areas of strength that I have identified, as well as the items that require follow-up and the conclusions reached are presented in the following sub-sections.

4.1 Primary Cooling Water System

4.1.1 Assessment

41. The primary cooling water system is described in the reactor chemistry PSR (Ref. 1). It is in fact not a defined single plant “system”, but consists of elements of several systems that encompass the flow path for the reactor coolant when the reactor is at power. This therefore includes parts of the feedwater system, condensate clean-up system, reactor pressure vessel and internals, fuel, Reactor Water Clean-Up (RWCU) system, steam lines, turbine and associated drains and condenser. This is shown schematically in Figure 1, below.



KEY: CR = Control Rods; RIP = Reactor Internal Pumps; MS = Main Steam; HP = High Pressure; MSH = Moisture Separator Heater; LP = Low Pressure; CF = Condensate Filter; CD = Condensate Demineraliser; CUW = Reactor Water Clean-Up system.

Figure 1: Schematic of the Primary Cooling Water System

42. The coolant within the system therefore contacts many surfaces within this circuit, including the fuel, RPV, steam, feed, and other pipework which constitutes the primary and secondary containment boundaries for radioactivity generated within the plant. Due to the direct cycle nature of the plant the pressure and temperature conditions vary greatly around the system, as does the material choices for the various components. The operating chemistry for this system therefore needs to balance these conditions while meeting the safety functions. The importance of this system has meant that a large portion of my assessment in Step 2 has been focussed here.

43. Before discussing the claims made by the RP for this system, some background information on chemistry effects in the system during normal operations is described below, to give context to the assessment that follows. These effects show how some of the main hazards in this system arise, namely radioactivity, gaseous radiolysis products and conditions which could degrade fuel or structural materials.

- As described previously an important factor is that the coolant is allowed to boil. This means that the coolant must necessarily be of a high purity to stop aggressive species accumulating on the fuel or in the reactor water. Preventing this accumulation of impurities is primarily why a RWCU system is needed.
- Steam that is produced in the RPV is transferred to the turbine, condensed, purified, re-heated and then returned to the RPV as feedwater. This also means that any volatile impurities within the coolant can be carried within the steam to the turbine systems. Conditions are such that all of the steam path surfaces are expected to have a water film.
- Due to the volume of the RPV and steam flow rate, the residence time of a given water molecule within the RPV is large. This means that as water flows through the core and is exposed to ionizing radiation (especially neutrons) a wide variety of radiolysis products are produced. For simplicity, the main species can be considered to be hydrogen (H_2) and hydrogen peroxide (H_2O_2). During boiling H_2 partitions to the steam phase so the reactor water is oxidant rich. H_2O_2 decomposes to water (H_2O) and oxygen (O_2), and the relative proportions of these vary with time and distance away from the core. Expressed as O_2, pure reactor water in a typical BWR would have several

hundred parts per billion (ppb) O_2 and only tens of ppb H_2. Essentially, all of the radiolysis products eventually go up with the steam as H_2 and O_2. They therefore need to be recombined in the off-gas system, which draws the condenser vacuum (after the turbine), to prevent a flammable atmosphere from developing.

- Also in the core, some ^{16}O is activated to ^{16}N, which has a half-life of only 7 seconds but is a very high energy gamma emitter. During operations ^{16}N is the dominant radionuclide for dose. In pure water, without the purposeful addition of H_2, the most stable form of nitrogen in a BWR is nitrate (NO_3^-), which remains soluble and stays within the reactor water. Similarly other non-radioactive precursor species exposed to the core radiation field can become activated, particularly metallic corrosion products, notably leading to the production of radionuclides such as: ^{60}Co, ^{58}Co, ^{54}Mn and ^{51}Cr, which dominate shutdown dose rates.

4.1.1.1 Basis and Purpose of Chemistry Control

44. The reactor chemistry PSR (Ref. 1) gives a useful description of the basis and purpose of chemistry control in BWRs, including its historic development. The PSR reports only on normal operations, with other phases (for example commissioning or accidents) to be included as the PCSR develops during GDA. The stated purposes of maintaining fuel integrity, maintaining structural material integrity, reducing dose rates, minimising radioactive waste and minimising radioactive releases to the environment are entirely reasonable and meet my expectations. These are also broadly consistent with the claims made on chemistry in other submissions, for example the BAT assessment from the environment submissions (Ref. 19). This demonstrates that the RP is considering the scope of chemistry in an adequate manner and their approach is reasonable for this stage of GDA.

45. The PSR also describes the basis of chemistry control in this system for UK ABWR, and importantly some of the reasons for this choice. In current operating BWRs there are two main approaches to chemistry control for the primary coolant system, Normal Water Chemistry (NWC) or some form of Hydrogen Water Chemistry (HWC). Zinc addition and iron control have also been adopted by some BWR operators in both cases.

- NWC is the original regime applied to all BWRs, and is still used in many BWRs outside of the US, including ABWRs in Japan. This is a simple regime of very pure water only. The reason for this approach was to mitigate Trans-Granular Stress Corrosion Cracking (TGSCC) of stainless steels, a well-known degradation mechanism for this family of materials when exposed to oxygenated environments with chlorides. This approach, however, failed to recognise the extent of the corrosive environment inherent to BWR operations (as described in para. 43 above) and early BWRs consequently suffered extensively from Intergranular Stress Corrosion Cracking (IGSCC) and other types of corrosion, particularly on external recirculation piping and core internals. Later plants addressed this through a combination of design, material and chemistry changes.
- HWC builds upon NWC but also includes the purposeful addition of hydrogen to the reactor water to turn the environment from oxidising to reducing, providing the opportunity to mitigate IGSCC of piping and reactor internals. Due to the water radiolysis and boiling processes in the core the amount of hydrogen necessary to provide mitigation to some parts of the plant can be high (and in some cases physically unobtainable). High hydrogen concentrations in the reactor water also changes the stable chemical form of ^{16}N to more volatile species such as $[NH_4]+$, increasing dose rates in the steam

and turbine systems by factors of up to five. Noble metal addition can be used to mitigate this increase. Noble metals act as efficient catalysts for the recombination reaction of hydrogen and oxygen, converting them back to water. On-Line NobleChem™ (OLNC) involves adding very small concentrations of noble metal chemicals to the feedwater for short set periods of time while the plant is at power, coating the reactor internals with nano-particles of catalyst, but repeated application is necessary to maintain protection.

- The addition of small quantities of zinc to the reactor coolant can reduce the level of radioactivity generated in the plant. Zinc is preferentially absorbed into the corrosion films reducing the uptake of cobalt and hence the deposition of cobalt activation products.
- Iron is the main corrosion product transported to the reactor from the feedwater system, with too little or too much iron increasing radioactivity and potentially interfering with other effects such as fuel crud generation and zinc addition. The optimum iron concentration is therefore plant design and chemistry specific, but is an important parameter to control.

46. The PSR notes that the proposed chemistry regime for UK ABWR will be HWC, OLNC and zinc addition, in addition to maintaining the high purity water required for NWC and controlling iron levels. This is an important decision taken by the RP, and it would be the first time that any BWR, including ABWRs, started operations under this chemistry regime (as all existing plant started under NWC). The implicit claim here is therefore that this regime reduces risks to ALARP. This appears to be a reasonable claim at this stage of GDA, but the arguments and evidence which support this claim, plus the engineering substantiation of the systems which deliver chemistry control in the primary systems, will be an important area of assessment for Steps 3 and 4 of GDA. This will also need to specifically consider the adoption of this technology on a new plant, as opposed to retro-fitting to an existing one, and the importance of these chemistry parameters in maintaining safety.

4.1.1.2 Claims on Chemistry Control

47. There are two explicit claims made for this system in Ref. 1:

- "*The chemistry regime for UK ABWR maintains the integrity of the fuel and structures in the reactor pressure vessel and reactor coolant system boundary.*"
- "*Radiation source term is minimized so far as is reasonably practicable by the combination of material selection and optimum water chemistry control to reduce operational radiation exposure.*"

48. I consider these to be reasonable claims, but they are currently at a high level for this important system. As the safety case develops I would expect more definition will be needed, including:

- The particular claims made on each chemistry parameter (for example, for hydrogen, zinc or iron) and the detailed chemistry controls that are needed for UK ABWR. It may be beneficial for the RP to consider splitting the safety case for the primary cooling water system into feedwater and reactor water. While these are linked, the chemistry control in each is somewhat distinct and the claims, arguments and evidence may be different. This may also make the safety case clearer. The reactor chemistry PSR (Ref. 1) goes some way towards describing these, but they are not explicitly called out in the report. For example:

  - Increased iron input to the reactor can increase dose rates, create deposits on fuel and is indicative of enhanced corrosion in the feedwater system. Conversely too little iron can also increase dose rates. To this end there are important claims made on maintaining a small amount of dissolved oxygen in the feedwater and controlling feedwater iron levels using the condensate purification and RWCU systems. I understand that the precise method of iron control can be important and the RP will need to develop their claims in this area further.
  - Some impurities, such as copper, may be particularly harmful for fuel cladding. The RP claims that there are no copper sources in the primary system of UK ABWR, but this may not necessarily relieve the need for control over these species.

- I would also expect that other claims may need to be made on the chemistry regime, and I have already identified instances of these implicit claims within the RP's submissions, as described in more detail in subsequent sections of my assessment, below.
- I would expect that there will also be claims made on those engineered systems which provide the necessary level of chemistry control, for example the RWCU system, condensate purification system and feedwater hydrogen dosing equipment etc.
- As noted, the PSR considers normal operations, including reactor start-up and shutdown. Although the description of these phases in the PSR is more developed for the primary cooling water system, the safety case will need to evolve to describe the effects of chemistry during these important periods further (for example, the impact of shutdown chemistry on radioactivity). This may mean that other claims will be needed to cover these phases.

49. I would expect the safety case to develop to include these requirements, including the arguments and evidence necessary to underpin them. I see no reason why this cannot be done. I judge that a suitable evidence base to support these claims, or the more detailed claims described above, could be provided by the RP during GDA.

50. Due to the significance and complexity of this system, I have considered the more specific application of these claims further below.

4.1.1.3 Materials

51. As is common for all reactor systems, the operating chemistry is part of the environment but it is the materials that are subject to degradation. The nature, severity and likelihood of this degradation are therefore a function of both the material choices and operating chemistry (plus other factors such as stress). The RP has recognised this in the reactor chemistry PSR (Ref. 1), and described the chemistry impact on some of the main mechanisms, particularly Stress Corrosion Cracking (SCC). This is part of the claim made on chemistry, "…*chemistry … maintains the integrity of the … structures in the reactor pressure vessel and reactor coolant system boundary*". Similarly, the structural integrity PSR (Ref. 12) makes a similar claim to the reactor chemistry PSR, but from the materials perspective (i.e. that the material choices reduce risks ALARP). This is not unexpected given the historic prevalence of SCC in BWRs.

52. Both of these PSRs (reactor chemistry and structural integrity) provide some information in relation to common degradation mechanisms for BWRs, but not specifically for UK ABWR. Those degradation mechanisms that can be influenced by the chemistry include SCC of stainless steels and nickel base alloys (TGSCC, IGSCC

and Irradiation Assisted SCC (IASCC)), and Flow Accelerated Corrosion (FAC) of feedwater piping. Several publicly available reports, including by the US Nuclear Regulatory Commission (Ref. 20) and EPRI (Ref. 21) describe potential corrosion threats to BWRs. The RP claims that such threats have been considered in the design and that mitigation and monitoring strategies will be provided later in GDA. I consider this to be reasonable for Step 2, but it will be important going forward for the RP to demonstrate what the risks are for UK ABWR, where they apply in the design and to justify that the balance of mitigation approaches (via materials, chemistry or monitoring) is appropriate.

53. More information on the approach to SCC mitigation in UK ABWR is provided in Ref. 22, which is a high level document summarising the basic approach. Most of the report is materials related, with only a small section related to water chemistry. The basis of the RP’s approach for ABWR is to select materials with an inherently low SCC susceptibility. In the context of chemistry, this report highlights low conductivity (as per NWC in Japanese ABWRs), degassing before operations and describes HWC as “*… additional techniques to other engineering mitigation… ”*. While this is reasonable at this stage, it is very high level and, as above, I would expect further details and clarity to be provided as GDA progresses, particularly in relation to the importance of chemistry mitigations and areas of residual risk. Clarity will also be needed over whether the mitigations are specifically aimed at inhibiting SCC crack initiation, propagation or both.

54. The critical parameter adopted in BWRs when relying on chemical means to mitigate SCC is to measure the Electro-chemical Corrosion Potential (ECP) of the structural materials. The significance of this parameter, and hence how it is monitored and controlled will be important aspects of the safety case I would expect the RP to develop as GDA progresses.

55. I have already identified examples of where the material choices for UK ABWR need to be justified. These are examples of where the chemistry choices may affect the design. There may be others and it will be important for the RP to demonstrate during GDA that this has been fully recognised in their design. The RP has committed to producing a “*material selection*” report early in Step 3 (RQ-ABWR-0084 (Ref. 23) refers), which I would expect to address these matters, amongst others.

- The RP has identified a possible material change to some of the RWCU piping, from carbon steel (as in existing ABWRs) to stainless steel, as described in the reactor chemistry PSR (Ref. 1). Under HWC conditions the dose rates in this piping would be high, potentially causing significant operator dose uptake during outages. Changing the material to stainless steel would alleviate this increase, but it would also mean that SCC of this piping may become possible.. The RP continues to evaluate which option is ALARP, but there will be claims made on the operating chemistry for whichever material is selected. Part of this potential change may involve the “*drain line*” from the RPV. I queried several aspects of this in RQ-ABWR-0082 (Ref. 23), including whether such a line was still needed for UK ABWR. The response indicated that crud accumulation and thermal gap concerns make a “*drain line*” necessary. Further justification will be needed in this area and I will progress this aspect during Step 3.
- The main feedwater lines in UK ABWR are carbon steel. There are various technical reasons for this, but it does mean that they are susceptible to FAC and it is necessary to maintain a small amount of dissolved oxygen in the feedwater to mitigate this risk. I queried the basis of this choice in RQ-ABWR-0103 (Ref. 23). The response did not provide the level of justification I was expecting and hence this aspect will also be followed up in Step 3.

56. Overall, I am content with the information provided on materials in the submissions for Step 2. I have identified areas where further work will be required moving forward, and based on what I have seen to date I believe this area will attract significant scrutiny in later steps. I have no reason to doubt that the RP will be able to provide an adequate safety case in this area, and have identified how this can be progressed, but a concerted effort by the RP, including coordination amongst technical disciplines, will be required to achieve this.

4.1.1.4 Radioactivity

57. There are essentially two mechanisms which lead to the production of radionuclides in a BWR. The first of these is fission of fuel material. Fission products are nominally contained within the fuel by the cladding, but defects can occur during operational states and release radioactivity to the coolant. The second mechanism is via activation of other materials, including structural elements in or around the core, the coolant (either water itself or species dissolved in it) and, most importantly for radiation field control, transition metals present in corrosion products. In the absence of fuel defects the activation of the coolant and species dissolved in it account for the vast majority of radioactivity within the primary coolant of an operational BWR. The control of coolant chemistry is therefore important to radiation field control and hence dose rates, and ultimately to radioactive waste management and discharges.

58. The reactor chemistry PSR (Ref. 1) recognises the importance of this relationship; making several implicit and one explicit claim (see Section 4.1.1.2). The implicit claims include:

- the use of more corrosion resistant steels for the condenser and heater drains;
- improved condensate clean-up system efficiency;
- adoption of oxygen injection into the feedwater;
- reduction of cobalt content (via Stellite™ reduction and use of low cobalt alloys); and
- use of zinc injection (as Depleted Zinc Oxide (DZO)).

59. The structural integrity PSR (Ref. 12) also makes claims on "*stainless steel … reactor internals will also reduce the occurrence … and level of radiation from the corrosion products"* and "*… low-cobalt steels will be used to minimise* ^{60}*Co*".

60. I judge these to be reasonable claims to make and to be of the type I would expect to see. I judge that it should be possible to provide suitable evidence to support these; for example RQ-ABWR-0002 (Ref. 23), queried the use of Stellite™ in UK ABWR. The response explained the general philosophy, and gave some information on the impact of various cobalt sources. It did also indicate that some of the less significant improvements made for Japanese ABWRs may not be included in UK ABWR, potentially leading to a slightly increased cobalt source term. This will be followed up during Step 3, as part of the work described below.

61. While the claims themselves are reasonable, there is currently no information presented on the likely radioactivity levels in the UK ABWR. The reactor chemistry PSR (Ref. 1) did not quantify the level of radioactivity expected in UK ABWR and none of the other Step 2 submissions did either (Refs 13 or 14 in particular). For example, the PSR for radiation protection (Ref. 13) defines what the sources of radiation are and claims they are conservative, but does not quantify what they are. This claim is based on a report summarising industry experience up to 1973 (and therefore does not consider the chemistry, nor materials proposed for UK ABWR). I consider this to be a key deficit in meeting my expectations for Step 2. I would have expected to be

provided with information on the likely level of radioactivity in the plant, even if the supporting evidence was not yet fully available.

62. Overall, while the claims made on chemistry related aspects of radioactivity in UK ABWR appear reasonable to make for Step 2, there is currently a lack of information on the radiological source terms. This will need to be a key part of justifying the design going forward. This has highlighted two main areas where further justification and evidence will be needed, namely:

- to define and justify the source terms for UK ABWR, including how these are used; and
- to demonstrate the impact of the material choices, operating chemistry and operating practices on radioactivity in the plant and to show that these reduce radioactivity ALARP.

63. To address these aspects I raised RO-ABWR-0006 and seven associated actions (Ref. 24) jointly with other related ONR technical areas and the Environment Agency. Resolution of this RO will also address several other chemistry aspects that will need to be considered, such as the behaviour of different species in the coolant and the influence of the various chemistry parameters on radioactivity generation, transport and accumulation. At the time of writing this report, I have reviewed a draft resolution plan for this RO and I judge it to be credible, giving me confidence that the RP will be able to address my concerns.

64. One aspect of the UK ABWR design which will influence the control and amount of radioactivity produced by the plant is the arrangement of the feedwater heater drains in the primary coolant system. For UK ABWR the contents of the high pressure heater drain tanks are pumped directly to the main feedwater line and the contents of the low pressure feedwater drains are returned to the outlet side of the condensate filter. I raised RQ-ABWR-0079 to seek further clarification as to why this arrangement has been selected for UK ABWR. The response (Ref. 23) highlights the commercial benefits of the current design but does not address the safety implications. This is an example of the type of justification I would expect to be provided as part of the response to RO-ABWR-0006.

65. Radioactivity will therefore be an important part of the Step 3 reactor chemistry assessment of UK ABWR.

4.1.1.5 Fuel

66. The PSR on reactor core and fuels (Ref. 15) highlights the key safety functions for the design. Reactor chemistry contributes towards two of these, “*removal of heat* …” and “*containment of radioactive substances …*”, through ensuring that corrosion or degradation of the fuel and crud deposits are minimised. The reactor chemistry PSR (Ref. 1) similarly notes the importance of chemistry on crud and corrosion related fuel issues, including the explicit claims on fuel integrity and minimisation of radioactivity. The main inference is that the controls necessary to mitigate SCC are also adequate to minimise fuel degradation, in particular dissolved oxygen and impurity minimisation.

67. Historically there were high numbers of BWR fuel failures, caused by many factors of which operating chemistry control was one. Fuel failures in modern BWR fuel are infrequent and stringent water chemistry control is a contributory factor to this. While chemistry related fuel failures during operation are unlikely, the impact of chemistry controls during start-up and shutdown periods on radioactivity release from leaking fuel may be important for this reactor given the direct cycle nature of the plant. The PSR provides only limited information on start-up and shutdown periods. While I would not

expect the interactions between fuel and the operating chemistry to be an important factor for the UK ABWR design, the RP will still need to provide the necessary evidence later in GDA to demonstrate that this is the case.

4.1.1.6 Radiolysis Products and Off-Gas Treatment

68. While strictly not part of the primary cooling water system, the reactor chemistry PSR does not consider the off-gas system for UK ABWR, nor does it mention the treatment of radiolysis products or volatile radioactive species. It is convenient however, to discuss this matter here. The PSR on Radioactive Waste Management System (Ref. 14) describes the UK ABWR off-gas system. This system draws the vacuum from the main condenser, via Steam Jet Air Injectors (SJAE) and processes the gas stream through recombiners (to remove hydrogen) and charcoal beds (to hold-up radioactive noble gases before discharge).

69. I have not considered the chemistry related aspects of this system in detail during Step 2, but will do so later in GDA due to its safety significance. I raised RQ-ABWR-0083 (Ref. 23) requesting the RP to provide some information on this system, in particular the function of abatement of discharges. The response answered my queries and represents a good starting point for my more detailed assessment in Step 3.

70. As described previously (Para. 43) while the radiolysis of the water coolant in BWRs has important consequences for the operating chemistry, it is also a significant hazard in its own right that needs to be mitigated and controlled by the design. As a result, all BWRs feature an off-gas system to remove the gaseous radiolysis products, i.e. hydrogen and oxygen, by recombining them back to water. Where this is inefficient and accumulation occurs there is the possibility of a hydrogen deflagration. There is a history of such events in BWRs, for example Refs 25, 26 and 27, and hence I would expect a modern design to take this into account and present this as part of the safety case.

71. In the context of control of radiolysis gases, the radioactive waste PSR (Ref. 14) does make claims on the off-gas system: "*reduces the risk of explosion … by providing hydrogen recombiners and ensuring that sufficient driving steam is supplied to the SJAE*". The presentation of safety claims in this PSR is complex and this stems from a main safety claim of *"… minimises the release of gaseous radioactivity generated by plant operation …*". In isolation these claims appear reasonable but given the potential safety significance of the off-gas system and the importance of demonstrating that radiolysis gases can be safely managed by the design, I judge that the safety case needs to develop to better represent these aspects. In order to address this I raised RQ-ABWR-0080, (Ref. 23) related to the generation of radiolysis gases. The RP's response indicates that UK ABWR is designed to a Japanese nuclear industry body standard on preventing the accumulation and combustion of radiolysis gases in vessels and pipework. Based on this response I have confidence that this matter can be addressed more comprehensively by the RP as GDA progresses.

72. The control of radiolysis gases are of interest to a number of other ONR assessment areas. Therefore, I will be part of a multi-disciplinary ONR team that will follow-up this topic during Step 3, to ensure that the structure of the safety case develops in a manner that adequately accounts for the hazards posed by radiolytic gases and demonstrates that the risks have been reduced to ALARP.

4.1.2 Strengths

73. The RP has identified, at this early stage, the operating chemistry for the primary cooling water system on which they intend to base their safety and environmental

submissions to support GDA. It has linked this to the main safety related purposes it provides and has identified a reasonable set of high level claims, upon which further development of the safety case can be based. The RP appears to be considering the impact and interactions of the water chemistry choices in an appropriate manner.

4.1.3 Items that Require Follow-up

74. During my Step 2 assessment of the chemistry aspects of the primary cooling water system I have identified the following shortcomings:

- Definition and justification of the radiological source terms for UK ABWR during normal operations, including demonstration that the risks are reduced SFAIRP. This is covered by RO-ABWR-0006 (Ref. 24);
- Management of radiolysis gas generation, accumulation and mitigation and its justification within the safety case;
- Justification for the material choices for UK ABWR and how this interacts with the operating chemistry and arguments which may be made regarding structural integrity and minimisation of radioactivity.

75. I have identified the following specific areas that I will follow-up during Step 3 (in addition to assessing the arguments that support the safety claims, provided by the RP during Step 2, related to the chemistry of the primary cooling water system):

- Further development of the claims, including the specific claims associated with each individual chemical parameter (i.e. hydrogen, platinum (noble metal) and zinc) and the claims for those engineered systems which control or deliver the operating chemistry;
- Implications for adoption of HWC, OLNC and zinc at an ABWR for the first time;
- The sampling and analysis arrangements which are part of the design;
- The chemistry controls during and effects of start-up and shutdown periods;
- Justification for some specific aspects of the design which have an impact on the operating chemistry, for example:
    - the arrangement of the feedwater heater drains (RQ-ABWR-0079 (Ref. 23) refers);
    - the capacity of the RWCU system; and
    - measures to mitigate seawater ingress (RQ-ABWR-0134 (Ref. 23) refers).
- Identification and development of chemistry related limits and conditions, particularly for those parameters which are not part of the Japanese ABWR operating chemistry with which the RP is familiar.

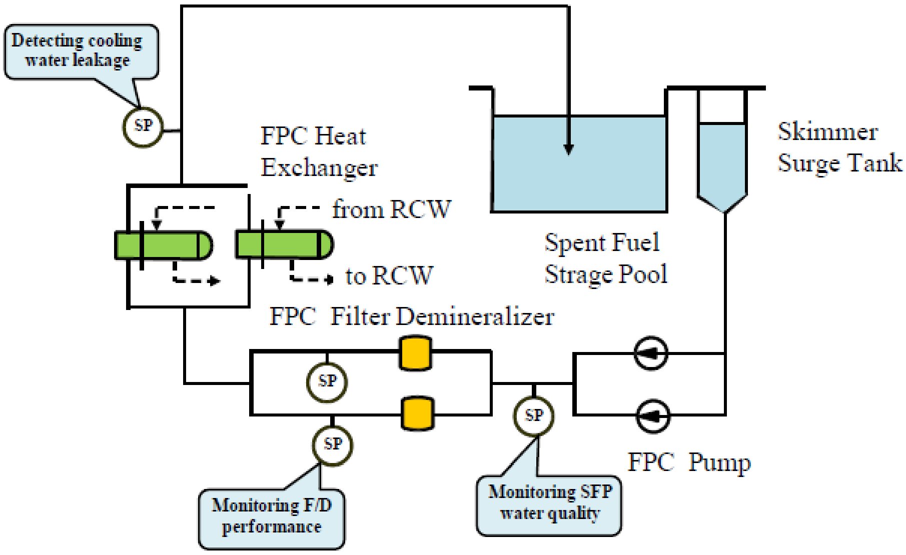
4.1.4 Conclusions

76. Based on the outcome of my assessment of the chemistry of the primary cooling water system, I have concluded that, while the claims identified for this system are at a high level at this stage, they are reasonable and I judge that they form an adequate basis for further development of the safety case. There are other claims made by the RP, although not explicit, which demonstrate that the RP has identified where chemistry plays a part in making the safety case for the design. I would expect a large portion of the remaining work required by the RP, for my assessment later in GDA, to be focussed on justifying the chemistry, materials, design and operations for the primary cooling water system. At this stage I have not identified any fundamental shortfalls which would suggest that this justification cannot be provided.

4.2 Spent Fuel Pool

4.2.1 Assessment

77. The UK ABWR Spent Fuel Pool (SFP) is described in the reactor chemistry PSR (Ref. 1). The system consists of a steel lined concrete pool which contains the fuel in borated stainless steel racks. The pool itself is filled with demineralised water. Unlike fuel pools at some other reactors Hitachi-GE claim there is no requirement on chemistry controls to maintain a sub-criticality margin i.e. the pool does not contain a soluble neutron poison in the form of boron (as other fixed poisons are used). The water is circulated for cooling and purification purposes. This is shown schematically in Figure 2, below.



KEY: SP = Sampling Point; FPC = Fuel Pool Cooling system; RCW = Reactor Cooling Water system; F/D = Filter Demineraliser.

Figure 2: Schematic of the Spent Fuel Pool

4.2.1.1 Basis and Purpose of Chemistry Control

78. The reactor chemistry PSR (Ref. 1) gives a succinct description of the basis and purpose of chemistry control in the SFP. This notes that the control of water chemistry in the pool minimises corrosion of the fuel, pool liner and storage racks. Adequate temperature control is also important for this purpose. Purification, in addition to maintaining water quality and removing radioactivity, maintains the clarity of the pool water, which is especially important during refuelling outages and fuel movements. The text also notes that, as the SFP water is mixed with the reactor water during refuelling, the SFP water quality must meet or be better than that required for the reactor during outages.

4.2.1.2 Claims on Chemistry Control

79. There are two explicit claims made for this system in Ref. 1:

- "*The chemistry of the spent fuel pool contributes to maintaining the integrity of the fuel and spent fuel pool structures and liner during refuelling, normal operations and storage.*"
- "*The chemistry regime of the spent fuel pool ensures that occupational radiation exposure (ORE) is kept ALARP.*"

80. I consider these to be reasonable claims, consistent with the basis and purpose described above. However, these claims do not reflect the point regarding mixing of the SFP and reactor water during outages. This is an important claim on the chemistry control in this system, which is noted in the PSR but not explicitly. Unlike the primary cooling water system, I am content that these claims appear to be at a reasonable level, given the simplicity of chemistry control in this system. However, I again consider that claims on the engineered systems which support the SFP chemistry control will be needed.

81. The claim on reduction of radioactivity ALARP in the SFP is important. I would expect this to be addressed as part of the response to RO-ABWR-0006 (Ref. 24).

82. In addition to the reactor chemistry PSR (Ref. 1), the RP also submitted an initial safety report on the SFP (Ref. 28). This document is mainly concerned with criticality hazards and loss of cooling faults, but does note the functions of the SFP clean-up systems in removing impurities, including radioactivity. This report also discusses the release of radioactive material in cases of boiling in the SFP, claiming this release to be small. It is not clear at this early stage in the development of the safety case why this particular claim needs to be made, but if required I will consider the chemistry aspects of it later in GDA.

83. Overall, I consider that the RP has made a reasonable start in preparing the chemistry related safety case for the SFP. While there will be more development needed during GDA, I am confident that this can be progressed by the RP during later stages of GDA.

4.2.2 Strengths

84. The RP has defined a reasonable basis on which to develop the chemistry related aspect of the SFP safety case for UK ABWR. The identified claims are reasonable and I judge that the RP will be able to provide the arguments and evidence to support these claims.

4.2.3 Items that Require Follow-up

85. During my assessment I have identified the following specific areas that I will follow-up during Step 3 (in addition to assessing the arguments that support the safety claims, provided by the RP during Step 2, related to the chemistry of the SFP):

- Further development of the chemistry related aspects of the safety case for refuelling operations in UK ABWR;
- Claims associated with those engineered systems which control or deliver the operating chemistry;
- The sampling and analysis arrangements which are part of the design.

4.2.4 Conclusions

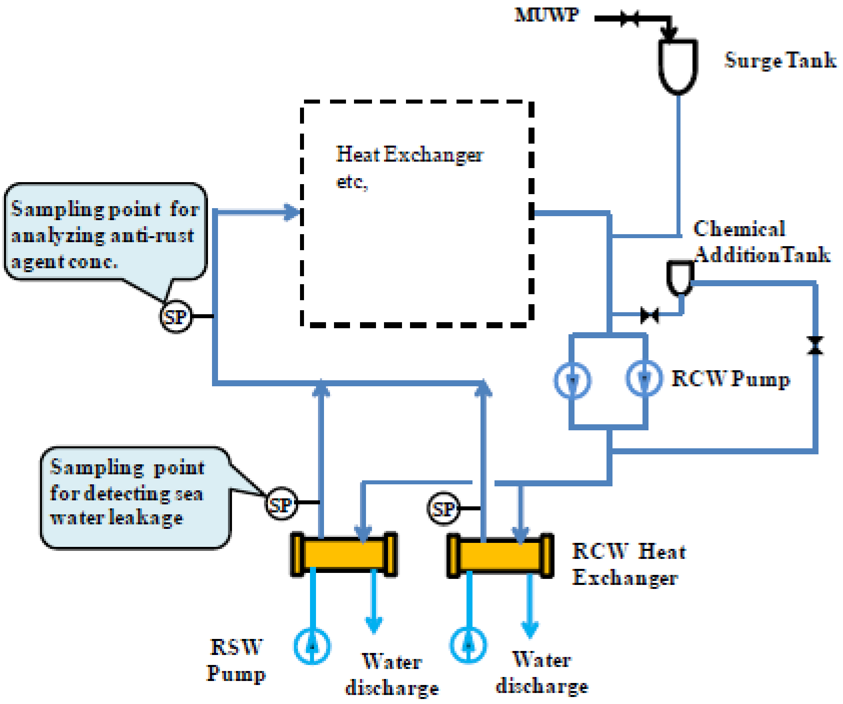
86. Based on the outcome of my assessment of the chemistry of the SFP, I have concluded that the RP has provided an adequate PSR for the operational chemistry aspects of this system. I am confident that the RP will be able to provide the expected level of arguments and evidence to support their claims

4.3 Component Cooling Water System

4.3.1 Assessment

87. The UK ABWR features a number of independent cooling water systems the function of which is to remove heat from process components, such as the SFP heat

exchangers or RWCU heat exchangers. These systems include the Reactor building Cooling Water (RCW), Reactor building Service Water (RSW) and turbine island cooling systems. The reactor chemistry PSR (Ref. 1) provides some basic overview information on these systems, noting that the detailed design (including materials and heat exchanger types) will be provided later in GDA, but that carbon steel is expected to be used for the main piping. The PSR uses the RCW system as an example; the RCW is a closed loop in which coolant is re-circulated to the components and the heat is rejected to the RSW system via heat exchangers. Corrosion inhibitors and make-up water are provided via an addition and surge tank. This is shown schematically in Figure 3, below.



KEY: SP = Sampling Point; RSW = Reactor building Service Water system; RCW = Reactor Cooling Water system; MUWP = Make-Up Water Purified system.

Figure 3: Schematic of the Reactor Cooling Water System

4.3.1.1 Basis and Purpose of Chemistry Control

88. The reactor chemistry PSR (Ref. 1) states that the main purpose of chemistry control in the RCW, and other component cooling water systems, is to prevent corrosion damage and hence maintain the cooling function. There is some discussion of the chemistry control regime, citing nitrite with pH control and possibly a copper corrosion inhibitor. As the system designs are not yet fully defined the selection of an appropriate operating chemistry regime is similarly uncertain. However, chemistry control of such closed cooling water system is standard across many nuclear plants and several options are available.

4.3.1.2 Claims on Chemistry Control

89. There is one explicit claims made for the component cooling water systems in Ref. 1:

- “*The chemistry of component cooling water minimizes the corrosion of its system materials to maintain their integrity and heat transfer function.*”

90. I am content that this claim is reasonable, given the relative simplicity of chemistry control in these systems. I do consider that other claims may become apparent for these systems as the safety case develops, for example in relation to minimising any harmful effects of leakage. I am content that their absence at this stage does not detract from any fundamental issues, from a chemistry perspective, with these systems. As is common with the other aspects considered in the PSR, I consider that claims on the engineered systems which support the chemistry control for the component cooling water systems will also be needed.

91. Overall, I consider that the RP has made a reasonable start in developing the safety case for the component cooling water systems for UK ABWR, given the on-going detailed design work. I am confident that this can be progressed by the RP during GDA.

4.3.2 Strengths

92. Despite some uncertainty over the system design and operating chemistry, the RP has started to consider the operating chemistry requirements for these systems. The claim made on chemistry at this stage is reasonable.

4.3.3 Items that Require Follow-up

93. Aside for making firm decisions over the chemistry, materials and design of these systems, I have identified no specific items for follow-up for the component cooling water systems, over and above the expected provision of arguments and evidence, and supporting engineering substantiation required to support the safety case.

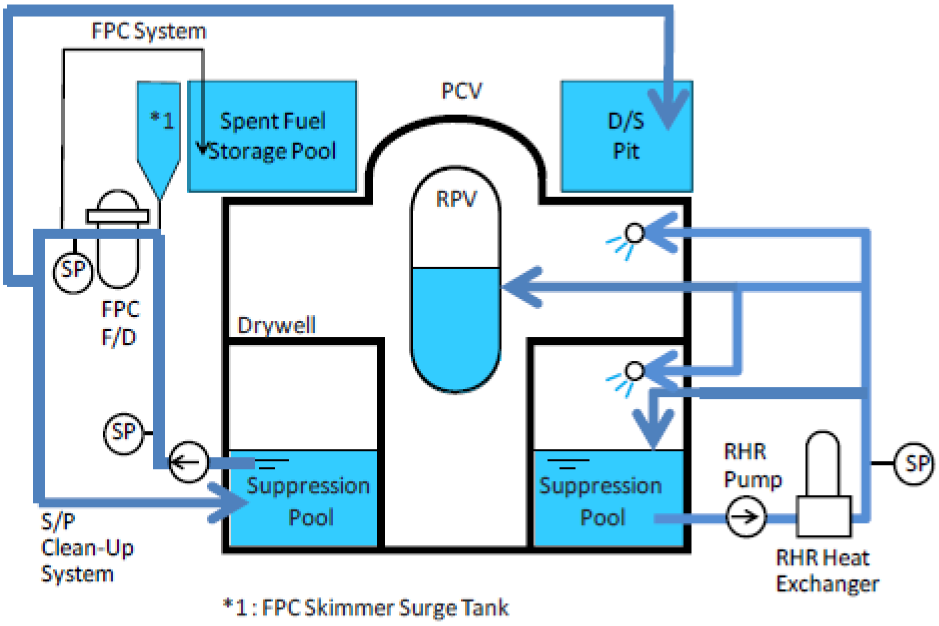
4.3.4 Conclusions

94. Based on the outcome of my assessment of the chemistry of the component cooling water systems, I have concluded that while the RP has not yet completed the detailed design for these systems, the information and claims that have been provided are sufficient to support Step 2. However, more information will be needed in the short term to allow my assessment of the chemistry of these systems to progress much beyond this.

4.4 Suppression Pool

4.4.1 Assessment

95. The suppression pool for UK ABWR is shown schematically in Figure 4, below.



KEY: SP = Sampling Point; S/P = Suppression Pool; FPC = Fuel Pool Cooling system; F/D = Filter Demineraliser; RPV = Reactor Pressure Vessel; PCV = Primary Containment Vessel; D/S = Dryer Separator, RHR = Residual Heat Removal system.

Figure 4: Schematic of the Suppression Pool and related systems

96. The suppression pool is a large volume, steel lined water store located at the bottom of the Primary Containment Vessel (PCV) that has functions during both normal operations and accident conditions. The pool contains demineralised water, which can be further purified using the SFP demineralisers. In normal operations the pool is the water source for filling the reactor well during refuelling and can also be the water source for other systems in certain conditions, such as the Residual Heat Removal (RHR) system. During a Loss of Coolant Accident (LOCA) the water in the pool is used:

- to quench steam released into the drywell by the reactor (either via the drywell connecting vents or drywell sprays);
- as a make-up coolant source; and
- to trap iodine releases in cases of fuel failures.

4.4.1.1 Basis and Purpose of Chemistry Control

97. The reactor chemistry PSR (Ref. 1) highlights that the main purposes for chemistry control in the suppression pool are to suppress volatile iodine during accidents and to supply pure water during refuelling. As the pool contains demineralised water the main chemistry control is to minimise impurities via the SFP demineralisers. I would expect radioactivity and impurity burden in this system to be low during normal operations.

98. During accidents, when the main chemistry focus of the suppression pool shifts to minimising volatile iodine, the PSR describes the chemistry controls. These relate to maintenance of an adequate pH which would ensure most of the iodine remains in the water phase. As the water does not contain a pH control additive (is unbuffered), relatively minor additions of impurities may have a large effect on the pH, for example even the absorption of carbon dioxide from air during outages may lower the pH significantly. The reference used by the RP to justify the effect of pH on iodine retention in the water is old, from 1981, and may not fully reflect some of the advances in understanding of iodine chemistry that have occurred in the last 25 years.

4.4.1.2 Claims on Chemistry Control

99. There is one explicit claim made for this system in Ref. 1:

- "*Suppression pool chemistry reduces the release of radioisotopes from the Reinforced Concrete Containment Vessel (RCCV) so far as is reasonably practicable during accident scenarios.*"

100. As with the SFP, this claim does not account for the main operational use of the suppression pool, namely as a source of clean water for refuelling and make-up for other systems. This is noted in the PSR, but no explicit claim is made. As is common with the other systems considered in the reactor chemistry PSR, I judge that additional claims may need to be made on the engineering systems which support this chemistry control, and on the impact of the suppression pool chemistry on the pool itself and the other systems it feeds. I would expect the RP to be able to justify these claims.

101. More significantly, based on the information presented by the RP to date I do not judge that the chemistry regime proposed for the suppression pool reduces risks ALARP. I will therefore require further information in order to understand the significance of this claim and be satisfied that it can be adequately substantiated, including:

- Ref. 29 indicates that it is well-known that minimising volatile iodine requires the water solution containing iodine to be basic (pH > 7) as opposed to acidic as suggested for UK ABWR. The RP will need to present robust arguments and evidence to justify that this meets relevant good practice and reduces risks ALARP.
- As the suppression pool in UK ABWR is unbuffered the pH will be dominated by chemical species introduced during an accident, for example from fuel degradation products. These will include a wide range of species that could be both acidic and basic in nature. Any argument based on pH would need to consider these appropriately.
- The speciation of iodine during the accident may be important, particularly if volatile organic iodine species form that are difficult to remove;
- The evidence which supports the claimed behaviour of iodine will need to be demonstrated to be suitable for conditions in UK ABWR (for example, under nitrogen atmospheres as opposed to air) and consistent with the current understanding of iodine behaviour;
- The overall safety case for accidents in UK ABWR, including the significance of this claim and when it may be needed.

102. I also note that the PSR suggests that sampling of the suppression pool may be difficult, with no direct sampling possible. This appears at odds with the chemical control requirements, particularly to assure a minimum pH and purity.

4.4.2 Strengths

103. The RP has identified the importance of chemistry control in the suppression pool and have started to recognise the claims that should be made for this system. I agree that the claim made regarding iodine retention during accidents will be important for UK ABWR.

4.4.3 Items that Require Follow-up

104. During my assessment I have identified the following specific areas that I will follow-up during Step 3 (in addition to assessing the arguments that support the safety claims, provided by the RP during Step 2, related to the chemistry of the suppression pool):

- The justification for the claim regarding pH control in the suppression pool, in particular whether it reduces risks ALARP;
- Further development of the claims for the suppression pool, including those engineered systems which control or deliver the operating chemistry;
- Details on other uses for the suppression pool water and relevance of the suppression pool water chemistry for these.
- The sampling and analysis arrangements which are part of the design;
- Identification and development of chemistry related limits and conditions.

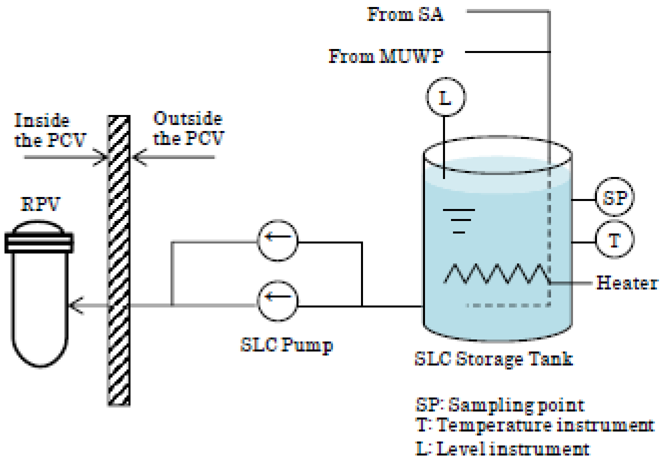
4.4.4 Conclusions

105. Based on the outcome of my assessment of the chemistry of the suppression pool, I have concluded that the RP has provided a sufficient safety case to support Step 2 of GDA, in that it has identified the most safety significant claims on chemistry for this system. However, I have identified that for the claim related to suppression of iodine volatility to be justified, the RP will need to provide robust arguments and evidence to demonstrate that the design meets relevant good practice and reduces risks ALARP.

4.5 Standby Liquid Control System

4.5.1 Assessment

106. The Standby Liquid Control (SLC) system consists of a storage tank and pumps which are designed to deliver a solution of sodium pentaborate to the reactor in the event of an Anticipated Transient Without Scram (ATWS) where the control rods do not fully insert. The boron solution is intended to bring the reactor to sub-criticality from full power and to maintain the reactor at a suitable sub-criticality shutdown margin. The SLC is shown schematically in Figure 5, below.



KEY: RPV = Reactor Pressure Vessel; PCV = Primary Containment Vessel; SLC = Stand-by Liquid Control system; SA = Service Air system; MUWP = Make-Up Water Purified system.

Figure 5: Schematic of the Standby Liquid Control system

4.5.1.1 Basis and Purpose of Chemistry Control

107. The main purpose of chemistry control in the SLC is to ensure that a sufficient reservoir of soluble boron is available to achieve sub-criticality. The solution itself is prepared directly in the tank, using demineralised water as make-up and air sparging. Precipitation is prevented via the use of submerged heaters.

4.5.1.2 Claims on Chemistry Control

108. There are two explicit claims made for the SLC system in Ref. 1:

- "*In the event of an ATWS, sufficient boron is supplied from the SLC to achieve cold sub criticality of the reactor.*"
- *"The design and chemistry of the SLC reduces corrosion within the SLC system so far as is reasonably practicable.*"

109. I consider these claims to be reasonable for Step 2 of GDA. I would consider the provision of arguments and evidence to support these should be part of the RP's safety case development during GDA and I see no reason why this cannot be provided. Similar to the other systems considered, there will be further claims necessary on the engineering systems which support the SLC chemistry.

110. I note that an important part of this first claim is that an active heating system is necessary. There may be alternative ways to design the SLC system to deliver its safety function without relying on control or active systems; RQ-ABWR-0081 (Ref. 23) refers. The response indicates that the RP considers the current design to be ALARP. I will follow up this matter further during Step 3, as part of my more detailed assessment of the chemistry of this system.

4.5.2 Strengths

111. The RP has identified an adequate set of chemistry related claims related to the operating chemistry controls necessary in the SLC system. These recognise the safety significance of this system.

4.5.3 Items that Require Follow-up

112. I have identified no specific items for follow-up for the SLC, over and above the expected development of the arguments and evidence, and engineering substantiation required to support the safety case.

4.5.4 Conclusions

113. Based on the outcome of my assessment of the SLC system, I have concluded that the RP has provided an adequate set of safety claims for Step 2 of GDA. I would expect the RP to provide the arguments and evidence to support these during GDA, and I see no reason why this cannot be done.

4.6 Accident Chemistry

4.6.1 Assessment

114. Accident chemistry is not specifically considered as part of the reactor chemistry PSR, but is part of a number of other submissions made during Step 2 (Refs 16 and 17). The reactor chemistry assessment of accidents is primarily concerned with the behaviour of radioactive species during the accident, for example what chemical form they take (their speciation), volatility, or reactions, as an input to the overall assessment of consequences. Due to the complexity of these processes it is a common approach to make bounding assumptions for their behaviour. Iodine is important in accidents due to its radiotoxicity and complex chemical behaviour and therefore assumptions made in this regard can be significant in radiological consequence calculations and the demonstration that risks have been reduced to ALARP.

115. There is some overlap of this topic with the claims made on the suppression pool, discussed in Section 4.4.

116. Ref. 16, the fault studies Step 2 submission, provides some information on the assumptions made by the RP for LOCA and Main Steam Line Break Accidents (MSLBA). In both cases the assumptions are similar, including the fractions of iodine in inorganic and organic form, deposition and removal processes. In effect, I would consider these to be claims made on the chemical behaviour. Aside from noting what these assumptions are, the report does not attempt to justify them. This is reasonable for this stage of GDA, but does mean that I am not able to comment on the adequacy of these claims, other than noting that I have seen similar values used previously but for Pressurised Water Reactors (PWRs) rather than BWRs. The origin of these assumptions is also unclear, but I note they appear similar to US NRC guidance (for example Ref. 30).

117. The severe accidents topic report (Ref. 17) describes, at a high level, the basic approach to severe accidents for UK ABWR, including a description of generic BWR severe accident phenomena. This report provides a high level description of the events that may occur during such an accident; however, there is nothing, for example on hydrogen generation, eutectic reactions (for example, between the fuel and structures), fuel-coolant reactions or re-criticality. The RP indicates that further modelling work will be undertaken during GDA using the MAAP (Modular Accident Analysis Programme) code to obtain information on the timing and magnitudes of releases. At this stage therefore, specific chemistry related information is limited.

118. Overall, for both design basis and severe accidents the chemistry related aspects of the safety case are in the early stages of development. The RP recognises this and is working towards providing further details later in GDA.

4.6.2 Strengths

119. The RP has started to consider the accident chemistry elements of their safety case for UK ABWR. Although at this stage the information is limited, the RP has committed to providing details later in GDA.

4.6.3 Items that Require Follow-up

120. There is insufficient information on accident chemistry in UK ABWR at this stage to identify any particular items for follow-up, aside from that already discussed related to the suppression pool. I therefore expect the normal development of the arguments and evidence, and engineering substantiation required to support the safety case, to be produced within GDA. I will follow up on these matters, in coordination with the GDA fault studies and severe accident teams, as part of my Step 3 assessment.

4.6.4 Conclusions

121. The entire topic of accident chemistry is still in the early stages of development by the RP. The RP has provided some high level information, but considerable work is still needed to adequately define the claims and subsequent arguments and evidence.

4.7 Out of Scope Items

122. I have left no items outside the scope of my Step 2 assessment of the reactor chemistry aspects of the UK ABWR safety case.

4.8 Comparison with Standards, Guidance and Relevant Good Practice

123. In Section 2.2 above I have listed the standards and criteria I have used during my assessment. My overall conclusions in this regard can be summarised as follows:

- SAPs: in general, many of the SAPs I considered as part of my Step 2 assessment cannot be stated to have been fully met. It is important to note however, that progress against the demonstration that these SAPs have been satisfied, with some exceptions, is reasonable, and broadly commensurate with my expectations for a submission received during Step 2. Those which are less well satisfied are associated with aspects I have identified for follow up during Step 3. Table 1 provides further details.
- TAGs: as for the SAPs, while the progress against the expectations contained in the TAGs is reasonable for this stage of GDA, much work will be needed to be done by the RP within GDA to fully meet these. I am confident that this should be possible.

4.9 Interactions with Other Regulators

124. There is overlap between my assessment of reactor chemistry and the assessments undertaken by the Environment Agency, particularly in relation to discharges and BAT. I have therefore worked closely with the EA during Step 2, including attending joint meetings, sharing information and assessment progress and, most importantly, on the joint normal operational source terms RO (RO-ABWR-0006 (Ref. 24)). I expect to continue this relationship during later stages of GDA, along similar lines, where our interests align.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

125. The RP has provided a PSR for the reactor chemistry aspects of the UK ABWR for assessment by ONR during Step 2 of GDA. This PSR, together with other supporting references and submissions, presents a reasonable set of claims in the area of reactor chemistry to underpin the safety of the UK ABWR, commensurate with this stage of GDA.

126. During Step 2 of GDA I have conducted an assessment of the reactor chemistry PSR against the expectations of the relevant SAPs and TAGs. From my assessment I conclude the following:

- Overall, the RP has identified the operating chemistry for most of the main safety related systems in the UK ABWR. They have linked this chemistry to the main safety related purposes it provides. The RP has used this to identify a reasonable set of claims, in some cases at a high level, upon which further development of the safety case can be based. I have no reason to suggest that these claims cannot be further developed as GDA progresses and the safety case becomes more refined.
- The RP appears to be considering the impact and interactions that water chemistry choices have on other aspects of the UK ABWR design in an appropriate manner and are considering UK regulatory expectations in their approach.
- I am confident that the RP should be able to provide such arguments and evidence as necessary to adequately support the claims that have been made on reactor chemistry during Step 2.
- In addition to development of the safety case and additional claims, during my assessment I have identified that specific follow-up will be necessary in the areas of:

    - Definition and justification of the radiological source terms for UK ABWR during normal operations, including a demonstration that the risks are reduced SFAIRP. This is covered by RO-ABWR-0006 and associated actions.
    - Generation, accumulation, management and mitigation of radiolysis gas during normal operations and the safety justification for this in the safety case.
    - Justification for the material choices for UK ABWR and how this interacts with the operating chemistry and arguments which may be made regarding structural integrity and minimisation of radioactivity.
    - Justification of the claim regarding pH control in the suppression pool, in particular whether it reduces risks SFAIRP.
    - Development of the chemistry related aspects of the design basis and severe accident analysis for the UK ABWR.

- I have found the RP to be responsive to my advice and open in our interactions. They have demonstrated a good level of technical knowledge and expertise and are committed to producing an adequate safety case which meets UK requirements, expectations and relevant good practice. I have noted some instances where there appeared to be a lack of communication between related technical disciplines in the RP, but this has improved throughout Step 2. My conclusion for Step 2 is that the level of SME resource in this area is suitable and sufficient at present.

127. Overall, I see no reason, on reactor chemistry grounds, why the UK ABWR should not proceed to Step 3 of the GDA process.

5.2 Recommendations

128. My recommendations are as follows:

- Recommendation 1: The UK ABWR should proceed to Step 3 of the GDA process.
- Recommendation 2: All the items identified in Step 2 as important to be followed up should be included in ONR's Step 3 Assessment Plan for reactor chemistry of the UK ABWR.

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Table 1

Relevant Safety Assessment Principles Considered During the Assessment

SAP No	Description	Interpretation	Comment
The regulatory assessment of safety cases			
SC.1	The process for producing safety cases should be designed and operated commensurate with the hazard, using concepts applied to high reliability engineered systems.	A safety case is a logical and hierarchical set of documents that describes the radiological hazards in terms of the facility, site and the modes of operation, including potential undesired modes, and those reasonably practicable measures that need to be implemented to prevent harm being incurred. It takes account of experience from the past, is written in the present, and sets expectations and guidance for the processes that should operate in the future if hazards are to be successfully controlled. These SAPs cover how safety cases should be produced and managed, what they need to do and what they should contain.	The RP has made a reasonable start in producing the chemistry aspects of the safety case for UK ABWR. The PSR considers the most safety significant systems and identifies a reasonable set of claims, albeit at a high level in some instances. The draft PCSR takes this approach further. There is still work to do in structuring the safety case to demonstrate the hazard of radiolysis gas generation can be safely managed and that normal operational risks are consequentially reduced to ALARP. While there is much work to do in order to fully meet these SAPs I am content with progress in this area for Step 2 of GDA. At this stage however, the overall judgement is that these SAPs are not yet fully satisfied.
SC.2	The safety case process should produce safety cases that facilitate safe operation.		
SC.3	For each life-cycle stage, control of radiological hazards should be demonstrated by a valid safety case that takes into account the implications from previous stages and for future stages.		
SC.4	A safety case should be accurate, objective and demonstrably complete for its intended purpose.		
SC.5	Safety cases should identify areas of optimism and uncertainty, together with their significance, in addition to strengths and any claimed conservatism.		
SC.6	The safety case for a facility or site should identify the important aspects of operation and management required for maintaining safety.		
Engineering principles: Ageing and degradation			

SAP No	Description	Interpretation	Comment
EAD. 1	The safe working life of structures, systems and components that are important to safety should be evaluated and defined at the design stage.	Ageing and degradation mechanisms can have an important impact on safety and should be considered as part of the safety case. This should start with identifying what the mechanisms are and lead to a demonstration that they can be adequately monitored and managed throughout the facility lifetime. These SAPs define ONRs expectations in this regard.	The RP has started to identify the most safety significant potential degradation mechanisms for UK ABWR. For reactor chemistry this includes SCC and other corrosion mechanisms. Therefore EAD.1 has been partly met, although further work will be necessary to fully satisfy this SAP. SAPs EAD.2, 3 and 4 will therefore follow on from this. I am confident this can be done later in GDA, and that progress against satisfying these SAPs is reasonable for this stage of GDA.
EAD. 2	Adequate margins should exist throughout the life of a facility to allow for the effects of materials ageing and degradation processes on structures, systems and components that are important to safety.		
EAD. 3	Where material properties could change with time and affect safety, provision should be made for periodic measurement of the properties.		
EAD. 4	Where parameters relevant to the design of plant could change with time and affect safety, provision should be made for their periodic measurement.		
Engineering principles: Integrity of metal components and structures			
EMC. 2	The safety case and its assessment should include a comprehensive examination of relevant scientific and technical issues, taking account of precedent when available.	These SAPs are concerned with the engineering assessment of the integrity of metallic components and structures such as pressure vessels, boilers, pressure parts, coolant circuits, pipework, core support, pumps, valves, storage tanks and the freestanding metal shell of pressure retaining containment structures. From a reactor chemistry perspective this mainly means the effect of the coolant chemistry on the metallic components in the various cooling systems, principally the primary cooling system.	Similar to the ageing and degradation SAPs, while the RP has made a reasonable start for these SAPs much work will be needed to produce a complete safety case which fully addresses them. For Step 2 of GDA the progress is reasonable.
EMC. 3	Evidence should be provided to demonstrate that the necessary level of integrity has been achieved for the most demanding situations.		
EMC. 21	Throughout their operating life, safety-related components and structures should be operated and controlled within defined limits consistent with the safe operating envelope defined in the safety case.		
Engineering principles: Safety systems			

SAP No	Description	Interpretation	Comment
ESS. 1	All nuclear facilities should be provided with safety systems that reduce the frequency or limit the consequences of fault sequences, and that achieve and maintain a defined safe state.	This SAP is about ensuring that suitable safety systems are provided as part of the reactor design. From a chemistry perspective this also includes those systems which mitigate or control the chemistry within the limits and conditions necessary for safety.	The RP has made a reasonable start in identifying the chemistry related aspects of the safety systems for UK ABWR. The claims made on those systems may prove to be challenging to justify in some instances, for example the claimed safety function of the chemistry of the suppression pool in reducing the release of radioisotopes from the RCCV SFAIRP.
Engineering principles: Control of nuclear matter			
ENM. 2	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.	These SAPs are concerned with ensuring that nuclear matter (from a chemistry perspective this mainly means the activity within the coolant) is adequately controlled. This includes, for example, the treatment and processing facilities and the design of systems, structures and components are such that accumulation is minimised.	In their PSR the RP has started to explain how nuclear matter will be controlled in the UK ABWR design. At this stage the information is limited, but I expect this to be addressed by RO-ABWR-0006, although I note that meeting these SAPs appears possible for UK ABWR as GDA progresses. .
ENM. 3	Unnecessary or unintended generation, transfer or accumulation of nuclear matter should be avoided.		
ENM. 4	Nuclear matter should be appropriately controlled and accounted for at all times.		
Engineering principles: Reactor core			
ERC. 1	The design and operation of the reactor should ensure the fundamental safety functions are delivered with an appropriate degree of confidence for permitted operating modes of the reactor.	This principle covers normal operation, refuelling, testing and shutdown and design basis fault conditions. The fundamental safety functions are: a) control of reactivity (including re-criticality following an event); b) removal of heat from the core; c) confinement or containment of radioactive substances. The coolant chemistry can have an impact on all of these functions.	The PSR produced by the RP, and the claims contained therein, link the operating chemistry to these main functions. The RP has therefore made a good start in demonstrating how the chemistry of UK ABWR will fulfil this SAP. I am satisfied that this SAP has been adequately met for this stage of GDA.
Engineering principles: Heat transport systems			

SAP No	Description	Interpretation	Comment
EHT. 5	The heat transport system should be designed to minimise radiological doses.	This SAP is concerned with ensuring that the design of the heat transport system(s), for example the primary cooling system or spent fuel cooling system, minimises radioactivity ALARP. This means that the design, construction and operation of the facility and the choice of heat transfer fluid should minimise the amount of radioactive substances in that fluid. Provision should be made to monitor and remove any significant build-up of radioactive substances from the heat transport fluid and associated containment. Components subject to neutron irradiation should be fabricated from materials that minimise the effects of neutron activation.	Due to the lack of information on the source terms in UK ABWR it is not yet possible to judge whether this SAP has, or can be, satisfied.
Fault analysis			
FA. 18	Calculational methods used for the analyses should adequately represent the physical and chemical processes taking place.	This SAP is concerned with ensuring that the transient, radiological or other analyses that may be used for fault studies uses assumptions or behaviour that adequately represents the chemical processes that occur.	Due to the lack of information on the assumptions or basis for the fault studies for UK ABWR it is not yet possible to judge compliance with this SAP. More information will become available as the safety case develops for UK ABWR.
Criticality safety			

SAP No	Description	Interpretation	Comment
ECR.1	Wherever significant amount of fissile materials may be present, there should be a system of safety measures to minimise the likelihood of unplanned criticality.	This SAP is about ensuring that suitable and sufficient safety measures are in place to ensure an unintentional criticality cannot occur. From a chemistry perspective this generally means the use of soluble poisons and ensuring coolant chemistry does not affect fixed poisons (for example via corrosion).	The safety case presented by the RP suggests that no soluble neutron poison is needed, either in the reactor coolant or in the fuel storage pond. Purely from a chemistry perspective therefore, this SAP can be considered to have been met in this regard. Further information will be needed as GDA progresses to demonstrate the claim made on SFP chemistry in maintaining the integrity of the borated steel fuel racks. At this stage, however, there is no reason to doubt that this aspect of the SAP will not be able to be fully satisfied by the end of GDA.

Table 2

Relevant Technical Assessment Guides Considered During the Assessment

TAG Reference	Revision	Title
NS-TAST-GD-004	4	Fundamental principles
NS-TAST-GD-005	5	ONR guidance on the demonstration of ALARP (as low as reasonably practicable)
NS-TAST-GD-014	3	Internal hazards
NS-TAST-GD-016	4	Integrity of metal components and structures
NS-TAST-GD-023	3	Control of processes involving nuclear matter
NS-TAST-GD-037	2	Heat transport systems
NS-TAST-GD-038	3	Radiological protection
NS-TAST-GD-051	3	The purpose, scope and content of nuclear safety cases
NS-TAST-GD-081	1	Safety aspects specific to storage of spent nuclear fuel
NS-TAST-GD-088	0	Chemistry of operating civil nuclear reactors