Office for Nuclear Regulation

New Reactor Division – Generic Design Assessment

Step 2 Assessment of the Chemistry of UK HPR1000 Reactor

Assessment Report ONR-GDA-UKHPR1000-AR-18-015
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EXECUTIVE SUMMARY

This report presents the results of my Chemistry assessment of the UK HPR1000 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 increasing in detail 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, including ONR's review of key nuclear safety and nuclear security claims (or assertions). The aim is to identify any fundamental safety or security shortfalls that could prevent ONR from permitting the construction of a power station based on the design.

During GDA Step 2 my work has focused on the assessment of the Chemistry aspects within the UK HPR1000 Preliminary Safety Report (PSR), and a number of supporting references and supplementary documents submitted by the RP, focusing on design concepts and claims.

The standards I have used to judge the adequacy of the RP's submissions in the area of Chemistry have been primarily ONR's Safety Assessment Principles (SAPs), in particular SAPs ECH.1 through ECH.4, and ONR's Technical Assessment Guides NS-TAST-GD-088 Chemistry of Operating Civil Nuclear Reactors and NS-TAST-GD-089 Chemistry Assessment in ONR.

My GDA Step 2 assessment work has involved regular engagement with the RP in the form of technical exchange workshops and progress meetings, including meetings with the plant designers.

The UK HPR1000 PSR is primarily based on the Reference Design, Fangchenggang Unit 3 (FCG3), which is currently under construction in China. Key aspects of the UK HPR1000 preliminary safety case related to Chemistry, as presented in the PSR, its supporting references and the supplementary documents submitted by the RP, can be summarised as follows:

- Those areas where the Chemistry or chemistry control of a system is claimed as directly contributing to safety
- Those areas where the Chemistry or chemistry control of a system is, by inference, significant to the availability or longevity of systems, structures and components important to safety
- Those areas where the Chemistry or chemistry control of a system has an influence on the exposure, or potential exposure, of workers or the public to ionising radiation, this includes during fault or accident scenarios.

During my GDA Step 2 assessment of the UK HPR1000 aspects of the safety case related to Chemistry I have identified the following areas of strength:

- The proposed approach to materials selection for UK HPR1000 is to use materials that exhibit low susceptibility to certain degradation mechanisms, such as flow accelerated corrosion. I consider that for the RP to have stated this early in Step 2 demonstrates positive bias in favour of safety and I consider this to be an area of strength.
- The RP is proposing a systematic approach to the Chemistry of the UK HPR1000 and has laid this out in a strategy document.
- The RP has recognised the importance of considering the source term early and the benefit of considering factors contributing to the generation of radioactivity.
- The RP has responded well to challenge and has recognised that additional work will be required in a number of areas, e.g. the impact of in vessel retention, zinc dosing.

- Overall, the RP has identified the operating Chemistry for many of the main safety related systems in UK HPR1000. While in some areas the claims are still at a high-level, I have no reason to suggest that they cannot be fully developed as the GDA of UK HPR1000 progresses.

During my GDA Step 2 assessment of the UK HPR1000 aspects of the safety case related to Chemistry I have identified areas that require follow-up, including:

- Identification and application of relevant codes and standards.
- Applicability of the Chemistry of the reference plant to UK HPR1000.
- Chemistry of the primary circuit.
- Accident Chemistry and the impact of In-Vessel Retention (IVR) on accident progression and the evolution of volatile species.
- Combustible gas behaviour in containment and the effectiveness of passive autocatalytic recombiners.
- Chemistry of the secondary circuit and in particular the impact of and approach to management of chloride ingress.
- Spent fuel pool cleanup and temperature control systems.
- Chemistry and chemistry control of auxiliary systems.
- Chemistry aspects of the waste management systems.
- Practical application of the proposed materials selection methodology and its impact on operating Chemistry.
- Source term and radionuclide selection and how the actinide baseline will be established.

During my GDA Step 2 assessment however, I have not identified any fundamental safety shortfalls in the area of Chemistry that might prevent the issue of a Design Acceptance Confirmation (DAC) for the UK HPR1000 design.

LIST OF ABBREVIATIONS

ALARP	As Low As Reasonably Practicable
APG[SGBS]	Steam generator blowdown system
AVT	All Volatile Treatment
BAT	Best Available Technique
BMS	Business Management System
BSL	Basic Safety Level (in SAPs)
BSO	Basic Safety Objective (in SAPs)
CGN	China General Nuclear Power Corporation
CIPS	Chloride Ingress Protection System
CRUD	Chalk River Unidentified Deposit
CVI[CVS]	Condensate vacuum system
DAC	Design Acceptance Confirmation
DBC	Design Basis Condition
DEL[SCWS]	Safety Chilled Water system
EA	Environment Agency
EDF	Électricité de France
EPRI	Electric Power Research Institute
FAC	Flow Accelerated Corrosion
FAP	Forward Action Plan
GNI	General Nuclear International
GNS	Generic Nuclear System Ltd
GSR	Generic Security Report
HVAC	Heating, ventilation and cooling
IAEA	International Atomic Energy Agency
IRWST	In-Containment Refuelling Water Storage Tank
IVR	In Vessel Retention
JPO	(Regulators') Joint Programme Office
NPP	Nuclear Power Plant
ONR	Office for Nuclear Regulation
PAR	Passive Autocatalytic Recombiner
PCSR	Pre-construction Safety Report

PCER	Pre-construction Environmental Report
PSR	Preliminary Safety Report (includes security and environment)
PTR[FPCTS]	Fuel pool cooling and treatment system
RCP[RCS]	Reactor coolant system
RCV[CVCS]	Chemical and volume control system
REA[RBWMS]	Reactor boron and water makeup system
REP[VDS]	Nuclear Island vent & drain system
RGP	Relevant Good Practice
RHWG	Reactor Harmonization Working Group (of WENRA)
RI	Regulatory Issue
RIA	Regulatory Issue Action
RIS[SIS]	Safety Injection system
REN[NSS]	Nuclear sampling system
RO	Regulatory Observation
ROA	Regulatory Observation Action
RP	Requesting Party
RQ	Regulatory Query
RRI[CCWS]	Component cooling water system
SAP(s)	Safety Assessment Principle(s)
SEL[LWDS(CI)	Conventional island liquid waste discharge system
SCWS	Safety Chilled Water System
SFP	Spent Fuel Pool
SFAIRP	So far as is reasonably practicable
SSCs	Systems, Structures and Components
TAG	Technical Assessment Guide(s)
TEP[CSTS]	Coolant storage and treatment system
TES[SWTS]	Solid waste treatment system
TEG[GWTS]	Gaseous waste treatment system
TER[NLWDS]	Nuclear island liquid waste discharge system
TEU[LWTS]	Liquid waste treatment system

TSC	Technical Support Contractor
TSF	Technical Support Framework
WENRA	Western European Nuclear Regulators’ Association

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1 INTRODUCTION

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 increasing in detail as the project progresses. General Nuclear System Ltd (GNS) has been established to act on behalf of the three joint requesting parties (China General Nuclear Power Corporation (CGN), Électricité de France (EDF) and General Nuclear International (GNI)) to implement the GDA of the UK HPR1000 reactor. For practical purposes GNS is referred to as the 'UK HPR1000 GDA Requesting Party'.

2. During Step 1 of GDA, which is the preparatory part of the design assessment process, the RP established its project management and technical teams and made arrangements for the GDA of the UK HPR1000 reactor. Also, during Step 1 the RP prepared submissions to be assessed by ONR and the Environment Agency (EA) during Step 2.

3. Step 2 commenced in November 2017. Step 2 of GDA is an overview of the acceptability, in accordance with the regulatory regime of Great Britain, of the design fundamentals, including ONR's assessment of key nuclear safety and nuclear security claims (or assertions). The aim is to identify any fundamental safety or security shortfalls that could prevent ONR permitting the construction of a power station based on the design.

4. My assessment has followed my GDA Step 2 Assessment Plan for Chemistry (Ref. 1, 16) prepared in October 2017 and shared with GNS to maximise openness and transparency.

5. This report presents the results of my Chemistry assessment of the UK HPR1000 as presented in the UK HPR1000 Preliminary Safety Report (PSR) (Ref. 2) and its supporting documentation (Refs. 3 to 8).

2 ASSESSMENT STRATEGY

6. This section presents my strategy for the GDA Step 2 assessment of the Chemistry aspects of the UK HPR1000. It also includes the scope of the assessment and the standards and criteria I have applied.

2.1 Scope of the Step 2 Chemistry Assessment

7. The objective of my GDA Step 2 assessment was to assess relevant design concepts and claims made by the RP related to Chemistry. In particular, my assessment has focussed on the following:

- Those areas where the Chemistry or Chemistry control of a system is claimed as directly contributing to safety.
- Those areas where the Chemistry or Chemistry control of a system is, by inference, significant to the availability or longevity of systems, structures and components (SSCs) important to safety.
- Those areas where the Chemistry or Chemistry control of a system has an influence on the exposure, or potential exposure, of workers or the public to ionising radiation, this includes during fault and accident scenarios.
- Chemistry effects relevant to the generation and management of combustible gasses, this includes during fault and accident scenarios.

8. During GDA Step 2 I have also evaluated whether the safety claims related to Chemistry are supported by a body of technical documentation sufficient to allow me to proceed with GDA work beyond Step 2.

9. Finally, during Step 2 I have undertaken the following preparatory work for my Step 3 assessment:

- Undertaken a coarse review of an early draft of the Pre Construction Safety Report (PCSR).
- Liaised with inspectors in other topic areas to inform my focus during Step 2 assessment and undertake preparatory discussions regarding interfaces during Step 3.
- Engaged with the RP to develop a Chemistry submission schedule with the aim of this informing my Step 3 assessment plan.

2.2 Standards and Criteria

10. For ONR, the primary goal of the GDA Step 2 assessment is to reach an independent and informed judgment on the adequacy of a preliminary nuclear safety and security case for the reactor technology being assessed. Assessment was undertaken in accordance with the requirements of the Office for Nuclear Regulation (ONR) How2 Business Management System (BMS) guide NS-PER-GD-014 (Ref. 1).

11. In addition, the Safety Assessment Principles (SAPs) (Ref. 9) constitute the regulatory principles against which duty holders’ and RP’s safety cases are judged. Consequently the SAPs are the basis for ONR’s nuclear safety assessment and have therefore been used for the GDA Step 2 assessment of the UK HPR1000. The SAPs 2014 Edition are aligned with the International Atomic Energy Agency (IAEA) standards and guidance.

12. Furthermore, ONR is a member of the Western European Nuclear Regulators’ Association (WENRA). WENRA has developed Reference Levels, which represent good practices for existing nuclear power plants, and Safety Objectives for new reactors. WENRA do not produce specific guidance or reference levels relating to Chemistry, however the general principles outlined in their documentation are relevant.

13. The relevant SAPs and IAEA standards are embodied and expanded on in the Technical Assessment Guides (TAGs) on Chemistry (Ref. 10). These guides provide the principal means for assessing the Chemistry aspects in practice.

2.2.1 Safety Assessment Principles

14. The key SAPs (Ref. 9) that I have directly applied within my assessment are ECH.1, ECH.2, ECH.3 and ECH.4 (see also Table 1 for further details).

15. In addition, I have considered aspects of the SAPs in other areas and disciplines where I have considered them relevant to my assessment; these include Engineering Key Principles (EKP), Fundamental Principles (FP) and Safety Case (SC).

2.2.2 Technical Assessment Guides

16. The following Technical Assessment Guides have been used as part of this assessment (Ref. 10):

- NS-TAST-GD-088 Chemistry of operating Civil Nuclear Reactors Revision 1, ONR, March 2017
- NS-TAST-GD-089 Chemistry Assessment Revision 0, ONR, Feb 2018

2.2.3 National and International Standards and Guidance

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

- Chemistry Programme for Water Cooled Nuclear Power Plants – Specific Safety Guide No. SSG-13, IAEA 2011 (Ref.14)
- Safety of Nuclear Power Plants: Design. Safety Requirements. International Atomic Energy Agency (IAEA). Safety Standards Series No. NS-R-1. IAEA. Vienna. 2000. www.iaea.org. (Ref. 14)
- A review of reference safety levels defined by WENRA found none *specific* to reactor Chemistry. However, aspects of this assessment will contribute to meeting the following reference levels: (Ref. 15)
  - Issue E: Design Basis Envelope of Existing Reactors
  - Issue H: Operational limits and conditions
  - Issue I: Ageing Management
- The reactor Chemistry assessment will also contribute towards the following safety objectives for new power reactors, defined by WENRA: (Ref.15)
  - 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

18. A large number of operating PWRs worldwide base their chemical specifications on standards and guidance produced by industry bodies like the Electric Power Research Institute (EPRI). While some of these documents form an authoritative reference, others are very general guides. In this assessment I have been cognisant of such publications but I have considered them as advice and as such they are not expressly referenced.

2.3 Use of Technical Support Contractors

19. During Step 2 I have not engaged Technical Support Contractors (TSCs) to support my assessment of the proposed Chemistry for the UK HPR1000.

2.4 Integration with Other Assessment Topics

20. Early in GDA I recognised that during the project there would be a need to consult with other inspectors (including Environment Agency's assessors) as part of the Chemistry assessment process. Similarly, other inspectors will seek input from my assessment of the Chemistry for the UK HPR1000. I consider these interactions very important to ensure the prevention of assessment gaps and duplications, and, therefore, they are key to the success of the project. Thus, from the start of the project, I made every effort to identify as many potential interactions as possible between the Chemistry and other technical areas, with the understanding that this position would evolve throughout the UK HPR1000 GDA.

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

- Reactor Chemistry provides input to the integrity and corrosion aspects of the overall assessment. The effects of the operating Chemistry (environment) on the susceptibility to material degradation mechanisms will be led by myself. However, the overall judgement on the adequacy of the safety case for material degradation aspects will be led by the structural integrity inspector.
- 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 and core inspector.
- Chemistry provides a key input in the area of radiological source term(s) which will impact on radiation protection, radwaste and decommissioning and the areas of assessment that will be considered by the Environment Agency. The impact of the operating Chemistry on the normal operational source term(s) for UK HPR1000 will be led by the reactor chemistry discipline, but radiological source term(s) is a broad area requiring coordination between disciplines.
- 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 Chemistry.

22. In addition to the above, during GDA Step 2 there have been interactions between Chemistry and the majority of other 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 technical assessment areas.

3 REQUESTING PARTY'S SAFETY CASE

23. During Step 2 of GDA the RP submitted a PSR and other supporting references, which outline a preliminary nuclear safety case for the UK HPR1000. This section presents a summary of GNS's preliminary safety case in the area of Chemistry. It also identifies the documents submitted by the RP which have formed the basis of my Chemistry assessment of the UK HPR1000 during GDA Step 2.

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

24. The aspects covered by the UK HPR1000 preliminary safety case in the area of Chemistry can be broadly grouped under five headings which I summarise as follows. I note that there are few express claims made on Chemistry and the majority of these areas are identified as claims by inference as I consider that they directly influence some aspect of safety:

- The Chemistry of the primary circuit: The proposed primary circuit Chemistry is designed to allow for the control of reactivity by the addition of soluble boron, while providing protection from corrosion for relevant Systems, Structures and Components (SSCs). Water quality control is used to minimise the production of fuel crud, and corrosion protection in the primary circuit is achieved through controlling the pH and scavenging radiolytic oxygen. Additional features include the control of impurities in the coolant and radiochemical clean-up systems which reduce the transport of radioactive materials and hence dose to operators and maintainers. These fundamental safety functions are delivered through a number of key Chemistry requirements that I consider to be safety claims. Reactivity control is delivered, by enriched boric acid, coordinated with pH control by addition of enriched lithium hydroxide. Hydrogen gas is added to scavenge radiolytic oxygen and reduce the overall propensity for corrosion. The control of impurities, specifically those implicated in the formation of insoluble crud, is delivered through make-up water Chemistry controls and dedicated clean-up systems.
- The Chemistry of the secondary circuit: The proposed secondary circuit Chemistry is primarily designed to protect the heat transfer interface (steam generator tube bundle), limit corrosion throughout the secondary plant and reduce the deposition of corrosion products in the SG. The proposed regime is one of all volatile treatment, comprising ammonia for pH control and hydrazine for oxygen scavenging
- The Chemistry of the fuel cooling pool: The proposed spent fuel pool Chemistry is designed to prevent corrosion of fuel in storage and control criticality through soluble boron, although no claim is made on the latter, and fixed neutron absorbers are proposed to maintain criticality control in use.
- Chemistry based claims and phenomena relevant during accident scenarios: The behaviour and volatility of potentially mobile species in the event of a severe accident and the evolution and control of combustible gasses, and the chemistry-based mitigations in place for both severe and design basis accidents.

25. In arriving at these five groups of claims I have considered the role of, or importance of Chemistry in any given area in accordance with the following principles derived from ONR guidance:

- 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;

- 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;
- Overall, the Chemistry of the design, including the effects of coolant Chemistry on reactivity, pressure boundary integrity, fuel and core component integrity, fuel storage in cooling pools, radioactive waste generation and radiological doses to workers.

3.2 Basis of Assessment: RP's Documentation

26. The RP's documentation that has formed the basis for my GDA Step 2 assessment of the safety claims related to the Chemistry aspects of the UK HPR1000 is presented in Refs 2 to 8;

- Preliminary Safety Report for UK HPR1000
  (Chemistry Chapter (21) plus aspects of other relevant chapters)
- Methodology for Primary Water Chemistry Regime
- Safety Case Strategy Reactor Chemistry
- Methodology of Accident Chemistry
- Normal Operation Source Term Strategy Report
- Report of Radionuclide Selection During Normal Operation
- Materials Selection Methodology

27. In addition, during April 2018 GNS submitted to ONR, for information, an advance copy of the UK HPR1000 PCSR. Chapter 21 addresses Chemistry. Having early visibility of the scope and content of this chapter/s has been useful in the planning and preparation of my GDA Step 3 assessment work.

4 ONR ASSESSMENT

28. This assessment has been carried out in accordance with HOW2 guide NS-PER-GD-014, “Purpose and Scope of Permissioning” (Ref. 1).

29. My Step 2 assessment work has involved regular engagement with the RP’s Chemistry specialists, 1 Technical Exchange Workshop (in China) and three progress meetings have been held in addition to telephone exchanges. I have also visited:

- Daya Bay Nuclear Power Base, although these reactors are not of the same design as UK HPR1000

30. During my GDA Step 2 assessment, I have identified some gaps in the documentation formally submitted to ONR. Consistent with ONR’s Guidance to Requesting Parties (Ref. 13), these normally lead to Regulatory Queries (RQs) being issued. At the time of writing my assessment report, in Chemistry, during Step 2, I had raised 10 RQs to facilitate my assessment.

31. Similarly, and again consistent with ONR’s Guidance to Requesting Parties (Ref. 13), more significant shortfalls against regulatory expectations in the generic safety case are captured by issuing Regulatory Observations (ROs). At the time of writing my assessment report in Chemistry, during Step 2, I had raised no ROs.

32. Details of my GDA Step 2 assessment of the UK HPR1000 preliminary safety case in the area of Chemistry, including the conclusions I have reached, are presented in the following sub-sections of the report. This includes the areas of strength I have identified, as well as the items that require follow-up during subsequent stages of the GDA of UK HPR1000.

33. My assessment overall has taken the form of a “broad, shallow” view of the Chemistry aspects of the UK HPR1000 design and safety case. A number of areas have emerged where I consider additional follow up to be appropriate and these will be among the areas that I will assess in greater detail during Step 3 and Step 4.

4.1 Safety Case Strategy (Reactor Chemistry)

4.1.1 Assessment

34. The RP for UK HPR1000 has provided (Ref. 4) a high level strategy that describes their proposed scope for the generic reactor Chemistry safety case. In addition to the overall proposed scope, the report also describes the key objectives they will consider during development of the safety case, the key interfaces with other topics and the overall hierarchy of documentation.

35. The strategy also states that the basis of the safety case for UK HPR1000 will be developed from the reference plant at Fangchenggang unit 3 (FCG3).

36. The strategy confirms that Chemistry will be considered in all modes of operation and also provides a list of structures, systems and components related to reactor Chemistry. While this is reasonable for this stage of GDA, I raised a regulatory query RQ-UK HPR1000-0122 (Ref. 18) relating to one aspect of the strategy paper relating to a statement that the feedwater chemical sampling system (SIT[FCSS]) and the chemical reagents injection system (SIR[CSS]) are “out of GDA scope”. The RP response confirmed the function of the relevant systems and that they will be present in the design, but that there would be no design reference document.

37. While the full engineering detail of those systems may not be necessary in order for me to complete my assessment, my expectation is that sufficient information will be supplied in GDA to demonstrate the ability of those systems to provide representative

sampling, and effective chemical control respectively. This will be an area that I will follow up as part of my Step 3 and Step 4 assessment.

38. The strategy identifies a list of interfaces with other topic areas and indicates the relevant PCSR chapters where the relevant information will be supplied. This list is a useful addition to the strategy but cannot be considered to be exhaustive at this stage and it is important for the RP to note that as my assessment progresses there will be emergent areas where interfaces with other topics occur that have not been identified at this time, and there will be requests for information that have not been anticipated in this strategy.

39. The strategy outlines the basis of the codes, standards and relevant good practice (RGP) that have been identified to date and that will inform the safety case, together with the high level functions delivered by Chemistry. The range of codes and standards described is in my opinion quite limited and it will be necessary for the RP to look more widely in order to provide a sound ALARP/RGP demonstration in some areas – much of the guidance referenced is legislative or very general and there is little in terms of how the detailed Chemistry will be shown to be optimised. This will be an area that I follow up during my Step 3 and Step 4 assessments.

40. The RP’s proposed work plan for Step 3 and Step 4 as provided in the strategy links with an included table of proposed submissions (and dates) but this is an area where change will be necessary as several of the submission dates proposed for key documents are too late, and in some instances outside the planned window for the GDA Step to which they relate. My expectation is that the majority of the submissions to be considered during Step 3 are provided at entry into Step 3 or shortly thereafter. While the currently proposed schedule does not provide for this I do not consider the situation insurmountable, although this is an area where significant work will be required by the RP to enable a meaningful and timely assessment.

4.1.2 Strengths

41. I consider the provision of a strategy for reactor Chemistry to be a strength, with the caveat that the strategy itself will need to evolve in order to meet my expectations.

4.1.3 Items that Require Follow-Up

42. I will engage with the RP regarding the timing and content of proposed submissions, also the range and scope of codes and standards that will be used to inform the safety case. The strategy in itself is also not exhaustive and there will be both interfaces between topics and technical aspects that emerge as areas of interest and these are not currently catered for.

4.1.4 Conclusions

43. The strategy provides a useful starting point and provides a route map by which the RP plans to develop the Chemistry topic for UK HPR1000, this is welcome but further work will be required to both the timing of submissions and the completeness of the plan as GDA progresses

4.2 Chemistry of the Primary Circuit

4.2.1 Assessment – Methodology for Primary Water Chemistry Regime

44. The RP has submitted their methodology report for the Chemistry (Ref. 3) of the primary circuit for UK HPR1000, in which a number of areas are described in varying levels of detail.

45. Following a brief description of the primary plant, the proposed methodology for defining claims is presented. This methodology identifies three very high level risks associated with primary Chemistry:

- Material degradation leading to structural degradation of SSCs
- Material degradation leading to fuel degradation
- Radionuclide inventory and release resulting in a radiological dose to the public and workers

46. While these risks are reasonable I consider them to be a particularly coarse representation of the role of Chemistry in overall plant safety. This said however, they can be argued to bracket almost all relevant Chemistry effects and as such, while I expect them to be significantly refined as GDA progresses, they are at such high level that nothing is omitted.

47. The report goes on to describe the Chemistry to be employed at the reference design (Fangchenggang 3). My expectation is that the RP will demonstrate how this Chemistry will be shown to be appropriate to the UK HPR1000 and shown to reduce risks ALARP:- this aspect is currently not well developed and will be a key aspect that I follow up during my Step 3 and Step 4 assessment.

48. Within the sub section on development of limits and conditions of operation the RP state that the primary water Chemistry regime will include dose reduction through the addition of zinc. I consider that the latest worldwide position on zinc dosing in PWR reactors presents a positive position and while I expect the RP to fully develop the case for zinc in this specific design, overall I welcome the inclusion.

4.2.2 Assessment – Reactivity control and pH

49. My assessment of the Chemistry for the UK HPR1000 primary circuit has included the relevant PSR chapters, supporting references and the responses to my related regulatory queries, i.e. :

- Preliminary Safety Report (PSR) Chapter 21 (Ref. 2)
- Aspects of PSR chapters 6, 7 and 10 (Ref. 2),
- Safety Case Strategy (Reactor Chemistry) (Ref. 4),
- Methodology for Primary Water Chemistry Regime (Ref. 3), and
- Related Regulatory queries (Ref. 18).

50. The RP has described (Ref. 2) a primary Chemistry operating regime that is based upon a co-ordinated boron-lithium Chemistry, to provide control of reactivity through coolant boron concentration while maintaining an alkaline pH. The use of soluble boron to control reactivity is commonplace in modern pressurised water reactors (PWR) and the adoption of boron enriched in boron 10, as in this case, is common to several current reactor designs.

51. The RP confirm in the PSR (Ref. 2) that the adoption of enriched boron is to allow for a lower overall boron inventory and as such, within any given range of lithium concentration, permits the plant to be operated at a higher pH:- I consider this to be beneficial in preventing bulk corrosion of reactor materials and am supportive of this

general approach. The specific pH(t) range for UKHPR 1000 is stated by the RP (Ref. 3) as pH 7.15 – 7.25 with a target of a constant pH(t) of 7.2. During the earliest part of the reactor cycle the RP propose a lower pH(t) of 7.12 to make allowance for the higher boron concentration that is necessary while fissionable poisons grow to equilibrium concentrations, while retaining the maximum lithium concentration below the specified upper limit of 3.5 mg/kg.

52. The lithium to be employed for pH control is stated to be enriched to 99.9% Li-7 to reduce the formation of tritium. I will consider lithium enrichment and its impact on the formation of tritium in conjunction with the radiation protection topic lead and this will be an area that I progress during Step 3.

53. The RP go on to state that within this general intent, they will undertake detailed ALARP assessment to determine the optimal pH for the UKHR1000 plant, incorporating the latest recommendations and operating experience available at the time. I support this position because many of the choices to be made and optimised relate to the detail of the materials selection process and while a materials selection methodology has been produced (Ref. 8), the materials selection itself is not yet finalised.

54. Overall, the Chemistry control approach in a PWR must provide for a number of key technical objectives:- broadly, my expectations in this area include:

- Limiting bulk corrosion of circuit materials
- Provide for the necessary reactivity control by soluble boron
- Be a balance between the solubility minima of reactor materials
- Maintain lithium below any concentration that might give rise to concentration mechanisms on the fuel surface, or caustic attack
- Promote the development of stable surface oxide layers on reactor materials
- Exhibit no decrease in solubility of dissolved species in the ΔT developed across the core, reducing the formation of “hard” crud

55. I am aware of a significant volume of worldwide OPEX that can be drawn from relating to operation at pH 7.2 and I am content that the RP will be able to demonstrate that the proposed pH control regime can meet my expectations in the UK HPR1000 and also show that the requirements of ONR SAP ECH.1 and ECH.3 are likely to be met.

56. Having considered the submission against my broad expectations as listed above, I am also content that the RP will be able to justify that the proposed regime for primary pH represents an appropriate balance in the interests of safety, in particular the balance between control of reactivity and minimisation of corrosion, I therefore expect that the requirements of ONR SAP ECH.2 will be met.

57. The precise means of control of both the pH and the soluble boron inventory have not been described in any detail at this time and will be an area that I will follow up during my assessment at Step 3 and Step 4, including that an appropriate ALARP balance has been demonstrated.

4.2.3 Assessment – Hydrogen dosing

58. Direct dosing with gaseous hydrogen is proposed (Ref. 2) by the RP as the means of scavenging for radiolytic oxygen in the primary circuit and overall minimisation of the electrochemical potential. Water radiolysis gives rise to a wide range of products that can exist as either transient or stable species in the coolant, many of which are oxidising and potentially corrosive. Addition of an excess of dissolved hydrogen serves to drive the equilibrium concentrations of these species down by promoting the rate of recombination into water above the rate of radiolytic degradation. Adding an excess of dissolved hydrogen also serves to promote reducing conditions throughout

the circuit, i.e. it favours conditions which serve to limit the corrosion and solubility (and transport) of metals about the circuit.

59. Worldwide, PWRs employ a range of hydrogen concentrations to achieve this outcome, normally within the bounding range of 10 – 50 cc dissolved hydrogen per kg of coolant. UK HPR1000 proposes to operate the plant dissolved hydrogen in the range of 17 – 50 cc per kg coolant:- this is within the range commonly encountered in PWR reactors and I am content that there is a significant body of international experience that can be drawn upon to justify dosing at this level. The precise operating envelope for hydrogen within this proposed range and the detail of its justification are areas that I will follow up during my assessment at Step 3 and 4.

60. The means of addition of hydrogen proposed for UK HPR1000 is one that I consider to be uncommon, utilising a jet-pump and mixing pipe rather than maintenance of a static overpressure of hydrogen on the volume control tank. The system is quite similar to that used in the UKEPR design and the approach was assessed in detail as part of that generic design assessment and found to be adequate. Operational experience is less widespread for this approach and I raised RQ-UK HPR1000-0017 (Ref. 18) to obtain additional information on the hydrogen injection system.

61. The response to this RQ describes a significant programme of testing and optimisation of the system proposed (550 test cycles) plus, the response provided information regarding a similar system has been installed at the Taishan EPR™ reactor, stating that the OPEX from that plant will be available.

62. Overall, the chosen operating range for dissolved hydrogen is within the generally expected range for a PWR and I consider that the RP will be able to demonstrate that this range of hydrogen addition will meet the required technical objectives, as required by ONR SAP ECH.1.

63. I consider the system chosen for hydrogen dosing to be uncommon in its design and this will be an area for scrutiny during my Step 3 and Step 4 assessments, where I will examine the OPEX that will be available, plus the results of rig testing, to form a judgement on the ability of this system to maintain and control the dissolved hydrogen concentration in the plant as required by ONR SAP ECH.3.

4.2.4 Assessment – Water purity and chemical additives

64. In addition to the specific additions discussed above, overall water quality and the minimisation of impurities is also important to the safe operation of the primary circuit.

65. I consider that the current position on zinc dosing of PWR reactors (worldwide) indicates that the relevant good practice is to dose PWR primary water with depleted zinc and a range of benefits have been cited. The RP for UK HPR1000 has based their proposed Chemistry on that employed at Fanchenggang 3 which does not currently dose the primary circuit with zinc. For UK HPR1000 the RP has not yet indicated their final intention regarding zinc, but have undertaken to consider this later in the GDA process. This will be an area that I follow up during my Step 3 and 4 assessment.

66. I consider overall water purity and quality of vital importance in a PWR as impurities can contribute to corrosion directly, or they may become concentrated at heat transfer surfaces (including the fuel surface), or contribute toward the formation of insoluble crud. Within the described UK HPR1000 primary circuit Chemistry the RP has proposed tight controls on the levels of common anions, common cations and silica. I am content that the importance of water purity is recognised by the RP. The precise impurity levels and their impact on the production and transport of radioactivity, the formation of fuel crud and impact on overall corrosion and degradation of the plant,

together with the capabilities of the systems for their control will be areas that I follow up during my assessment at Step 3 and 4.

4.2.5 Strengths

67. I have identified the following as areas of strength in the submissions provided to date that are relevant to Reactor Chemistry:

- The RP has proposed a Chemistry strategy for the safety case
- The RP is considering zinc addition despite it not currently being in use at the reference plant
- The RP has recognised the interrelation between Chemistry and materials selection and the necessity to consider both as part of their ALARP optimisation

4.2.6 Items that Require Follow-up

68. During my GDA Step 2 assessment of Chemistry I have identified the following shortcomings:

- I have not identified any significant shortcomings during my Step 2 assessment

69. During my GDA Step 2 assessment of the Chemistry of the primary circuit I have identified the following additional potential shortcomings that I will follow-up during Step 3:

- The means of control of pH and boron in the primary circuit will be an area that I follow up during my assessment at Step 3 and Step 4.
- The system for the dosing and maintenance of dissolved hydrogen is one I consider to be uncommon and the performance of this system will be a topic for assessment during Step 3 and 4:- I will require the RP to provide further evidence as to the performance and capabilities of the proposed hydrogen dosing system.
- I expect the RP to develop and provide their justification for zinc dosing of the primary circuit.
- The control of impurities and the function and capacity of clean-up systems
- The overall ALARP demonstration for the Chemistry of the primary circuit

70. During my GDA Step 2 assessment of the Chemistry of the primary circuit I have identified the following areas that may require research to be undertaken by GNS. I will follow up these matters, as appropriate, during Step 3:

- The RP will be considering zinc addition for the UKHPR 1000 and as this is not currently undertaken at the reference plant it is likely that research will be required to support their final position.

4.2.7 Conclusions

71. Based on the outcome of my assessment of the Chemistry of the primary circuit I have identified no significant shortcomings. Based upon the information submitted to date I consider that the RP will be able to adequately justify the proposed primary circuit Chemistry regime and controls later in the GDA process.

4.3 Chemistry of the Secondary Circuit

4.3.1 Assessment

4.3.2 My assessment of the Chemistry for the UK HPR1000 secondary circuit has included the relevant PSR chapters and my related regulatory queries:

- PSR Chapter 21 (Ref. 2)
- Aspects of PSR chapters 6, 7 and 10 (Ref. 2)
- Safety Case Strategy (Reactor Chemistry) (Ref. 4)
- Related regulatory queries (Ref. 18)

72. The RP has described a proposed secondary Chemistry regime that is based upon an all volatile treatment (AVT) regime, involving dosing with ammonia and hydrazine to maintain basic and reducing conditions throughout the circuit.

73. My expectation for the secondary system Chemistry is to be able to be shown to protect the heat transfer surfaces (tube bundle) of the steam generator from corrosion and fouling and in turn minimise corrosion throughout the other wetted systems forming the secondary plant.

74. One of the significant sensitivities applicable to the secondary circuit of a PWR is the concentration mechanism in the steam generator and as such there are significant demands on secondary water quality to avoid both fouling and possible chemical attack.

75. I consider that the PSR alone left ambiguity regarding the proposed approach to secondary water quality and I sought clarification in regulatory query RQ-UK HPR1000-0094 (Ref. 18). The RP subsequently clarified that their intent for UK HPR1000 is to include a condensate polishing system (ATE[CPS]) capable of handling the full condensate flow. The system described can be bypassed when not required, reducing the unnecessary generation of wastes. This RQ response also clarified that the intention for UK HPR1000 is to use materials that exhibit good resistance to both general corrosion and FAC for the majority of the secondary circuit.

76. The response to my RQ-UK HPR1000-0094 (Ref. 18) also includes a list of measures by which areas identified as being at risk of Flow Accelerated Corrosion (FAC) will be design-optimised in terms of shape, size and layout to further reduce the propensity for FAC. This results in reduced demands on the system Chemistry control, e.g. by removing any requirement to dose & subsequently scavenge for oxygen.

77. My related regulatory query RQ-UK HPR1000-0122 (Ref. 18) was to seek additional detail of both the chemical reagents injection system (SIR[CIS]) and the feedwater chemical sampling system (SIT[FCSS]) as the safety case strategy for reactor Chemistry (Ref. 4) states that these systems are considered to be out of scope for GDA by the RP. I clearly stated in the RQ that my expectation in this area is for all systems for the sampling or control of Chemistry to be in-scope as the control of Chemistry is a safety function. The response to RQ-UK HPR1000-0122 (Ref. 18) states that the systems mentioned will be demonstrated in PCSR chapter 21 but that there will be no “design reference document”. I consider that this reply remains somewhat ambiguous and this will be a matter that I follow up during Step 3 and Step 4, against the expectation I have clearly stated.

78. The RP has not stated the precise regime proposed for UK HPR1000 as some of the materials selection choices are not yet made, but refers to the regimes at Daya Bay where the pH(25°C) of the secondary system is maintained at 9.6 – 9.8. The respective levels of ammonia and hydrazine (which is also basic) are not stated, although this is adequate at this stage of the GDA process.

79. The proposed all volatile treatment (AVT) regime is commonly encountered worldwide and there is a significant body of evidence to support this approach providing a safe secondary Chemistry environment. I have no doubt that the RP will be able to provide an adequate justification for this approach as part of their overall justification for the UK HPR1000 secondary circuit.

80. I consider that the risk of chloride ingress following major condenser failure or even a minor tube perforation to be a potentially significant risk in normal operation and I sought further information relating to this in RQ-UK HPR1000-0094 (Ref. 18). The response to this RQ indicates that in the event of seawater ingress the operator is required to respond to an alarm and take action. The initial response to chloride ingress seen across the UK reactor fleet, including the PWR at SZB, is provided for by a dedicated Chloride Ingress Protection System (CIPS). While the design / materials considerations contributing to that position might be different for UK HPR1000 this will be an area for follow up during my assessment at Step 3 and 4.

81. The selection of all secondary system materials is yet to be finalised but the RP has stated that in areas and systems where conditions might give rise to flow accelerated corrosion the choice will be for alloys that minimise susceptibility to this mechanism. This approach demonstrates the use of operating Chemistry as a supplement to good materials choices, rather than a substitute for them and I consider this approach to the interface between materials choice and Chemistry to be a strength.

82. Overall, in developing their case for their proposed secondary circuit operating Chemistry I expect the RP will be able to demonstrate that their regime meets the expectations of ONR SAPS ECH.1 - 4

4.3.3 Strengths

83. The stated intent throughout the documents submitted to date is to use only materials exhibiting low susceptibility to flow accelerated corrosion in vulnerable areas of the secondary circuit. I consider this intention to “engineer out” Chemistry requirements that exist at some plants to be a strength in the UK HPR1000 approach to the Chemistry of the secondary circuit.

84. Other reactor designs use a range of options to ensure feed water quality and I consider that the inclusion of a full-flow condensate polishing system (ATE[CPS]) to be a robust choice in the interests of safe operation and I consider this to be a strength.

4.3.4 Items that Require Follow-up

- The proposed secondary system design places demands upon the operator in the event of a condenser tube leak/failure:- this was confirmed in my RQ-UK HPR1000-0094 (Ref. 18). This will be an area that I will follow up as part of my assessment during Step 3 and 4.
- The exact chemistry regime proposed for UK HPR1000 has not yet been stated. I do not consider this a significant shortcoming at Step 2 but once the final materials selection choices are made my expectation is that the details of the safe operating envelope will be determined and will form the basis of the final proposed Chemistry regime.
- The capability and capacity of the SIR[CIS] and SIT[FCSS] systems are important to safety and will be an area that I follow up during Step 3 and 4.

4.3.5 Conclusions

85. Based on the outcome of my assessment of the Chemistry of the secondary circuit I have concluded that there are no significant shortcomings apparent in the information submitted to date and I consider that the RP will be able to adequately justify the proposed Chemistry regime and controls.

4.4 Chemistry of the Fuel Cooling Pool

4.4.1 Assessment

86. My assessment of the Chemistry for the UK HPR1000 spent fuel pool has included the submissions;

- Preliminary Safety Report Chapter 21 (Ref. 2),
- Chapters 6, 7 and 10 (Ref. 2),
- Safety Case Strategy (Reactor Chemistry) (Ref. 4),
- Related regulatory queries. (Ref. 18)

87. The fuel pool for UK HPR1000 serves to store new fuel prior to loading into the core, to cool and store spent fuel pending export for longer term storage or disposal and to store any failed fuel that may occur. The control of the Chemistry of the pool is important to prevent the corrosion of the cladding of both new and used fuel and to minimise the spread of radioactivity arising from failed fuel.

88. The spent fuel pool, (SFP), is hydraulically connected to the primary circuit during fuelling/refuelling periods and the Chemistry requirement at those times is dictated by the requirements of the primary circuit and I consider that the SFP must be able to provide for water quality & Chemistry equivalent to that of the primary circuit.

89. The RP has not yet provided any information on the details of the proposed Chemistry of the SFP, other than to clarify that they make no claim on the presence of soluble boron for the control of criticality, instead relying upon fixed neutron absorbers.

90. These fixed absorbers are described as composites of aluminium and boron carbide and materials of this type have been identified as susceptible to corrosion in spent fuel pools, with the potential to exhibit relocation of the boron content (Ref 17). I have raised RQ-UK HPR1000-122 and 135 (Ref. 18) to seek further information on how it will be shown that these neutron absorbers will not corrode, exhibit boron relocation or otherwise cease to be effective over the lifetime of the spent fuel pool. This is will be an area for follow up during my Step 3 and 4 assessment.

91. The response to my RQ-UK HPR1000-0092 (Ref. 18) states that the fuel pool operating temperature limits will be 15 and 50°C depending upon the thermal load. I consider the evaporation of tritium from the spent fuel pool together with the overall inventory as areas that should be reduced so far as is reasonably practicable. The performance of both aspects of the fuel pool cooling and treatment system (PTR[FPCTS]) are therefore areas of significant interest that I will follow up.

92. The RP state that crystallisation of boron will not occur above 0°C and, that in normal operation there are in any event no claims made on the soluble boron content of the spent fuel pool, only upon the presence of the fixed neutron absorbers. The possibility of over-cooling of the pond and its impact on the water Chemistry will be an area that I follow up during my Step 3 and 4 assessment.

93. During refuelling, or during any requirement for core offload, the spent fuel pool will contain fuel with crud and may contain failed fuel. My expectation is that the pool cleanup system must be capable of maintaining the spent fuel pool coolant radiochemical inventory at a low level during all anticipated operations.

94. The response to my RQ-UK HPR1000-0092 (Ref. 18) states that the spent fuel pool cleanup system is able to “reduce the radioactivity to a reasonable level” but this level is not defined, nor is there any reference made to the actual system performance. I consider this to be a claim that was omitted from the PSR. While I have not identified any significant shortcomings in the Chemistry controls proposed for the UK HPR1000

spent fuel pool, these topics will be areas that I follow up during my assessment at Step3 and 4.

4.4.2 Strengths

95. The safety case proposed for the spent fuel pool and associated systems remains at a high level and my assessment to date has not identified any particular areas of strength.

4.4.3 Items that Require Follow-up

- Performance of the fuel pool cooling and treatment system (PTR[FPCTS]) and hence;
    - the radiochemical inventory
    - evaporation of tritiated water (and any other volatile species)
- The means by which it will be shown that the proposed fixed neutron absorbers will not:
    - corrode,
    - exhibit boron relocation
    - otherwise cease to be effective over the lifetime of the spent fuel pool

4.4.4 Conclusions

96. My assessment of the Chemistry of the spent fuel pool has given rise to a number of questions, particularly relating to the potential for corrosion of the proposed fixed neutron absorbers. Not all of my related regulatory queries have been fully answered at the time of preparing this report.

97. Performance of the fixed neutron absorbers over the lifetime of the plant has been identified above as an area that I will follow up during my Step 3 and 4 assessment and in particular, I will expect the RP to demonstrate that the degradation mechanisms reported elsewhere do not apply to UK HPR1000.

98. One emergent matter that I have identified relates to potential degradation of fixed neutron absorbers and this will be a matter that I follow up in Steps 3 and 4.

4.5 Chemistry of Auxiliary Systems

4.5.1 Assessment

99. Chapter 10 of the PSR (Ref. 2) provides descriptions and functional requirements of a number of Chemistry-related auxiliary systems. The described systems include:

- the chemical and volume control system (RCV[CVCS]),
- the coolant storage and treatment system (TEP[CSTS]),
- the nuclear sampling system (REN[NSS]),
- the component cooling water system(RRI[CCWS]) and
- the safety chilled water system (DEL[SC WS])

100. I consider that this is an acceptable range of systems to describe at this stage but few or no express claims are currently made on these systems and I expect the RP to consider the effects of Chemistry on a wider range of systems as GDA progresses.

101. While these auxiliary systems perform various plant Chemistry related functions, the PSR and supporting submissions provide only very basic information about their Chemistry and capacity to date. I have stated that my expectation is for all systems relating to the sampling, dosing or chemical control of any plant area are considered to be in-scope for GDA and there are currently omissions in this area. I do not consider this a significant shortcoming at Step 2 as these systems while contributing to safety,

or being safety related in their operation are not novel when compared to other PWRs and can be described in greater detail during Step 3 and 4, and will be examined in much greater detail at that time.

4.5.2 Items that require follow-up

- The Chemistry of the full range of systems with safety or safety related functions
- The Chemistry control of those systems

4.5.3 Conclusions

102. The Chemistry of auxiliary systems has not been presented in any detail in the PSR and supporting submissions, the information provided being in the form of a number of basic high-level descriptions. The safety significance of many of these systems may be lower than that of e.g. the primary circuit so I am content with this approach at this time, but I will pursue additional detail on the Chemistry of these systems during Step 3 and 4.

4.6 Chemistry of Radwaste Systems

4.6.1 Assessment

103. My assessment of the Chemistry of radwaste systems of the UK HPR1000 is informed by

- The PSR (Ref. 2) and
- Regulatory Query 0093 (Ref. 18)

104. The Chemistry aspects of the UK HPR1000 liquid and gaseous waste treatment systems are not detailed in the PSR and this led me to raise a Regulatory Query RQ-UK HPR1000-0093 (Ref. 18) to seek further information.

105. The RP do very broadly claim that the “design, commissioning and Chemistry regimes will minimise radiation and chemicals for workers, public, plant and environment through ALARP in normal and fault conditions”, but detail of how this will be delivered is deferred to the PCSR chapter 21.

106. Similarly, the liquid waste treatment system (TEU[LWTS]) has only a high level claim, with the detail being deferred to PCSR chapter 23 and the PCER chapter 3.

107. Regarding the gaseous waste management & treatment system, the RP make the same claim and same deferral as for liquid waste above.

108. The RP does state that short-lived gaseous activity such as noble gasses and iodine isotopes have short half-lives and will be removed through the delay beds in the TEG[GWTS] system, although no detail of this system is provided other than to state that it has been redesigned for Fangchenggang unit 3. Details are deferred once more to the relevant chapters of the PCSR and PCER.

4.6.2 Strengths

109. In assessing the Chemistry aspects of the gaseous and liquid radwaste systems of UK HPR1000 I have identified no areas of particular strength.

4.6.3 Items that require Follow-up

110. The Chemistry aspects of design and performance of the liquid and gaseous radwaste systems will be areas that I follow up during my Step 3 and 4 assessment.

4.6.4 Conclusions

111. Little information has been provided regarding the Chemistry aspects of waste management but I have not identified any significant shortcomings to date.

4.7 Accident Chemistry

4.7.1 Assessment

112. My assessment of the accident Chemistry of the UKHR1000 is informed by:

- Methodology of Accident Chemistry (Ref. 5) and
- one related regulatory query (Ref. 18)

113. The RPs methodology report (Ref. 5) describes the UK HPR1000 systems most directly associated with the Chemistry related aspects of accident progression and identifies a number of postulated initiating events. Those postulated initiating events are cited as giving rise to a number of bounding design basis conditions that have been identified for analysis to determine their radiological consequences to workers, the public and the environment.

114. The associated Chemistry claims are, that:

- The management of DBC Chemistry contributes to maintaining the integrity of the first barrier (fuel cladding) and the second barrier (the reactor coolant pressure boundary)
- The management of the DBC accident Chemistry contributes to the reduction of radiological consequences and limits the impact on the environment.

115. Further claims that are inferred as outcomes from the deployment or activation of mitigation measures are:

- That the in-containment refuelling water storage tank (IRWST) pH will be maintained above 7 in an accident, and that this will significantly limit the transport / volatility of iodine
- That the crystallisation of boron will not occur in a way that reduces the heat transfer performance of the plant (potentially making an accident worse)
- That the combustible gas control system will limit the hydrogen concentration in containment to less than 4%

116. I do not consider these fundamental claims to be unreasonable but much of the supporting information to date has been of a largely theoretical nature and the RP has work to do in this area to develop a comprehensive safety case for accident Chemistry.

117. The impact of in vessel retention, (IVR), where in the case of an accident the molten core remains confined within the reactor vessel, needs to be significantly developed, both in terms of successful IVR and unsuccessful, and linked to the production and mobility of both combustible gas and radioactivity in both cases.

118. The rate-performance of the proposed passive autocatalytic recombiners, (PARs), which act to reduce the hydrogen concentration in containment following an accident, is not currently well defined.

119. The containment combustible gas control system (EUH[CCGCS]) performance is stated to be sufficient to control hydrogen below 4% in design basis accidents and below 10% in severe accidents. How this performance will be justified, the impact of steam-air mixture on the flammability and LEL for hydrogen in severe accidents and how explosive conditions will be avoided during severe accident evolution will be areas that I follow up during my assessment at Step 3 and 4.

4.7.2 Strengths

120. The safety case proposed for accident Chemistry and the associated systems remains at a high level and my assessment to date has not identified any notable areas of strength.

4.7.3 Items that Require Follow-up

121. Of the areas that I have examined during my assessment at Step 2 the area of accident Chemistry is the one that I consider to be least mature. While I have not identified any major shortfalls at this time I consider that the RP has significant work to do in this area in order to develop and present an adequate case for the accident Chemistry of the UK HPR1000.

122. I anticipate that I will need to engage significantly with the assessment leads for fuel & core, fault studies and radiological consequences (as a minimum) as the wider severe accident safety case develops and this will be an area that I will follow up during my assessment at Step 3 and Step 4.

123. The applicability of codes and standards in the event of successful in vessel retention remains an unknown at this time. IVR may significantly alter the behaviour of the plant under accident conditions and this is an area where it is likely that I will commission a TSC to support my assessment as GDA progresses.

124. Hydrogen generation, removal and behaviour in accident conditions will be an area for follow-up as GDA progresses.

4.7.4 Conclusions

125. While the area of accident Chemistry is the least developed of the sub-topic areas I have considered during this assessment, I do not consider that the RP will be unable to develop an adequate safety case in this area, based on the information provided to date. I will be required to engage with other topic leads extensively in this area as GDA progresses, and may also engage TSC support in this area.

4.8 Materials Selection Methodology

4.8.1 Assessment

126. In forming this assessment I have considered the GDA Materials Selection Methodology (Ref. 8).

127. The Materials Selection Methodology for UK HPR1000 describes, at a high level, a Stepwise approach to materials selection that is proposed by the RP for UK HPR1000. The flow through decision informing Steps is described, followed by a single reporting/output step:

- Material selection principles
- Input information (e.g. functional requirements)
- Preliminary selection
- Justification & optimisation
- Materials selection report.

128. Practical considerations such as manufacturability, weldability etc. form part of this process and are relevant to materials selection but lie outside the Chemistry assessment area and hence are not considered further here - Structural Integrity will be the lead topic for materials selection.

129. It is my expectation that the relationship between Chemistry and materials selection should be one where the control of Chemistry acts as a *supplement* to good materials selection and not as a *substitute*. As such, my assessment in this area seeks to identify any areas where significant (or even unnecessary) reliance upon Chemistry control emerges as a result of materials selection.

130. Within the described framework there are descriptions of a number of discrete criteria that will be considered as part of the material selection process, but there is no information as to the degree of weighting that will be applied to any particular criteria or step. My expectation in this area is that the materials selection considerations identified should be associated with their relative importance to safety and weighted accordingly.

131. It is step 3 of the proposed process where the first technical considerations are examined, these include the code/class for the SSC, the environmental conditions in which it is to operate, radiological dose and available OPEX/feedback. There is once more, no indication of any weighting to be applied. While I welcome the inclusion of environmental conditions and radiological implications as these are of relevance from a Chemistry viewpoint, these criteria are only partly developed and how the RP will determine their overall significance in the decision process remains to be shown.

4.8.2 Strengths

132. The provided submission on Materials Selection methodology comprises a high-level process flow with some explanatory text, I consider that the RP can build upon this methodology to present a fit for purpose materials selection process. Specific areas of strength include:

- The recognition that an ALARP optimisation/justification is required
- Consideration of a range of degradation mechanisms/threats
- Consideration of wider OPEX in materials selection

4.8.3 Items that Require Follow-up

133. I consider that while the overall methodology represents a good place from which to start, it will be necessary for the RP to show how the selection process will be applied in a proportionate way, to which SSCs and how the process detail / flow charts evolve.

134. My opinion is RP will also need to implement some consideration of weighting in their approach to materials selection as it evolves, and better demonstrate how the expectations of different topic areas will be balanced and addressed.

135. The methodology does contain the main drivers I expect to be present but is let down by a lack of clarity in several areas and the uncertainty arising from this, together with the actual implementation of this methodology will be areas that I will follow up during my Step 3 and 4 assessment.

136. Materials selection will require a fully multidisciplinary assessment during GDA and is an area where I expect to engage with a range of other disciplines, including:

- Structural integrity
- Mechanical engineering
- Radiation protection
- Radwaste

4.8.4 Conclusions

137. Overall, I consider that from a Chemistry perspective the RP will be able to develop a suitable materials selection justification based upon the principles outlined in the methodology (Ref. 8) as supplied and I anticipate that I will engage with a number of other topic leads in this area as GDA progresses. The written standard of submissions in this area will need to be improved significantly in later Steps but I have not identified any significant shortfalls to date.

4.9 Source Term and Radionuclide Selection

4.9.1 Assessment

138. In forming this assessment I have considered the RPs submissions;

- Normal Operation Source Term Strategy Report (Ref. 6) and
- Report of Radionuclide Selection During Normal Operation (Ref. 7).

139. The determination of a valid normal operational radiological source term is important because it is a key component of the process to justify that the production and transport of radioactivity in UK HPR1000 has been minimised at the source. Within this definition, the strategy submitted calls for the identification of the most significant SSCs that might contribute to the radiological source term, and has sought to subdivide the radiological source term into seven components according to location and origin:

- The primary coolant source term
- Spent fuel source term
- Secondary coolant source term
- Derived source term
- Gaseous & liquid discharges
- Airborne activity
- Activated structures source term

140. The key SSCs of significance in the determination and evolution of the source term are also defined:

- Reactor coolant system (RCP[RCS])
- Chemical and volume control system(RCV[CVCS])
- Safety injection system (RIS[SIS])Nuclear Sampling system (REN[NSS])
- Nuclear Island vent & drain system (REP[VDS])
- Reactor boron and water makeup system (REA[RBWMS])
- Steam generator blowdown system(APG[SGBS])
- Fuel pool cooling and treatment system (PTR[FPCTS])
- Coolant storage and treatment system (TEP[CSTS])
- Solid waste treatment system (TES[SWTS])
- Gaseous waste treatment system (TEG[GWTS])
- Liquid waste treatment system (TEU[LWTS])
- Nuclear island liquid waste discharge system (TER[NLWDS])
- Conventional island liquid waste discharge system (SEL[LWDS(CI)])
- Condensate vacuum system (CVI[CVS])
- HVAC system (HVAC)
- Etc. (recognising that this list may not be exhaustive)

141. It is clear from the range of sources and systems described that this topic area will require a wide multidisciplinary assessment by ONR and I anticipate extensive engagement with other disciplines as GDA evolves.

142. The proposed strategy clearly states that the radiological source term should comprise a balance of calculated and measured (OPEX) data without undue reliance upon either and should be able to be demonstrated to be realistic but with an appropriate degree of conservatism.

143. The strategy also recognises that there are a number of “users” of the radiological source term that do not all share the same requirements, e.g. with radiation protection being a user of all significant source terms, but decommissioning being focussed upon the activation of structures etc.

144. The RP has stated that the submissions on source term strategy lack maturity and this is reflected in the document itself.

145. The submission Radionuclide selection during normal operation (Ref.7) provides the basis for the selection process that will be applied to identify the nuclides considered during development of the radiological source term.

146. The selection process identifies fission products, activation products, corrosion products and actinides and outlines the criteria applied in determining their significance and in the overall source term. The exact grounds for inclusion or exclusion are not however well developed and there are both omissions and errors in the submission in this area.

147. The RP has made a broad statement that actinides are proposed to be excluded from the normal operation source term. The justification for this approach is stated as being because the rate of fuel failures is low and the concentration of tramp uranium is variable. While these statements may be true, my expectation is that the determination of actinide concentrations in the coolant will inform the baseline against which changes in tramp uranium, or fuel failures, can be compared in order to determine their significance. This will be an area that I follow up during my assessment at Step 3 and Step 4.

4.9.2 Strengths

148. I consider that this is an area where the RP has gone beyond the necessary minimum in terms of the scope of the information that has been submitted at this Step

4.9.3 Items that Require Follow-up

149. The general areas of source term, nuclide selection and accident Chemistry are closely related and while there have been no significant shortfalls identified during my assessment at Step 2 the RP has significant work to do in these areas to further develop the safety case for UK HPR1000, I will follow up these areas during my Step 3 and Step 4 assessment.

4.9.4 Conclusions

150. The RP has work to do in the topic areas of source term and radionuclide selection in order to progress with GDA of the UK HPR1000, however, I consider that the information provided to date can be developed to produce a suitable safety case and I have identified no shortfalls that I do not consider can be addressed later in GDA, or that would prevent ONR issuing a DAC.

4.10 Out of Scope Items

151. My Step 2 assessment of the Chemistry of the UK HPR1000 has taken the form of a broad shallow overview as appropriate at this Step. I have not undertaken any detailed assessment of some headline cross-cutting topics such as ALARP and cat & class methodologies because these will only become fully developed later in GDA.

Similarly, I have not considered the specific limits and conditions that have been stated in some submissions because these will be part of my assessment at Step 3 and 4 and are not relevant at this time.

152. It should be noted that the above omissions do not invalidate the conclusions from my GDA Step 2 assessment. During my GDA Step 3 assessment I will follow-up the above out-of-scope items as appropriate; I will capture this within my GDA Step 3 Assessment Plan.

4.11 Comparison with Standards, Guidance and Relevant Good Practice

153. In Section 2.2 above I have listed the principal standards and criteria I have used during my GDA Step 2 assessment of the UK HPR1000 Chemistry to judge the adequacy of the preliminary safety case. My overall conclusions in this regard can be summarised as follows:

- SAPs: While there is work to be done in some areas I am broadly content that the RP will be able to develop a safety case for the Chemistry of the UK HPR1000 that meets the expectations of ONR SAPs ECH.1 to ECH.4.
- TAGs: ONR Technical assessment guides NS-TAST-GD-088 and NS-TAST-GD-089 are applicable to this assessment and while these TAGS outline ONRs expectations at a level that goes beyond my expectations for GDA Step 2 in a number of areas, I have not identified any shortfalls that I consider the RP will be unable to address fully as GDA progresses.

4.12 Interactions with Other Regulators

154. My interactions with other regulators have been limited to date and in forming this assessment I have engaged in only informal discussion with the Environment Agency. I consider that engagement with the EA will need to take place on a more formal footing as Steps 3 and 4 progress, particularly in the area of source term.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

155. During Step 2 of GDA the RP submitted a PSR and other supporting references, which outline a preliminary nuclear safety case for the UK HPR1000. These documents have been formally assessed by ONR. The PSR together with its supporting references present at a high level the claims in the area of Chemistry that underpin the safety of the UK HPR1000.

156. During Step 2 of GDA I have targeted my assessment at the content of the PSR and those references that are of most relevance to the area of Chemistry; against the expectations of ONR's SAPs and TAGs and other guidance which ONR regards as Relevant Good Practice. From the UK HPR1000 assessment done so far, I conclude the following:

- There are few *explicit* safety claims made on Chemistry for the UKHRP1000 at this time. The role of Chemistry in reducing corrosion, controlling criticality and minimising the production and transport of radioactivity at the source is however well established and the majority of associated Chemistry claims exist by inference.
- In forming my assessment I have identified numerous minor shortcomings and omissions, but none of these are of a scale that might alter the overall outcome of the assessment. These shortcomings and omissions will, however, act to inform my Step 3 assessment plan.
- My level of overall understanding of the technology of the UK HPR1000 remains at a basic level at the moment, commensurate with the level of detail required for Step 2. It will be necessary for me to significantly expand my understanding of the plant, and specifically the role of Chemistry, as GDA progresses.
- While I am of a view that the quality of written submissions will need to improve as Step 3 and Step 4 progress, I have no reason to doubt the ability of the RP to make and justify a case for the proposed operating chemistries of the UK HPR1000.
- The RP has submitted several methodology and strategy reports that describe their future approach for the design and safety case. The requirement for, and the intent to demonstrate both optimisation and justification is a recurring theme in these submissions. I consider this as evidence of the RP commitment to show an ALARP balance as part of their ongoing decision process. How an ALARP balance is demonstrated in practice will be a matter that I will follow up during my Step 3 and 4 assessment.

157. Overall, during my GDA Step 2 assessment, I have not identified any fundamental safety shortfalls in the area of Chemistry that might prevent the issue of a Design Acceptance Confirmation (DAC) for the UK HPR1000 design.

5.2 Recommendations

158. My recommendations are as follows :

- Recommendation 1: ONR should consider the findings of my assessment in deciding whether to proceed to Step 3 of GDA for the UK HPR1000.
- Recommendation 2: All the items identified in Step 2 as important to be followed up should be included in ONR's GDA Step 3 Chemistry Assessment Plan for the UK HPR1000.

6 REFERENCES

1. ONR Guide, Purpose and Scope of Permissioning, Revision 6, NS-PER-GD-014, November 2016. http://www.onr.org.uk/operational/assessment/index.htm

2. ONR Generic Design Assessment of GNS's UK HPR1000 - Step 2 Assessment Plan for Chemistry - ONR-GDA-UK HPR1000-AP-17-015 Revision 0. ONR, November 2017. TRIM Ref. 2017/376938.

3. General Nuclear System Ltd UK HPR1000 Project HPR/GDA/PSR Preliminary Safety Report for UK HPR1000 TRIM Ref. 2018/14773.

4. Generic Design Assessment (GDA) for UK HPR 1000 GH X 00100 005 DCHS 03 GN Methodology for Primary Water Chemistry Regime NE15BW-X-AF-0000-000158 Trim Ref. 2018/180671.

5. Generic Design Assessment (GDA) for UK HPR 1000 GH X 00100 095 DCHS 03 GN Safety Case Strategy Reactor Chemistry NE15BW-X-HS-0000-00031 Trim Ref. 2018/180705.

6. Generic Design Assessment (GDA) for UK HPR 1000 GH X 00100 002 DRAF 03 GN Methodology of Accident Chemistry NE15BW-X-HS-0000-00025 Trim Ref. 2018/180709.

7. Generic Design Assessment (GDA) for UK HPR1000 GH X 90300 002 DNFP 03 GN Normal Operation Source Term Strategy Report Trim Ref. 2018/215200.

8. Generic Design Assessment (GDA) for UK HPR1000 GH 0080 001 DRDG 03 GN Report of Radionuclide Selection During Normal Operation ~Trim Ref. 2018/215055.

9. Generic Design Assessment (GDA for UK HPR1000 GH X 00100 06 DPCH 03 GN Materials Selection Methodology Trim Ref. 2018/211845.

10. ONR Safety Assessment Principles for Nuclear Facilities. 2014 Edition Revision 0. November 2014. http://www.onr.org.uk/saps/saps2014.pdf

11. ONR Technical Assessment Guides –
    - Chemistry of operating Civil Nuclear Reactors NS-TAST-GD-088 Revision 1. ONR. March 2017
    - Chemistry Assessment NS-TAST-GD-089 Revision 0. ONR. Feb 2018 http://www.onr.org.uk/operational/tech_asst_guides/index.htm

12. Generic Design Assessment (GDA) for UK HPR1000 GH X 00620 021 KPGB 02 GN DRAFT Pre-Construction Safety Report Chapter 21Reactor Chemistry

13. ONR-GDA-GD-001 GDA Guidance to Requesting Parties Revision 3, September 2016

14. IAEA guidance –
    - Chemistry Programme for Water Cooled Nuclear Power Plants – Specific Safety Guide No. SSG-13, IAEA 2011
    - Safety of Nuclear Power Plants: Design. Safety Requirements. International Atomic Energy Agency (IAEA), Safety Standards Series No. NS-R-1, IAEA. Vienna. 2000.

www.iaea.org.

15. Western European Nuclear Regulators' Association (WENRA do not produce specific guidance or reference levels relating to Chemistry, however the general principles outlined in their documentation are relevant)

    - Safety Reference Levels for existing reactors WENRA September 2014, Reactor Harmonisation Working Group report on Safety of new NPP designs WENRA March 2013,

    - Wenra Handbook Part II – WENRA Statements and Safety Reference Levels, Version 2, December 2014

    http://www.wenra.org/

16. ONR Guidance on Mechanics of Assessment within the Office for Nuclear Regulation (ONR) – TRIM Ref. 2013/204124.

17. Strategy for Managing the Long Term Use of BORAL in Spent Fuel Storage Pools – EPRI Technical Report 2012.

18. UK HPR1000 - Regulatory Query (RQ) Tracking Sheet - 2 November 2017. TRIM Ref. 2018/315144.

Table 1

Relevant Safety Assessment Principles Considered During the Assessment

SAP No and Title	Description	Interpretation	Comment
ECH.1 Safety Cases	Safety cases should, by applying a systematic process, address all chemistry effects important to safety	This principle sets the framework and requires that chemistry based limits and conditions be defined and applied. It further requires that possible reactions, side reactions, impurities and chemistry behaviour during faults be addressed	The information submitted to date is variable in terms of quality and depth but I have not identified anything to indicate that it cannot be developed to fully justify the expectations of ECH.1
ECH.2 Resolution of conflicting chemical parameters	Where the effects of different chemistry parameters conflict with one another, the safety case should demonstrate that an appropriate balance for safety has been achieved.	This principle requires that positive and negative effects of chemistry should be considered, and an appropriate balance identified such that risks are reduced SFAIRP	The detailed balance in the interests of safety is an area I will explore as GDA advances but I have identified nothing to date to indicate that the RP will be unable to demonstrate that they can meet the expectations of ECH.2
ECH.3 Control of Chemistry	Suitable and sufficient systems, processes and procedures should be provided to maintain chemistry parameters within the limits and conditions identified in the safety case.	This principle requires that the plant SSCs and operating procedures, together with the quantities and quality of the feedstuffs held, are able to effectively deliver chemistry control in normal, transient and accident conditions.	Only limited information on the means of control of chemistry has been provided at Step 2, with a small number of exceptions. This is however not inappropriate for this Step and I have identified nothing to indicate that the expectations of ECH.3 will be unable to be met by UK HPR1000
ECH.4 Monitoring, sampling and analysis	Suitable and sufficient systems, processes and procedures should be provided for monitoring, sampling and analysis so that all chemistry parameters important to safety are properly controlled	Sampling systems should be properly representative of the system being sampled and arrangements for control should possess both resolution and headroom regarding their ability to control chemistry within the defined limits and conditions, in all modes of operation.	Only limited information on the means of control of chemistry has been provided at Step 2, with a small number of exceptions. This is however not inappropriate for this Step and I have identified nothing to indicate that the expectations of ECH.4 will be unable to be met by UK HPR1000
RW.2 Generation of Radioactive Waste	The generation of radioactive waste should be prevented or, where this is not reasonably practicable, minimised in terms of quantity and activity.	Control of chemistry, well informed materials selection and suitable and sufficient procedures should be defined to ensure that the production and transport of radioactivity is minimised at the source.	The submissions I have considered to date indicate that the production of radioactive waste is being considered by the RP for UK HPR1000, I intent to liaise with the RP and Radwaste topic leads in this area ad GDA progresses

EKP.1 Engineering Principles : Key Principles	Inherent Safety	This principle requires that he underpinning safety aim for any nuclear facility should be an inherently safe design, consistent with the operational purposes of the facility.	There is evidence within the submissions that I have considered that this expectation is recognised by the RP and forms part of their proposed strategies for chemistry and materials selection.
EHT.5 Engineering Principles : Heat Transport Systems	Minimisation of radiological doses	This Principle requires that the heat transport system should be designed to minimise radiological doses. In GDA context, both operating chemistry and materials choices should be shown to contribute to the reduction in the production and transport of radioactivity at the source.	There is evidence within the submissions that I have considered that this expectation is recognised by the RP and forms part of their proposed strategies for chemistry and materials selection.