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Holtec Britain Ltd	HI-2240352
Sponsoring Company	**Document Reference**
1	23 September 2025
Revision No.	**Issue Date**
Report	Non-proprietary
Record Type	**Proprietary Classification**
ISO 9001	No
Quality Class	**Export Control Applicability**

Record Title:

PSR Part B Chapter 23 Reactor Chemistry

Proprietary Classification

This record does not contain commercial or business sensitive information.

Export Control Status

Export Control restrictions do not apply to this record.

Revision Log

Revision	Description of Changes
0	First Issue to Regulators to support PSR v0
1	Second Issue to Regulators to support PSR v1

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23.1 INTRODUCTION

The Fundamental Purpose of the Generic Design Assessment (GDA) Safety, Security and Environment Case (SSEC) is to demonstrate that the generic Small Modular Reactor (SMR)-300 can be constructed, commissioned, operated, and decommissioned on a generic site in the United Kingdom (UK) to fulfil the future licensee's legal duties to be safe, secure and protect people and the environment, as defined in Part A Chapter 1 Introduction [1].

The Fundamental Purpose is achieved through the Fundamental Objective of the Preliminary Safety Report (PSR), which is to summarise the safety standards and criteria, safety management and organisation, claims, arguments and evidence to demonstrate that the generic SMR-300 design risks to people are likely to be tolerable and As Low As Reasonably Practicable (ALARP) [1].

Part B Chapter 23 of the PSR presents the Claims, Arguments and Evidence (CAE) for the Reactor Chemistry topic.

23.1.1 Purpose and Scope

The overarching SSEC claims are presented in Part A Chapter 3.

Part B Chapter 23 links to the overarching claim through Claim 2.2.

Claim 2.2: The design of the systems and associated processes are developed taking cognisance of relevant good practice and substantiated to achieve their safety and non-safety functional requirements.

As set out in Part A Chapter 3, Claim 2.2 is further decomposed across several engineering disciplines which are responsible for development of the design of relevant Structures, Systems, Components (SSCs).

Part B Chapter 23 presents the Reactor Chemistry aspects of the SMR-300 and directly supports Claim 2.2 by satisfying Claim 2.2.14.

Claim 2.2.14: The SMR-300 chemistry regime and systems reduce chemistry-related risks during all normal operating modes and accident conditions for all phases of the lifecycle.

Further discussion on how Claim 2.2.14 is broken down into Level 4 claims and how the Level 4 claims are met is provided in sub-chapter 23.2.

Sub-chapter 23.3 presents the codes, standards and design philosophy associated with the chemistry of the SMR-300.

Sub-chapter 23.4 provides an introduction to each of the systems important to the chemistry safety case on the Nuclear Island (NI), before presenting CAE for each Level 4 claim.

Sub-chapter 23.5 provides an introduction to each of the systems important to the chemistry safety case on the Turbine Island (TI), before presenting CAE for each Level 4 claim.

Sub-chapter 23.6 provides a consolidated presentation of all chemical and radiochemical control limits and conditions defined for both NI and TI systems.

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Finally, sub-chapter 23.7 provides a technical summary of how the claims for this chapter have been achieved, together with a summary of key contributions from this chapter to the overall ALARP demonstration as presented in Part A Chapter 5 Summary of ALARP and SSEC [2]. Sub-section 23.7.3 also discusses any GDA Commitments that have been raised.

A master list of definitions and abbreviations relevant to all PSR chapters can be found in Part A Chapter 2 General Design Aspects and Site Characteristics [3].

The scope of Part B Chapter 23 covers the chemistry aspects of SSCs of the NI and the TI. The focus of Part B Chapter 23 at this issue of the Safety Report is on the operational lifecycle phase of the SMR-300, specifically Power Operation. Where available, information on other modes and lifecycle phases is presented, this will be expanded on in future iterations of the SSEC.

23.1.2 Assumptions

There are no assumptions raised in relation to Part B Chapter 23. Any assumptions relevant to this topic that are identified in the future will be formally captured in the Capturing and Managing Commitments, Assumptions and Requirements process [4]. Further details of this process are provided in Part A Chapter 4 Lifecycle Management of Safety and Quality Assurance [5].

23.1.3 Interfaces with Other SSEC Chapters

Reactor Chemistry interfaces with multiple topic areas across the SSEC as summarised below.

Part B Chapters 1 Reactor Coolant System and Engineered Safety Features [6], 2 Reactor [5], 5 Reactor Supporting Facilities [7], and 13 Radioactive Waste Management [8] provide systems-based views of SSCs of relevance to Reactor Chemistry. These chapters also hold the system level safety functional requirements which are to be met by individual systems and for which dependencies or requirements on Reactor Chemistry may be placed (e.g. the adequate provision of boron in accident conditions).

Reactor Chemistry interfaces with Fault Studies, Hazard and Safety Analysis (Part B Chapters 14 Design Basis Analysis (Fault Studies) [9], 15 BDBA, Severe Accident Analysis, and Emergency Preparedness [10], 17 Human Factors [11] and 22 Internal Hazards [12]) by ensuring that safety functions are met where adequate chemistry provisions, controls or monitoring is required. Further information on the development of the UK Fault and Protection Schedule and UK-aligned set of design basis faults is provided in Part B Chapter 14 and the GDA Commitment C_Faul_103. Where there are dependencies on Reactor Chemistry human actions to perform safety significant actions, such as monitoring boron concentrations, these will be systematically identified and assessed in support of future licensing phases and the resolution of GDA Commitment C_Huma_003.

Reactor Chemistry interfaces with Part B Chapter 9 Description of Operational Aspects and Conduct of Operations [13] through providing chemistry-derived operational control limits and conditions. In support of Part B Chapter 25 Construction & Commissioning Approach [14], Reactor Chemistry ensures the appropriate preservation of SSCs and supports integrated system commissioning phases such as Hot Functional Testing (HFT). Reactor Chemistry will ensure that HFT chemistry control is aligned with industry best practice such that operational

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degradation is minimised. In support of Part B Chapter 26 Decommissioning Approach [15], Reactor Chemistry supports by minimising the primary circuit source term and the uncontrolled accumulation of radioactivity in plant SSCs. CAE, as well as associated limits and conditions, related to these lifecycle phases will be introduced and expanded upon in future iterations of the SSEC.

Reactor Chemistry supports source terms, which as a topic is led by Part B Chapter 10 Radiological Protection [16]. Reactor Chemistry supports this chapter through demonstration that the Reactor Coolant System (RCS) normal operation source term is appropriately representative of the operating plant and that it is minimised. In this way Reactor Chemistry supports the overall strategy of minimising Operational Radiation Exposure (ORE). Reactor Chemistry interfaces with Part B Chapter 13 Radioactive Waste Management [8] through the minimisation of radioactivity generation and accumulation.

Reactor Chemistry supports Part B Chapters 18 Structural Integrity [17], 19 Mechanical Engineering [18] and 20 Civil Engineering [19] through optimisation of chemistry regimes and operational philosophies to minimise degradation of the SSCs presented in these chapters.

Reactor Chemistry supports the minimisation of conventional and radiological harm to the environment in support of Preliminary Environmental Report (PER) Chapters 1 Radioactive Waste Management Arrangements [20], 2 Quantification of Effluent Discharges and Limits [21], 3 Radiological Impact Assessment [22], 4 Conventional Impact Assessment [23] and 5 Monitoring and Sampling [24]. Reactor Chemistry also provides technical detail and evidence in support of PER Chapter 6 Demonstration of BAT [25]. For example, sub-section 23.4.7 provides discussion of strategies which minimise operational source term; these strategies are inherently derived with consideration of Best Available Technique (BAT). A summary of contributions from the PER to the PSR is provided by Part B 11 Environmental Protection [26].

23.2 REACTOR CHEMISTRY CLAIMS, ARGUMENTS AND EVIDENCE

This chapter presents the Reactor Chemistry aspects for the generic SMR-300 and therefore directly supports Claim 2.2.14.

Claim 2.2.14: The SMR-300 chemistry regime and systems reduce chemistry-related risks during all normal operating modes and accident conditions for all phases of the lifecycle.

Level 3 Claim 2.2.14 has been decomposed within this chapter to Level 4 claims which largely reflect the fundamental nuclear safety functions that Reactor Chemistry provides support to. These are the control of reactivity, removal of heat and confinement and control of radiation. Confinement and control of radiation has been split into two claims regarding confinement (delivered through supporting structural material integrity) and minimisation of the primary coolant source term. A further claim has also been developed which addresses monitoring and chemical control of systems of the NI.

Two additional claims have been decomposed from Claim 2.2.14 to ensure consideration of the TI Steam and Power Generation systems and TI Auxiliary systems. These Level 4 claims, which relate to confinement and monitoring and chemical control, are consistent with those presented for the NI.

Table 1 shows the breakdown of Claim 2.2.14 and identifies in which section of Part B Chapter 23 the Level 4 claims are demonstrated to be met to an appropriate maturity.

Table 1: Claims Covered by Part B Chapter 23

Claim No.	Claim	Chapter Section
2.2.14.1	The chemistry of Nuclear Island systems reduces risks relevant to the control of fuel reactivity.	23.4.4 Chemistry Support to Fuel Reactivity
2.2.14.2	The chemistry of Nuclear Island systems reduces risks relevant to fuel heat removal.	23.4.5 Chemistry Support to Fuel Heat Removal
2.2.14.3	The chemistry of Nuclear Island systems reduces risks relevant to the integrity of structural materials and confinement of radioactivity.	23.4.6 Chemistry Support to Structural Material Integrity and Confinement of Radioactivity
2.2.14.4	The chemistry of Nuclear Island systems reduces the normal operation source term of the reactor coolant.	23.4.7 Chemistry Support to Radioactive Source Term
2.2.14.5	Plant Auxiliary systems enable management of Nuclear Island chemistry.	23.4.8 Chemistry Monitoring and Control
2.2.14.6	The chemistry of the Steam and Power Conversion systems reduces risks relevant to the integrity of structural materials and confinement of radioactivity.	23.5.2 Chemistry Support to Structural Material Integrity and Confinement of Radioactivity
2.2.14.7	Steam and Power Conversion supporting systems enable management of TI chemistry.	23.5.3 Chemistry Monitoring and Control

In line with the expectations of a PSR, the claims architecture has been decomposed to a level which supports demonstration of the fundamental adequacy of the design and the safety, security, and environmental cases. The claims presented within this chapter are currently supported by associated prose (Arguments) to connect the claims to the supporting documentation (Evidence), which at this early stage is often indicative or not fully mature. Where this is the case, gaps are acknowledged and methodologies and philosophies to address these gaps are presented. Primarily this is delivered through use of GDA Commitments in line with the Capturing and Managing Commitments, Assumptions and Requirements [4] GDA process.

Appendix A provides a full claims, arguments and evidence mapping for Part B Chapter 23, which includes any lower-level claims, arguments and evidence needed to support the claims in the table above. This includes identification of evidence available at PSR v1 and aspects for future development of evidence to support these claims beyond PSR v1.

23.3 REACTOR CHEMISTRY CODES AND STANDARDS / DESIGN PHILOSOPHY

The design philosophy and high-level requirements for the SMR-300 are defined in SMR-300 Top Level Plant Design Requirements [27] and informed by content adopted from the Electric Power Research Institute (EPRI) Utilities Requirements Document (URD) [28].

The EPRI URD provides a set of requirements that ensure that the SMR-300 design appropriately takes Operating Experience (OPEX) and engineering best practice into account. Materials requirements (Tier 2, Chapter 1 - Overall Requirements - Section 5) are defined to avoid material degradation from a large number of causes (e.g., intergranular attack, Stress Corrosion Cracking (SCC), crevice corrosion, thermal and mechanical fatigue, radiation effects, welding related failures, bolting failures, and casting flaws) and to minimise the release and transport of corrosion products, and other specific species such as cobalt. Requirements unique to specific components and detailed design requirements implementing Reactor Chemistry best practices are addressed in specific system chapters (e.g., Tier 2 - Chapter 2 - Power Generation Systems, Chapter 3 - Reactor Coolant System and Reactor Non-Safety Auxiliary Systems and Chapter 4 - Reactor Systems).

Top level plant design requirements #1054 and #1057 are of most relevance to Reactor Chemistry. Requirement #1057 '*Plant primary and secondary chemistry shall comply with the plant water chemistry requirements of HI-2240463, SMR-300 Water Chemistry Requirements*' [27] [29] is the mechanism by which operational chemistry limits and conditions are integrated into the design of the SMR-300. These operational limits and conditions are consistent with the requirements raised in the Nuclear Energy Institute (NEI) publications NEI 03-08, Materials Management [30] and NEI 97-06, Steam Generator Program [31] and the EPRI documents Pressurized Water Reactor Primary Water Chemistry Guidelines [32] and Pressurized Water Reactor Secondary Water Chemistry Guidelines [33].

NEI 03-08 [30] and NEI 97-06 [31] are produced by the NEI which is the organisation responsible in the United States (US) for establishing unified industry policy on matters affecting the nuclear energy industry, including the regulatory aspects of generic operational and technical issues. Holtec International, as an NEI Member, is committed to the proactive, integrated and coordinated management of chemistry and material issues through NEI 03-08 [30] and NEI 97-06 [31]. The SMR-300 therefore has been designed in an industrial culture that ensures that the management of materials degradation and ageing is forward-looking, focused on issues commensurate with their safety significance and coordinated to the maximum extent practical.

The EPRI Pressurized Water Reactor Primary Water Chemistry Guidelines [32] and Pressurized Water Reactor Secondary Water Chemistry Guidelines [33] are state-of-the-art water chemistry programmes produced by a committee of industry experts, including utility specialists, nuclear steam supply system and fuel vendor representatives, Institute of Nuclear Power Operations (INPO) representatives, consultants and EPRI staff. These guidelines prescribe production of Strategic Water Chemistry Plans and optimisation of new plant chemistry regimes therein by adapting the extensive OPEX and guidance provided. Adherence to these water chemistry programmes also satisfies the EPRI URD requirements.

Requirement #1054 '*Plant systems subject to flow accelerated corrosion (FAC) and similar accelerated erosion-corrosion degradation mechanisms shall be fabricated from erosion-*

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corrosion resistance materials’ [27] demonstrates the commitment of Holtec International to mitigating the risk of FAC through appropriate material selection.

The SMR-300 design philosophy has been shown to largely meet UK Context (including UK regulatory expectations as set out in the relevant Office for Nuclear Regulation (ONR) Safety Assessment Principles (SAP) [34] and Technical Assessment Guides (TAG) [35] [36]) and International Atomic Energy Agency (IAEA) guidance [37]. This is demonstrated in UK Context – Gap Analysis of SMR-300 versus the ONR Chemistry SAPs and TAGs [38] and UK Gap Analysis of SMR-300 Design Philosophy Against Chemistry Codes and Standards [39]. A number of minor compliance deltas have been identified which either have or will be managed by the relevant Holtec Britain (HB) design risk and management processes [40].

23.4 THE CHEMISTRY OF NUCLEAR ISLAND SYSTEMS

This sub-chapter provides a brief introduction to the SSCs important to chemistry before presentation of CAE for each of the Level 4 claims that applies to the NI systems. Further information on these SSCs is provided in Part B Chapters 1 [6], 2 [41], 5 [7] and the relevant System Design Descriptions (SDDs).

23.4.1 Overview of the Reactor Coolant System

The RCS, as presented in Part B Chapter 1 [6], transfers heat produced in the Reactor Pressure Vessel (RPV) and core to the Steam Generator (SGE) or the appropriate decay heat removal system (Residual Heat Removal System (RHR) or Passive Core Cooling System (PCC)).

Chemical and radiochemical control is required to help minimise risks associated with the use of water as the RCS fluid. Water, especially at elevated temperatures and with dissolved chemical species, is a potentially aggressive medium when in contact with fuel cladding and system structural materials including SGE tubing. Chemical control of the RCS fluid consists of managing chemical additives and minimising chemical impurities. Such control supports criticality management and minimises corrosion phenomena potentially affecting SSCs. Radiochemical control involves monitoring radioactivity to ensure SMR-300 operations comply with safety limits and minimise radiological protection and environmental impacts.

The chemistry of the SMR-300 RCS during Power Operation, start-up and shutdown follows conventional Pressurized Water Reactor (PWR) practices. Natural boric acid is added to the RCS to control reactivity and promote a uniform neutron flux within the core. Enriched lithium-7 hydroxide is introduced to counteract the acidity of boric acid to maintain an alkaline pH, in accordance with the 'modified coordinated pH chemistry control regime' detailed in Appendix B. Hydrogen is added during power operation to create a reducing environment in the primary circuit, minimising corrosion by eliminating dissolved oxygen. Impurities in the RCS are reduced through demineralisation and filtration systems in the Chemical and Volume Control System (CVC) (and Spent Fuel Pool Cooling System (SFC) during refuelling periods). Zinc acetate is injected during power operation to reduce the source term.

During plant shutdown and transitioning between operating modes different challenges are presented to delivering an effective RCS chemistry regime. Hydrazine and hydrogen peroxide are used during start-up and shutdown to control oxygen and mitigate chemistry-related risks associated with transient conditions. Further details on the SMR-300 chemistry management of start-up and shutdowns, system preservation activities and construction and commissioning phases will be provided in future iterations of the Safety Case. SMR-300 chemistry management of all lifecycle phases will align with international best practice.

The materials present in the RCS that interact with the coolant include zirconium alloy, [REDACTED] as the fuel cladding, stainless steel, zirconium and nickel-based alloys used as structural materials within the reactor core, nickel-based alloy [REDACTED] SGE tubing material and stainless steel cladding and piping for all other wetted surfaces [42] [43] [44].

The SMR-300 Modes of Operation are presented in Part B Chapter 9 [13]. Whilst the scope of Part B Chapter 23 focuses on Mode 1 (Power Operation), Modes 1 - 6 encompass all normal operating modes. Discussion of chemistry during Design Basis, Beyond Design Basis and Severe Accidents, referred to collectively as ‘accident conditions’, is also covered.

23.4.2 Overview of Nuclear Island Auxiliary Systems

23.4.2.1 Residual Heat Removal System

The RHR, as presented in Part B Chapter 5 [7], removes decay heat from the RCS to reduce the reactor coolant temperature during normal shutdown and refuelling.

During normal shutdown operations, the RHR, which contains two parallel trains, draws RCS fluid from a Hot Leg connection to the RHR Heat Exchangers (HXs) before returning it to the cold leg. The RHR is used to fill the RCS following refuelling activities.

The chemistry regime of the RHR aligns with that of the RCS to mitigate the risks of boron dilution and contamination of the RCS with impurities. The RHR includes cross-connections to the SFC enabling it to provide backup cooling if required to the Spent Fuel Pool (SFP). Prior to placing RHR in service for normal RCS cooldown, the RHR fluid is recirculated from/to the Refuelling Water Storage Tank (RWST) to avoid any potential risk of boron dilution. The RHR also provides capability to provide flow of RCS fluid to the CVC (for filtration and purification) during low pressure conditions.

All equipment and piping in contact with reactor coolant is made of stainless steel.

23.4.2.2 Spent Fuel Pool and Spent Fuel Pool Cooling System

The SFC, as presented in Part B Chapter 5 [7], provides a recirculation loop for the SFP which removes decay heat from the SFP. The SFP contains the Spent Fuel Storage Racks (SFSRs) which house new and spent fuel.

Due to the presence of new and spent fuel (the fuel cladding for which must be protected from degradation) and because the SFP mixes with the RCS coolant during refuelling operations (as a result of reactor cavity flood up) the SFC provides chemistry control of the SFP fluid, and that of the RCS during reactor cavity flood up, through filtration and purification SSCs. These maintain the chemistry of the SFP during all modes of plant operation.

The SFC is also used to maintain the chemistry of the RWST, the Passive Core Makeup Water System Tank (PCMWT) and the RHR / RCS during normal shutdown and refuelling operations. The RWST is an atmospheric pressure, borated water tank which supplies inventory to fill the SFP during refuelling. The RWST fluid is circulated through the RHR prior to its alignment for RCS cooling.

All materials in contact with fluid within the SFC are stainless steel or stainless steel clad.

23.4.2.3 Component Cooling Water System

The Component Cooling Water System (CCW) is a closed loop system designed to provide cooling to the following SSCs within the Containment Structure (CS) and RAB [45]:

- RCS Reactor Coolant Pumps.
- RHR HX.
- CVC Letdown HX.
- SFC HX.
- Primary Sampling System (PSL) sample coolers.

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The system accomplishes this by providing components with a continuous supply of cooling water to facilitate heat rejection. The CCW system provides flow through the shell side of heat exchangers for each of these components.

Control of chemistry within this system is required to avoid undue corrosion of the physical interfaces with the systems it provides cooling to. This ensures containment of potentially radioactive fluids and minimises the risk of contaminating NI systems with CCW coolant.

The CCW consists of two parallel trains each equipped with a dedicated pump and heat exchanger designed to provide cooling across all normal operating modes and transient conditions. The system includes a flanged connection on the expansion tank to a chemical addition tank which allows for chemical dosing of the system. A normally closed recirculation line can be opened to allow for chemicals to be mixed into the CCW working fluid [45].

The CCW and piping is formed of various grades of carbon and stainless steels. The HXs shells are carbon steel and the tubing (separating CCW fluid from RHR, CVC, SFC and PSL fluid) is stainless steel.

23.4.2.4 Chemical and Volume Control System

The CVC, as presented in Part B Chapter 5 [7], is designed to control RCS fluid inventory and chemistry during plant normal operations and when shutdown. In plant start-ups, the RHR system provides forced flow to the CVC during the transition to Hot Standby; the CVC system provides the capability to control the boron concentration and meet the concentration required by reactor physics for start-up / criticality search. During Power Operation, the pressure differential between the RCS and the CVC drives fluid flow to the CVC for constant purification of the coolant. During plant shutdowns, the CVC provides the capability to accommodate Pressuriser (PZR) level changes, control reactivity and meet chemical limits (including degasification to remove hydrogen).

Chemical control is achieved in the following ways [46]:

- Coolant purification.
  - This capability is provided by two mixed bed demineralisers (one in operation, one on standby), a cation demineraliser (operated intermittently), a deborating bed demineraliser (operated intermittently) and reactor coolant filters (normally aligned).
- Chemical additions.
  - The CVC charging pumps supply chemicals, including lithium hydroxide, from the chemical mixing tank to control RCS coolant chemical concentrations and pH as part of the reactor coolant chemistry control. Lithium hydroxide, and other chemical species, may be removed from the RCS coolant by the demineralisers or alternatively by feed and bleed. This allows for balancing of boric acid and lithium hydroxide levels enabling pH control.
  - The CVC zinc injection skid supplies a blend of depleted zinc acetate and demineralised water to the CVC Charging Pumps [47].
- Oxygen control.
  - During Power Operations, hydrogen is supplied as a Volume Control Tank cover gas to minimise RCS oxygen levels.
  - During plant start-up, hydrazine, an oxygen scavenger is added to the RCS (through the charging pump directly using blended make up) or the PZR (via

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auxiliary spray connections). During plant shutdown, hydrogen peroxide, an oxidising agent is added to the RCS via the charging pump or the PZR.

- Boron management.
    - The CVC introduces blended makeup of demineralised water and boric acid to increase RCS boron concentration. Boron is removed via dilution or by the deborating bed demineraliser.
- Degasification.
    - The CVC, via the Volume Control Tank, is capable of removing gases via vapor space venting to the Gaseous RadWaste system (GRW).
- Control of NI Auxiliaries and Engineered Safety Features (ESFs) by the CVC.
    - The CVC is used to add blended makeup and chemicals to various NI auxiliary systems. Chemicals can be added from either the chemical mixing tank or Boric Acid Storage Tank (BAST) with demineralised water connections. This is used to supply the SFP, PCMWT, PCC Accumulators, and the RWST. More information on various line up options are presented in [48].

All piping and components of the CVC are stainless steel. The demineralisers are stainless steel vessels equipped with screens to retain ion exchange resin. The filters are stainless steel vessels equipped with disposable cartridges which are loaded with filter media.

23.4.2.5 Primary Sampling System

The PSL, as presented in Part B Chapter 5 [7], samples liquid and gaseous process streams from various points in the CS and the RAB allowing for sampling and monitoring of chemistry parameters across the NI.

Within containment, two trains (with two independent containment penetrations) are provided which separate fluid streams of the RCS Hot Legs and Pressuriser from the PCC Accumulators. These lines, and the connections in the RAB from the CVC, deliver sample fluids to a centralised location, the sample panel. A separate (cross connected but normally not aligned) line is also included which continuously samples the CVC system before demineralisation. This continuous line runs to the corrosion product sample panel, located outside of the sampling room.

The PSL includes a Nitrogen-16 delay coil, shielding for sampling stations and interfaces with the area radiation monitors from the Radiation Monitoring System (RMS) to reduce ORE.

All piping and components of the PSL are stainless steel.

23.4.2.6 Demineralised Water Transfer System

The Demineralised Water Transfer System (DWS) takes water outputted by the Demineralised Water Treatment System (DWT) to provide makeup for the RCS and the NI Auxiliary systems.

Detailed system design has not been developed for the SMR-300 DWS however this water source, in preliminary optioneering studies, has been chosen to be deoxygenated and to meet the specification provided in the DWS output quality position paper [49].

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23.4.3 Overview of Engineered Safety Features

23.4.3.1 Passive Core Cooling System

The PCC, as presented in Part B Chapter 1 [6], is designed to provide emergency core heat removal and makeup water during postulated accident conditions. The PCC consists of the following sub-systems of relevance to chemistry control:

- Primary Decay Heat Removal System (PDH).
    - Provides passive core cooling for non-Loss Of Cooling Accidents (non-LOCA) accident conditions by removing core decay heat directly from the RCS Hot Leg and rejecting it to the PCMWT by the PDH HX. Coolant is then returned to the RCS via the SGE Lower Head.
    - Material integrity of the piping that connects the RCS to the PDH HX (which is located in the PCMWT) and the HX itself must be maintained to ensure safe, reliable operation of the PDH when called upon in accident conditions.
    - During normal operations the PDH is filled with RCS fluid and isolated. High point level instrumentation is used to detect accumulation of gasses in the system during normal operation which can be vented to the PCMWT so that flow is not obstructed should it be required.
    - PDH piping material is austenitic stainless steel, and the HX is made from nickel-based alloy [REDACTED] tubing and stainless steel channels [50].
- Secondary Decay Heat Removal System (SDH).
    - Provides additional passive core cooling for non-LOCA scenarios by removing core decay heat indirectly from the RCS via the SGE shell-side (secondary), and rejecting it to the Annular Reservoir (AR) by the SDH HX.
    - Material integrity of the piping that connects the SGE shell-side to the SDH HX (which is located in the AR) and the HX itself must be maintained to ensure safe, reliable operation of the SDH when called upon in accident conditions.
    - SDH piping material is austenitic stainless steel, and the HX is made from stainless steel tubing and stainless steel channels [51].
- Passive Core Makeup Water System (PCM).
    - Provides borated water to the RCS for emergency cooling and reactivity control of the reactor core in the event of a Loss of Coolant Accident (LOCA).
    - The PCM, comprised of two nitrogen charged accumulators and a vented tank (the PCMWT) are connected to the RPV through Direct Vessel Injection (DVI) lines. These rely on piping and SSCs which provide flow to remain unblocked. This, and for material integrity protection purposes, requires chemistry control of the system. The PCMWT also provides water, by gravity drain, for refuelling operations which is supplemented by water from the RWST which also means that chemistry control is required to avoid contamination of SFP and RCS fluids with impurities when these fluids become mixed.
    - During normal operations the accumulators and PCMWT are isolated from the RCS but fluid is sufficiently borated to mitigate dilution risk. The PCMWT is purified and filtered by alignment to the SFC. Strainers located in the PCMWT are designed to minimise debris and chemical precipitates clogging the DVI lines when called upon in accident conditions.
    - The two accumulators, the PCMWT and all PCM piping (including DVI) are austenitic stainless steel.

23.4.3.2 Passive Containment Heat Removal System

The Passive Containment Heat Removal System (PCH), as presented in Part B Chapter 20 [19], maintains the containment atmospheric pressure and temperature within design limits during accident conditions by transferring heat from the CS to the water inventory of the AR (and eventually the atmosphere as ultimate heat sink) [52].

Material integrity of the CS, Containment Enclosure Structure (CES) and the equipment contained within the AR (including the SDH HX) must be maintained to ensure safe, reliable operation of the PCH when called upon in accident conditions.

The AR is demineralised water which is chemically treated to minimise degradation, fouling of the heat transfer surface and biological induced corrosion. The PCH includes a recirculation loop which provides the chemistry control capability, freeze protection, and a makeup connection from the DWS. The recirculation loop has a recirculation pump, two recirculation heaters, a filter, a chemical addition tank, a chemical addition pump, piping, and components.

The AR is in contact with the CS and CES which are formed of carbon steel covered in a coating to remove these materials from the chemical environment. The AR is also in contact with the stainless steel materials of the SDH HX.

23.4.4 Chemistry Support to Fuel Reactivity

Claim 2.2.14.1: The chemistry of Nuclear Island systems reduces risks relevant to the control of fuel reactivity.

The SMR-300 will use a combination of Rod Cluster Control Assemblies (RCCA), burnable in-core poisons and a soluble neutron absorber to maximise homogeneity of neutron flux within the core and provide reactivity control.

Reactor Chemistry supports this through selection and control of an appropriate soluble neutron absorber. To demonstrate that risks relevant to fuel reactivity are reduced So Far As Is Reasonably Practicable (SFAIRP) Reactor Chemistry must:

- Consider the benefits and disbenefits of viable options and demonstrate that selection of a soluble neutron absorber for the SMR-300 minimises chemistry related risks.
- Demonstrate that the system level chemistry-related risks associated with the selected soluble neutron absorber are minimised.
- Demonstrate that the system-of-system level chemistry-related risks with the selected soluble neutron absorber are minimised.
- Demonstrate that suitable and sufficient chemistry conditions and limits have been established that minimise fuel reactivity risks.

This has resulted in the decomposition of Claim 2.2.14.1 into Arguments A1, A2, A3 and A4 which address these aspects respectively.

23.4.4.1 Natural Boric Acid

Argument 2.2.14.1 – A1: Natural boric acid as soluble neutron absorber minimises chemistry-related risks.

Key Evidence for Argument 2.2.14.1 – A1:

- **HI-2240459, SMR-300 Primary Water Chemistry Strategic Plan** [53]**:** Describes the choice of natural boric acid over the main viable alternative, Enriched Boric Acid (EBA).

Boric acid has been selected to provide soluble reactivity control as this readily dissolves in RCS coolant and absorbs neutrons via the reaction B-10(n,α)Li-7. Boron-10 (B-10) has a high neutron absorption cross section and provides the neutron absorption capability of boric acid [53].

Natural boric acid will be used which has not been isotopically enriched and so is approximately 80% radiologically inert Boron-11 (B-11) and 20% B-10. The basis for selection of boric acid over EBA is based on balancing the following factors:

- Achievable pH regime when coordinated with a pH raiser.
- Axial Offset Anomaly (AOA) considerations.
- Plant design and analytical capability considerations.
- Tritium reduction strategies.
- Crystallisation risks.

During a cycle, the B-10 concentration decreases in the RCS due to the neutronic absorption reactions in the core. The risk of B-10 depletion is manageable through periodic monitoring of the B-10:B-11 ratio in the NI systems, see sub-section 23.4.4.4.

23.4.4.2 System Level Boron Management

Argument 2.2.14.1 – A2: System level chemistry-related risks associated with the use of natural boric acid are minimised.

Key Evidence for Argument 2.2.14.1 – A2:

- **HI-2240459, SMR-300 Primary Water Chemistry Strategic Plan** [53]**:** Provides a description of the approach to management of boron throughout a cycle. Provides an assessment of AOA risk for the SMR-300.
- **HI-2240271, Boric Acid Storage Tank Sizing Calculation** [54]**:** Provides a justification for the sizing of the BAST. This document also provides reference solubility limits for natural boric acid.
- **HI-2240850, SMR-300 Boron Precipitation Scoping Study** [55]**:** Demonstrates that in response to a Large Break LOCA (LBLOCA) boric acid solubility limits are not challenged as accident conditions progress for a minimum of 72 hours.
- **HI-2230971, SMR-300 CRA Nuclear Analysis** [56]**:** Provides a calculation of the boron concentration required to maintain reactor subcriticality throughout the core lifetime.

The risks associated with the use of natural boric acid at a system level are minimised through development of an optimised approach to boron management.

1. Reduction of risk of precipitation of boric acid: Precipitation (or crystallisation), a temperature dependant process, would risk losing boron from solution and could threaten the control of fuel reactivity and heat removal.

Whilst detailed B-10 reactivity requirements across a cycle are yet to be derived, the concentration of boron expected at the Beginning of Cycle (BOC) is [REDACTED] which will drop to [REDACTED] by the End of Cycle (EOC). On transition from Power Operation to Cold Shutdown boron concentration is once more increased, to counteract the increase in reactivity associated with moderator density changes, to [REDACTED] [56] [57].

These boron concentrations are far below the associated limits of solubility of natural boric acid, are achievable and will be met by operation of the CVC [46], see sub-section 23.4.8.

The NI system which holds the highest concentration of borated water, and so approaches closest the limit of solubility for boric acid, is the BAST in the CVC. This tank is sized to be able to provide enough boron to the RCS to transition from EOC boron concentrations ([REDACTED]) to the design basis concentration of [REDACTED] [54]. For this purpose the BAST is maintained at [REDACTED]. This is sufficiently below the operating temperature of the BAST, which is located in the RAB, of [REDACTED]. The risk of precipitation in the BAST is minimised by inclusion of two dual speed pumps which provide recirculation and an electric heater to ensure the limit of solubility is never met. The BAST also contains heating elements and connected pipes are trace heated to ensure no precipitation of boric acid occurs [46].

ESF system design requirements are described in Part B Chapter 1 [6]. During normal operating modes the Accumulators and PCMWT are filled with [REDACTED] boron water which is verified periodically by operators. This offers a separate means of shutdown from control rod insertion. These systems are called upon in various accident conditions which require injection of fluid via the DVI piping to the core to provide passive emergency cooling; during these situations they must also retain reactivity control and avoid diluting boron concentration [58].

A bounding assessment of boron precipitation risks in response to accident conditions has demonstrated that in the event of a LBLOCA boric acid solubility limits are not challenged for a minimum of 72 hours without operator intervention [55].

Discussion on fuel heat removal risks caused by boron precipitation is presented in sub-section 0.

2. Reduction of risk of AOA: AOA defined as a significant axial power distribution deviation from prediction is caused by boron hideout in fuel assembly deposits (crud).

Development of AOA requires sufficient soluble boron in the coolant and fuel crud deposition onto fuel cladding. Fuel crud deposition is demonstrated to be minimised, see sub-section 23.4.6.1. The total concentrations of boron required in the SMR-300 are comparable to other operational PWRs and the susceptibility to AOA is estimated to be [REDACTED] in accordance with industry risk assessment guidelines [53].

The SMR-300 will inject zinc, primarily for dose reduction, see sub-section 23.4.7.2, which can affect fuel crud deposits. Zinc addition, for which OPEX has shown forms a more uniform, more porous crud along the length of the fuel assembly gives at least a non-negative impact on crud formation and AOA susceptibility [59].

3. Reduction of risk of inadequate mixing throughout the RCS leading to variable local concentrations.

Boron concentration is maintained homogeneous throughout the RCS, for example by continuous flow through the PZR which ensures PZR fluid is at approximately the same boron concentration as bulk RCS fluid [42].

4. Reduction of corrosion and material integrity risks.

Introduction of natural boric acid which is a weak acid into RCS coolant poses a risk of accelerating corrosion of RCS materials. This is countered through coordination with a pH raiser, see sub-section 23.4.6.

5. Tritium minimisation.

Use of B-10 in natural boric acid for reactivity control relies on neutronic absorption. The major reaction pathway is B-10(n,α)Li-7 which produces lithium-7 (Li-7). Li-7 is already present in the RCS coolant for pH control purposes, see sub-section 23.4.6.2. A minor reaction pathway however is B-10(n,2α)H-3. By minimising the total amount of boron required through use of RCCAs and burnable in core neutron poisons the amount of tritium generated via neutron activation of B-10 is minimised.

23.4.4.3 System-of-System Level Boron Management

Argument 2.2.14.1 – A3: System-of-system level chemistry-related risks associated with the use of natural boric acid are minimised.

Key Evidence for Argument 2.2.14.1 – A3:

- **HI-2240271, Boric Acid Storage Tank Sizing Calculation** [54]**:** Provides a justification for the size of the BAST, which is held at significantly higher boron concentration than the RCS.
- **HI-2230971, SMR-300 CRA Nuclear Analysis** [56]**:** Provides a calculation of the boron concentration required to maintain reactor subcriticality throughout the core lifetime. Results are found to be bounded by the design basis limit of boron concentration of 2500 ppm.

The NI Auxiliary systems interface with RCS coolant at various points during normal operations and accident conditions; therefore, system-of-system level boron management is required to mitigate the risk of boron dilution of the RCS.

The CVC controls the concentration of boron in RCS coolant by providing borated makeup to the RCS, see sub-section 23.4.8.1. During Power Operation the CVC automatically adds a preset amount of borated and demineralised water which is controlled by manual setting of the Boric Acid Flow Control Valve and the Demineralized Water Flow Control Valve. This controls the ratio of boric acid to demineralized water fed forward to the RCS. The CVC includes isolation valves on the DWS makeup supply line to prevent inadvertent dilution of

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boron concentration. These are activated either manually or on receipt of Plant Safety System (PSS) signal [60].

The boron concentration of other NI Auxiliary systems and ESFs must also be controlled to eliminate boron dilution risk. Prior to placing the RHR in service for normal operation cooling, the RHR is recirculated with the suction and discharge aligned to the RWST to ensure adequate and homogenous boron throughout the RHR before it is placed in service. The RHR is sampled for boron concentration before being connected to the RCS [61].

In the SFP, sufficient boron concentration is maintained to eliminate the risk of boron dilution in RCS coolant when the two fluids interact which is planned during Refuelling [62] [63]. This boron concentration requirement is also applied to systems which may be connected to the SFP (the PCMWT and RWST).

The two Accumulators of the PCC contain sufficiently borated water to eliminate the risk of diluting RCS boron concentrations by inadvertent activation of the PCC [58].

Where unborated systems interface with borated systems, such as in CCW heat exchangers, boron dilution may occur when system integrity is lost. The risk of heat exchanger failure resulting in boron dilution is minimised by appropriate material selection and chemistry regimes, see sub-section 23.4.6 and monitoring interfacing fluids for leak detection purposes.

23.4.4.4 Operational Chemistry Control Limits and Conditions

Argument 2.2.14.1 – A4: Suitable and sufficient operational chemistry limits and conditions are in place to minimise chemistry-related risks relevant to the control of fuel reactivity.

Key Evidence for Argument 2.2.14.1 – A5:

- **HI-2240463, SMR-300 Water Chemistry Requirements** [29]**:** Provides limits and conditions for concentration of boron in the RCS, SFP, RWST and PCC fluids (Accumulators and the PCMWT).
- **HI-2240459, SMR-300 Primary Water Chemistry Strategic Plan** [53]**:** Provides a description of the approach to management of boron throughout a fuel cycle.

Operational chemistry limits and conditions supporting the minimisation of risks associated with Reactor Chemistry support to fuel reactivity are identified in [29]. The following chemistry parameters are identified as key for Power Operation:

- Boron (RCS).
    - In accordance with boron reactivity requirements ([REDACTED]). See Appendix B for coordination of boron with lithium.
- B-10:B-11 ratio (RCS).
    - Used to monitor loss of B-10, which provides neutron absorption capability of boric acid, from RCS due to neutronic absorptions
- Boron (SFP, PCMWT, PCC Accumulators, RWST).
    - Sufficient boron concentration is required to eliminate risk of dilution.

A consolidated list of the chemistry limits and conditions is provided in sub-chapter 23.6; note these will be refined and expanded upon as a function of design development.

23.4.4.5 CAE Summary

Claim 2.2.14.1 has been decomposed into four arguments which align with how Reactor Chemistry supports the control of reactivity and risks associated with the choice of natural boric acid as a soluble neutron absorber.

For Argument A1, selection of natural boric acid has been shown to minimise risks when compared to the main viable alternative, EBA.

For Argument A2, risks associated with the selection of natural boric acid as a soluble neutron absorber have been reduced through appropriate mitigation of precipitation, AOA, fluid homogeneity, corrosion and tritium generation risks.

For Argument A3, the risk of system-of-system dilution events is reduced through minimum limits imposed on fluids which can interface with the RCS coolant and through ensuring system integrity of systems which share physical interfaces with boron containing systems but are unborated.

For Argument A4, suitable and sufficient limits and conditions have been placed on SSCs to reduce chemistry-related risks relevant to the control of fuel reactivity.

All arguments and evidence are sufficiently mature for a PSR, therefore Claim 2.2.14.1 has been met.

23.4.5 Chemistry Support to Fuel Heat Removal

Claim 2.2.14.2: The chemistry of Nuclear Island systems reduces risks relevant to fuel heat removal.

During Power Operation, the SMR-300 is typical of operating PWRs in that it relies on forced flow of coolant through the core to remove heat.

Reactor Chemistry supports fuel heat removal by:

- Reducing the risk of blockage caused by boric acid crystallisation.
- Reducing the generation of fuel crud on fuel rods which may impair fuel heat removal and block NI systems in extreme cases.
- Reducing the risk of NI system blockages from chemical effects and byproducts such as gels.

This has resulted in the decomposition of Claim 2.2.14.2 into Arguments A1, A2 and A3 which address these aspects respectively.

The operational chemistry control limits and conditions derived in support of Claims 2.2.14.1, 2.2.14.3 and 2.2.14.4 are suitable and sufficient to meet the needs of Claim 2.2.14.2, as such no additional limits and conditions are identified.

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23.4.5.1 Blockage by Crystallisation

Argument 2.2.14.2 – A1: NI system blockages caused by boric acid crystals do not compromise fuel heat removal.

Key evidence for Argument 2.2.14.2 – A1 is consistent with that presented for Argument 2.2.14.1 – A2 (sub-section 23.4.4.2) which relates to the system-level management of boric acid.

Crystallisation is the process by which a species is lost from solution and solid crystalline precipitate is formed. Crystallisation of boric acid from solution if unmitigated could lead to the blocking of flow in SSCs.

The risk of boric acid crystallisation in the RCS and NI systems is minimised, through the establishment of an effective boric acid management strategy, as presented in sub-section 23.4.4.2.

23.4.5.2 Thermal Blanketing of Fuel Rods and Blockage by Fuel Crud

Argument 2.2.14.2 – A2: Fuel assembly thermal blanketing and NI system blockages caused by fuel crud do not compromise fuel heat removal.

Key evidence for Argument 2.2.14.2 – A2 is consistent with that presented for Argument 2.2.14.3 – A1 (sub-section 23.4.6.1) which relates to the minimisation of fuel cladding degradation and fuel crud deposition.

Crud, consisting of corrosion and wear products, which forms on fuel cladding leads to impaired heat transfer in extreme cases from fuel assemblies. The associated increase in heat transfer resistance is referred to as thermal blanketing of the fuel. The mass release of fuel crud may also challenge fuel heat removal in systems intolerant to blockage. Crud deposition / generation, and therefore its implication in the thermal blanketing of fuel rods and in the blockage of NI systems, is demonstrated to be minimised in support of Argument 2.2.14.3 – A1 (sub-section 23.4.6.1).

23.4.5.3 Blockage by Chemical Effects and Byproducts

Argument 2.2.14.2 – A3: NI system blockages caused by chemical effects and byproducts in the post-loss-of-coolant accident environment do not compromise fuel heat removal.

Key Evidence for Argument 2.2.14.2 – A3:

- **HI-2250423, Accident Chemistry Strategy** [64]**:** Provides a description of the approach that will be taken in the SMR-300 with regards to reactor cavity flood up volume pH adjustment and choice of [REDACTED] over alternatives.
- **HI-2240053, SMR-300 Specification - Insulation** [65]**:** Provides technical specification for design, procurement, fabrication, installation and inspection of thermal insulation on pipework across the SMR-300.
- **PS-8002-0020, SMR-300 Specification – Protective Coatings** [66]**:** Provides technical specification for coatings of SSCs across the SMR-300.

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In accident scenarios the PCC provides passive core cooling ensuring sufficient long-term supply of water to the core and / or RPV. Cooling is ensured by PCC SSCs such as recirculation piping, strainers and screens remaining unblocked during accident conditons. During flood up situations, the SFP, RCS and PCMWT fluids mix to flood the reactor cavity. Physical debris generated in an accident could consist of fibrous insulation, coatings, fire barriers, shielding blankets, and other materials located near a pipe break. Chemical species that cause blockage are species which precipitate out of solution to form either solid or gel-like substances, such as silicate, aluminium or zinc-based species.

The following Reactor Chemistry factors contribute to minimising the risk of blockages by chemical effects and byproducts during post-LOCA accident conditions:

- Minimisation of species that can form gels and precipitates.
    - Reflective Metal Insulation (RMI), which is stainless steel, will be used on all piping within the reactor cavity flood up volume. This minimises the introduction of chemical species into the recirculating coolant, such as those typically implicated in the formation of silicate precipitates found in the reactor cavity flood up [65]. Use of fibrous insulation within containment is restricted [67].
    - All coated surfaces within the SFP and reactor cavity flood up volume will be subject to the highest (Coating Service Level 1) requirements which applies to all coatings where coating failure could adversely affect post-accident fluid systems [66].
    - The total mass of aluminium / zinc allowed inside containment shall be limited with amounts determined during strainer design development [67].
- PCMWT strainer design.
    - The two PCMWT strainers are spatially separated and designed such that risk of blockage by either physical debris or chemical species is minimised.
    - Whilst efforts to minimise the debris source term includes considerations of chemical effects, in line with meeting the requirements of US Nuclear Regulatory Commission (NRC) Guidance Letter 2002-04 [68] and the findings of NRC Generic Safety Issue-191 [69], the SMR-300 PCMWT strainers will be designed for worst case debris compositions. This worst-case debris loading includes chemical reaction products generated in the RPV or within the containment flood up volume [58].
- Chemical control of reactor flood up volume.
    - [REDACTED] has preliminarily been chosen for pH control and fission product retention of the reactor cavity flood up volume during an accident [64], as discussed in 23.4.6. The choice of [REDACTED] over alternatives is principally to reduce the risk of the formation of gels and precipitates associated with strainer blockages.

23.4.5.4 CAE Summary

Claim 2.2.14.4 has been decomposed into three arguments which align with how Reactor Chemistry supports the removal of heat during all normal operating modes and accident conditions.

For Argument A1, the risk of blockage by boric acid crystallisation is minimised. This Argument is bounded by evidence provided in support of Argument 2.2.14.1 – A2 (section 23.4.4.2).

For Argument A2, the risk of the thermal blanketing of fuel rods and blockage of NI systems by fuel crud is minimised, through minimising the amount of corrosion products generated and deposited on fuel cladding. This Argument is bounded by evidence provided in support of Argument 2.2.14.3 – A1 (section 23.4.6.1).

For Argument A3, during reactor cavity flood ups, recirculation pipework and connections remain free of physical and chemical blockages.

All arguments and evidence are sufficiently mature for a PSR, therefore Claim 2.2.14.2 has been met.

23.4.6 Chemistry Support to Structural Material Integrity and Confinement of Radioactivity

Claim 2.2.14.3: The chemistry of Nuclear Island systems reduces risks relevant to the integrity of structural materials and confinement of radioactivity.

A key goal of Reactor Chemistry is to support the integrity of plant structural materials by reducing degradation. This ensures safe and reliable operation of SSCs across the NI, whilst ensuring that barriers to radioactivity release remain effective. Reactor Chemistry supports minimisation of degradation in the following SSCs:

- Fuel cladding.
- RCS structural materials (including RPV Internals, SGE primary side tubing).
- NI Auxiliary systems and ESFs.

Demonstration that degradation of these SSCs has been minimised is reflected in the decomposition of Claim 2.2.14.3 into the Arguments A1, A2, and A3 respectively.

Reactor Chemistry also supports the integrity of structural materials and confinement of radioactivity in the event of accident conditions. This is reflected in decomposition of Claim 2.2.14.3 into a further Argument, A4.

An additional Argument, A5, has been decomposed from Claim 2.2.14.3 which ensures that suitable and sufficient chemistry conditions and limits have been placed on systems that support reduction of material degradation and confinement of radioactivity.

23.4.6.1 Fuel Cladding

Argument 2.2.14.3 – A1: Fuel clad degradation is minimised.

Key Evidence for Argument 2.2.14.3 – A1:

- **HI-2240459, SMR-300 Primary Water Chemistry Strategic Plan** [53]**:** Provides justification and description of the selected primary water chemistry regime. This includes optimisation of conflicting parameters to minimise corrosion of RCS materials and fuel cladding. Provides a preliminary calculation of the degree of sub-cooled nucleate boiling duty in the core, which is linked to the risk of crud deposition. Provides a description of the advantages of selection of Metamic.
- **EXT-000476, PWR Fuel Reactor Coolant Chemistry Supplemental Guidelines** [70]**:** Provides fuel vendor guidance on derivation of water chemistry requirements for

the minimisation of degradation of fuel assemblies within the RCS and the SFP which the Primary Water Chemistry Strategic Plan [53] is aligned to.

Fuel cladding acts as the first barrier to fission product release. Reactor Chemistry supports the minimisation of degradation of fuel clad both within the RCS (whilst it is in place within the RPV) and whilst it is held in interim storage within the SFP.

The following factors minimise degradation of fuel cladding in the RCS:

- Fuel cladding material selection.
    - [REDACTED] alloy will be used as the fuel cladding for the SMR-300. This alloy is industry proven and has been used in a wide range of plants demonstrating excellent OPEX [41].
- Primary circuit chemistry control and radiochemistry monitoring.
    - Operational chemistry limits and conditions minimise degradation of fuel cladding (see sub-section 23.4.6.5 and 23.6) during Power Operation.
    - Operational chemistry limits and conditions will be established in future iterations of the SSEC for periods outside of Power Operation (such as during transients) to minimise degradation of fuel cladding.
    - Operational chemistry limits and conditions are implemented on systems which interface with the RCS to ensure alignment and minimisation of the risk of material degradation caused by impurities (see sub-section 23.4.6.3).
    - Radiochemistry monitoring of the primary circuit enables the early detection of fuel failures and informs decision making to prevent further cladding deterioration (see sub-section 23.4.6.5 and 23.6).
- Minimisation of fuel crud deposition.
    - Fuel crud deposition is the process by which corrosion products released into the primary coolant deposit onto fuel cladding. This process is driven by local evaporation and concentration of species near the cladding surface. Fuel crud deposition may further increase cladding through Crud-Induced Localised Corrosion (CILC).
    - The degree of sub-cooled nucleate boiling duty in the core is a significant contributing cause of crud deposition in PWRs. The SMR-300 core design, is estimated to be [REDACTED] [53] which reduces the risk of crud deposition.
    - The amount of material available to form crud is minimised by minimising RCS material degradation, see sub-section 23.4.6.2, and through effective control of transients, such as start-up or shutdown crud bursts.
    - A positive gradient of solubility for nickel through the core is established by the operational chemistry regime, predominantly pH, thus minimising deposition in the core [53].

The following factors minimise degradation of fresh and spent fuel cladding in the SFP:

- Fuel cladding material selection.
    - As above, [REDACTED] alloy has been used in a wide range of plants demonstrating excellent OPEX [41].
- SFSR material selection.
    - Metamic has been selected for use in the SFSR which is made of blended aluminium oxide and boron carbide on an aluminium structure. The choice of

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Metamic eliminates a potential source of the impurity silica which has been historically associated with use of Boraflex in SFSRs.

- SFC material selection.
    - The amount of material released to the SFP is minimised by minimising SFC material degradation, which is primarily achieved through selection of stainless steel for all wetted surfaces of the SFC, see sub-section 23.4.2.2.
- SFP Chemistry control and radiochemistry monitoring.
    - Operational chemistry limits and conditions are implemented on the SFP and interfacing systems to ensure alignment and minimisation of the risk of material degradation (see sub-section 23.4.6.5 and 23.6).
    - Radiochemistry monitoring of the SFP enables the early detection of fuel failures.

23.4.6.2 RCS Structural Materials

Argument 2.2.14.3 – A2: Reactor Coolant System structural material degradation is minimised.

Key Evidence for Argument 2.2.14.3 – A2:

- **HI-2240459, SMR-300 Primary Water Chemistry Strategic Plan** [53]**:** Provides justification and description of the selected primary water chemistry regime. This includes optimisation of conflicting parameters to minimise corrosion of RCS materials. Provides an evaluation of the susceptibility of SMR-300 RCS materials to Primary Water Stress Corrosion Cracking (PWSCC) and general corrosion.
- **HI-2240861, Overview of Holtec SMR-300 Fuel Design and Core Components** [44]**:** Provides a description of the SMR-300 core including the selected RPV internal SSC materials.

To protect the second barrier to fission product release and ensure safe and reliable operation of its SSCs degradation of the RCS must be minimised. Reactor Chemistry supports by minimising degradation of the stainless steels, nickel-based and zirconium based alloys employed in the RCS [53] in the following ways:

- Material selection which aligns with best practice in the nuclear industry.
    - Design of the fuel assemblies and the upper and lower RPV Internals is described in Part B Chapter 2 [41]**.** Material selection is highly corrosion resistant materials including a variety of grades of stainless steel, zirconium alloys and nickel base alloy materials informed by international OPEX [71]. These materials are also well known to the nuclear industry for their successful application in high strength SSCs needing to demonstrate excellent SCC resistance [72].
    - Wetted surfaces of the wider RCS are either clad in austenitic stainless steel or utilise stainless steel weld material and piping. Austenitic stainless steels have high corrosion resistance and have performed excellently in operating PWRs. The stainless steel components used on the SMR-300 are found to have ‘low’ susceptibility to PWSCC and general corrosion [53].
    - [REDACTED] and its compatible weld metals are selected for SGE tubing. Adoption of [REDACTED] across the nuclear industry has greatly diminished the rate of SGE tubing material degradation experienced, and no SCC has

been reported globally after up to 20 years in PWR primary service [72]. This material has also resisted cracking in more severe laboratory tests. [REDACTED] in the SMR-300 has 'low' susceptibility to PWSCC and general corrosion [53].

- Core design considerations.
    - OPEX shows that certain baffle-to-former bolts used in core heavy reflectors are at risk of Irradiation-Assisted Stress Corrosion Cracking (IASCC). [REDACTED] [44].
- Optimised RCS chemistry regime which balances conflicting parameters.
    - Operational chemistry limits and conditions minimise degradation of RCS materials (see sub-section 23.4.6.5 and 23.6).
    - Operational chemistry limits and conditions will be established in future iterations of the SSEC for periods outside of Power Operation (such as during transients) to minimise degradation of RCS materials.

23.4.6.3 NI Auxiliary Systems and ESFs

Argument 2.2.14.3 – A3: NI Auxiliary Systems and Engineered Safety Features structural material degradation is minimised.

Key Evidence for Argument 2.2.14.3 – A3:

- **HI-2240722, Decision Paper on the SMR-300 Annular Reservoir Water Sources of Makeup and Chemistry Requirements** [73]**:** Provides justification and down selection of the AR chemistry regime including consideration of alternative water sources and chemical treatment strategies.
- **RRTI-3302-0002, Summarization of Classic Metamic Qualification** [74]**:** Provides a summary of the evidence which qualifies Metamic for use in the SFP for the lifetime of the plant.
- **HI-2250348, Containment Structure System Based View** [75]**:** Presents a vertical slice through the safety case and wider documentation focusing on capability and novel features of the PCH. Provides a description of CS material selection, CS coatings and degradation management approach.
- **HI-2240599, SMR-300 Closed Cooling Water Chemistry Strategic Plan** [76]**:** Provides a description of various closed cooling water chemistry regimes and an assessment of applicability to the SMR-300 design. This includes a justification for and down-selection of the chemistry regime to be applied to the fluid of the CCW and AR.

The material state of the NI Auxiliary systems and ESFs (RHR, SFP, SFC, CCW, PDH, SDH, PCM, and PCH) must be ensured to enable their functioning, to reduce contamination of the primary system (which a number of these systems have physical interfaces with) and to ensure that where systems contain radioactive fluid, this is retained effectively. NI Auxiliary systems and ESF material degradation is minimised with the following aspects highlighted:

- Material Selection.
    - The system overviews (see sub-section 23.4.2 and 23.4.3), for NI systems and ESFs demonstrate that material selection has chosen highly corrosion resistant stainless steels or nickel-based alloys, consistent with best practice for minimisation of degradation. This has been paired with appropriate chemistry regimes.

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- Spent Fuel Pool and Spent Fuel Pool Cooling System.
    - The SFSR material, Metamic is exposed to SFP fluid and is qualified for the life of the plant [74].
    - Limits are placed on impurities present in the SFP / SFC to minimise degradation of materials exposed to SFP fluid [29].
- Component Cooling Water System.
    - The chemistry regime of the CCW is [REDACTED] corrosion inhibitor with additions of [REDACTED], for pH control, and [REDACTED], for biological growth control. This is supplemented by limits placed on impurities to minimise degradation of the system [76].
- Passive Containment Heat Removal System.
    - The chemistry regime of the AR is demineralised water (supplied by the DWS) which is chemically dosed with [REDACTED], for pH control, and [REDACTED], for biological growth control. This is supplemented by limits placed on impurities and hardness to minimise scale formation and degradation of the CS, CES and SDH HX [73] [75]. The AR is continually recirculated by the PCH recirculation loop to minimise risk of chemical stratification of the AR.
    - Structural material integrity through life is primarily ensured through appropriate design including material selection, see Part B Chapter 19 [18], and the use of coatings, see Part B Chapter 20 [19]. The CS is subject to a GDA Commitment raised in [19], C_Civi_093, concerning the overall degradation management strategy employed on the AR.

23.4.6.4 Accident Chemistry

Argument 2.2.14.3 – A4: Accident chemistry minimises structural material degradation and the confinement of radioactivity.

Key Evidence for Argument 2.2.14.3 – A4:

- **HI-2250423, UK Context – Accident Chemistry Strategy** [64]**:** Describes the SMR-300 accident chemistry. This focuses on combustible gas control, fission product retention, core melt scenarios and post accident monitoring. Provides an assessment of the expected design activities and a preliminary demonstration that the design will meet the regulatory expectations of the UK.
- **HI-2241360, SMR-300 Containment Pool pH During MHA LOCA** [77]**:** Provides a calculation of the post accident pH of the reactor cavity flood up volume during Maximum Hypothetical Accident (MHA) LOCA.

Reactor Chemistry supports in the prevention and mitigation of accident conditions which if unmitigated would threaten the integrity of structural materials and radioactivity barriers such as the RCS and the CS [64]. Prevention and mitigation relating to the three major areas of accident chemistry are as follows:

- Combustible Gas Control.
    - The Combustible Gas Control System (CGC) monitors for the presence of combustible mixtures generated through normal operation (primarily hydrogen and oxygen mixtures) [7].
    - The containment design and CGC limits the presence of combustible mixtures by:

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        - Natural convective mixing of the in-containment atmosphere (avoiding accumulation).
        - Passive Autocatalytic Recombiners (PAR); which eliminate hydrogen and oxygen mixtures by recombining these to make water.
    - The CGC will be designed to limit in-containment hydrogen concentration, and this will involve a size, number and distribution of PARs which accounts for capacity inhibiting affects (such as iodine poisoning) and accident scenarios where 100% fuel cladding – coolant interaction occurs (this ensures total PAR capacity is sufficient to remove bounding expected hydrogen production volumes) [64].
    - A review of the development of the design of the CGC showed that it is aligned with UK Context [64].
    - Non-condensable gases generated in the RCS during operation are managed by the CVC, see sub-section 23.4.2.4.
- Fission product retention.
    - During accident conditions, the Containment Isolation System (CIS) prevents the release of radioactivity from the CS [6].
    - The chemical conditions that develop during accident conditions can dictate the release rates of radioactive species, hence PWR designs typically include an alkalising agent to avoid low pH conditions expected to develop in reactor cavity volume during flood up scenarios. This ensures that radioactive species are retained in solution rather than released in volatile forms to the containment atmosphere.
    - The SMR-300 will include a post-accident pH modifier to adjust the pH of the reactor cavity flood up volume post-accident. A preliminary choice of [REDACTED] has been made [64], and further development is expected which will take into account materials present in the reactor cavity flood up volume (such as SFSR material) and will be informed by calculations such as that presented post accident pH following MHA LOCA [77]. A GDA Commitment, C_Reac_106, has been raised for the finalisation of activities to implement the post-accident pH modifier into the design of the SMR-300, see sub-section 23.7.3.
- Core Melt Scenarios.
    - In the event of a core melt scenario, the SMR-300 is designed for In-Vessel Retention (IVR) whereby the corium produced by a core melt is contained within the RPV [64]. Cooling is provided by the reactor cavity flood up volume provided by RCS leakage and the PCC which remove core heat.
    - It has been demonstrated that the SMR-300 approach and modelling of core melt scenarios is aligned with UK Context [64].

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23.4.6.5 Operational Chemistry Control Limits and Conditions

Argument 2.2.14.3 – A5: Suitable and sufficient operational chemistry limits and conditions are in place to minimise chemistry-related risks relevant to the integrity of structural materials and confinement of radioactivity.

Key Evidence for Argument 2.2.14.3 – A5:

- **HI-2240463, SMR-300 Water Chemistry Requirements** [29]**:** Provides limits and conditions for the RCS, SFP and interfacing systems (RWST and PCC fluids).
  HI-2240459, SMR-300 Primary Water Chemistry Strategic Plan [53]**:** Provides a description of the chemical parameters important to safety in the SMR-300. Also provides preliminary information on chemistry control during transitions between operating modes.

Operational chemistry limits and conditions supporting minimisation of risks of degradation of structural materials and confinement of radioactivity are identified in [29]. The following chemistry parameters are identified as key for Power Operation:

- $pH_{300°C}$ (RCS), Lithium (RCS).
  - RCS coolant is maintained at an alkaline pH by lithium-7 hydroxide to minimise general corrosion of RCS materials, see sub-section 23.4.4. Boric acid and lithium-7 hydroxide are coordinated as presented in Appendix B (following a 'modified coordinated chemistry control' regime) to achieve an alkaline pH across the whole of the fuel cycle.
  - For pH control, lithium concentration would ideally be higher in support of Argument 2 (see sub-section 23.4.6.2), however this has been limited to avoid exceeding fuel vendor guidance which would have deleterious impact on Argument 1 (see sub-section 23.4.6.1). Limits have been optimised, balancing conflicting chemistry risks and opportunities as further discussed in the Primary Water Chemistry Strategic Plan [53].
- Oxygen (RCS).
  - Oxygen, present as a dissolved gas, is minimised to minimise fuel cladding oxidation and general corrosion and SCC of RCS materials. Dissolved oxygen levels are minimised by management of the make up water source (DWS) [49] and by maintaining a positive inventory of hydrogen [53].
- Hydrogen (RCS).
  - A reducing environment is maintained in the RCS to minimise fuel cladding oxidation in addition to general corrosion and SCC of RCS materials. A positive inventory of hydrogen is maintained during Power Operation. Hydrogen concentration also has an upper limit to account for fuel cladding hydriding. This is in line with fuel vendor guidance and informed by OPEX [70]. Limits have been optimised, balancing conflicting chemistry risks and opportunities as further discussed in the Primary Water Chemistry Strategic Plan [53].
- Chloride (RCS), fluoride (RCS), and sulphate (RCS).
  - Impurities associated with an increased risk of fuel cladding and RCS material degradation are minimised by suitable limits on the make up water source [49], and through filtration and purification systems, see sub-section 23.4.8.
  - These species are limited in line with industry best practice to minimise SCC risk.

- Dose Equivalent Iodine-131 (RCS) and Dose Equivalent Xe-133 (RCS).
  - Radionuclides are monitored to ensure that losses of cladding integrity are detected and that limits of primary coolant radioactivity defined by radiological consequence studies are not exceeded.
  - Candidate limits have been derived for these parameters based on the US NRC Standard Technical Specifications (STS) specific activity Limiting Conditions for Operation (LCOs) limits for similar, albeit larger, PWRs [78].

A pH modifier, as yet without an associated limit, is required to ensure that during LOCA flood-up conditions, sufficient alkalinity of the water keeps radioactive species in non-volatile form. This limit will be identified as part of GDA Commitment, C_Reac_106 (see sub-section 23.7.3).

For start-up and shutdown transients, chemistry control limits and conditions will be established as a function of design development.

A consolidated list of the chemistry limits and conditions is provided in sub-section 23.6; note these will be refined and expanded upon as a function of design development.

23.4.6.6 CAE Summary

Claim 2.2.14.3 has been decomposed into five arguments which aligns with how Reactor Chemistry supports the integrity of plant structural materials and confinement of radioactivity by reducing degradation during normal operating modes and accident conditions.

For Argument A1, fuel cladding degradation has been demonstrated to be minimised whilst in the RCS and the SFP. This argument relies on the choice of fuel cladding material, the minimisation of fuel crud deposition and suitable system chemistry regimes which have been developed to minimise corrosion. This is supported by consideration of interfacing systems and failed fuel monitoring enabling the early detection of fuel cladding failure.

For Argument A2, the degradation of RCS structural materials has been minimised. This is achieved through material selection and an optimised RCS chemistry regime which balances conflicting parameters.

For Argument A3, the degradation of the NI Auxiliary systems and ESFs has been minimised. This relies on selection of corrosion resistant materials, consistent with best practice, and appropriate chemistry regimes.

For Argument A4, the SMR-300 includes adequate provisions for Reactor Chemistry to deliver support to combustible gas control, fission product retention and core melt and that further design development is expected to meet UK regulatory expectations. This is with the exception of a pH modifier to adjust the pH of the reactor cavity flood up volume post-accident which will be finalised prior to site-specific deployment. A GDA Commitment, C_Reac_106, has been raised to cover this delta, see sub-section 23.7.3.

For Argument A5, suitable and sufficient limits and conditions have been placed on systems in support of degradation minimisation and confinement of radioactivity.

Contingent on fulfilling the GDA Commitment raised for this claim, all evidence presented is judged to be of sufficient maturity to meet the requirements of fundamental assessment.

Therefore, it can be concluded that, contingent on delivery of GDA Commitment, C_Reac_106, Claim 2.2.14.3 has been met.

23.4.7 Chemistry Support to Radioactive Source Term

Claim 2.2.14.4: The chemistry of Nuclear Island systems reduces the normal operation source term of the reactor coolant.

The normal operation source term describes the types, quantities and physical / chemical forms of the radionuclides present in the SMR-300 that are of safety and environmental significance. The normal operation source term topic is led by Radiological Protection (Part B Chapter 10 [16]) and is used as a key input to multiple technical areas across the PSR and PER.

Reactor Chemistry supports the development of the normal operation source term by:

- Minimising the observed normal operation source term of the RCS.
- Minimising uncontrolled accumulation of radionuclides.
- Demonstrating that the calculated normal operation source term is representative of the SMR-300 plant.

These three goals are reflected in the decomposition of Claim 2.2.14.4 into the Arguments A1, A2 and A3.

An additional argument, A4, has been decomposed from Claim 2.2.14.4 which ensures that suitable and sufficient chemistry conditions and limits have been placed on systems that support the reduction of the normal operation source term.

23.4.7.1 Radionuclide Generation

Argument 2.2.14.4 – A1: The generation of radionuclides in the RCS is minimised.

Key Evidence for Argument 2.2.14.4 – A1:

- **HI-2240462, SMR-300 Nuclear Island Minimalization Strategy of Activity Generation and Accumulation** [79]**:** Presents the strategy for minimising the generation of radionuclides across all normal operating modes. This focuses on reducing corrosion product radionuclides such as those of cobalt, silver and antimony, which are linked to high dose rates in PWRs.
- **HI-2240459, SMR-300 Primary Water Chemistry Strategic Plan** [53]**:** Provides justification for the downselected primary chemistry regime of the SMR-300 which is appropriate for the materials selected and minimises generation of radionuclides through minimising corrosion. Provides justification for the selection of chemical additives taking cognisance of their impact has on the generation of radionuclides.
- **HI-2240242, SMR-300 Contained Radiation Sources for Normal Operation** [80]**:** Provides the estimated normal operation source term for the SMR-300 in the form of a 'Realistic' set of RCS coolant specific activities.
- **HI-2241579, Evaluation of SMR-300 Calculated Source Terms Against Publicly Available Information** [81]**:** Demonstrates that the estimated normal operation source term is in line with other nuclear reactors of its class and is smaller than larger light water reactors, on a per GW_t basis, at a similar point in preliminary design process.

Radionuclide generation in RCS coolant is minimised by the following factors:

- Minimisation of residency time of corrosion products in neutron flux.
    - The retention of corrosion products in the core in the form of fuel crud has been shown to be minimised through the minimisation of fuel crud deposition, see sub-section 23.4.6.1.
- Minimisation of RCS, NI Auxiliary and ESF materials degradation reducing the RCS corrosion product inventory available for activation under neutron flux (see subsection 23.4.6.2 and 23.4.6.3).
- Minimisation of fuel cladding degradation ensuring the retention of radionuclides in the fuel rods, see sub-section 23.4.6.1.
- Zinc injection
    - Zinc supports the development of stable protective oxides on RCS materials, thus reducing general corrosion rates and the availability of corrosion products to be activated in the core. Zinc also reduces the risk of uncontrolled radionuclide accumulation, see sub-section 23.4.7.2. As presented in the EPRI Primary Water Chemistry Guidelines [32], 'no negative impact of zinc injection on fuel corrosion/oxidation has been observed within the current industry database' and 'dose rate reductions are achievable'.
- Minimisation of cobalt.
    - Radioactive Cobalt-60 (Co-60) is an important radionuclide to minimise due to its contribution to shutdown dose rates. Elimination of its parent isotope, Cobalt-59 (Co-59), as an impurity in RCS structural materials is performed in accordance with international best practices.
        - SGE tubing makes up a significant proportion of the RCS by wetted surface area. Cobalt impurities in the SGE tubing material are restricted to [REDACTED] [79].
        - For all other areas where materials are in contact with RCS coolant, cobalt content is restricted to less than [REDACTED]. This includes cobalt residuals in stainless steels such as those used in lower internals of the RPV [79].
    - Co-59 is also used in the form of Stellite, a chromium-cobalt alloy used for hard facing. Minimisation of Stellite is in accordance with the strategy provided by [79]; The SMR-300 shall only use Stellite where no proven alternative exists or where it is ALARP to do so.
- Minimisation of silver.
    - Generation of silver-110m (Ag-110m) is reduced by restricting use of silver to only the RPV head gasket and parts of the RCCAs not in contact with the primary fluid [79].
- Minimisation of antimony.
    - Generation of radioactive Antimony-122 (Sb-122) and antimony-123 (Sb-123) is minimised by limiting the use of antimony to locations not in contact with the primary fluid (such as the Reactor Coolant Pump (RCP) bearings and seals and secondary neutron sources) [79].
- Selection and control of chemical additives.
    - Natural boric acid will be added to the RCS coolant, principally for reactivity control. The amount required is minimised by the use of RCCAs and burnable in core neutron poisons which in turn minimises the amount of tritium generated via neutron activation of B-10, see sub-section 23.4.4.2.

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  - Lithium hydroxide will be added to the RCS coolant, principally to control pH of bulk RCS coolant, see sub-section 23.4.6.2. This will be isotopically enriched in Li-7 meaning that tritium generation via neutron activation of Li-6 is minimised.
  - Zinc in the form of depleted zinc acetate to minimise the formation of radioactive zinc-65 (Zn-65) will be injected into the RCS.

These factors have resulted in an estimated normal operation source term [80] for RCS coolant which is, on a per GW_t basis, smaller than the values calculated for the UK EPR [81].

23.4.7.2 Radionuclide Accumulation

Argument 2.2.14.4 – A2: The uncontrolled accumulation of radionuclides in the Reactor Coolant System is minimised.

Key Evidence for Argument 2.2.14.4 – A2:

- **HI-2240462, SMR-300 Nuclear Island Minimalization Strategy of Activity Generation and Accumulation** [79]**:** Provides an overview of the systems present in the SMR-300 to reduce radionuclide generation and accumulation. Provides a preliminary strategy to control radionuclide solubility during plant transients such as start-up and shutdown.

The SMR-300 minimises the uncontrolled accumulation of radionuclides throughout the RCS and SFP in order to minimise the normal operation source term of the operating plant. This is achieved by containing and concentrating radioactivity in preferred locations in the following ways:

- Filtration and purification systems.
  - Soluble and insoluble corrosion products and fission products are removed from the RCS by alignment of letdown coolant flow through the CVC demineralisers and filters [46] [48]. This concentrates activity within these components which is then controllably transferred to the Solid Radwaste System (SRW) [82].
  - Soluble and insoluble corrosion products and fission products are similarly removed from the SFP by the SFC demineralisers and filters [83]. This is particularly important during Refuelling when RCS and SFP fluids are mixed.
- Removal of radioactive gaseous species.
  - The CVC directs RCS coolant letdown flow to the Volume Control Tank via a spray nozzle which promotes removal of dissolved gases from solution such that these accumulate in the Volume Control Tank vapor space. Capability to remove the accumulated gases is provided by manipulating Volume Control Tank volume level, nitrogen purge provisions and connections to the Gaseous Radwaste System [46] [84]. This vapour space will be routinely purged prior to shutdown.
- Chemistry control of plant transients.
  - Chemical oxygenation and deoxygenation of the RCS and dedicated crud burst demineraliser beds support the management of transients [79]. Detailed start-up and shutdown procedures will be developed as a function of design maturity.
- RCS design principles.

  - Pipework length will be minimised and low flow and occluded regions are eliminated [79]. Hence, activated corrosion products are retained in solution through the RCS and the opportunity for corrosion product chemical species to concentrate and precipitate out on pipework is minimised.
- Zinc injection.
  - Injection of zinc acetate at low concentrations reduces the opportunities for incorporation of radionuclides such as Co-58 and Co-60 into the passive oxide layer on plant piping [79]. This avoids deposition of these radionuclides allowing for controlled removal in the CVC [46].
- Surface finish requirements.
  - Surface roughness requirements will be specified by requirements in the purchase specifications, and / or design specifications, for materials in contact with RCS coolant. These limits reduce the surface area over which interaction between RCS materials and coolant occurs thus reducing the extent to which potentially activated species may be incorporated into system pipework by limiting the interaction sites [79].
  - Commensurate with the current design stage a full suite of purchase specifications have not been issued however SGE tubing (primary side) is restricted to [REDACTED] root mean square roughness [79] [85]. In the absence of specified requirements an absolute roughness of [REDACTED] will be applied to all RCS SSCs. The reactor coolant pumps will undergo electropolishing and be passivated by the manufacturer prior to installation.

23.4.7.3 Estimated Normal Operation Source Term

Argument 2.2.14.4 – A3: The SMR-300 estimated normal operation source term is representative.

Key Evidence for Argument 2.2.14.4 – A3:

- **HI-2240242, SMR-300 Contained Radiation Sources for Normal Operation** [80]**:** Provides the estimated normal operation source for the SMR-300 in the form of a 'Realistic' set of RCS coolant specific activities.
  HI-2241579, Evaluation of SMR-300 Calculated Source Terms Against Publicly Available Information [81]**:** Demonstrates that the estimated normal operation source term is in line with other nuclear undergoing design.

The Realistic source terms [80] represent an estimation of the normal operational plant source term. Analysis of the normal operation source term demonstrates [81]:

- The normal operation source term has been calculated using appropriate methodologies which are appropriately adapted to the SMR-300.
- The calculations methodologies used build in OPEX appropriately through use of the American National Standards Institute (ANSI) / American Nuclear Society (ANS) 18.1 standard and appropriately justified values for parameters such as failed fuel fractions.
- Understood, appropriate conservatisms are built into the calculation of the normal operation source term.
- The normal operation source term is consistent with other estimated source terms, on a per GW_t basis. Any differences to OPEX are explained demonstrating that the normal operation source term for the plant is well understood.

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This has produced a set of source terms that is adequately representative of the SMR-300 and appropriate for this stage of design development.

23.4.7.4 Operational Chemistry Control Limits and Conditions

Argument 2.2.14.4 – A4: Suitable and sufficient operational chemistry limits and conditions are in place to reduce the normal operation source term.

Evidence for Argument 2.2.14.4 – A4:

- **HI-2240463, SMR-300 Water Chemistry Requirements** [29]**:** Provides limits and conditions for the RCS, including for zinc injection.

Operational chemistry limits and conditions supporting minimisation of the normal operation source term are identified in [29]. The following chemistry parameters are identified as key for Power Operation:

- Zinc (RCS).
    - A positive inventory is maintained to minimise the generation and uncontrolled accumulation of radionuclides. A minimum level is set to ensure that zinc is preferentially incorporated into the oxide layers of plant pipework over other potentially activated species (cobalt ions). A maximum level is specified in line with industry best practice [32].
- Operational chemistry control limits and conditions support minimising material degradation and release of activatable species to RCS coolant (Argument 2.2.14.4 – A3, see sub-section 23.4.6).

A consolidated list of the chemistry limits and conditions is provided in sub-section 23.6; note these will be refined and expanded upon as a function of design development.

23.4.7.5 CAE Summary

Claim 2.2.14.4 has been decomposed into four arguments which align with how Reactor Chemistry reduces the normal operation source term.

For Argument A1, the generation of radionuclides is minimised through minimising the time spent by activatable material in the neutron flux dense regions of the plant, minimising material degradation and careful selection and control of chemical additives.

For Argument A2, filtration and purification systems, predominantly the CVC but also the SFC, as well as RCS design and zinc injection minimises the uncontrolled accumulation of radionuclides throughout the plant.

For Argument A3, the estimated normal operation source term has been appropriately calculated making use of well understood conservatisms. The evidence presented demonstrates that the normal operation source term is adequately representative of the SMR-300 and appropriate for this stage of design development.

For Argument A4, suitable and sufficient limits and conditions have been placed on systems in support of minimisation of normal operation source term.

As all arguments and evidence are sufficiently mature for a PSR it can be concluded that Claim 2.2.14.4 has been met.

23.4.8 Chemistry Monitoring and Control

Claim 2.2.14.5: Plant Auxiliary systems enable management of Nuclear Island chemistry.

To meet the limits and conditions identified by in the Primary Water Chemistry Strategic Plan [53] and the Water Chemistry Requirements [29], Reactor Chemistry must demonstrate that there are sufficient and suitable provisions included in the SMR-300 design to allow for:

- Adequate chemistry control (addition / removal of chemical parameters) of system fluids present on the NI.
- Adequate, representative sampling and monitoring of system fluids present on the NI.

These two goals are reflected in the decomposition of Claim 2.2.14.5 into Arguments A1 and A2.

23.4.8.1 Chemistry Control

Argument 2.2.14.5 – A1: NI chemical addition and purification systems are suitable and sufficient.

Key Evidence for Argument 2.2.14.5 – A1:

- **HI-2241591, UK Context – Gap Analysis of SMR-300 versus the ONR Chemistry SAPs and TAGs** [38]**:** Provides a comparison of the SMR-300 design, including the CVC, to the regulatory expectations of the UK including chemistry relevant SAPs (ECH 1 – 4 in [34]) and TAGs (088 [35] and 089 [36]).
- **HI-2241059, UK Gap Analysis of SMR-300 Design Philosophy Against Chemistry Codes and Standards** [39]**:** Provides a comparison of the SMR-300 design to the chemistry relevant codes and standards used in the UK including guidance provided by the IAEA and the World Association of Nuclear Operators (WANO). This includes demonstration that the CVC integrates relevant codes and standards and chemistry considerations.

Aspects which demonstrate that the CVC includes adequate provisions for chemistry control include:

- System design.
    - The design basis arrangement of demineralisation and filtration is aligned with the EPRI URD requirements which is based on collective industry experience and utility OPEX [28].
- Deboration capability.
    - RCS boron dilution is achieved when adding water at boron concentrations lower than the RCS. The deborating bed demineraliser may also be used to reduce the amount of soluble boron available in the primary circuit. This capability minimises discharges to the environment at the end of a cycle [28].
- Adequate sizing of SSCs that deliver chemistry control.

  - The BAST is sized for the most demanding change in concentration of boron of the RCS, see sub-section 23.4.4 [54].
  - Each demineraliser is sized for full RCS coolant flow and can purify reactor coolant for one fuel cycle at maximum expected activity without resin replacement [46].
  - Each of the system filters are sized for system design flow and are designed to operate for a fuel cycle without cartridge replacement [51].
  - The effluent Holdup Tanks (HUT) are sized for the most demanding changes in RCS volume (which occurs during criticality search) [86].
  - CVC piping is sized for the expected system flow rates [87].
  - The Volume Control Tank is sized for sufficient volume to provide full rated charging flow for [REDACTED], for maximum RCS leakage makeup and for sufficient gas space to provide maximum dilution rate for [REDACTED] plus additional safety margin [88].
  - Each charging pump is sized to achieve a complete turnover of the RCS volume in eight hours [89].
- Comparison to UK standards, codes and regulatory expectations.
  - It has been demonstrated that the CVC largely meets the regulatory expectations of the UK [38] and also codes and standards which provide international Relevant Good Practice (RGP) typically employed in the UK [39].

A summary of chemistry addition and removal methods for RCS, which is delivered by the CVC [46], is presented in Table 2:

Table 2: Summary of Chemistry Control of RCS Coolant

Parameter	Method
RCS lithium	Addition – CVC Chemical Mixing Tank and Charging Pumps.
	Removal – CVC demineraliser (cation bed) or feed and bleed.
RCS boron	Addition – CVC BASTs, Boric Acid Recirculation Pumps (to the Volume Control Tank) and Charging Pumps (direct to the RCS).
	Removal – CVC deborating bed and dilution of boron in makeup to RCS or feed and bleed.
RCS oxygen	Addition – CVC Chemical Mixing Tank (via hydrogen peroxide addition).
	Removal – Hydrogen cover blanket on Volume Control Tank. Chemical Mixing Tank (via hydrazine)
RCS hydrogen	Addition – Hydrogen is added by maintaining a hydrogen atmosphere on the Volume Control Tank vapor space.
	Removal – Nitrogen may be used to purge the Volume Control Tank vapor space (removing hydrogen and accumulated gasses). Volume Control Tank level is used to move accumulated gasses out of the Volume Control Tank vapor space. Alternatively gases may be removed from the RCS Pressuriser via the PSL to the Volume Control Tank.
RCS zinc	Addition – CVC Zinc Injection skid.
	Removal – CVC demineralisers or feed and bleed.
RCS impurities (and conductivity control)	Addition – N/A
	Removal – CVC demineralisers and filters. Alternatively feed and bleed.

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A summary of chemistry addition and removal methods for NI Auxiliaries and the PCC, which is delivered by the CVC [46] and the SFC [83], is presented in Table 3:

Table 3: Summary of Chemistry Control of NI Auxiliary Systems and the PCC (Including SFP, PCMWT, PCC Accumulators and RWST)

Parameter	Control
Boron	Addition – CVC BASTs via the Effluent Hold Up Tanks and High Pressure Pump.
	Removal – N/A (feed and bleed is available).
Impurities	Addition – N/A
	Removal – CVC and SFP demineralisers. Alternatively feed and bleed, important for species such as silica in the SFP.

A summary of chemistry addition and removal methods for the CCW, which is delivered by the chemical addition tank, is presented in Table 4:

Table 4: Summary of Chemistry Control of the CCW

Parameter	Control
pH ([REDACTED])	Addition – Flanged connection to chemical addition tank.
	Removal – Feed and bleed.
Corrosion inhibitor ([REDACTED])	Addition – Flanged connection to chemical addition tank.
	Removal – Feed and bleed.
Biological growth inhibitor ([REDACTED])	Addition – Flanged connection to chemical addition tank.
	Removal – Feed and bleed.
Impurities	Addition – N/A
	Removal – Feed and bleed.

PCH - AR Chemistry Control

Chemicals are injected into the AR via the PCH using the PCH Chemical Addition Tank and Chemical Addition Pump. Chemicals are circulated into the AR water via the Recirculation Pump which prevent biological growth and control pH to inhibit corrosion to the CES, CS, and SDH HX. Recirculation heaters provide freeze protection to the AR [52] [73].

The SMR-300 PCH does not include permanently installed capability to perform chemical purificaition of the AR besides feed and bleed [90]. A GDA Commitment, C_Reac_105, has been raised to incorporate temporary demineralisation skid connections and assess if permanent demineralisers are required to reduce risks SFAIRP, see sub-section 23.7.3.

Post Accident Chemistry Control

In the event of accident scenarios resulting in reactor cavity flood up, the expected pH of in the reactor cavity following a bounding LOCA will be acidic if unmitigated [77]. A chemical pH modifier is required to meet fission production retention requirements, as discussed in GDA Commitment C_Reac_106, see sub-section 23.4.6.4 and 23.7.3. Information on the addition and removal of this pH modifier will be included in a future iteration of the SSEC.

23.4.8.2 Monitoring and Sampling

Argument 2.2.14.5 – A2: NI monitoring and sampling systems are suitable and sufficient.

Key Evidence for Argument 2.2.14.5 – A2:

- **UK Context - Gap Analysis of SMR-300 Primary Sampling and Monitoring Arrangements** [91]**:** Provides an initial review of an early iteration of the PSL design against the regulatory expectations of the UK, RGP and OPEX. This largely substantiated the PSL design including consideration of factors such as compatible material for the sampling lines, turbulent flow rates, and equipment in place for operator dose reduction such as sample delay coils. A number of potential recommendations and deviations from UK regulatory expectations were captured in this document which were considered in further detail by [92]**.**
- **Primary Sampling System – Preliminary Chemistry Engineering Justification** [92]**:** Provides a systematic assessment of an early iteration of the PSL design and its capability to deliver representative samples for chemical and radiochemical analysis. This document proposed areas of design development that have been reflected in the PSL design as presented in Design Reference Point 1.1.
- **HI-2250423, UK Context – Accident Chemistry Strategy** [64]**:** Describes the strategy and approach to addressing accident chemistry within the design of the SMR-300 including an assessment of the Post Accident Monitoring System (PAM) compared to UK RGP and Regulatory Expectations.
- **HI-2241059, UK Gap Analysis of SMR-300 Design Philosophy Against Chemistry Codes and Standards** [39]**:** Provides a comparison of the SMR-300 design to the chemistry relevant codes and standards used in the UK including guidance provided by the IAEA and the WANO. This includes an assessment of the PSL against relevant codes and standards.
- **HI-2241591, UK Context – Gap Analysis of SMR-300 versus the ONR Chemistry SAPs and TAGs** [38]**:** Provides a comparison of the SMR-300 design to the regulatory expectations of the UK including monitoring system relevant SAPs (primarily ECH 4 in [34]) and TAGs 088 [35] and 089 [36].

The PSL provides a means for obtaining liquid and gaseous samples for laboratory analyses of chemical and radiochemical conditions of NI systems [93]. Assessment of the PSL in a UK context is explored primarily in the Chemistry Engineering Justification of the PSL [92] but also PSL Gap Analysis [91], Accident Chemistry Strategy [64], Codes and Standards Gap Analysis [39] and SAPs and TAGs gap analysis [38]. A summary of options considered to reduce risk is provided in sub-section 23.7.2.3.

The Chemistry Engineering Justification [92] conservatively identified all parameters needing to be sampled across the NI, and systematically evaluated the adequacy and appropriateness of their sampling by the PSL. A summary of how reliable, redundant and representative sampling of safety-related chemistry parameters is achieved by the PSL design, adapted from [94], is provided below:

- Reliability.
    - Direct and indirect ways of sampling all investigated chemical parameters are available to the operator. The sampling methods and analytical techniques proposed for the SMR-300 are aligned with conventional PWR sampling methods, supporting reliable monitoring.
- Redundancy.
    - Where required, redundancy of chemical monitoring is provided. This is principally through the use of a two train design architecture for systems sampled in containment. The use of a continuous CVC letdown sampling line further reinforces the SMR-300's demonstration of sufficient redundancy of chemical monitoring.
- Representativity.
    - Representativity is ensured through the minimisation of cross-contamination risk, principally through the use of a two train design architecture and the separation of chemically-dissimilar systems.
    - Zinc and corrosion products will be monitored via the CVC continuous letdown line and the corrosion product sampling panel in a manner consistent with other PWRs to ensure representative monitoring.
- Waste Generation.
    - Sampled fluids are preferentially returned to the Volume Control Tank to minimise waste.

Consistent with ensuring that UK RGP is incorporated into the SMR-300 design, a GDA Commitment, C_Reac_075, has been raised to use continuous online boron monitoring for UK deployments of the SMR-300 (see sub-section 23.7.3).

Aspects of the chemistry monitoring design basis of the PSL are provided in [92], justifying the adequacy of the system. A summary of the conclusions is provided below as Evidence:

- The systems sampled by the PSL system for the purposes of chemistry monitoring are consistent with other PWRs that have undergone the UK GDA.
- The use of the continuous CVC letdown sampling line for corrosion product sampling, whilst novel in the UK, is used in other PWRs and offers several advantages over the use of a dedicated RCS capillary line (such as the avoidance of an additional containment penetration) minimising ORE as the continuous sampling method for the monitoring.
- The SMR-300 choice of monitoring liquid and gaseous samples with the same sampling line, whilst novel in the UK, is used at other PWRs and supports design simplification.

In accident scenarios the PSL provides post accident monitoring capability in support of the PAM. The PSL enables the remote measurement of containment atmosphere as well as RCS and reactor cavity flood up chemistry parameters such as boron, gamma spectrum and gross activity without requiring entry into containment [93] [95]. Monitoring of the reactor cavity flood up volume in the PSL design, detailed in [94], is provided via the RCS Hot Leg line or by local drain line connections to the RHR and SFC. Analysis demonstrates that the PAM will meet all regulatory expectations [64].

Outside of the systems covered in the scope of [92], it is also important to ensure that chemistry of all NI Auxiliary systems and the ESFs are adequately monitored. Systems which are accessible during Power Operation are provided with local sample connection points. Further sample connection points will be defined as a function of design development and appropriately placed to ensure representative sampling.

23.4.8.3 CAE Summary

Claim 2.2.14.5 has been decomposed into two arguments which align with Reactor Chemistry support to continued and safe operation through chemical monitoring and control.

For Argument A1, suitable and sufficient chemical addition and purification systems are included in the design to provide adequate chemistry control on the NI. This is met to a level commensurate with a PSR with the exception of GDA Commitment C_Reac_105 which relates to demonstrating suitable and sufficient purification of the AR fluid.

For Argument A2, sampling systems are shown to provide adequate monitoring of all NI system chemistry parameters. This is with the exception of continuous boron monitoring which has been identified as GDA Commitment, C_Reac_075.

Contingent on fulfilling the GDA Commitments raised for this claim, all evidence presented is judged to be of sufficient maturity to meet the requirements of a PSR. Therefore, it can be concluded that, contingent on delivery of GDA Commitments C_Reac_105 and C_Reac_075, Claim 2.2.14.5 has been met.

23.5 THE CHEMISTRY OF TURBINE ISLAND SYSTEMS

This sub-chapter provides a brief introduction to the TI SSCs important to chemistry before presentation of CAE for each of the relevant Level 4 claims that applies to the TI systems.

Further information on the SSCs presented in this sub-chapter is available in Part B Chapters 1 [6], 5 [7] and the relevant system SDDs.

23.5.1 Overview of the Steam and Power Conversion and Turbine Island Auxiliary Systems

The Steam and Power Conversion systems considered by this sub-chapter includes those which make up the secondary circuit of the SMR-300 including the secondary side of the SGE, the Main Feedwater System (MFS) and the Main Steam System (MSS). These systems take heat generated by the RCS and converts liquid water to superheated steam and then converts the thermal energy of this steam to useful electrical output.

Chemical and radiochemical control of these systems is required to help minimise risks associated with the use of water as the secondary coolant fluid. Across the secondary circuit, coolant water is expected to take on a range of conditions varying in temperatures, pressures and physical states. At elevated temperatures and with dissolved species, this forms potentially aggressive mediums when in contact with SGE tubing and secondary circuit structural materials. Chemical control of the secondary coolant consists of managing chemical additives and minimising chemical impurities. Such control supports minimisation of corrosion phenomena potentially affecting SSCs. Radiochemical control allows for the monitoring of radionuclides that might indicate degradation of SGE tubing and the transfer of primary coolant to the secondary circuit.

The chemistry of the SMR-300 secondary circuit during Power Operation, start-up and shutdown follows conventional PWR practices. All Volatile Treatment (AVT) will be adopted which involves injecting Ethanolamine (ETA) into the feedwater to maintain an alkaline pH throughout the secondary circuit. The chemistry of feedwater delivered to the SGE will be tightly controlled by the MFS deaerator and injection of hydrazine. This maintains deoxygenated, reducing conditions in the final feedwater and SGE protecting materials from corrosion phenomena. Impurity minimisation is achieved by full flow condensate polishing in the Condensate Polisher System (CPO) and is supported by the Steam Generator Blowdown System (SGB).

The SGE Design Specification [43] presents the materials selected for the SMR-300 SGE. These comprise materials aligned with industry best practice such as the nickel-base [REDACTED] for SGE tubing and stainless and low-alloy steels for the structural materials. Materials chosen for the various systems comprising the secondary circuit, such as the MFS and Condensate System (CNS), are presented in reference [96] and summarised in Table 5. Discussion on the appropriateness of these material choices is provided in sub-sections 23.5.2.1 and 23.5.2.2.

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Table 5: Preliminary Secondary Circuit Material Selection

System	Conditions of Service	Piping size	Material	Reference
MSS	Superheated steam	Large bore	Carbon steel [REDACTED]	[96]
		Small bore	Low alloy steel [REDACTED]	[96]
MFS	All service conditions	All sizes	Low alloy steel [REDACTED]	[96]
Extraction Steam System (ESS)	Wet steam	All sizes	Low alloy steel [REDACTED]	[96]
Auxiliary Steam System (AXS)	All service conditions	All sizes	Low alloy steel [REDACTED]	[96]
CNS[1]	All service conditions	All sizes	Carbon steel [REDACTED]	[96]
Heater Drain System (HDS)	All service conditions	All sizes	Low alloy steel [REDACTED]	[96]
Main Turbine System (MTS)	All service conditions	All sizes	Low alloy steel or stainless steel [REDACTED]	[96]

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[1] Locations identified as susceptible to potential FAC will be low alloy steel or better corrosion resistant material, see sub-section 23.5.2.2.

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23.5.2 Chemistry Support to Structural Material Integrity and Confinement of Radioactivity

Claim 2.2.14.6: The chemistry of the Steam and Power Conversion systems reduces risks relevant to the integrity of structural materials and confinement of radioactivity.

The secondary circuit acts as the normal operating heat sink for the RCS during operation of the SMR-300. Reactor Chemistry support to minimising degradation within the secondary circuit is an important part of ensuring safe and reliable operation of the plant. In addition to this, the secondary circuit shares an interface with the RCS pressure retaining boundary and second barrier to fission product release, the tubing of the SGE. Reactor Chemistry supports the minimisation of degradation of the following:

- SGE materials.
- Secondary circuit structural materials.

Demonstration that degradation of these SSCs has been minimised is reflected in the decomposition of Claim 2.2.14.6 into the Arguments A1, and A2.

An additional Argument, A3, has been decomposed from Claim 2.2.14.6 which ensures that suitable and sufficient chemistry conditions and limits have been placed on systems that support reduction of material degradation and confinement of radioactivity.

23.5.2.1 Steam Generator

Argument 2.2.14.6 – A1: Steam generator degradation and fouling is minimised.

Key Evidence for Argument 2.2.14.6 – A1:

- **HI-2240598, SMR-300 Secondary Water Chemistry Strategic Plan** [97]**:** Provides justification and description of the selected secondary water chemistry regime. This includes how impurities are minimised and how corrosion of SGE materials is minimised. This document also provides preliminary discussion of SGE layup practices.
  HI-2240157, Design Specification for the SMR-300 Steam Generator [43]**:** Provides the design specification for the Once Through Steam Generator (OTSG) including materials, manufacturing processes, prohibited materials and provisions for testing, inspection and cleaning. Provides requirement for the SGE to include the capacity to be mechanically / chemically cleaned.

The integrity of the SGE is ensured by the following:

- Design, manufacture and operation of the SGE.
- Application of optimised secondary circuit chemistry regime.
- SGE lay up practices.

23.5.2.1.1 Design, Manufacture and Operation of the SGE

Due to the design and operation of the OTSG, all soluble ionic species are volatilized in the SGE and carried over in the steam to the MSS and onto the wider secondary circuit during Power Operation. This minimises the potential of localised aggressive chemistry environments within the SGE, and shifts the potential for deposits and corrosion to the MTS as steam condenses and further round the secondary circuit [97].

OTSGs are a novelty in the UK for PWRs but are a proven technology and see extensive use in the US. Historic OTSGs with Alloy 600MA tubing materials have '*experienced substantially fewer tube failures*' than their Alloy 600MA Recirculating Steam Generator (RSG) equivalents [98]. In general, [REDACTED] is expected to be subject to the same modes of degradation as Alloy 600, but with much lower susceptibility [97].

The SGE design specification includes several provisions supporting its integrity including [43]:

- SGE tubing and structural material selection.
    - SGE tubing will be [REDACTED].
    - Corrosion resistant low alloy and stainless steel materials have been selected as SGE materials [43].
    - The use of Alloy 600 and its associated weld metals are prohibited. This is in line with the global nuclear industry trend to move away from this material based on reliability / corrosion concerns for SGE tubing service.
    - Use of sensitised austenitic stainless steel is prohibited reducing risk of Intergranular SCC (IGSCC) in these materials.
- Manufacturing processes and controls.
    - [REDACTED]
    - Sulphur, lead, copper, mercury, aluminium, antimony, arsenic, and other low melting point elements, plus their alloys and compounds, are prohibited from their use in fabrication, testing, shipping, or installation.
- Provisions supporting inspection and cleaning.
    - Inspection and cleaning will be facilitated by the provision of openings and handholes. The location of handholes / inspection ports will be proposed by the SGE manufacturer. Cleaning of the SGE during construction, commissioning and maintenance periods will be performed in accordance with Holtec International processes and procedures.
    - The presence of deposits in the SGE which require cleanses to remove will be prevented as much as possible through effective and optimised chemistry. However, provisions that enable chemical and mechanical cleaning to be performed, [REDACTED], are included in the design as a precautionary measure. Mechanical cleaning involves physical removal of deposits of debris and corrosion products. Analysis will be undertaken on samples of these debris as this can provide insight on material degradation throughout the secondary circuit and so can be used to inform Examination, Inspection, Maintenance and Testing (EIMT) activities. Chemical cleaning involves using cleaning chemicals to dissolve scales and corrosion products which cannot be removed by mechanical means. Both processes are complementary to other preventative measures such as hot soaks.

23.5.2.1.2 Secondary Circuit Chemistry

An optimised secondary chemistry regime will be implemented which minimises the degradation of the SGE materials and the formation of deleterious chemical environments in the SGE. The secondary circuit regime is alkaline reducing with limited impurities, see sub-

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section 23.5.1. This environment minimises the degradation of secondary circuit materials reducing the delivery of corrosion products to the SGE which may form sludges and debris that may serve to concentrate deleterious chemical species. Operational chemistry limits and conditions (see sub-section 23.5.2.3 and 23.6) are applied to the secondary circuit and interfacing systems to minimise SGE material degradation.

Radiochemistry monitoring of the secondary circuit, by the SGB [99], RMS [100] and PAM [95] systems, is also performed to detect of primary-to-secondary leakage and Steam Generator Tube Rupture (SGTR) events. This information is used to inform operational decision making and prevent further deterioration of SGE tubing (see sub-section 23.5.2.3 and 23.6).

23.5.2.1.3 SGE Layup Practices

SGE lay up practices are required to protect the SGE during Cold Shutdown and periods outside of plant operation.

For the purposes of degradation minimisation, the default will be to place the SGE into wet layup as part of shutdown [42]. This involves filling the SGE with demineralised water (from the DWS) and controlling oxygen and pH [97]. The SGB provides a connection to the nitrogen gas system which is used during wet layup to mix SGE secondary side water inventory (avoiding chemical stratification) and inert the gaseous volume above the water level. This nitrogen blanket applied to the SGE also decreases the amounts of dissolved gases such as oxygen present in SGE lay up water [99].

The SGE can be drained for dry lay up, if required in support of plant maintenance activities, which is achieved by the SGB [99]. In these scenarios the SGE will be dehumidified (using dry air or nitrogen) and maintained under an inert atmosphere [97]. This enables inspection and maintenance activities.

23.5.2.2 Secondary Circuit

Argument 2.2.14.6 – A2: Secondary circuit structural material degradation is minimised.

Key Evidence for Argument 2.2.14.6 – A2:

- **HI-2240598, SMR-300 Secondary Water Chemistry Strategic Plan** [97]**:** Provides justification and description of the selected secondary water chemistry regimes. This includes how impurities are minimised and how corrosion of SGE and secondary circuit materials is minimised. This document provides a technical description of SMR-300 secondary circuit specific phenomena and approach to mitigation including FAC and Turbine Wash.
- **HI-2241364, SMR-300 Basis Paper on Piping Corrosion Allowance and Material Selection** [96]**:** Provides a basis for corrosion allowance (additional piping thickness) and material selection to be applied throughout the secondary circuit to meet the design life of the plant. This provides the preliminary approach to FAC mitigation.

The integrity of the secondary circuit is ensured by the following:

- Material selection.
- Application of optimised secondary circuit chemistry regime.

23.5.2.2.1 Secondary Circuit Material Selection

The design of the secondary circuit from a chemistry perspective is directed by minimisation of the risk of FAC and the Top Level Plant Requirement #1054 *'Plant systems subject to flow accelerated corrosion (FAC) and similar accelerated erosion-corrosion degradation mechanisms shall be fabricated from erosion-corrosion resistance materials'* [27]. Unmitigated, FAC poses a risk of accelerated degradation of secondary circuit materials. This mechanism involves removal of the protect oxide layer on system pipework leaving the underlying material exposed and prone to corrosion. This can be the origin of leaks or ruptures if not detected by an effective FAC inspection strategy.

The risk of FAC is principally minimised through appropriate material selection and placing minimum alloying requirements in susceptible areas. As the design maturity develops, further assessment of FAC risk will be performed to demonstrate that the risk is reduced SFAIRP. For the purpose of PSR, the following aspects of the SMR-300 FAC minimisation approach are highlighted:

- Preliminary secondary circuit materials includes stainless steel or low alloy chrome-moly steel pipework across regions susceptible to FAC. Systems for which the default material selection choice is carbon steel will have upgraded materials (to higher FAC resistant materials) in locations identified as susceptible. This is in line with the recommendations set out in the Piping Corrosion Allowance and Material Selection basis paper [96].
- Carbon steels are only to be used in locations where there is sufficient superheat to preclude wetted conditions, such as in the MSS, or where process conditions result in reduced FAC risk (colder, monophasic regions of the CNS).
- Hydrazine injection and a deaerator have been included in the secondary circuit design. This supports the control of the secondary circuit oxygen concentration, a key mitigating factor in determining FAC risk [97].
- ETA is used to maintain an alkaline pH throughout the secondary circuit. This mitigates a key factor in FAC risk [97].
- The MFS design and layout of piping shall consider the effect on erosion-corrosion of process conditions such as fluid velocity, bend locations, and the location of flashpoints [101].
- The MFS makes use of ultrasonic-type flow meters instead of venturi technology for flow measurements. This design aspect should reduce the risk of turbulence downstream of venturis impacting FAC susceptibility [101].

Further aspects of the secondary circuit design that minimise chemistry-related risks are:

- Elimination of copper alloys across the secondary circuit enables operation at an increased pH, which is beneficial for the limitation of FAC and general corrosion. Copper has been associated with localized corrosion phenomena in SGEs so its reduction is also beneficial to SGE degradation and fouling.
- Secondary circuit heat exchanger tubing materials, where defined, are stainless steel or titanium, thus eliminating common PWR issues with the preservation of carbon steel materials [102].
    - Condenser tubing is titanium or stainless steel [103].
    - Low Pressure (LP) Feed Water Heater (FWH) tubing is stainless steel [103].
    - Moisture Separator Reheater (MSR) tubing is stainless steel [104].

  - The materials of the Gland Steam System condenser and High Pressure (HP) FWH design will be developed in line with design maturity.
- Incorporation of a corrosion allowance aligned with industry guidance (e.g., EPRI) and industry design information [96].

23.5.2.2.2 Secondary Circuit Chemistry

An optimised secondary chemistry regime will be implemented which minimises the degradation of secondary circuit materials and the formation of deleterious chemical environments in the SGE. The secondary circuit regime is alkaline reducing with limited impurities, see sub-section 23.5.1. Operational chemistry limits and conditions (see sub-section 23.5.2.3 and 23.6) are applied to the secondary circuit and interfacing systems to minimise material degradation.

Of specific relevance to OTSGs and the secondary circuit is the phenomenon of ‘turbine wash’ where chemical species are carried over into the MSS from the SGE. The risks associated with turbine wash are minimised by full flow condensate polishing which ensures high quality feedwater is fed to the SGE during plant operation and this subsequently reduces the amount of impurities carried over to the MSS and onto the MTS [97].

23.5.2.3 Operational Chemistry Control Limits and Conditions

Argument 2.2.14.6 – A3: Suitable and sufficient operational chemistry limits and conditions are in place to reduce steam generator and secondary circuit material degradation.

Key Evidence for Argument 2.2.14.6 – A3:

- **HI-2240463, SMR-300 Water Chemistry Requirements** [29]**:** Provides limits and conditions for the secondary circuit including SGB, MFS, and CNS.
- **HI-2240598, SMR-300 Secondary Water Chemistry Strategic Plan** [97]**:** Provides justification and description of the selected secondary water chemistry regimes. Provides justification for the selection of secondary water chemistry chemical additives.

Operational chemistry limits and conditions supporting minimisation of the risk of degradation of TI structural materials and confinement of radioactivity are identified in [29].

During operation of the SMR-300 in Mode 1 (Power Operation) at reactor power greater than 15%, SGE chemical conditions resemble the conditions in the MFS (due to selection of a OTSG) and as such limits and conditions are equivalent. SGB limits and conditions are monitored intermittently during Power Operation however are important on plant start-up.

The following chemistry parameters are identified as key for Power Operation:

- $pH_{25°C}$ (CNS, SGB, MFS).
  - pH throughout the secondary circuit, including the SGE, will be maintained alkaline to minimise corrosion of secondary circuit materials.
- Specific conductivity (CNS, SGB, MFS).
  - Specific conductivity is monitored to ensure it is commensurate with $pH_{25°C}$, and as an early indication of CRS/impurity ingress into the secondary circuit.
- Cation conductivity (SGB, MFS, CNS Hotwell).

  - Cation conductivity provides an indication of large increases in anionic species and the presence of organic acid species (which may be formed by excessive thermal decomposition of pH raiser agent).
- Hydrazine (SGB, MFS).
  - Hydrazine is used as an oxygen scavenger and dosed at concentration of at least [REDACTED] times the dissolved oxygen concentration of feedwater source. A reducing environment is maintained in the final feedwater supplied to the SGE to minimise general corrosion and SCC of structural materials.
- Dissolved oxygen (CNS, SGB, MFS).
  - Oxygen, present as a dissolved gas, is minimised in final feed to the SGE to minimise general corrosion and SCC of SGE and secondary materials.
- ETA (CNS, SGB, MFS).
  - ETA, an amine based pH raiser, has been selected to produce net alkaline conditions throughout the secondary circuit due to its ability to control pH in liquid phase regions and because it degrades to ammonia which partitions to the vapour phase.
- Sodium (CNS, CNS Hotwell, SGB, MFS), chloride (CNS, SGB, MFS), sulphate (CNS, SGB, MFS), silica (SGB, MFS) and fluoride (SGB)
  - Impurities associated with an increased risk of secondary circuit and SGE material degradation are minimised by suitable limits on the make up water source [49] and the use of filtration and purification systems, see sub-section 23.5.3.
  - These species are limited in Feedwater, Condensate and SGB in line with industry best practice.
- Iron (SGB, MFS).
  - Iron concentration will be monitored as an indicator of corrosion in the secondary circuit.
- Total Gamma and Primary-to-secondary leakage rate (SGB, RMS).
  - Radioactivity will be monitored regularly via the SGB and RMS systems to ensure that, should one occur, SGTRs are promptly detected and that primary-to-secondary leakage is minimised.

23.5.2.4 CAE Summary

Claim 2.2.14.6 has been decomposed into three arguments which aligns with how Reactor Chemistry supports the integrity of plant structural materials and confinement of radioactivity on the TI.

For Argument A1, degradation and fouling of the SGE is minimised through a combination of design, manufacture, operational chemistry including impurity control and through protective activities (lay up and cleaning).

For Argument A2, degradation of secondary circuit materials has been minimised. This is achieved through material selection combined with an optimised secondary chemistry regime as well as adequate consideration of secondary circuit specific factors such as FAC and turbine wash.

For Argument A3, suitable and sufficient limits and conditions have been placed on systems in support of degradation minimisation and retention of radioactivity.

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As all arguments and evidence are sufficiently mature for a fundamental assessment it can be concluded that Claim 2.2.14.6 has been met.

23.5.3 Chemistry Monitoring and Control

Claim 2.2.14.7: Steam and Power Conversion supporting systems enable management of TI chemistry.

To meet the limits and conditions identified by the Secondary Water Chemistry Strategic Plan [97] and the Water Chemistry Requirements [29], Reactor Chemistry must demonstrate that there are sufficient and suitable provisions included in the SMR-300 design to allow for:

- Adequate chemistry control (addition / removal of chemical parameters) of system fluids present on the TI.
- Adequate, representative sampling and monitoring of system fluids present on the TI.

These two goals are reflected in the decomposition of Claim 2.2.14.7 into the Arguments A1 and A2.

23.5.3.1 Secondary Circuit Chemistry Control

Argument 2.2.14.7 – A1: TI chemical addition and purification systems are suitable and sufficient.

Key Evidence for Argument 2.2.14.7 – A1:

- **HI-2240598, SMR-300 Secondary Water Chemistry Strategic Plan** [97]**:** Provides justification and description of the selected secondary water chemistry regimes and overall operating approach. This includes how impurities are minimised and down selection of various chemical agents needed to be added to the secondary circuit for chemistry control.

Chemical control of the secondary circuit is provided for by the Chemical Feed System (CFS), the CPO and the SGB systems. Further information on how these are adequately designed to deliver chemistry control is provided below:

- Chemical Feed System [105].
    - The CFS injects the chemicals required to achieve the secondary chemistry regime. This includes oxygen scavenging (hydrazine) and pH control (ETA) agents into the CNS and MFS via two separate injection skids [97].
    - Preliminary design includes chemical dosing tanks and chemical injection pumps.
    - Wetted components of the CFS are all formed of varying grades of stainless steel (with the exception of pump diaphragms).
- Condensate Polisher System [103].
    - The condensate polisher package of the CPO is the primary method for impurity and corrosion product removal in the secondary circuit and maintains the feedwater chemical purity within specified limits.
    - Full flow treatment minimises chemistry-related risks associated with OTSG operation and CRS ingress events.

  - During plant start-up and prior to any feed initiated by the MFS to the SGE, one condensate pump is used to recirculate the contents of the main condenser hotwell through the CPO until the water chemistry meets MFS requirements thus reducing risk of impurity transport to the MFS and SGEs during plant start-up.
- Steam Generator Blowdown System [99].
  - The SGB provides the capability to remove concentrated impurities in the SGE by performing SGE blowdown.
  - SGB consists of a main blowdown line equipped with a flow control valve, drain pump, cooling jacket, nitrogen sparging line, and a sample line connection to the Secondary Sampling System (SSS). SGB when operated routes coolant directly from the SGE secondary side back to the CPO or to waste for disposal.
  - The SGB is sized to continuously blowdown [REDACTED] of the Maximum Recirculating Steaming Rate (MRSR) of the secondary circuit when operated. Operating the SGB during Power Operation would be informed by MFS sampling, see sub-section 23.5.3.2.
  - The SGB will be operated during plant start-up where it brings SGE chemistry into specification.
  - The SGB is designed to allow for outward flushing of the SGE during Cold Shutdown which also removes contaminants built up during periods of shutdown and maintenance.
  - The SGB provides capability to control lay up of the SGE, see sub-section 23.5.2.1.3, providing chemistry control during periods outside of operations.

A summary of chemistry addition and removal methods for secondary circuit, which is delivered by the CFS [105], the CNS(/CPO) [103] and the SGB [99] is presented in Table 6:

Table 6: Summary of Chemistry Control of Secondary Coolant

Parameter	Method
Feedwater / SGE hydrazine	Addition – CFS chemical addition tanks and pumps.
	Removal – N/A (feed and bleed is available, however this requires hydrazine destruction techniques).
Feedwater / SGE dissolved oxygen	Addition – N/A
	Removal – Deaerator and by reaction with injected hydrazine.
Feedwater / SGE ETA	Addition – CFS chemical addition tanks and pumps.
	Removal – Feed and bleed is available. Some ETA is removed by CPO demineralisers but major loss is by thermal decomposition to organic acids which are removed by the CPO(/SGB blowdown).
Feedwater / SGE impurities (and conductivity control)	Addition – N/A
	Removal – Secondary coolant undergoes full flow condensate polishing. Alternatively feed and bleed.

23.5.3.2 Secondary Circuit Monitoring and Sampling

Argument 2.2.14.7 – A2: TI monitoring and sampling systems are suitable and sufficient.

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Commensurate with design maturity no SDD is available for the SSS at the time of writing, system design will be developed as part of future design stages. The SSS is ruled out of scope of GDA, however due to its importance verifying the chemical condition of secondary circuit fluids, preliminary information is provided below on the systems which are sampled by the SSS [103] [101] [99] [100].

The SSS will be designed to permit sampling of the following sample point locations during all normal operating modes [29]:

- MSS.
- MFS.
- CNS CPO output.
- CNS Condensate Storage Tank.
- Deaerator reservoir.
- Extraction steam.
- Feedwater Heater Drains.
- MSR drain tank.

The RMS also has capability for radiation monitoring of the secondary circuit, including the MSS and SGB, to provide early indication of SGTR during normal operating modes [100].

23.5.3.3 CAE Summary

Claim 2.2.14.7 has been decomposed into two arguments which aligns with how Reactor Chemistry supports continued, safe operation through chemical monitoring and control of the secondary circuit.

For Argument A1, it has been demonstrated that suitable and sufficient systems are included for chemical addition and purification of secondary circuit coolant.

For Argument A2, although detailed system information for the SSS is not yet available, this is commensurate with design maturity and the current licensing phase.

As all arguments and evidence are sufficiently mature for a fundamental assessment it can be concluded that Claim 2.2.14.7 has been met.

23.6 SMR-300 CHEMICAL AND RADIOCHEMICAL CONTROL LIMITS AND CONDITIONS

Table 7 through Table 12 present the chemistry control parameters and sampling requirements for the SMR-300 plant in Power Operation [29]. Limits and conditions for other modes of operation will be provided in future iterations of the SSEC.

Table 7: Chemical and Radiochemical Control Limits and Conditions for RCS in Power Operation (Mode 1)

[REDACTED]

Table 8: Chemical and Radiochemical Control Limits and Conditions for SFC/RWST/PCMWT and PCC Accumulators

[REDACTED]

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Table 9: Chemical and Radiochemical Control Limits and Conditions for Condensate (All-Volatile Treatment) When In Service

[REDACTED]

Table 10: Chemical and Radiochemical Control Limits and Conditions for Condensate Hotwell When In Service

[REDACTED]

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Table 11: Chemical and Radiochemical Control Limits and Conditions for SGB in Power Operation (Mode 1)

[REDACTED]

Table 12: Chemical and Radiochemical Control Limits and Conditions for Feedwater in Power Operation (Mode 1)

[REDACTED]

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23.7 CHAPTER SUMMARY AND CONTRIBUTION TO ALARP

This sub-chapter provides an overall summary and conclusion of the Reactor Chemistry chapter and how this chapter contributes to the overall demonstration of ALARP for the generic SMR-300. Part A Chapter 5 [2] sets out the overall approach for demonstration of ALARP and how contributions from individual chapters are consolidated.

This sub-chapter therefore consists of the following elements:

- Technical Summary.
- ALARP Summary.
    - Demonstration of Relevant RGP.
    - Evaluation of Risk and Demonstration Against Risk Targets (where applicable).
    - Options Considered to Reduce Risk.
- GDA Commitments.
- Conclusion.

A review against these elements is presented below under the corresponding headings.

23.7.1 Technical Summary

This chapter aims to demonstrate the following Level 3 claim to a maturity appropriate for a PSR:

Claim 2.2.14: The SMR-300 chemistry regime and systems reduce chemistry-related risks during all normal operating modes and accident conditions for all phases of the lifecycle.

At a high level the chemistry regimes, including material selection and coolant chemical properties, of the SMR-300 seeks to support the nuclear safety objectives of controlling reactivity, ensuring fuel heat removal, and confinement of radioactive substances. This is enabled and verified by appropriate chemical management (addition, purification and monitoring) systems. These regimes and systems have been derived making use of internationally recognised state-of-the-art water chemistry programmes, namely the EPRI URD [28] and inclusion of the primary and secondary water chemistry guidelines therein [32] [33].

Claim 2.2.14 has been decomposed to Level 4 claims against which arguments and underpinning evidence have been provided and discussed in detail throughout. A summary of these Level 4 claims and arguments is provided below.

With regards to Reactor Chemistry support to fuel reactivity control, Claim 2.2.14.1, the SMR-300 seeks to avoid first of a kind engineering and so natural boric acid has been selected to deliver soluble reactivity control function to the design. Additional arguments and evidence supporting this claim demonstrated that an optimal boron management strategy has been developed for the systems of the NI (including RCS and NI Auxiliaries, and ESFs) which ensures that adequate boron will be provided in all normal operating modes and accident conditions. Natural boric acid is an appropriate source of boron in the RCS and the risks associated with its choice (and the system of system level risk of dilution of a soluble neutron absorber) has been shown to be minimised. This has included balancing against conflicting parameters which support other Level 4 claims; for this purpose, boron concentration will be coordinated with lithium hydroxide.

Reactor Chemistry support to fuel heat removal, Claim 2.2.14.2, is largely bounded by the demonstration provided against the first Level 4 claim that boron management has been optimised and that the risk of boric acid crystallisation risk is minimised. This has been used to demonstrate that the risk of blocking heat removal channels in the design is minimised. To add to this, demonstration that fuel crud deposition is minimised is called upon to demonstrate that thermal blanketing of fuel assemblies is avoided. Finally in support of fuel heat removal, Reactor Chemistry has demonstrated that the risks associated with chemical precipitates blocking recirculation pipework, strainers and screens has been minimised.

Reactor Chemistry support to structural material integrity and confinement of radiation, Claim 2.2.14.3, focuses on minimising the degradation of RCS (including materials within the core, such as fuel cladding and structural materials) and NI SSCs. RCS fuel cladding and structural materials are protected through appropriate material selection and optimised chemistry regimes. Radiochemical monitoring allows for the rapid determination of fuel failures, thus allowing operators to act to prevent further deterioration of the fuel. In the event of accident conditions, Reactor Chemistry has demonstrated that sufficient provisions are included in the SMR-300 design to adequately minimise risk for the three main areas of accident chemistry; combustible gas control, fission product retention and core melt severe accident scenarios. Work is underway for the selection and inclusion of a post-accident pH modifier to adjust the pH of the reactor cavity flood up volume into the design. A GDA Commitment, C_Reac_106, has been raised to capture this future work.

Reactor Chemistry support to the minimisation of the normal operation source term, Claim 2.2.14.4, ensures that radionuclide generation is minimised and that measures which reduce uncontrolled accumulation of radioactivity are included in the design. To add to this it has been demonstrated that the estimated normal operation source term has been appropriately calculated.

Reactor Chemistry control and monitoring systems, Claim 2.2.14.5, are able to control and verify Reactor Chemistry imposed limits and conditions on the NI systems. This is largely met by the PSL and CVC inclusion in the design. GDA Commitment C_Reac_075 has been raised to capture future work required for the integration of continuous online boron monitoring equipment into the design of the SMR-300 for future UK deployments. GDA Commitment C_Reac_105 has been raised to assess if the existing use of temporary demineralisation skids reduces risks SFAIRP.

Reactor Chemistry support to structural material integrity and confinement of radioactivity within the secondary circuit, Claim 2.2.14.6, focuses on minimising degradation of the secondary circuit materials and the SGE. It has been demonstrated that appropriate materials have been selected for use on the SMR-300 which are paired with an optimised secondary chemistry regime. The Reactor Chemistry control and monitoring systems, Claim 2.2.14.7, that control and verify Reactor Chemistry imposed limits and conditions on the TI systems are suitable and sufficient for a PSR.

Through decomposition of the Level 3 claim for Reactor Chemistry to Level 4 claims and underpinning arguments and evidence this Part B Chapter has demonstrated that the Level 3 claim has been met for PSR Rev. 1, contingent on three GDA Commitments discussed in greater detail in sub-section 23.7.3.

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23.7.2 ALARP Summary

23.7.2.1 Demonstration of RGP

Reactor Chemistry has demonstrated that the SMR-300 design philosophy adequately and appropriately integrates chemistry Codes and Standards see sub-chapter 23.3. The following assessments have also been performed against UK context and RGP:

- UK Gap Analysis of SMR-300 Design Philosophy Against Chemistry Codes and Standards.
- UK Context – Gap Analysis of SMR-300 versus the ONR Chemistry SAPs and TAGs.
- Primary Sampling System – Preliminary Chemistry Engineering Justification
- Accident Chemistry Strategy.

The chemistry approach of the SMR-300 is consistent with UK context and RGP [39] [38] [64] [92]; where deviations from UK regulatory expectations have been identified these have either been confirmed as GDA Commitments or closed through positive design development.

23.7.2.2 Evaluation of Risk and Demonstration Against Risk Targets

The numerical targets against which the demonstration of ALARP is considered can be found in PSR Part A Chapter 2 [3].

The evaluation of the normal operations and accident risks against Targets 1-9 is summarised in Part A Chapter 5 [2], which Reactor Chemistry indirectly supports through minimisation of the normal operation source term, see Level 4 Claim 2.2.14.4 sub-section 23.4.7.

23.7.2.3 Options Considered to Reduce Risk

Design improvements have been identified and closed out as part of system design. Table 13 presents options assessments that have been undertaken to support the demonstration of risk ALARP:

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Table 13: Options Considered to Reduce Risk

Document Title	Reference	Description / options assessed
SMR-300 Primary Water Chemistry Strategic Plan	[53]	Downselection and justification of overall approach to primary chemistry. Different pH operating regimes (coordinate, modified coordinated, elevated). Alternatives to Natural Boric Acid (such as EBA) evaluated.
SMR-300 Secondary Water Chemistry Strategic Plan	[97]	Downselection and justification of overall approach to secondary chemistry. ETA considered against other secondary pH raising chemicals such as ammonia, morphaline and aminomethyl propanol.
SMR-300 Closed Cooling Water Chemistry Strategic Plan	[76]	Downselection and justification of various chemistry regimes of closed cooling systems across the plant including the CCW and PCH.
Decision Paper on the SMR-300 Annular Reservoir Water Sources of Makeup and Chemistry Requirements	[73]	Downselection and justification of the chemistry regime of the AR including chemical additives and use of demineralised water to fill the AR over other options such as Cooling Tower basin water, Service Water, Lake water, and potable water.
Position Paper on SMR-300 Plant Demineralized Water Treatment System Output Quality Considerations and Requirements	[49]	Recommends chemistry requirements for the SMR-300 DWS. These inherently affect the chemistry control of all other systems as the DWS is used for makeup to the RCS, NI Auxiliaries, ESF (AR and PCC) and the secondary system.
Primary Sampling System – Preliminary Chemistry Engineering Justification UK Gap Analysis of SMR-300 Design Philosophy Against Chemistry Codes and Standards UK Context – Gap Analysis of SMR-300 versus the ONR Chemistry SAPs and TAGs	[92] [39] [38]	These documents have identified where deviations from UK context exist in the SMR-300 design. Design development activities have subsequently taken place to close the identified deltas. Key examples include the CVC, which was updated to include further clarification on the zinc injection capability, and the PSL, which has been updated based on the findings of [92]. This includes provision of an additional train which enables UK context redundancy and representativity expectations to be met by physical separation of chemically dissimilar sampling lines.

23.7.3 GDA Commitments

At Revision 1 there are three GDA commitments identified for Part B Chapter 23 Reactor Chemistry, these are presented in Table 14.

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Table 14: Reactor Chemistry GDA Commitments

Commitment ID	Commitment
C_Reac_075	The SMR-300 Design Reference Point 1.1 (HI-2240648-R2) does not include the capability to continually monitor the boron concentration of the primary circuit, a capability considered RGP in the UK. A Commitment is raised to incorporate continuous online boron monitoring of the primary circuit for the UK deployment of the SMR-300 following appropriate DBAA. Target for Resolution – Issue of UK Pre-Construction SSEC.
C_Reac_105	The SMR-300 Design Reference Point 1.1 (HI-2240648-R2) does not include a permanently-installed demineralisation capability for ensuring chemistry control of the Annular Reservoir. A Commitment is made to incorporate the capability to use temporary demineralisation skids (as identified in DWG-15213-R2.0) and assess if these enable risks to be reduced SFAIRP. Target for Resolution - Issue of UK Pre-Construction SSEC.
C_Reac_106	The SMR-300 Design Reference Point 1.1 (HI-2240648-R2) does not include the capability to chemically modify reactor cavity sump pH post-LOCA for the purpose of iodine retention, a capability considered RGP in the UK. A Commitment is raised to incorporate a post-LOCA reactor cavity sump pH modifier into the design such that risks are minimised SFAIRP. Target for Resolution - Issue of Pre-Construction SSEC.

23.7.4 Conclusion

Appropriate chemistry control ensures the continued integrity, reliability, and availability of the SSCs that are important to safety and ensures that the plant operates within the design intent. Part B Chapter 23, Reactor Chemistry, is structured to make the safety importance of chemistry control clear to the reader and the CAE constructed supports this objective.

Chemistry related risks exist in PWRs, and by extension the SMR-300, because of the use of fluids which interact at pressure and temperature with a number of different systems comprising differing materials. There is no single chemistry regime that is optimum for all of these fluids. The system-of-system nature of fluids used across the SMR-300 requires that the benefits of a specific chemistry regime in one system be balanced against the disbenefits in a different system. This also holds true for the balancing requirements between overarching project considerations such as safety, discharges to the environment and radiation protection. This chapter has demonstrated the approach to Reactor Chemistry for the SMR-300 sufficiently integrates codes, standards and RGP and in doing so has optimally balanced the important factors as needed to derive an adequate chemistry basis for operating the plant.

Reactor Chemistry Part B Chapter 23 demonstrates Level 4 Claims 2.2.14.1 - 7 are adequately underpinned by arguments and evidence such that the Level 3 Claim 2.2.14 can be substantiated at PSR rev 1. This is contingent upon three GDA Commitments which will be taken forward as part of the processes defined in Part A Chapter 4 [5].

Part A Chapter 5 of this PSR ALARP Summary [2] concludes that it can be demonstrated that the generic SMR-300 reduces risks to ALARP and that the Fundamental Purpose of the SSEC has been fulfilled.

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23.9 LIST OF APPENDICES

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Appendix A Part B Chapter 23 CAE Route Map

Table 15: Part B Chapter 23 CAE Route Map

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Appendix B Modified Coordinated Chemistry Control Regime

REDACTED

Appendix B Figure 1: Boron and Lithium Control Limits for SMR-300 Modified Coordinated Chemistry Control Regime

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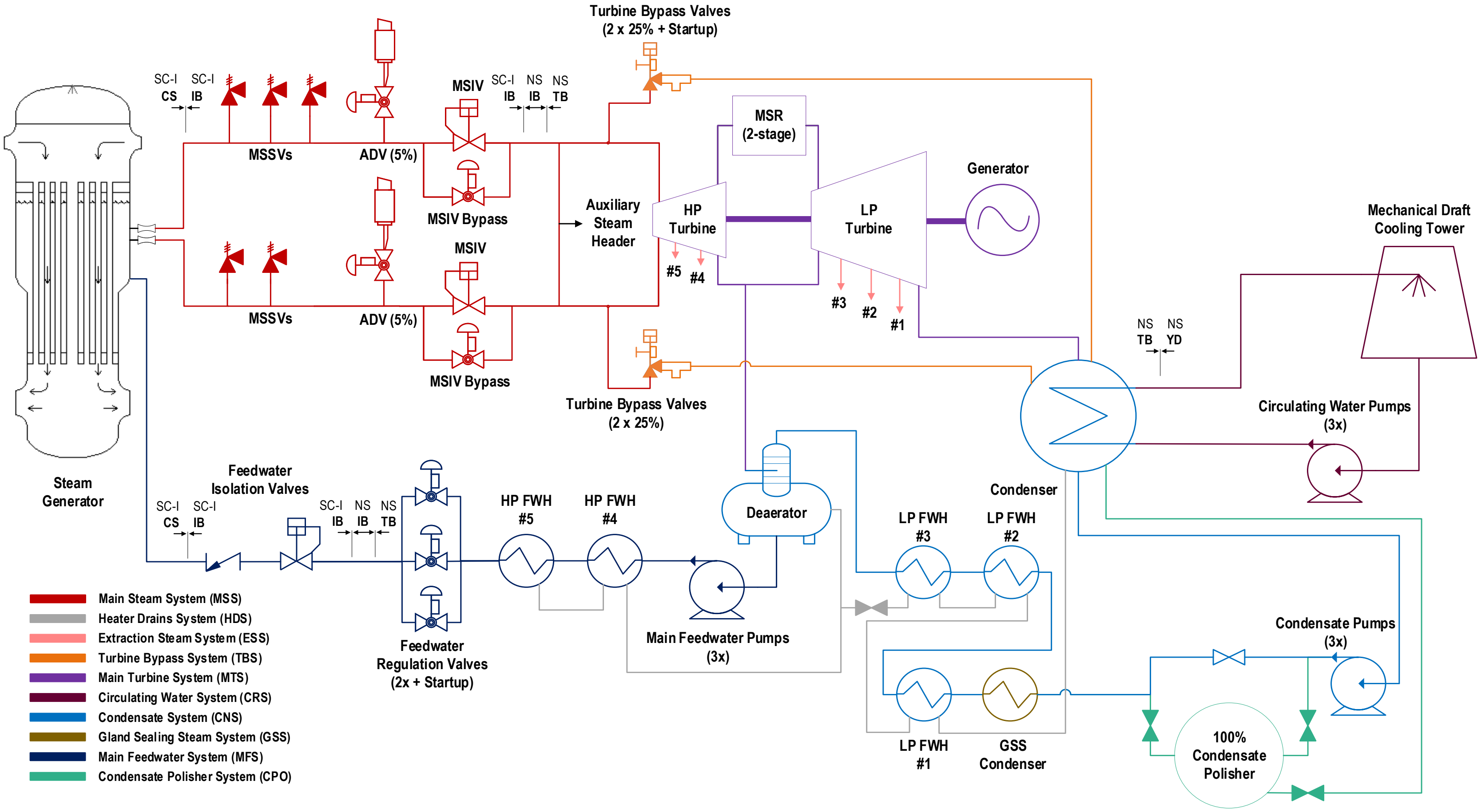
Appendix C SMR-300 Secondary Circuit



Appendix C Figure 1: General Arrangement of Power Conversion Systems [106]

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