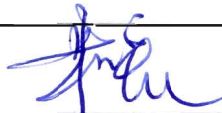




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21.1 List of Abbreviations and Acronyms

ALARP	As Low As Reasonably Practicable
ADG	Feedwater Deaerating Tank and Gas Stripper System [FDTGSS]
APG	Steam Generator Blowdown System [SGBS]
ASG	Emergency Feedwater System [EFWS]
ATE	Condensate Polishing System [CPS]
AVT	All Volatile Treatment
BAT	Best Available Technology
BOC	Beginning of Cycle
CEX	Condensate Extraction System [CES]
CGN	China General Nuclear Power Corporation
CIPS	Crud Induced Power Shifts
CPR1000	Chinese Pressurised Reactor
CRDM	Control Rod Drive Mechanism
CRUD	Chalk River Unidentified Deposit
DBC	Design Basis Condition
DEC	Design Extension Condition
DEC-A	Design Extension Condition A
DEC-B	Design Extension Condition B
DEL	Safety Chilled Water System [SCWS]
DER	Operational Chilled Water System [OCWS]
EBA	Enriched Boric Acid
EHR	Containment Heat Removal System [CHRS]
EUF	Containment Filtration and Exhaust System [CFES]
EUH	Containment Combustible Gas Control System [CCGCS]
FAC	Flow-Accelerated Corrosion
GDA	Generic Design Assessment
HFT	Hot Functional Test

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HPR1000 (FCG3)	Hua-long Pressurised Reactor under Construction at Fangchenggang nuclear power plant unit 3
IAEA	International Atomic Energy Agency
I&C	Instrumentation and Control
IGA	Intergranular Attack
IRWST	In-containment Refuelling Water Storage Tank
IVR	In-Vessel Retention
LHSI	Low Head Safety Injection
LOCA	Loss of Coolant Accident
MCL	Main Coolant Line
MHSI	Medium Head Safety Injection
MSR	Moisture Separator Reheater
NI	Nuclear Island
OPEX	Operation Experience
PARs	Passive Autocatalytic Recombiners
PCER	Pre-Construction Environment Report
PCSR	Pre-Construction Safety Report
pH _T	The high-temperature pH Value
PSA	Probabilistic Safety Assessment
PTR	Fuel Pool Cooling and Treatment System [FPCTS]
PWR	Pressurised Water Reactor
PWSCC	Primary Water Stress Corrosion Cracking
PZR	Pressuriser
QA	Quality Assurance
RBS	Emergency Boration System [EBS]
RCP	Reactor Coolant System [RCS]
RCV	Chemical and Volume Control System [CVCS]
REA	Reactor Boron and Water Makeup System [RBWMS]

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REN	Nuclear Sampling System [NSS]
RGP	Relevant Good Practice
RHR	Residual Heat Removal
RIS	Safety Injection System [SIS]
RPE	Nuclear Island Vent and Drain System [VDS]
RPV	Reactor Pressure Vessel
RRI	Component Cooling Water System [CCWS]
RVI	Reactor Vessel Internals
SAP	Safety Assessment Principle (UK)
SCC	Stress Corrosion Cracking
SED	NI Demineralised Water Distribution System [DWDS(NI)]
SER	CI Demineralised Water Distribution System [DWDS(CI)]
SFP	Spent Fuel Pool
SG	Steam Generator
SGH	Hydrogen Distribution System [HDS]
SGN	Nitrogen Gas Distribution System [NGDS]
SIH	NI Chemical Reagents Distribution System [CDS]
SIR	Chemical Reagents Injection System [CIS]
SIT	Feedwater Chemical Sampling System [FCSS]
SSC	Systems, Structures and Components
STP	Standard temperature and pressure (273.15 K and 1 atm)
TAG	Technical Assessment Guide (UK)
TEG	Gaseous Waste Treatment System [GWTS]
TEP	Coolant Storage and Treatment System [CSTS]
TEU	Liquid Waste Treatment System [LWTS]
TSP	Tri-Sodium Phosphate
UK HPR1000	UK version of the Hua-long Pressurised Reactor
VCT	Volume Control Tank

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WENRA

Western European Nuclear Regulators Association

System codes (XXX) and system abbreviations (YYY) are provided for completeness in the format (XXX [YYY]), e.g. Extra Cooling System (ECS [ECS]).

21.2 Introduction

The purpose of this Pre-Construction Safety Report (PCSR) Chapter 21 is to demonstrate that the design of reactor chemistry is substantiated according to the *Safety Case Strategy (Reactor Chemistry)*, Reference [1], and to provide a support to produce the safety case for UK version of the Hua-long Pressurised Reactor (UK HPR1000), which is developed based on the reference plant of Hua-long Pressurised Reactor under Construction at Fangchenggang nuclear power plant unit 3 (HPR1000 (FCG3)). According to the Generic Design Assessment (GDA) scope document, Reference [2], the scope of reactor chemistry includes the following issues of T-21.2-1.

T-21.2-1 Scope of Reactor Chemistry

Scope	Extent of Scope for GDA
Chemistry regime	Demonstration and justification of effects of coolant chemistry on: <ul style="list-style-type: none"> • Reactivity control • Pressure boundary integrity • Fuel cladding and core component integrity • Out of core radiation fields • Releases during accident conditions • Waste generation • Principles applicable to commissioning
	Definition of UK HPR1000 chemistry regime for the primary and secondary water systems, which will focus on the limits and conditions only, under all modes of operations: <ul style="list-style-type: none"> • Construction and commissioning including Hot Functional Test (HFT) • Start-up • Power operation • Shutdown • Transient • Decommissioning
	Demonstration that the primary and secondary chemistry regimes

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Scope	Extent of Scope for GDA
	reduce risks As Low As Reasonably Practicable (ALARP) overall, when considering the balance between different areas including mechanical engineering, structural integrity, corrosion products, dose rate, impurity ingress prevention and material selection.
Monitoring and sampling systems	Reactor chemistry control for fault and accidents conditions. Demonstration and/or justification that chemistry monitoring and sampling systems can provide adequate control and capacity through all normal operating modes and post-accident conditions.
Control systems	Demonstrations and/or justification of chemical control systems are adequate for maintaining chemistry parameters within the defined limits and conditions.
Integrity of pressure boundary	Interfaces with structure integrity and mechanical engineering, including the impact analysis and justification of chemistry on materials, structural integrity of the pressure boundary, and integrity of key component and fuel cladding.
Fuel performance	Interfaces with fuel and core, including the chemistry impact analysis and justification on fuel, Chalk River Unidentified Deposit (CRUD) formation and degradation mechanisms.
Source terms	Analysis and justification of chemical processes influence source terms.

21.2.1 Chapter Route Map

The *Fundamental Objective* of UK HPR1000 is that: The Generic UK HPR1000 could be constructed, operated, and decommissioned in the UK on a site bounded by the generic site envelope in a way that is safe, secure and that protects people and the environment.

To underpin this objective, five high level claims and a number of level 2 claims are developed and presented in Chapter 1. This chapter supports the *Claim 3.3* derived from the high level *Claim 3*.

Claim 3: Nuclear safety

The design and intended construction and operation of the UK HPR1000 will protect the workers and the public by providing multiple levels of defence to fulfil the fundamental safety functions, reducing the nuclear safety risks to a level that is ALARP.

Claim 3.3: The design of the processes and systems has been substantiated and the safety aspects of operation and management have been substantiated.

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Claim 3.3.10: The chemistry aspects of the plant design have been developed to reduce the nuclear safety risk ALARP.

To support the Claim 3.3.10, sub-claims of reactor chemistry are developed for assisting in the following safety functions:

- a) Reactivity control by the neutron poisoning from boron;
- b) Integrity of fuel cladding and Systems, Structures and Components (SSC);
- c) Radioactive waste generation and radiological doses to workers and the public.

The sub-claims for Chapter 21 are developed as followings based on the risks described above, and supported by multi-arguments, which are presented in the T-21.2-2.

Sub claim 3.3.10.1: The requirements for chemistry important to nuclear safety have been derived.

Sub claim 3.3.10.2: The design is substantiated against the requirements for chemistry important to nuclear safety in all modes of operations and fault conditions.

Sub claim 3.3.10.3: The design for chemistry regimes minimises the negative impact of radiation and chemicals on workers, public, plant and environment through ALARP in all modes of operations and fault conditions.

Sub claim 3.3.10.4: The effects of ageing of the chemistry related systems important to nuclear safety have been addressed in the design and selection of an optimum chemistry regime.

T-21.2-2 Arguments and Evidence of Sub-chapter

Argument	Evidence
A-1: Deterioration of heat transfer performance for fuel and spent fuel is impacted by limiting impurities related to CRUD formation and deposition on the surface.	21.4.1/21.4.2 21.6.1/21.6.2
A-2: Boric acid concentration satisfies the requirement of controlling relatively slow reactivity changes.	21.4.2/21.4.3 21.6.2/21.6.3
A-3: The risk of radiation dose to the works is reduced by optimisation of the chemistry regime and material selection.	21.4.5 21.6.1/21.6.2
A-4: Chemistry control assists in mitigating the hydrogen and radiologic release under accident condition to an acceptable limit.	21.7.2
A-5: The control parameters for the safety predication are monitored by sampling systems and laboratory in all modes of operations and	21.8

Argument	Evidence
fault conditions.	
A-6: Enriched lithium hydroxide coordinated with boron acid is designed to maintain an optimum pH to reduce the corrosion of fuel cladding and SSC.	21.4.3/21.4.4
A-7: Low operating range of hydrogen concentration is designed based on the Alloy 690TT of SG tubes for the reducing environment by suppressing water radiolysis.	21.4.3/21.4.4
A-8: Hydrazine is designed for the oxygen removal from the primary circuit during the start-up and the secondary circuit under normal operation with enough safety protection.	21.4.3/21.4.4 21.5.3/21.5.4
A-9: The addition of chemicals and removal of impurities are achieved by the dosing and purification systems according to the chemistry requirement.	21.4.4/21.5.4 21.6.4
A-10: All Volatile Treatment (AVT) is designed for water quality conditioning via ammonia and hydrazine dosing in the secondary circuit with full-ferric system.	21.5.3 21.5.4
A-11: The wastes activated from the corrosion products in the primary circuit are disposed through the waste treatment systems.	21.4.4

21.2.2 Chapter Structure

The chapter structure is shown in T-21.2-3.

T-21.2-3 Structure of Chapter 21

Sub-chapter	Title	Content Introduction
21.1	List of Abbreviations and Acronyms	List of the abbreviations, acronyms that are used in Chapter 21.
21.2	Introduction	General introduction of chapter structure, scope, interfaces with other topics, and claims development.
21.3	Applicable Codes and Standards	Codes and guidelines for the chemistry.
21.4	Primary Water Chemistry and Associated Systems	<ul style="list-style-type: none"> The technical basis for the chemistry regime;

Sub-chapter	Title	Content Introduction
21.5	Secondary Water Chemistry and Associated Systems	<ul style="list-style-type: none"> • Chemistry control method; • Associated systems; • Operation and Optimisation.
21.6	Auxiliary Water Chemistry and Associated Systems	
21.7	Accident Chemistry and Associated Systems	<p>Three parts related to accident chemistry as below:</p> <ul style="list-style-type: none"> • Fission product control; • Combustible gas control; • Core melt and corium retention.
21.8	Sampling and Monitoring	<ul style="list-style-type: none"> • The sampling arrangement and control parameters; • Justify that Nuclear Sampling System (REN [RSS]) and Feedwater Chemical Sampling System (SIT [FCSS]) can monitor the control parameters to ensure safety operation of the systems.
21.9	ALARP Assessment	Provide the Relevant Good Practice (RGP), e.g. International Atomic Energy Agency (IAEA) safety guide and Operation Experience (OPEX) to support the ALARP.
21.10	Concluding Remarks	
21.11	References	

21.2.3 Interfaces with other Chapters

The interfaces with other Chapters are mainly focus on the interactions between the different chapters of PCSR, which is listed in the following T-21.2-4.

T-21.2-4 Interfaces between Chapter 21 and Other Chapters

Chapter	Interface
Chapter 1 Introduction	Chapter 1 provides the Fundamental Objective, Level 1 Claims and Level 2 Claims. Chapter 21 provides chapter claims, arguments to support relevant claims that are addressed in Chapter 1.

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Chapter	Interface
Chapter 4 General Safety and Design Principles	Chapter 4 provides selection principles of applicable codes and design. Chapter 21 provides codes and guidelines applied in chemistry.
Chapter 5 Fuel and Core	Chapter 5 provides design requirement of fuel and core, and the concentration of boron with fuel burnup. Chapter 21 provides the chemistry regime for the integrity of fuel cladding.
Chapter 6 Reactor Coolant System	Chapter 21 provides the water chemistry specification for the primary coolant. Chapter 6 provides system design parameters of the primary coolant.
Chapter 7 Safety Systems	Chapter 21 provides the information on the chemistry control and sampling requirement supported by the related systems (such as water quality control by chemical addition, and impurities control by clean-up), which is substantiated by the systems in the system chapter.
Chapter 10 Auxiliary Systems	
Chapter 11 Steam & Power Conversion System	
Chapter 12 Fault Studies	Chapter 12 and its supporting documents contain description of chemical effects that related to Design Basis Condition (DBC) source term analysis, including fission product control and iodine retention and transport.
Chapter 13 Severe Accidents	Chapter 21 contains description of chemical effects that relate to Design Extension Condition A (DEC-A) and Design Extension Condition B (DEC-B) events. Chapter 13 and its supporting documents provide accident analysis of DEC-A and DEC-B events, including chemical effects on fission product control, combustible gases control, and core melt and retention.
Chapter 17 Structural Integrity	Chapter 21 presents the information of reactor chemistry which is applicable to the assessment of ageing and degradation from the materials selection and chemistry regime for chapter 17.
Chapter 20 MSQA and Safety Case	Chapter 20 provides the organisational arrangements and Quality Assurance (QA) arrangements which are implemented in design process and in the production of

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Chapter	Interface
Management	Chapter 21.
Chapter 22 Radiological Protection	Chapter 21 provides optimum reactor chemistry controls for the minimisation of source term. Chapter 22 provides the definition of radioactive sources for UK HPR1000 and covers the various source terms present during normal operation.
Chapter 23 Radioactive Waste Management	Chapter 21 provides optimum reactor chemistry controls on the minimisation of source term, and this is beneficial for the treatment systems and decommissioning. Chapter 23 provides the detailed treatment process and strategy of radioactive waste, and Chapter 24 provides the decommissioning strategy.
Chapter 24 Decommissioning	
Chapter 25 Conventional Safety and Fire Safety	Chapter 25 provides the hazardous substances and explosive hazard management techniques and general prevention measures in reactor chemistry area.
Chapter 28 Fuel Route and Storage	Chapter 28 covers the fuel cooling and control of criticality during fuel handling and storage operations, and water quality of coolant in reactor pool and spent fuel pool is included in Chapter 21.
Chapter 30 Commissioning	Chapter 21 provides the objectives for commissioning from the chemistry and material aspects. Chapter 30 provides the arrangements and requirements for commissioning according to these objectives.
Chapter 31 Operational Management	Chapter 21 provides the limit of reactor chemistry. Chapter 31 provides arrangement of chemistry specification identified from reactor chemistry.
Chapter 33 ALARP Evaluation	Chapter 21 demonstrates that the chemistry aspects of the plant design have been optimised to reduce the risk ALARP, which supports the the overall ALARP demonstration addressed in Chapter 33.

21.3 Applicable Codes and Standards

The applicable codes and standards applied to reactor chemistry comply with Chinese and UK current existing requirements of applicable laws (acts), regulations and other statutory instruments. The codes and standards used in the design and assessment of UK HPR1000 are adopted according to the selection principles and the selection process described in Chapter 4 that have considered the scope of application, degree

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of familiarity, application in practical engineering and relationship with the reference plant. After the selection process and the suitability analysis, the applicable codes and standard can be adopted, and its applicability, adequacy and sufficiency can also be ensured.

The design of reactor chemistry for UK HPR1000 is developed based on the reference plant of HPR1000 (FCG3) that in accordance with the international standards, considering the UK expectations and the continuous feedback from the Chinese Pressurised Reactor (CPR1000) and other worldwide Pressurised Water Reactor (PWR) units.

The topic of reactor chemistry implements the following requirements to all aspects of the design and processes:

- a) Take into account of Safety Assessment Principle (UK) (SAP) and Technical Assessment Guide (UK) (TAG), including *Chemistry of operating civil nuclear reactor (NS-TAST-GD-088)* and *Chemistry Assessment (NS-TAST-GD-089)*, Reference [3], [4] and [5];
- b) Comply with the safety requirements of IAEA, and the main relevant items are listed in T-21.3-1;
- c) Consider some chemistry related issues of Western European Nuclear Regulators Association (WENRA), such as design basis envelope, operational limits and conditions, ageing management, accidents, radiation protection and waste management;
- d) Incorporate OPEX from international association and other Generic Design Assessment (GDA), including UK EPR, UK AP1000 and UK ABWR;
- e) Analyse the codes and standards used in reference plant design.

According to the applicable analysis of UK HPR1000 design, the conformity is confirmed. However, the differences between current applied codes and latest version which may have an effect on the existing design, and more detailed comparison with UK contexts is developed during the nuclear site licensing phase.

T-21.3-1 Applicable Codes and Standards for Chapter 21

Standards Number	Version	Title	Application for UK HPR1000 Design
IAEA Safety Standards, No. SSG-13	2011	<i>Chemistry Programme for Water Cooled Nuclear Power Plants, Specific Safety Guide,</i> Reference [6]	Adopted for chemistry programme

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Standards Number	Version	Title	Application for UK HPR1000 Design
IAEA Safety Standards, No. SSR-2/1	2016	<i>Safety of Nuclear Power Plants: Design, Specific Safety Requirements, Reference [7]</i>	Adopted for safety assessment principles
IAEA Safety Standards, No. SSR-2/2	2016	<i>Safety of Nuclear Power Plants: Commissioning and Operation, Specific Safety Requirements, Reference [8]</i>	Adopted for commissioning and operation chemistry
IAEA Safety Standard, No. NS-G-1.9	2004	<i>Design of the Reactor Coolant and Associated Systems in Nuclear Power Plants, Reference [9]</i>	Adopted for chemistry related system design substantiate
IAEA Safety Standards, No. NS-G-2.2	2005	<i>Operational Limits and Conditions and Operating Procedures for Nuclear Power Plants, Reference [10]</i>	Adopted for defining the safety limits for operating chemistry
IAEA Safety Standards, No. NS-G-1.12	2005	<i>Design of the Reactor Core for Nuclear Power Plants. Safety Guide, Reference [11]</i>	Adopted for enriched boric acid for reactivity control

21.4 Primary Water Chemistry and Associated Systems

To achieve these safety requirements claimed in Sub-chapter 21.2, a primary water chemistry control strategy aimed at maintaining chemistry regime in the primary circuit within specified ranges is adopted. This involves the primary circuit scope, material selection, chemistry control basis, method, and associated system, including the optimisation from the operation chemistry and material selection.

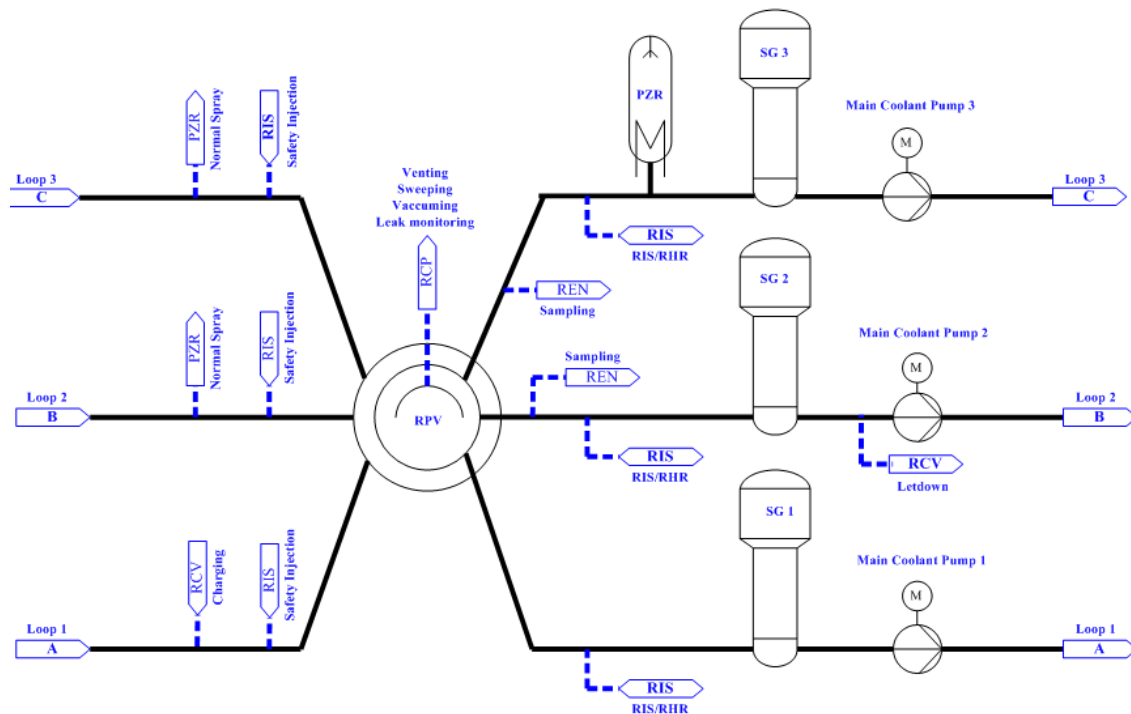
21.4.1 Primary Circuit

The primary coolant of Reactor Coolant System (RCP [RCS]) is conditioned in order to control reactivity, limit corrosion and reduce radioactivity of the primary circuit. The RCP [RCS] consists of the Reactor Pressure Vessel (RPV), Steam Generators (SGs), Pressuriser (PRZ), Reactor Coolant Pump (RCP) and Main Coolant Line (MCL). The simplified diagram of main loops is shown as F-21.4-1. The detailed information is described in Chapter 6.

The basic design parameters of RCP [RCS] are shown in the T-21.4-1.

T-21.4-1 Basic Design Parameters of RCP [RCS]

No.	Parameter	Unit	Values	Remarks
1	Design pressure	MPa (g)	17.13	More detailed information is described in Chapter 6
2	Design temperature	°C	343	
3	Normal operating pressure	MPa (a)	15.5	
4	RPV inlet temperature	°C	289.5	
5	RPV outlet temperature	°C	324.5	



F-21.4-1 Simplified Diagram of RCP [RCS] Main Loops

21.4.2 Material Selection

Material selection of the main equipment and fuel cladding satisfies the following two main design objectives:

- Corrosion is minimised to maintain the structural integrity of SSCs and fuel cladding under the defined chemistry regime;
- Radioactive source terms are reduced to ALARP through judicious material selection.

21.4.2.1 Material for Fuel Cladding

The fuel rod cladding is made of CZ alloy, which is Zr-Nb alloy {

}

21.4.2.2 Material for Main Equipment

Material selection of UK HPR1000 metallic SSCs is carried out on basis of recognised and appropriate international codes and China General Nuclear Power Corporation (CGN)'s experience from construction and operation of CPR1000 units, as well as OPEX from the worldwide PWRs. A “*Material Selection Methodology*” report is prepared for UK HPR1000 in Reference [12]. A “*Material Selection Report of SSCs*” will be established according to this reference, to provide robust demonstration of material selection for metallic SSCs.

T-21.4-2 and T-21.4-3 present the material to be used in SSCs contacting with reactor coolant for UK HPR1000.

T-21.4-2 Main Base Metal in Contact with Reactor Coolant

Equipment and Component	Type of Material	Chapter of Code
Reactor Vessel Internals (RVI)	Z2 CN 19-10 + N ₂	RCC-M M3301, M3302, M3304, M3306, M3307, M3310
	Z3 CN 18-10 + N ₂	RCC-M M3302
	Z2 CND 18-12+N ₂ (cold hardening)	RCC-M M3308
	Z6 CND 17-12+N ₂ (cold hardening)	RCC-M M 3308, M 5140
MCL	X2CrNi19-10+N ₂	RCC-M M3321
RCP	Z3CN20-09M	RCC-M M3405
RPV	NC30Fe	RCC-M M4108
SG	UNS N06690	ASME SB-163

Equipment and Component	Type of Material	Chapter of Code
PZR	Z2 CND 18-12+N2	RCC-M M 3306\ M 3301\ M 3308
	Z2 CND 17-12	RCC-M M 3304\ M 3307\ M 3306
	Z2 CN 19-10 + N2	RCC-M M 3307

T-21.4-3 Main Filler Metal in Contact with Reactor Coolant

Welds	Type	Chapter of code	Equipment
Austenitic stainless steel overlay and butt weld	ER309L/ER308L	AWS A5.9/ AWS A5.9+RCC-M S2910	RPV SG PZR
	EQ309L/EQ308L	RCC-M S2970/ RCC-M S2960	
	E309L/E308L	RCC-M S2930/ RCC-M S2920	
Nickel based alloy overlay and butt weld	ENiCrFe-7	AWS A5.11+ RCC-M S2986	
	ERNiCrFe-7/7A	AWS A5.14+ RCC-M S2981/ AWS A5.14	
Cobalt based alloy hardfacing	ERCoCr-A	AWS A5.21+ RCC-M S 8000, Gr 6	

21.4.2.3 Corrosion Factors

The structural integrity of SSCs in UK HPR1000 is maintained by judicious material selection and appropriate reactor chemistry control to eliminate/mitigate the material degradation, such as corrosion and environmental fatigue.

The selected materials are compatible with and tolerant to the reactor chemistry conditions by retaining superior resistance to various types of corrosion over design life time.

Reactor chemistry is well controlled to minimise the general and local corrosion of materials, which include maintaining the reactor chemistry regime under alkaline-reducing conditions, stringent control of detrimental impurities such as halogens (e.g. fluorides and chlorides), sulphate, as well as dissolved oxygen.

a) General corrosion

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General corrosion causes uniform surface loss of the materials in the primary circuit. It can occur in high temperature and aqueous environments. The influencing factors of general corrosion include material type, surface finish, temperature, pH and electrochemical potential.

In UK HPR1000, the SSCs in contact with reactor coolant are either constructed from, or clad with austenitic stainless steels or nickel based alloy (only Alloy 690 and its welding metal), due to their lower general corrosion rate in reactor coolant.

The surface roughness of the SSCs contacting with the coolant is strictly controlled. The surface roughness after manufacturing is less than 6.3µm in most case. During HFT, passivation will be carried out for all the surfaces in contact with the coolant to minimise the corrosion rate during operation.

b) Localised corrosion

Special attention is paid to the main form of local corrosion in UK HPR1000, notably for Stress Corrosion Cracking (SCC). SCC is a major concern for stainless steels and nickel base alloys as their corrosion resistance is provided by a thin oxide layer. SCC occurs when combinations of susceptible material, tensile stress and corrosive environment exist. Environmental factors influencing SCC include pH, electrochemical potential, temperature, hydrogen concentration, temperature and contaminant species (e.g. chlorides, fluorides and sulphates).

Material is thought to be another determinate factor of SCC, and the following measures are taken into account to mitigate SCC in UK HPR1000:

1) Appropriate material selection and fabrication procedure control

In the primary circuit, Alloy 690 is used instead of Alloy 600. It is widely accepted that Alloy 690 is much more resistant to SCC compared with Alloy 600. For example, the steam generator tube, which has the largest surface areas in the primary circuit, is made from Alloy 690TT.

2) Sensitisation prevention

Stainless steel with sensitised grain boundary microstructure has high propensity toward SCC. The majority of stainless steels in contact with reactor coolant are ultra-low carbon austenitic stainless steel with less susceptibility to sensitisation.

3) Residual stress control

Residual stress in material is another contributing factor of SCC. Studies have shown that residual stress induced either by extensive cold work or by welding initiates SCC for both stainless steels and nickel base alloys. In the primary circuit of UK HPR1000, cold work hardening stainless steels are

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only used in fasteners such as pins and screws.

The reports related to “*Aging and Degradation of SSCs*” will give more detailed information on degradation.

21.4.3 Chemistry Control

Chemistry control is required to help minimise risks associated with the primary coolant. The coolant at elevated temperatures and with chemical species is a potentially aggressive medium when in contact with structural materials. Chemical control of the primary coolant consists of managing chemical additives and minimising chemical impurities, in order to improve performance, minimise the risk of loss of barrier integrity and limit radiation impacts.

The determination of chemistry control parameters is based on the maintenance of materials integrity, fuel cladding integrity and radiation field control. The rational of risks mitigation from the chemistry is shown in the follow T-21.4-4.

T-21.4-4 Rational of Risks Mitigation from the Chemistry

Risks	Chemical Measures	Objective
Corrosion production, transport, activation, and deposition; Radiation field increasing	pH control by lithium hydroxide	To maintain an alkaline reducing environment of the primary circuit for the benefit of minimising corrosion and controlling the behaviour of corrosion products. To increase the pH and compensate for the acidity of the boric acid used for reactivity control, which impact the transport of corrosion products to the core and subsequent activation and deposition.
Corrosion caused by oxidising species from the radiolysis of coolant and ingress	Hydrogen control	To limit the oxidising species from coolant radiolysis and maintain reducing conditions.
Radiation field increase and SCC	Zinc injection	To reduce general corrosion, the deposition of cobalt into the out of core surfaces and the risk of SCC initiation.
Corrosion, Heat transfer degradation by CRUD formation	Impurities control	To minimised corrosion in the primary circuit and the formation of deposits.

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21.4.3.1 Technical Basis

a) pH

1) Boric acid

The boron is injected into the primary coolant for the reactivity control as neutron absorber. The boron is added and removed in the form of a solution of boric acid mixed with demineralised water to the required concentration. The concentration of boron is varied during normal operations only to control reactivity slow changes relatively, principally to accommodate the effects of fuel burnup. The detailed information relating to how the boric acid solution is used as a chemical reactivity poison and the operating range of the boron concentration is determined in the core and fuel design of Chapter 5.

For HPR1000 (FCG3) an isotopic abundance of 35at% for B-10 has been selected and this value has been considered as reference for UK HPR1000. Enriched Boric Acid (EBA) is used for reactivity control, which can be maintained using a lower concentration of boric acid in the coolant, and allows a constant pH to be used throughout the cycle.

2) Operating pH_T effect

Due to pH variation with the temperature, boric acid decreases the high-temperature pH Value (pH_T) within the primary coolant leading to impacts of the acid/alkaline conditions.

Maintaining the higher pH_T of alkaline conditions in the primary coolant contributes to minimisation of fuel cladding corrosion and general corrosion. The radiation field is decrease due to the pH_T effect on the solubility of corrosion products and their consequent transfer.

CRUD deposition on fuel cladding and inducing the fuel cladding failures is highly dependent on pH_T , the lower operating limit is defined to improve the condition of the primary coolant.

The selection of the optimal pH_T programme is based on the balance between the target pH value and the lithium concentration in the primary coolant. While high pH can present benefits for the corrosion product management, elevated lithium concentrations can present concerns about the fuel cladding corrosion. The upper limit of lithium concentration is important for maintaining the integrity of the first barrier on fuel cladding corrosion in the medium and long term. The lower limit of lithium concentration is relevant to radiation field.

3) Lithium hydroxide

Lithium hydroxide (LiOH) has been selected for the pH_T conditioning of the

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primary coolant of UK HPR1000. Other alkaline reagents such as ammonia, or sodium and/or potassium hydroxide present some drawbacks compared with lithium hydroxide, because they are not as thermally and radiolytically stable. In addition, the sodium and the potassium can be activated in Na-24 and K-42 leading to increase the radioactivity of the RCP [RCS] and auxiliary systems.

Lithium hydroxide enriched in Li-7 to 99.9% is used, because this isotope leads to negligible production of H-3 (tritium) under thermal neutron flux, unlike the isotope Li-6 which is present in the natural product. The choice of injecting enriched lithium hydroxide is the result of a Best Available Technology (BAT) for optimising the tritium source term demonstrated in the Pre-Construction Environment Report (PCER).

4) Operating limits

The operating pH_T of 6.9-7.4 and the criteria associated with the concentration of the alkaline reagents result from the compromise of the above factors. According to the worldwide research and OPEX, it is determined that the optimal pH programme for UK HPR1000 at a constant high $pH_{300^\circ C}$ is 7.2 along with the operating lithium limits of { } mg/kg. This value is used to determine the boron-lithium coordination during the fuel cycle.

In order to justify the pH strategy from the balance among material integrity, radiation field and fuel integrity, the primary water pH control chemistry regime for UK HPR1000 will be defined.

b) Hydrogen

1) Control of oxidising species

Oxygen in the primary coolant has a negative impact on the general corrosion, cladding corrosion, CRUD deposit, SCC (material), and pitting corrosion. In addition, C-14 is formed due to the activation of oxygen. The source of oxygen mainly includes the following aspects:

- The produced oxygen from water radiolysis of the primary coolant;
- The dissolved oxygen from the makeup water;
- The oxygen ingress from the system leaking.

The oxygen content during the power operation is less than 10 ppb through the addition of hydrogen. During the start-up operation oxygen concentration is limited to less than 100 ppb by hydrazine dosing.

2) Effect of hydrogen

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Hydrogen added into the primary coolant during power operation is justified by the requirement to scavenge oxygen and limit the generation of oxidising species from water radiolysis in the RCP [RCS], thus reducing the material corrosion.

It is important to ensure that there is an excess of hydrogen in the reactor at all times. However there is a need to limit the hydrogen concentration to maintain the integrity of the first and second barriers in the medium and long term.

3) Operating limits

The lower limit of hydrogen concentration has to be applied as regarding:

- Improvement of material integrity: The hydrogen suppresses the generation of oxygen in the primary coolant during power operation. Thus, it contributes to reducing the general corrosion, the Primary Water Stress Corrosion Cracking (PWSCC) and low temperature crack propagation of nickel alloys.
- Optimisation of radiation field: The hydrogen affects the redox potential of the medium with an impact on the corrosion product solubility.

The upper limit of hydrogen concentration has to be applied in regards to:

- Hazard protection

The hydrogen degassing in vessels could lead to the potential risk of hydrogen/oxygen mixture inside the equipment and/or release into the building atmosphere.

The shutdown planning can be affected by the degassing operation, because the hydrogen has to be removed from the primary coolant before the oxygenation phase in order to avoid the hydrogen/oxygen flammability risks.

More information about the hazard protection is described in Chapter 25.

- Hydrogen pickup

There is a risk that elevated dissolved hydrogen will result in enhanced hydrogen pickup fraction by zirconium-based fuel assembly materials. It is believed low diffusion of hydrogen can lead to the formation of zirconium hydrides (ZrH_2) that cause degradation of material mechanical properties. More information will be described in Chapter 5.

2) Operating range

The upper limit of hydrogen concentration of $50\text{cm}^3/\text{kg}$ (STP) is determined

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according to hazard protection and hydrogen pickup on the fuel cladding, and the lower limit of 10cm³/kg (STP) for the improvement of material integrity and radiation field.

According to OPEX from CPR1000 units, the operating range 25cm³/kg (STP)-35cm³/kg (STP) has been verified to meet the requirements of reducing condition for corrosion protection. Meanwhile, some optimisation of hydrogen concentration also is taken into consideration for UK HPR1000 described in Sub-chapter 21.4.5.

c) Impurities

Impurities present in the primary coolant are not benefit for the corrosion, including general corrosion, cladding corrosion, CRUD deposition, SCC (material), pitting corrosion and other risk of activation by radiation of the core. The main concerned impurities in the primary coolant contain the oxygen, fluoride, chloride, sulphate, aluminium, calcium, magnesium, silica, nickel, sodium, and suspend solids.

1) Fluoride, chloride and sulphate

Sulphate and chloride are implicated in SCC and pitting of austenitic stainless steels, but the effects at normal PWR operating conditions are minimal at typical chloride concentrations. Fuel assemblies may contain non-zirconium components such as stainless steel grid sleeves.

For UK HPR1000, the limit of impurities above is less than 0.15ppm for normal operation.

2) Aluminium, calcium, magnesium, and silica

Aluminium, calcium, and magnesium impurities may be observed intermittently in the reactor coolant as a result of makeup water, refuelling water, or boric acid contaminants. The oxides and silicates of aluminium, calcium, and magnesium have negative temperature coefficients of solubility, i.e., they will deposit preferentially on the fuel rods and could increase corrosion of the cladding.

3) Sodium

Sodium concentration is limited in the makeup water as a consequence of the capacity of these ions to cause corrosion on zircaloy and steam generator heat exchanger tube.

4) Suspended solids and nickel

Suspended solids as a diagnostic parameter in the reactor coolant can be activated, when they pass through the core, and contribute to activation of

plant systems and increase dose rates. It has been demonstrated that the removal of Ni before activation can help to reduce Co-58. In addition, nickel has a negative impact on the CRUD deposition inducing the corrosion of fuel cladding, so nickel is defined as a diagnostic parameter during the start-up.

T-21.4-5 Primary Coolant Limit during Normal Operation at $T \geq 295^\circ\text{C}$

Parameter	Unit	Expected Value	Limited Value
Oxygen	mg/kg	<0.01	<0.10
Chloride	mg/kg	<0.05	<0.15
Fluoride	mg/kg	<0.05	<0.15
Sulphate	mg/kg	<0.05	<0.15
Silica	mg SiO ₂ /kg	<0.6	<1.0
Aluminium	mg/kg	-	<0.05
Calcium	mg/kg	-	<0.05
Magnesium	mg/kg	-	<0.05
Suspended solids	mg/kg	<1	-

d) Zinc

According to present research, zinc continues to show significant benefits in radiation field reduction, and is beneficial in mitigating PWSCC initiation and some crack propagation on nickel based alloys. Predominantly, plants are adding zinc primarily for dose rate reduction, although some cite the additional goal of mitigating PWSCC. The descriptions of the benefits are provided below:

- 1) Radiation field and dose management due to the replacement of cobalt in the out of core surfaces by non-radioactive zinc, as well as the reduction in general corrosion leading to a decrease in the source term.
- 2) Minimisation of fuel CRUD, due to the minimisation of releases from the SG tubes and the reduction of residence time of corrosion product deposits on the fuel cladding.

Natural zinc refers to zinc compounds containing the normal distribution of isotopes present in nature with the following content Zn-64 at 48.6 at% abundance. The use of zinc depleted (in Zn-64 instead of natural zinc) is due to the generation (following the activation of Zn-64 isotope) of Zn-65 which has a high gamma energy. Zn-65 limitation will be taken into the consideration of zinc application.

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According to worldwide OPEX of zinc application in the PWRs, zinc is injected as depleted zinc acetate ($C_4H_6O_4Zn \cdot 2H_2O$) with Zn-64 < 1 at% and with reduced content of impurities (according to the specifications from the supplier).

21.4.3.2 Chemistry Control Method

The chemistry regime for UK HPR1000 is based on the reference plant of HPR1000 (FCG3), which is considering OPEX from the similar PWRs in China and operated by CGN.

a) pH control strategy

The primary coolant is a solution of boric acid. Boric acid is a weak acid with good physical and chemical stability with a limited impact on the corrosion of material which can be managed with the injection of an alkaline reagent. In order to achieve the operating target $pH_{300^\circ C}$ of 7.2, the elevated pH_T chemistry regime with B-Li coordinated regulation is applied in UK HPR1000.

1) Start-up

In the Beginning of Cycle (BOC), the maximum lithium is fixed at { } mg/kg. The lithium concentration limited for the fuel cladding will result in an initial phase in the BOC where $pH_{300^\circ C}$ is not at the target value for the high concentration of boric acid.

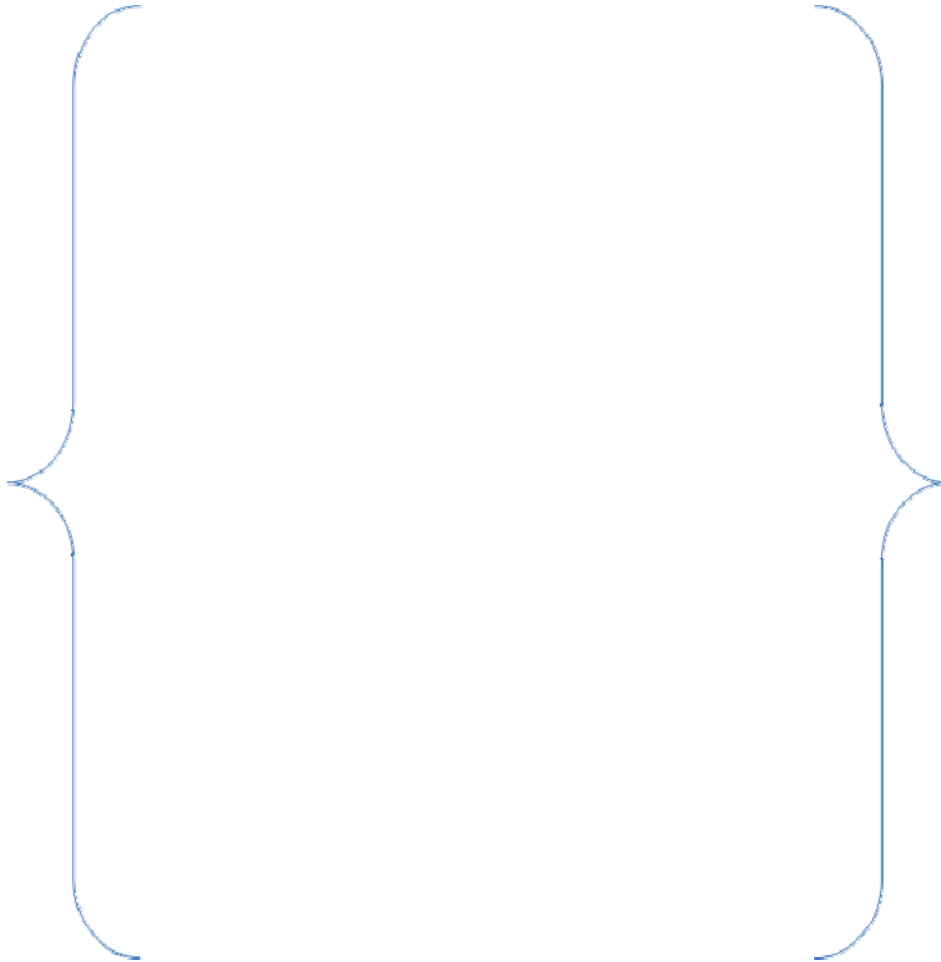
2) Normal operation

As the boron concentration is decreased throughout the fuel cycle, to compensate for fuel burnup, the $pH_{300^\circ C}$ may increase to the target value. After this point, the concentration of lithium hydroxide will be coordinated with that of boric acid to maintain the target $pH_{300^\circ C}$, reducing steadily until the end of the fuel cycle.

The simple pH control regime figure of B-Li coordinated regulation is shown in the F-21.4-2.

The addition and removal of lithium hydroxide and boric acid are controlled by the Chemical and Volume Control System (RCV [CVCS]), which will be substantiated in Sub-chapter 21.4.4.

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F-21.4-2 B-Li Coordinated Regulation of pH_{300c}

b) Hydrogen concentration control

The primary coolant is maintained in reducing conditions through the following ways for UK HPR1000:

1) Normal operation

Hydrogen is added into the primary circuit as a gas during the normal operation. Hydrogen risk is managed via specific devices, such as the Volume Control Tank (VCT) and an on-line recombiner in the Gaseous Waste Treatment System (TEG [GWTS]) loops. Based on the ammonia drawbacks and hydrogen risk, the hydrogen injection has been selected incorporating a specific hydrogenation station in RCV [CVCS], more information about the hydrogen control will be described in Sub-chapter 21.4.4.

2) Start-up

Hydrazine is used to remove the oxygen in the circuit during the start-up of the reactor. However, the amount of usage is minimised, because it presents disadvantages as the nitrogen is activated to C-14 and its potential impact on resins.

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3) Shutdown

Hydrogen peroxide can be injected during shutdown for chemical dehydrogenation (for removing the dissolved hydrogen before the oxygenation) and for the primary coolant oxygenation at temperature lower than 80°C in order to favour dissolution and purification of corrosion products.

The addition of hydrogen is controlled by the RCV [CVCS] system, which will be substantiated in Sub-chapter 21.4.4.

c) Impurities control

The limitation of impurities in the primary coolant includes the following measures:

- 1) Makeup water control: the water quality of makeup water is ensured by the SED [DWDS (NI)] system treatment, which are described in Sub-chapter 21.6.4.
- 2) Clean-up systems: the filters and demineralisers are used to remove the impurities, and the clean-up units are included the systems of RCV [CVCS], Fuel Pool Cooling and Treatment System (PTR [FPCTS]) and Coolant Storage and Treatment System (TEP [CSTS]), which will be described in Sub-chapter 21.4.4 and Sub-chapter 21.6.4.

A topic report will give more information on the impurity control in the primary coolant.

21.4.4 Associated Systems

21.4.4.1 Chemical and Volume Control System

a) System functions and configurations related to chemistry

The RCV [CVCS] system is designed to perform the following chemistry related functions in the normal operation:

- 1) The purification unit of RCV [CVCS] which consists of two reactor coolant filters, two mix-bed demineralisers, one cation-bed demineraliser and two resin trap filters provides purification function to remove corrosive and fission products from the reactor coolant.
- 2) The chemical unit of RCV [CVCS] injects lithium hydroxide into the reactor coolant upstream of the charging pump through a chemical injection pump as needed, to maintain the weak alkalinity of the reactor coolant during normal operation.
- 3) The chemical unit of RCV [CVCS] can inject hydrazine into the reactor

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coolant upstream of the charging pump through a chemical injection pump as needed for deoxygenation.

- 4) The hydrogenation station of RCV [CVCS] continuously adds hydrogen into the reactor coolant in order to keep the dissolved hydrogen concentration at the required value. The hydrogenation station is consisted of a water jet pump, a mixing pipe and a gas separator. There are several monitors installed at the hydrogenation station to detect the hydrogen concentration to prevent the hydrogen explosion.

b) System operation

1) Normal operation

– Purification unit

One reactor coolant filter, one mixed-bed demineralisers and one resin trap filter are put in operation whilst the other is standby. Downstream of the mixed-bed demineraliser, the cation-bed demineraliser can be put into intermittent operation as necessary to remove excess lithium, molybdenum and ytterbium from the reactor coolant.

– Hydrogenation unit

After purification and degassing, the reactor coolant (about 90% of the flow) enters into the hydrogenation station. The pressure of the VCT can be adjusted manually to improve hydrogenation performance of the hydrogenation station so as to meet the requirements of the primary water chemistry relating to hydrogen concentration. The hydrogen concentration can be detected by the REN [NSS].

– Chemical injection unit

In order to maintain the weak alkalinity of the reactor coolant, lithium hydroxide can be injected into the reactor coolant upstream of the charging pump by the use of a chemical injection pump as needed for pH control.

During the start-up, hydrazine can be added to the reactor coolant for the deoxygenation by the use of a chemical injection pump before the reactor coolant temperature reaches 120°C.

2) Failure of the RCV [CVCS] parts related to chemical control

The purification unit will be bypassed automatically for its protection when:

- The temperature at the inlet of the purification unit exceeds 65°C;
- The pressure at the inlet of the purification unit is higher than high-high

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level;

- The differential pressure of the filters is higher than high-high level and the differential pressure of the demineralisers is higher than high-high level.

If the hydrogen leakage in the hydrogenation station has been detected by the hydrogen monitors, it will be isolated automatically and the isolation valve of the hydrogen supply line will also be closed automatically, to protect the hydrogenation station from hydrogen explosion.

Detailed information of the system is presented in Chapter 10.

21.4.4.2 Reactor Boron and Water Makeup System

a) System functions and configurations related to chemistry

The Reactor Boron and Water Makeup System (REA [RBWMS]) controls the reactivity in the core by adjusting the boron concentration in the RCP [RCS] via the RCV [CVCS] under normal conditions. It also controls the reactivity change in the core along with the control rods during unit start-up, shutdown and burn-up change.

REA [RBWMS] system performs the following chemistry related functions to satisfy the chemistry specifications:

- 1) Prepares and stores 4% boric acid solution, and provides the borated water to RCP [RCS] to adjust its boron concentration via RCV [CVCS], for the purpose of controlling the slow reactivity change in the core. It also serves other boron-bearing systems (Emergency Boration System (RBS [EBS]) emergency boric acid tanks, Fuel Pool Cooling and Treatment System (PTR [FPCTS]) and In-containment Refuelling Water Storage Tank (IRWST) by supplying borated water.
- 2) Monitoring of chemical characteristics of the boric acid mixing tank by local sampling, and monitoring of chemical characteristics of boric acid storage tanks by REN [NSS] system, this function is further described in the sub-chapter of sampling and monitoring.

The REA [RBWMS] is composed of three parts: boric acid mixing and distribution subsystem (REA1), boric acid storage and injection subsystem (REA2&3) and demineralised water injection subsystem (REA4&5).

During plant normal operation, in order to monitor the chemical characteristics of boric acid mixing tank and boric acid storage tanks, the REA [RBWMS] is designed with corresponding sample locations.

b) System operation

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The REA [RBWMS] provide the initial filling of borated water and makeup for RCP [RCS] and other boron-bearing systems.

If two trains of the boric acid storage and injection subsystem or demineralised water injection subsystem fail, and the VCT level falls lower than the pre-set limit, the inlet of charging pump will be switched to IRWST.

When the boric acid mixing and distribution subsystem is unavailable, the boric acid storage capacity of REA [RBWMS], RBS [EBS], PTR [FPCTS] and Safety Injection System (RIS [SIS]) can satisfy the volume required by the corresponding system. When the solution in the boric acid storage tank deviates from the chemical specification, the solution will be sent to TEP [CSTS] for retreatment.

21.4.4.3 Coolant Storage and Treatment System

The Coolant Storage and Treatment System (TEP [CSTS]) receives and stores reusable primary coolant during normal operation. It prepares demineralised water and 7000mg/kg boric acid solution via the evaporation process and transfers them to storage tanks for reuse. It reduces radioactivity level in the primary circuit through the degasification process.

The TEP [CSTS] stores the primary effluents discharged by the RCV [CVCS] and collected by the Nuclear Island Vent and Drain System (RPE [VDS]), and then purifies them through the demineraliser (whose main function is removing caesium which is not eliminated by the RCV [CVCS], meanwhile the excess lithium can be also removed) and separates the primary effluents into demineralised water and boric acid of 7000mg/kg.

The TEP [CSTS] degasses the coolant for direct re-injection via the RCV [CVCS] without any change in boron concentration. The specific design basis and system operation of TEP [CSTS] is described in Sub-chapter 10.4.

21.4.4.4 Waste Treatment Process

a) Liquid waste treatment system

Liquid Waste Treatment System (TEU [LWTS]) is designed to monitor, collect, store and treat the unrecyclable radioactive liquid waste produced during unit normal operation. It is used to separate radionuclides from radioactive liquid wastes so that the activity concentration of the treated liquid wastes reaches an appropriate level.

Radioactive liquid wastes are divided into four categories, which are process drains, chemical drains, floor drains and laundry drains. TEU [LWTS] is equipped with demineralisation unit, evaporation unit and filtration unit to treat the radioactive liquid wastes. The process drains are usually treated by

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demineralisation. The chemical drains are usually treated by evaporation. The floor drains and laundry drains are usually treated by the filtration.

The design assumption and system operation of TEU [LWTS] is described in Sub-chapter 23.5.

b) Gaseous waste treatment system

TEG [GWTS] is a gaseous radioactive waste management system which is designed to collect, treat and discharge the gaseous radioactive waste generated from the containers, tanks and other degassing component which containing reactor coolant in the all the normal operation conditions. It continuously flushes the gas space connected to TEG [GWTS] system by nitrogen to avoid hydrogen accumulation and controls the hydrogen/oxygen concentration under the flammability limits. It treats the radioactive noble gases and iodine isotopes by dynamic adsorption of the delay beds to reach an acceptable radiation level before release to the environment.

Hydrogen is added through RCV [CVCS] system to control the oxygen concentration of reactor coolant to allow it to be released to the relevant components containing reactor coolant. TEG [GWTS] connects the gas space of these components together and flushes them with nitrogen continuously to avoid hydrogen accumulated in these components. A recombiner is included in TEG [GWTS] to recombine the released hydrogen with the added oxygen into water. The hydrogen and oxygen concentration are monitored and controlled under 0.3% (volume) and 0.1% (volume), respectively after recombination. Controlling oxygen concentration in the gas phase contributes to the reducing the oxygen dissolved in the reactor coolant, therefore reducing corrosion.

The main composition of the gases released from the reactor coolant is small amount of hydrogen, oxygen, radioactive noble gases, iodine isotopes, carbon-14 and water vapour. The radionuclides identified in TEG [GWTS] are mainly noble gases and iodine isotopes. Most of the radionuclides have relatively short half-life and undergo rapid decay. A dedicated delay unit consisted of three delay beds are configured to providing a period of decay time for the radionuclides before discharge therefore contributing to the minimisation of radioactivity that is discharged into the environment.

The design assumption and system operation of TEG [GWTS] is described in Sub-chapter 23.6.

21.4.5 Commissioning, Operation and Optimisation

21.4.5.1 Commissioning

The commissioning process is important for establishing stable oxide films in the plant and this may subsequently reduce general corrosion rates and plant radiation

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fields. Industry operating experience will be taken into account in developing the chemistry commissioning regime for UK HPR1000.

Materials used in the primary circuit are specified and selected to minimise primary circuit activity. The following phases have been improved for UK HPR1000:

- a) The chemistry regime during HFT are optimised in order to passivate the surfaces of the SGs permitting reduction of the nickel source term;
- b) Water quality & control for commissioning phase;
- c) A compatibility process is developed for consumables applied on SSCs in stages of manufacturing, packaging, transportation, installation on the construction site and commissioning to avoid contamination on clean-up surfaces of SSCs and prevent corrosion before operation according to requirement in RCC-M F6400.

For a further demonstrate the strategy and objective for the commissioning will be developed. More detailed process of commissioning will be developed during the nuclear site licensing phase.

21.4.5.2 Operation Chemistry

Operation chemistry is developed taking into consideration experience from PWRs of CGN. The normal operating conditions of the RCP [RCS] contain refuelling, start-up, power operation and shutdown.

a) Refuelling

In this condition, the RCP [RCS] is filled with coolant and connected with the reactor cavity and SFP. The chemistry parameters are the same as the reactor cavity and SFP. During this “open state”, the plant is highly vulnerable to impurity ingress, operators need to focus on monitoring the chemistry parameters, with significant attention to both coolant purity and boron concentration during this time.

b) Start-up

During this condition, chemistry operations are as follows:

- 1) The boron concentration in RCP [RCS] is more than or equal to the boron concentration required for shutdown condition;
- 2) Monitoring the chemistry parameters in RCP [RCS].(e.g. different requirements of sulphate, chloride and fluoride concentration at different temperatures);
- 3) The chemistry characteristics establishment phase begins. The chemical reagents are injected during this condition. For example, hydrazine is used to scavenge oxygen and lithium hydroxide is used to control pH value.

c) Power operation

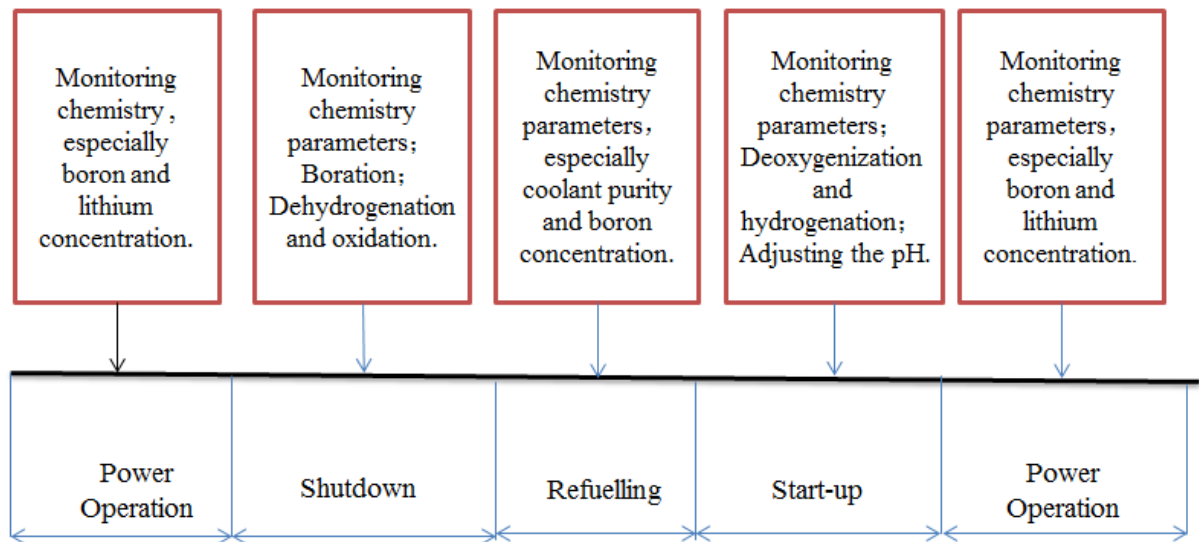
In this condition, operators monitor the chemistry parameters. The chemistry parameters are relatively stable except for boron and lithium concentration. The concentration of lithium is adjusted according to boron concentration to ensure the appropriate operational pH value.

d) Shutdown

In this condition, chemistry operations are as follows:

- 1) Boration to prevent the core returning to criticality;
- 2) Monitoring the chemistry parameters in RCP [RCS];
- 3) Monitoring the RCP [RCS] radioactivity to meet personnel protection during the following conditions: prior to PZR bubble collapse, the last reactor coolant pump is stopped and the reactor coolant system is opened;
- 4) When RCP [RCS] temperature is about 80°C in NS/RIS-RHR mode, hydrogen peroxide is injected to RCP [RCS] system. Before injection of hydrogen peroxide, the hydrogen is limited at a safe concentration by nitrogen flushing.

These chemistry operations are schematically shown in F-21.4-3



F-21.4-3 Chemical Operations for Different Operating Conditions

21.4.5.3 Optimisation from Chemistry Control

The optimised primary water chemistry for UK HPR1000 needs to achieve a balance of the benefits and detriments for all of the chemicals to provide the good integrity, minimised corrosion and minimised the radiation fields.

The primary water chemistry is controlled to minimise the production, transfer, build

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up and deposition on the core surface for minimising the primary circuit activity. The optimisation performed on chemistry control and material selection for decreasing the accumulative contamination in the circuits will have a positive impact on decommissioning operations.

UK HPR1000 has been developed from CPR1000 incorporating over 30 years' operating experience. In addition to its own operating experience, several new design features have been incorporated into UK HPR1000 design including EBA application for pH strategy, hydrogen adding station, and zinc injection is under the study as a good practice.

a) EBA

There are a number of benefits for EBA application over boric acid including:

- 1) It allows a higher pH to be used throughout the cycle and decreases the boron concentration at the beginning of the cycle;
- 2) It allows a constant pH to be used throughout the cycle (once the xenon equilibrium has been achieved after the first few days) avoiding any effects induced by changing the pH;
- 3) The maximum lithium concentrations needed to maintain the high pH value at the start of cycle are lower, reducing the potential for corrosion of the zirconium alloy fuel cladding;
- 4) The volume of borated water that the RBS [EBS] needs to inject in the event of Design Basis Condition (DBC) 2-4 and Design Extension Condition A (DEC-A) conditions is less compared with natural boric acid, avoiding the PZR overflowing.

b) pH optimisation

The high constant pH is beneficial for the primary water chemistry condition, resulting in reduced corrosion and deposition. The use of EBA is necessary for UK HPR1000 to reach a $\text{pH}_{300^\circ\text{C}}$ of 7.2 while complying with the limit value of lithium concentration { }.

The pH management has been selected in order to:

- 1) Minimise the general corrosion of materials;
- 2) Limit the corrosion product transfer between the ex-core zones and core regions;
- 3) Limit deposition on the core surface.

There are two other additional requirements for fuel performance which the pH programme will comply with:

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- 1) Limit lithium concentration to prevent cladding corrosion;
- 2) Limit the boron concentration to prevent borate deposition on the fuel cladding and the subsequent neutron flux distortion due to the neutron-absorbing characteristics of boron.

c) Optimised hydrogen management at full power

Through the use of Alloy 690TT, UK HPR1000 higher operating concentration of hydrogen is not necessary to suppress the PWSCC of the components in the primary circuit.

The optimisation of hydrogen concentration in the primary water is evaluated through the analysis of the following physiochemical phenomena:

- 1) Water radiolysis (control of the concentration of oxidation products);
- 2) Corrosion cracking risk of materials in the primary circuit;
- 3) Plant contamination (transport and deposition of corrosion products).

The optimum hydrogen concentration is still on going and focusing on the following areas:

- 1) Optimised Hydrogen Management at shutdown;
- 2) Optimised Hydrogen Management at start up.

The operating range, upper and lower limits will be further justified.

d) Optimised zinc injection

The justification for the incorporation of zinc addition into UK HPR1000 design is based on RGP, particularly at similar PWR plants which have injected zinc from the beginning of plant life. The addition of zinc minimises the risk of PWSCC in susceptible materials, and reduces on-going corrosion in the primary circuit. Lower corrosion release, in turn, reduces the risk of CIPS (Crud Induced Power Shifts), and also minimises plant dose rates.

It is noted that the elevated levels of zinc within the primary circuit may cause zinc oxide or zinc silicate to deposit within CRUD on the core and increase fuel cladding corrosion due to the solubility limit of zinc. Thus, the concentration of zinc is controlled to maintain the benefits of the dose reduction from zinc, while limiting the potential for fuel cladding corrosion.

For the reason that zinc injection has not been applied in the reference plant of HPR1000 (FCG3), whether zinc injection is applied in UK HPR1000 will be determined according to the more study and research, so the concentration of zinc will be confirmed later.

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The selection of the zinc injection programme is based on experimental and theoretical data as well as plant operating experience. The advantages and drawbacks for the material integrity, radiation field, fuel CRUD management and plant availability will be analysed in order to determine the optimal conditions of injection. In order to justify the feasibility of zinc injection in UK HPR1000, a topic report on zinc injection will give more detailed information.

e) Purification optimisation

In order to maintain low levels of impurities in the primary circuit and auxiliary circuits such as the TEP [CSTS] and REA [RBWMS] boric acid storage tanks, UK HPR1000 coolant will be purified at optimum conditions through the use of demineralisers and filters.

21.4.5.4 Optimisation from Material Selection

In UK HPR1000, reducing the radioactive source terms to ALARP is fundamental when performing the material selection. Surface treatment applied in the design, construction and commissioning plays an important role in reducing radioactive source terms.

a) Limitation on activated elements

For SSCs in UK HPR1000, the activated elements which significantly contribute to the radioactive dose rate are strictly limited. The key reference for this sub-chapter is the '*Report of Radionuclide Selection during Normal Operation*', Reference [13], which presents the methodology and the result of the key radionuclides that need to be taken into account for source term analysis.

1) Cobalt -60

Co-60, which is activated from Cobalt-59, is the dominant source of radioactive dose. The total amount of Cobalt-59 needs to be minimised in the primary circuit to achieve radioactive dose reduction in UK HPR1000.

In UK HPR1000, the use of cobalt base alloy is restricted to very few assemblies in Control Rod Drive Mechanism (CRDM), RVI and Valves. Cobalt-free alloy is preferred to alloy on condition that the performance and reliability of the components can be assured during the design life time.

A report on application of cobalt based alloy in SSCs is preparing and more information is described.

As a residual element in stainless steels and nickel based alloy, the cobalt content is strictly limited in SSCs of UK HPR1000, the requirements which meet or go beyond code minimum requirements are stipulated, for example:

- For the stainless steels used in RVI and MCL, cobalt content is less than

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or equal to 0.06%. For the stainless steels used in CRDM, cobalt content is less than or equal to 0.10% ($\text{Co} \leq 0.20\%$ in RCC-M).

- For SG tubes, cobalt content is less than or equal to 0.016% ($\text{Co} \leq 0.035\%$ in RCC-M).
- For nickel based alloy welding metal of claddings contacting reactor coolant, the cobalt content is less than or equal to 0.050% ($\text{Co} \leq 0.20\%$ in RCC-M). For nickel based alloy buttering and welds, the cobalt content is less than 0.06% ($\text{Co} \leq 0.20\%$ in RCC-M).
- For stainless steel welding metal of metal cladding and welds contacting reactor coolant, the cobalt content is less than or equal to 0.050% ($\text{Co} \leq 0.20\%$ in RCC-M).
- For low alloy steels (both base metal and weld metal) in the core region, the cobalt content is less than or equal to 0.03% according to RCC-M.

2) Other activated elements

- Ag-110m is mainly produced by corrosion and activation of Ag-109 from materials containing silver; silver is only incorporated in RPV seal gasket in UK HPR1000.
- Sb-112 and Sb-124 are the activation products from the materials which contain antimony. Antimony alloy are not used for any component in the primary circuit, and antimony is controlled as a residual element of the materials used in the primary circuit.
- The other radionuclides are generated either from iron-base alloys, or nickel based alloys of the RCS [CVCS] due to their corrosion products release, transportation to the core region and activation. The measures to reduce the total amount of these radionuclides are to minimise the corrosion product, which is described in Sub-chapter 21.4.4.1.

b) Surface treatment

In UK HPR1000, appropriate treatment is conducted to the surface of SSCs in contact with the reactor coolant to improve corrosion resistance. This acts to reduce the generation of corrosion products and also to reduce the deposition of corrosion products and species in the reactor coolant. This in turn results in the radioactive dose rate being minimised. The main measures are listed as below:

- 1) In UK HPR1000, the surface of SSCs in contact with reactor coolant is required to be as smooth as possible ($R_a \leq 6.3 \mu\text{m}$ in most case), considering the feasibility of current processing techniques during manufacturing, a stricter surface roughness requirement can be stipulated. For example, for MCL inner surface, the surface roughness is required to be no more than

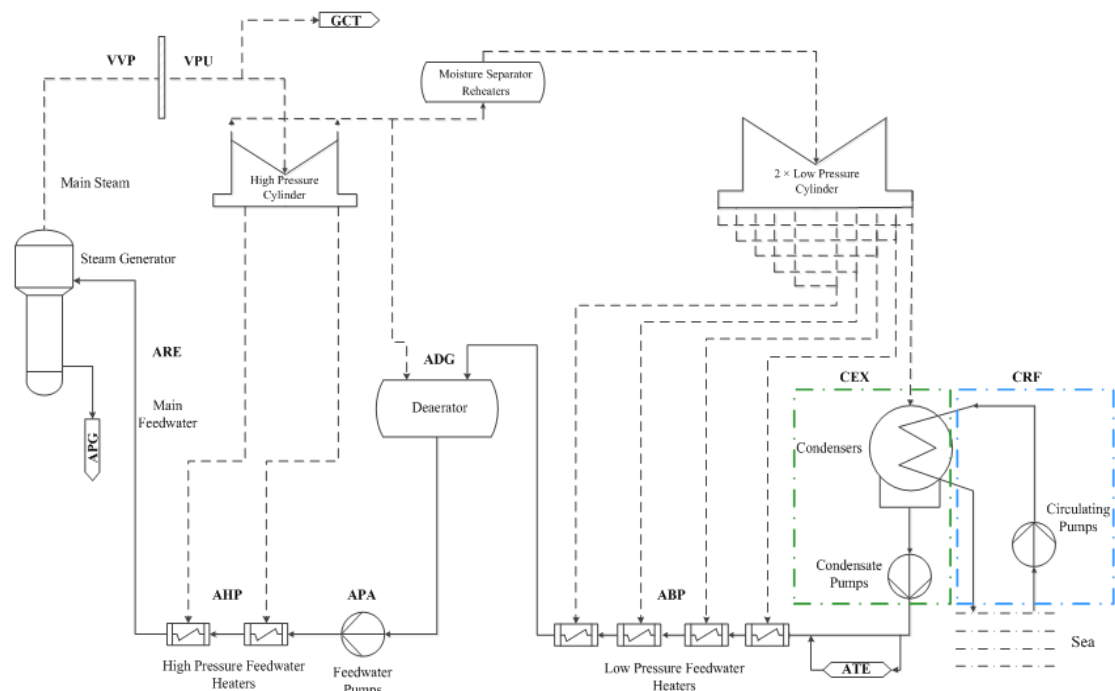
3.2µm.

- 2) Electro-polishing is applied to the inner surface of SG channel head, which has been shown to improve the corrosion resistance and reduce the corrosion product release from the components.
- 3) The wrought stainless steel components are pickled and passivated during manufacturing to facilitate the formation of passive oxide.

21.5 Secondary Water Chemistry and Associated Systems

21.5.1 Secondary Circuit

The secondary coolant is conditioned in order to control the corrosion of secondary circuit materials to maintain the integrity of the secondary interface at the SG tubes and reduce the heat removal degradation of SGs. The main equipment of the secondary circuit covers the SG, Steam Turbine, Moisture Separator Reheater (MSR), condenser, condensate pump, low pressure feedwater reheater, deaerator, feedwater pump and high pressure feedwater reheater. The simplified diagram of secondary circuit is shown as F-21.5-1. The detailed description is present in Chapter 11.



F-21.5-1 Simplified Diagram of Steam and Water Conversion Systems

The basic design parameters of secondary side are shown in the T-21.5-1.

T-21.5-2 Basic Design Parameters of the Secondary Side

Parameter	Value
Design Temperature of Secondary Side	303 °C
Main Feedwater Inlet Temperature	228 °C

21.5.2 Material Selection

For SSCs in the secondary circuit, materials selected are aimed to meet the requirements of maintaining the structural integrity and reducing the risk due to corrosion.

In the secondary circuit, copper or copper alloy is prohibited to be used in SSCs as the released copper ions could lower the pH of secondary water and accelerate the corrosion of the SSCs within the systems.

The most notable aging and degradation mode is Flow-Accelerated Corrosion (FAC) in the secondary circuit. Stainless steels, nickel based alloy, as well as carbon or low alloy steels with the Cr content controlled are selected to reduce FAC.

The main materials used in secondary circuit are listed in the following tables (T-21.5-3, T-21.5-3 and T-21.5-5).

T-21.5-3 Materials of Major Assemblies in SG Secondary Side

Assemblies	Material type	Material grade
Tubesheet	Low alloy steel	ASME SA-508 Gr.3 Cl.2 (Cr: 0.10 wt. %-0.25 wt.%)
Feedwater assemblies	Low alloy steel	ASME SA-335 P22, SA-234 WP22 (Cr: 1.9 wt. %-2.6 wt.%)
Tube support plate	Stainless steel	ASME SA-240 Type 410S
Separator	Stainless steel	ASTM A 511 MT304L ASME SA-240 Type 304L
Main Feedwater Header J-tube Assembly	Nickel based alloy	ASME SB-167 UNS N06690
Tubes	Nickel based alloy	ASME SB-163 UNS N06690

T-21.5-4 Materials for the Major Pipe of Secondary Piping Systems

Name of piping system	Material type
Main steam line	P280GH (Cr: 0.15 wt.%-0.25 wt.%)
Feedwater line	Carbon steel (Cr: 0.2 wt.%-0.3 wt.%)
Condensate system piping	Carbon steel (Cr: 0.2 wt.%-0.3 wt.%)
Drain water piping	Stainless steel

T-21.5-5 Materials of Equipment in Secondary Systems

Equipment	Assemblies	Material type
Feedwater heater	Impingement plate	Stainless steel
	Tubing	Stainless steel
Moisture separator reheater	Tubing	Stainless steel
Condenser	Tubing	Titanium alloy

21.5.3 Chemistry Control

The main objectives of the secondary water chemistry are to maintain the integrity and performance of the SGs and secondary systems through chemistry conditioning, material selection and clean-up design to avoid the following risks:

a) SG tube corrosion and heat transfer degradation

In general, the materials of SG tube (Alloy 690TT) and tube support plate (stainless steel) have very low corrosion rates, but corrosions e.g. Intergranular Attack (IGA)/SCC would occur in the SG if environments with concentrated impurities existed. The impurities together with the corrosion products transported into the SG could also contribute to the generation of deposit that leads to SG tube fouling and Tube Support Plate clogging.

b) General corrosion and Flow-Accelerated Corrosion (FAC) in secondary systems

FAC is a corrosion of carbon steel and low alloyed steels accelerated by increased flow velocity which it is caused by the protective oxide layer on carbon steel and low alloyed steels being dissolved and removed by water. FAC could occur under both single and two-phase flow conditions but does not occur in dry or super heat stream conditions. Under sufficient reducing conditions, the protective oxide layer at the oxide-water interface is dissolved. FAC mitigation is the primary consideration of secondary water chemistry, because it could lead to significant damage of the secondary components and lead to corrosion products entering the SGs.

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To mitigate these risks, the secondary water conditioning of UK HPR1000 is performed with AVT chemistry control to create alkaline conditions in combination with a reduced oxygen environment. The conditions established by AVT chemistry control promote the formation of a stable oxide layer on the steel surface, a key factor in minimising the general oxidation of ferrous materials and subsequent deposition of corrosion products on SG surfaces.

AVT in UK HPR1000 is performed by volatile chemicals being added into the feedwater. Hydrazine is added for scavenging the trace amount of oxygen and ammonia is added for pH control. The AVT allows for no other chemicals to react in the steam generator. It is based entirely on removal of oxygen and the exclusion of other contaminants from the feedwater before entering the SG.

21.5.3.1 Technical Basis

The optimal chemistry conditioning and impurity control contribute to the minimisation of the corrosion, fouling and clogging risk of SG tube and Tube Support Plate. It also prevents the impurity ingress and corrosion products transferring to the secondary side of SG, together with appropriate material selection and clean-up systems.

a) pH

General corrosion and FAC of secondary side materials are sensitive to pH. Optimised pH will reduce corrosion of secondary steam-water circuit and limit corrosion products entering into SG, thus reduce SG fouling, clogging and corrosion.

1) pH impact on generalised corrosion

Carbon steel and low alloyed steel in the secondary systems are sensitive to generalised corrosion. At operating temperature of the secondary side, the pH impact is related with the solubility of the protective oxide layer. Minimal corrosion is found to occur when $\text{pH}_{25^\circ\text{C}}$ is higher than 9.

2) pH impact on FAC

Optimal pH could contribute to a decrease of FAC rates in the secondary circuit. The selection of pH control reagent and localised pH_T at sensitive areas to FAC will be taken into consideration for the justification of optimal pH range.

3) pH impact on SG fouling and clogging

The SG fouling phenomena is caused by corrosion products entering into the SGs and depositing on the surface of SG tubes. The deposit can grow and solidify to form a thermally resistant layer which impacts the heat removal function of SG tubes from the RCP [RCS].

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Corrosion products entering into the SG is also the major cause to Tube Support Plate clogging phenomena. Iron oxides e.g. magnetite particles could precipitate in the tube support crevices and interstices between the SG tubes and Tube Support Plate.

The pH impact on the SG fouling and clogging are rated to its reduction of the general corrosion and FAC rates, thus reduce the corrosion products transport into the SG.

Selection of the optimal pH programme is based on the performance of different materials under various operating conditions in the secondary circuit. It also related to the chemical additives used for pH control. Ammonia is assumed to be used in UK HPR1000, the same as HPR1000 (FCG3) as it's widely used in Chinese PWRs. But amines e.g. ethanolamine and morpholine will also be taken account in UK HPR1000 based on the worldwide OPEX and environmental requirement in UK.

b) Dissolved oxygen

The influences of dissolved oxygen on secondary side water chemistry are:

- 1) Inducing corrosion of metal, or;
- 2) Oxidising other species into detrimental species.

In order to protect SG materials, dissolved oxygen concentration are maintained below control values during both normal operation and commissioning. The bulk of oxygen is removed by the deaerators of the Feedwater Deaerating Tank and Gas Stripper System (ADG [FDTGSS]).

Hydrazine is added to the secondary systems in PWR plants to minimise material corrosion by limiting the residual oxygen content, maintaining a reducing potential and developing a protective film on the metal (magnetite).

1) Oxygen/hydrazine impact on IGA/SCC

The IGA/SCC phenomena are directed related with the electrochemical potential. In oxidising conditions the risk of IGA/SCC increases. Dosing of hydrazine as a reducing reagent is considered necessary to prevent IGA/SCC by decreasing the corrosion potential of metal in the secondary circuit e.g. Alloy 690, stainless steel, carbon steel and low-alloyed steels.

2) Oxygen/hydrazine impact on FAC

Low oxygen together with optimal pH contributes to decrease of FAC rate, but very low oxygen level could lead to accelerated FAC with low pH. The hydrazine could adversely affect FAC if the hydrazine concentration is reduced and the oxygen level falls below the critical level to maintain a stable

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oxide layer.

c) Impurity

Impurities can have a detrimental impact to the secondary system. This impact consists of four groups which are generally considered responsible for corrosion of SG tubes in confined areas:

- 1) Highly concentrated caustic impurities e.g. sodium;
- 2) Sulphate species which could come from resin thermal decomposition;
- 3) Reaction products from the sulphate species in a reducing environment (and associated species like sulphides, sulphates and thiosulphates);
- 4) Highly concentrated salty solutions, coming from condenser leakages e.g. sodium, chloride.

To prevent corrosion e.g. IGA/SCC in secondary circuit, as well as SG fouling and clogging, the following impurities are limited in the secondary circuit:

1) Sodium

Sodium is one of the main factors leading to corrosion of SG tubing alloys in caustic environments, even for Alloy 690TT, whose fissures could occur in very concentrated sodium solutions.

2) Cation conductivity

Cation conductivity measurement is performed to assess the anionic pollutions or organic pollutions. A small amount of chlorides or sulphates could result in cation conductivity variations.

3) Chloride

Although Alloy 690 has good resistance to chloride stress corrosion, SG chloride levels are restricted by the need for high water quality for AVT control. The presence of chloride in the blowdown is normally indicative of a condenser leak, generally detected by an increase in cation conductivity.

The magnitude of such a leak can be determined from blowdown rate and chloride concentration in the makeup water, blowdown water and condenser cooling water.

4) Sulphate

In oxidizing and acid environment, sulphates can attack Alloy 690. But Alloy 690 has a very good resistance to SCC due to sulphates in neutral or mildly alkaline environments. In AVT environment and very low concentration of impurity concentrations, sulphates do not lead to SCC of Alloy 690.

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5) Silica

Silica is a volatile element whose concentration in the steam depends on the pH of the water in the SGs, the silica content and steam pressure.

If the silica content is reduced in the SGs, its concentration in the steam can be minimised and silica deposit are avoided on the turbine blades and valves.

6) Iron, Corrosion Products and Suspended Solids

The oxidizing state of corrosion products is a key factor to determine their aggressiveness. The role of hydrazine is to keep iron species in magnetite form which is not aggressive to tube alloys.

Elevated ionic impurities in the presences of excess sludge piles or crevices have demonstrated the formation of environments conducive to denting, resulting in a localised stress condition within the pipework.

21.5.3.2 Chemistry Control Method

The chemistry regime for UK HPR1000 is defined based on the reference plant of HPR1000 (FCG3), which has been developed using OPEX from the similar PWRs of CGN.

a) pH control

Alkaline reagent e.g. ammonia is added into secondary circuit to maintain the pH_T reaching the target value during various modes of operation. The following measures are performed for pH control of secondary circuit:

- 1) Alkaline reagent is dosed into the feedwater cycle via the dosing lines of Chemical Reagents Injection System (SIR [CIS]) during plant power operation;
- 2) Alkaline reagent is dosed into the Emergency Feedwater System (ASG [EFWS]) via the dosing lines of SIR [CIS] during plant start-up and the SG wet lay-up;
- 3) Makeup water for the secondary circuit is supplied with ammoniated demineralised water via the CI Demineralised Water Distribution System (SER DWDS [CI]), the pH of secondary circuit makeup water is about 9.

b) Hydrazine dosing

Hydrazine is added into the secondary circuit to maintain the dissolved oxygen content within the limits during various modes of operation. The following measures are performed for hydrazine dosing to secondary circuit:

- 1) Hydrazine is dosed into the feedwater cycle via the dosing lines of SIR [CIS] during plant power operation;

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2) Hydrazine is dosed into the ASG [EFWS] via the dosing lines of SIR [CIS] during plant start-up and the SG wet lay-up.

c) Impurity control

The limitation of impurities in the secondary coolant includes the following measures:

- 1) Makeup water control: the water quality of makeup water is ensured by the SED [DWDS (NI)] system treatment, which are described in Sub-chapter 21.6.4;
- 2) Clean-up systems: the filters and demineralisers are used to remove the impurities, and the purification units are included in the systems of the team Generator Blowdown System (APG [SGBS]) and the Condensate Polishing System (ATE [CPS]), which are described in Sub-chapter 21.5.4.

21.5.4 Associated Systems

21.5.4.1 Steam Generator Blowdown System

a) System functions and configurations related to chemistry

The APG [SGBS] system performs the following chemistry related functions to satisfy the chemistry specifications:

- 1) Continuous collecting and treating the blowdown of SG at a predetermined flow to maintain the SG secondary water chemistry regime within the required limit;
- 2) Recovery and treatment of water sample taken from the SG secondary side.

b) System description

During plant normal operation, the APG [SGBS] is designed to satisfy the purification requirement by the following measures:

1) Filters

The APG [SGBS] filters are used for mechanical filtration of the blowdown water, to remove suspended particles and to prevent the downstream demineralisers from being plugged.

The resin trap filters are installed downstream of the demineralisers to prevent the resins from getting into the secondary circuit.

2) Demineralisers

The APG [SGBS] has two demineralisation trains in parallel. Each one is composed of a cationic demineraliser, an anionic demineraliser and a resin trap filter. The blowdown water is recycled and reused after being treated. By

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removing ions in the blowdown water, the demineraliser ensures that the water chemistry regime satisfies the requirements for recycling and reuse.

Detailed information of the system is presented in Chapter 10.

21.5.4.2 Condensate Polishing System

a) System functions and configurations related to chemistry

ATE [CPS] is designed to remove traces of silicon, copper, iron and dissolved salts from the condensate to ensure the feedwater and steam qualities meet the requirements. It also protects the secondary systems from the contamination if there is a condenser tube leakage.

b) System description

The ATE [CPS] consists of a full flow bypass design for operation flexibility. The polishing units of ATE [CPS] consist of five multiple cation polishing units, five multiple mixed bed polishing units and three 50% booster pumps.

ATE [CPS] is put into operation during start-up of the plant. Condensate enters into the ATE [CPS] via the condensate header and loops through the cation polishing units and the mixed bed polishing units so as to allow removal of the suspended solids and ionic impurities. The purified condensate is pumped back to the condensate header by the booster pumps.

During the plant power operation, the ATE [CPS] is in a standby state. In case of condenser leakage the ATE [CPS] is put into operation to remove the impurities from the condensate and give the operator more time and flexibility of operation before shutdown.

More details of the ATE [CPS] are present in Sub-chapter 11.5.7.

21.5.4.3 Chemical Reagents Injection System

a) System functions and configurations related to chemistry

The function of the SIR [CIS] is to provide a chemical means of controlling the water chemistry of the feed cycle in order to minimise corrosion and deposition of solids in the steam generators. In addition a separate chemical injection facility provides corrosion inhibition for the closed loop cooling facilities.

The consumer systems of SIR [CIS] are:

- 1) ADG [FDTGSS];
- 2) Condensate Extraction System (CEX [CES]);
- 3) ASG [EFWS];
- 4) Closed loop cooling water systems.

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b) System description

The system is designed to inject three types of chemical into the water systems.

- 1) Alkaline reagent e.g. ammonia and hydrazine are injected into the main feed cycle at the condenser discharge, deaerator downcomers, deaerator recirculation line and the NI feedwater dosing points.
- 2) Tri-Sodium Phosphate (TSP) is introduced into the closed loop cooling system. The system consists of two sets of dosing devices located within the turbine hall with stainless steel pipework running from the dosing devices to the relevant dosing points.

During plant normal operations, chemicals are normally dosed continuously to make up losses due to steam generator blow down and condenser vacuum. The dosing rate is varied as indicated by the SIT [FCSS].

21.5.5 Operation and Optimisation

21.5.5.1 Operation Chemistry

The normal operating conditions of the secondary circuit contain start-up, power operation and shutdown. The chemistry operation is from the reference plant which has been developed from the experience and feedback from PWRs of CGN.

a) Start-up

During plant start-up, the dissolved oxygen is controlled to minimise the corrosion of secondary circuit and keep a reducing medium in the SG. The oxygen concentration is limited within 100µg/kg when the temperature is higher than 120°C, which is generally considered as a temperature threshold beyond which corrosion issues can appear in some environments, especially oxygenated media. Removal of oxygen depends on the deaerators of the ADG [FDTGSS] and addition of hydrazine.

The impurity level of secondary circuit during plant start-up needs to be controlled to minimise the inventory of corrosion products in the feedwater, which could be transported to the SG. The parameters of sodium, cation conductivity and suspended solids are monitored in the feedwater as indicators of impurity ingress to the SG. The APG [SGBS] is operated with the maximum blowdown rate to reach the impurity level of power operation in the SGs.

The ATE [CPS] is put on-line during plant start-up to remove the impurities of corrosion products, dissolved solids and other impurities from the condensate by condensate polishers and ensure the feedwater quality during start-up.

b) Power operation

The parameters with their operating ranges and safety limits during plant power

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operation are those currently considered appropriate to protect the SGs and balance of plant. These parameters can be classified as either control parameters or diagnostic parameters:

- 1) Control parameters are those which have a demonstrated relationship to SG and secondary systems degradation. Plant operations have procedures in place to maintain these parameters within specified values.
- 2) Diagnostic parameters are important for monitoring the programme effectiveness, identifying programmatic problems, or assisting in problem diagnosis.

Secondary water chemistry specifications of the control and diagnostic parameters are provided for feedwater, SG blowdown and condensate. The parameters with their operating limits, safety limits analysis frequency and considerations for secondary water chemistry of UK HPR1000 during power operation are listed in T-21.5-6.

c) Shutdown

1) Hot shutdown

During hot shutdown, the feedwater dissolved oxygen concentration is also limited within 100µg/kg by hydrazine addition. The hydrazine limit is the same as that used during power operation.

Due to the thermal exchange between the primary and secondary coolant being reduced, the water chemistry environment in the SGs is less aggressive during hot shutdown than it is during power operation, however, the reduction of thermal exchange could also lead to the hide-out return phenomena, leading to pollutants concentrated in SG crevices being released, resulting in an increase of impurities e.g. sodium, cation conductivity, etc. The impurities have to be limited in order to maintain an optimal operating condition.

2) SG Layup

The SG layup during shutdown is to keep the SGs in a clean state and allow start-up in good condition. Two types of SG layup including wet layup and dry layup could be performed depending on the shutdown operation.

– Wet layup

The SG wet layup with chemical treated water is desirable to minimise corrosion and oxidation during plant shutdown and subsequent start-up and power operation. Protection is provided by ammonia for pH control and hydrazine to maintain a protective oxidising film and a reducing environment.

The specification of SG wet layup depends on the duration. For a short layup less than a week, the SG has not to be drained and filled with the secondary medium; the water quality required is the same as hot shutdown. For layup of more than one week, additional ammonia and hydrazine are injected into the SGs to limit the risks of corrosion.

– Dry layup

Dry layup would only be implemented when wet layup is not possible. The relative humidity is controlled and limited to limit the condensation of impurities, especially chlorides, which could be present in the air.

T-21.5-6 Secondary Water Chemistry Specifications during Power Operation

Control Parameter	Location	Unit	Operating Range	Analysis Frequency
pH (25°C)	Feedwater	/	9.5-10	On-line
Ammonia	Feedwater	mg/kg	As needed to reach pH value	Occasional
Hydrazine	Feedwater	µg/kg	30-200	On-line
Oxygen	Feedwater	µg/kg	<3	On-line
	Condensate	µg/kg	<10	On-line
Cation Conductivity	SG Blowdown	µS/cm	<1	On-line
Sodium	SG Blowdown	µg/kg	<20	On-line
Diagnostic Parameter	Location	Consideration		Analysis Frequency
Total Iron	Feedwater	Indicator of SG fouling and clogging		Occasional
Chloride	SG Blowdown	Indicator of SG corrosion		Occasional
Sulphate	SG Blowdown	Indicator of SG corrosion		Occasional
Silica	SG Blowdown	Indicator of crevice chemistry and steam quality		Occasional
Suspended Solids	SG Blowdown	Indicator of SG fouling and clogging		Occasional
Cation Conductivity	Condensate	Indicator of condenser leakage		On-line
Sodium	Condensate	Indicator of condenser leakage		On-line

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21.5.5.2 Optimisation from Chemistry Control

The major function of secondary circuit chemistry is controlling the corrosion of materials exposed to the secondary water, including structural components. As discussed in Sub-chapter 21.5.3, FAC mitigation is the primary consideration of secondary water chemistry because its detriment to secondary components. Therefore, optimum chemical specifications are required to be established.

Optimisation of the pH plays an important role in the FAC reduction of carbon steel and/or low alloy steel of the secondary circuit. The pH control strategy in UK HPR1000 secondary circuits is developed from the reference plant of HPR1000 (FCG3) incorporating over 30 years' operating experience of CPR1000. Ammonia is assumed to be used as alkaline reagent and the target value of $\text{pH}_{25^{\circ}\text{C}}$ in feedwater has been raised to above 9.8, experience has shown that this brings significant benefits to the reduction of iron trend and sludge in SG.

Meanwhile, according to worldwide RGP and OPEX, amines e.g. ethanolamine and morpholine will also be taken account to archive the balance between the efficiency of corrosion prevention and the impact on nitrogen waste discharge to the environment. The secondary system design of UK HPR1000 allows it to be operated using different alkaline reagents.

A topic report on the secondary water alkaline reagent will give more detailed information on the demonstration, including the environmental impacts.

21.6 Auxiliary Water Chemistry and Associated Systems

21.6.1 Auxiliary Circuits

Auxiliary circuits in this chapter are focused on the controlling of water quality for SFP water, Nuclear Island (NI) closed cooling water and makeup water, in relation to the concerning of the chloride pitting corrosion.

21.6.2 Material Selection

The material selected for the SFP racks which contain fixed sources of boron as a neutron absorber is an aluminium-boron carbide composite. It is fixed outside the wall of the storage cell with stainless steel cover plate. BORAL is not used in the SFP of UK HPR1000.

There is neutron absorber material fixed by cover plates between each storage cell. The criticality safety calculation shows that effective neutron multiplication factor, i.e. k factor, of SFP is less than 0.95 in case of absence of soluble boron in water, and so SFP has adequate criticality safety margins. Actually there is soluble boron in SFP to maintain a further safety margins.

Liner for SFP is made of stainless steel, and the major pipes of auxiliary piping systems for RRI [CCWS]/DEL [SCWS]/DER [OCWS] are made of carbon steel.

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21.6.3 Chemistry Control

a) Control for SFP

The SFP water chemistry is controlled to reduce corrosion of the spent fuel assemblies and the structural components through filtration and the surface skimming to maintain visibility in the SFP.

The concentration of boric acid in SFP is 1300mg/kg -1400mg/kg (35% isotopic abundance in B-10), the crystallisation temperature of boric acid is less than 0°C.

b) Control for piping corrosion

Compared with the other corrosion inhibitors, tri-sodium phosphate is a non-volatile base that maintains a sufficient high pH to minimise the corrosion of the carbon steels. In addition, the phosphate also enables the formation of oxides with protective properties.

For the closed cooling circuits even in contact with air, the tri-sodium phosphate constitutes a more efficient corrosion inhibitor than volatile bases whose efficiency decreases due to their volatility leading to a lower pH with more carbonation risk.

In addition, TSP has been used in many PWRs including CPR1000. Considering the different material makeup of the components, a pH value is more than 10 (treated with TSP) to prevent corrosion for UK HPR1000.

21.6.4 Associated Systems

21.6.4.1 Fuel Pool Cooling and Treatment System Water Chemistry

a) System functions and configurations related to chemistry

The Fuel Pool Cooling and Treatment System (PTR [FPCTS]) supply the sub-critical margin and remove the decay heat for the fuel assemblies stored in the SFP. Furthermore, the PTR [FPCTS] provides the water purification of the boric acid water in the fuel building pools (including SFP, transfer compartment and cask loading pit), the reactor pools (including Reactor Cavity and Internals Storage Compartment), the IRWST and the In-Vessel Retention (IVR) tank. Skimming of the reactor building pools and the fuel building pools is also performed by PTR [FPCTS].

This chemistry related functions are required to be performed during normal operation:

- 1) Purification of the SFP and reactor pools: The purification unit performs the purify functions for the SFP and reactor pools, which contains two filters, a demineraliser and a resin trap filter. Two purification pumps provide the operating head needed for circulation. The control valves are used to adjust

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the flow rate of purification.

- 2) Purification of the IRWST and IVR tank: The PTR [FPCTS] provides the relative interfaces for purification, using the PTR [FPCTS] purification unit.
- 3) Skimming of the SFP and reactor pools: each skimming loop contains a skimming pump. The SFP skimming loop contains a filter downstream of the pump.

The purify function of the PTR [FPCTS] is to remove impurities and dissolved radioactive substances from the water to maintain the chemical concentration so as to minimise corrosion of stored fuel assemblies and of pool structure and to maintain the visibility of the water. The purification capacity meets the requirement that the SFP or reactor pools are purified a minimum of once every 24 hours.

The PTR [FPCTS] purification unit has one mixed-bed demineraliser to satisfy the requirements, which followed by a resin trap for eliminating fragments of resin. Upstream of the demineraliser, two trains of mechanical filters with 100% capacity each are used to remove suspended particles.

b) System operation

The purification loop of the SFP is operating continuously with a flow rate of 90m³/h. Sampling of the SFP is undertaken by opening the sampling valve downstream of the purification unit. The operating of the SFP skimming loop is continuously operated with flow rate of approximately 5m³/h.

The water temperature in the SFP is maintained at 15°C - 50°C by one train of PTR [FPCTS] operation during the normal power operation and by two trains of PTR [FPCTS] system operation during the reactor refuelling stage. The specific temperature of SFP is related to the cooling water temperature of the Component Cooling Water System (RRI [CCWS]) and the thermal load in SFP.

During normal operation, the range of temperature for RRI [CCWS] system supplies is at 15°C-38°C. In actual operation, the water temperature that RRI [CCWS] system supplies is expected to be stable at about 25°C. This is achieved by adjusting the flow control valve and the heat exchanger bypass control valve in RRI [CCWS] system.

During fuel handling, the skimming loop in the reactor pools is usually in operating to provide good visibility. The reactor pool skimming loop can be operated only in the purification loop running. The failure of purification can be monitored through the alarms generated in main control room, which including the pressure of pump inlet is low, the flow rate of the purification is too low or high, or the temperature downstream the purification pump is high.

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Detailed information of the system description is presented in Chapter 10.

21.6.4.2 NI Closed Cooling Water System

a) Component cooling water system

The Component Cooling Water System (RRI [CCWS]) provides cooling water for the users of NI systems (including nuclear auxiliary systems and safety-classified systems) under normal operating conditions and accident conditions.

The RRI [CCWS] system satisfies the chemistry specifications through the following functions:

- 1) The NI Chemical Reagents Distribution System (SIH [CDS]) provides Na_3PO_4 for the RRI [CCWS] to guarantee that the water quality parameter of pH value is within the predetermined limit;
- 2) Monitoring of chemical characteristics of the RRI [CCWS] by local sampling.

More details about component cooling water are described in Sub-chapter 10.4.

b) Chilled water systems

Chilled water systems contain the Safety Chilled Water System (DEL [SCWS]) and Operational Chilled Water System (DER [OCWS]). The quality of Water within these systems is conditioned to meet requirements of anti-corrosion by chemical dosing of the NI Chemical Reagents Distribution System (SIH [CDS]).

More information about the chilled water is presented in Sub-chapter 10.6.

21.6.4.3 Demineralised Water and Gas Supply

a) Demineralised water distribution system

Demineralised water distribution systems contain NI Demineralised Water Distribution System (SED [DWDS (NI)]) and CI Demineralised Water Distribution System (SER [DWDS (CI)]).

SED [DWDS (NI)] has a set of neutral demineralised water storage and distribution tanks. These are used to receive and storage demineralised water from the demineralised water production system.

SER [DWDS (CI)] has a set of alkaline demineralised water storage and distribution tanks. Dosing of the ammonia solution into the demineralised water from the demineralised water production system occurs before entering the storage tanks. More information of water quality is shown in

T-21.6-1.

T-21.6-1 Demineralised Water Quality

Parameter	Unit	Expected Value	Limit Value
Na	µg/kg	<2	<5
Total silica	µg SiO ₂ /kg	<50	-
Chloride + Fluoride	µg/kg	-	<100
Suspended Solids	µg/kg	<50	<100

b) Hydrogen

The hydrogen plant provides hydrogen used in NI under any operational conditions, The Hydrogen Distribution System (SGH [HDS]) supplies hydrogen to the RCV [CVCS].

c) Nitrogen

The function of the Nitrogen Gas Distribution System (SGN [NGDS]) is to provide nitrogen for related systems and equipment of the NI, including RCV [CVCS], TEG [GWTS] and RPE [VDS].

More information about the water and gas is presented in Sub-chapter 10.5.

21.7 Accident Chemistry and Associated Systems

21.7.1 Fault and Accident Scenarios

Design Basis Conditions (DBC), Probabilistic Safety Assessment (PSA) and Design Extension Conditions (DEC) events are analysed to assess the safety level of reactor. This assessment will include suitable and sufficient consideration of accident chemistry and the potential consequences, including fission product control, combustible gases control, and core melt and corium retention.

During the progression of an accident at a nuclear power plant, the behaviour of the chemical components contributes to the radiological and non-radiological consequences of the accident.

A DBC or DEC-A accident at a nuclear power plant could result in radiological release to the environment and severe accident could result in the coolant temperatures being excessively high resulting in melted fuel assemblies. At a nuclear power plant, a conventional accident could result in non-radiological consequences due to explosive mixtures of flammable gases.

For DBC, chemical aspects related to radiological consequences and combustible gas are considered. For DEC, chemical aspects related to fission products control,

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combustible gas, core melt and corium retention are considered.

The key phenomena of accident chemistry for radiological and non-radiological consequences, and the main SSCs involved are identified.

The accident chemistry involves Systems, Structures and Components which are listed in T-21.7-1 with the relative chapters in PCSR.

T-21.7-1 Systems, Structures and components for Accident Chemistry

Scope	SSCs	PCSR Chapter
RCP [RCS]	Primary pressurised water boundary	6
Primary coolant Auxiliary Systems and Components	IRWST	10
Safety Systems including Flammable Gases Mitigation	Containment Heat Removal System (EHR [CHRS])	7
	RIS [SIS]	7
	Containment Filtration and Exhaust System (EUF [CFES])	7
	Containment Combustible Gas Control System (EUH [CCGCS])	7

The methodology of accident chemistry is described in a dedicated document, Reference [14]. The assessments of DBC and DEC events related to accident chemistry are incorporated in Chapter 12, Chapter 13 and relevant accident analysis documents.

A report on accident source terms analysis and containment combustible gas control system will give more information.

21.7.2 Associated Systems

21.7.2.1 Containment Combustible Gas Control System

a) System functions and configurations related to chemistry

The Containment Combustible Gas Control System (EUH [CCGCS]) performs the hydrogen removal and hydrogen concentration monitoring functions.

The EUH [CCGCS] performs the following chemistry related post-accident functions to satisfy the chemistry specifications:

- 1) Hydrogen removal under design basis accident conditions;

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- 2) Hydrogen removal under severe accident conditions;
- 3) Monitoring of hydrogen concentration in containment.

To fulfil the functions, the EUH [CCGCS] is designed with the following configuration:

- 1) The Passive Autocatalytic Recombiners (PARs) is used to remove the hydrogen by combining the hydrogen and oxygen into water in ambient temperature conditions;
- 2) The hydrogen monitoring system is put into operation manually in the case of accidents.

b) Design basis

In the standard conditions (0.15MPa (abs), 50°C and hydrogen volume concentration of 4%), the hydrogen removal rates of the large recombiners and the small ones are about 5.4 kg/h and 2.4kg/h respectively.

The following main equipment is designed to fulfil the performance of the purification functions:

1) Passive autocatalytic recombiners

The PARs is used to remove the hydrogen by combining the hydrogen and oxygen into water in the ambient temperature conditions. There are 29 PARs in the recombiner sub-system, including 18 large ones and 11 small ones.

During DBCs (particularly the Loss of Coolant Accident (LOCA)), Two large PARs are provided due to the single failure criterion and redundancy requirement are considered in design.

In severe accident conditions, 27 PARs are used to provide the hydrogen elimination function. In the 27 PARs, there are 16 large ones and 11 small ones. The single failure criterion and redundancy requirement are not considered.

2) Hydrogen sensor

The hydrogen monitoring system contains two redundant trains, each fitted with local hydrogen sensor. Each train comprises 5 hydrogen sensors installed in the containment dome, annulus space and Instrumentation and Control (I&C) processing cabinet unit.

21.7.2.2 Safety Injection System

a) System functions and configurations related to chemistry

The RIS [SIS] contributes to the control of reactivity and maintains water

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inventory compensation by injecting borated water into the RCP [RCS].

Under accident conditions of Loss of Coolant Accident (LOCA), the RIS [SIS] is used to passively adjust the pH value through adjustment basket. The adjustment basket containing granulated TSP is placed in reactor building and in the water flow path to the IRWST after the occurrence of LOCA.

In order to ensure that the boron concentration meets the safety requirement, the boron concentration of IRWST is controlled at 1300 mg/kg - 1400 mg/kg by REA [RBWMS].

b) System operation

When the reactor is in power operation, hot shutdown and hot standby, the safety injection lines are filled with borated water. The safety injection pumps, including Low Head Safety Injection (LHSI) pump and Medium Head Safety Injection (MHSI) pump are in standby state. They can start to perform the safety injection functions (automatically or manually) at any time after receiving the safety injection signal.

To prevent inadvertent dilution, the RRI [CCWS] is separated from the residual heat removal heat exchanger (shell side) of the RIS [SIS] and the mechanical seal cooling of the LHSI pump while the cooling circuit of the pump motor is in operation.

Detailed information of the system is presented in Chapter 7.

21.7.2.3 Containment Filtration and Exhaust System

The EUF [CFES] is provided to perform active pressure relief to lower the pressure inside the containment and maintain the integrity of the containment only during a severe accident (in case of active function failure of the EHR [CHRS]). The system is mainly composed of one set of a filtration assembly, two containment isolation valves, together with other valves and pipelines.

The chemistry related function is required to be performed after accidents. The filtration assembly can effectively detain radioactive aerosol and iodine in the exhaust gas. The filtration assembly is filled with special chemicals, which is specifically designed by Supplier of the EUF [CFES], to retain the radioactive aerosol and iodine in the exhaust gas during the discharge of the system. The aerosol and iodine retention rates of the filtration are required to be more than 99.9%.

The EUF [CFES] is designed to reduce the radioactivity released to the environment to the minimum. Therefore, one set of radiation monitor equipment is arranged to monitor the radiation before the radioactive substances are released to the stack.

Detailed information of EUF [CFES] can be founded in Chapter 7.

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21.7.2.4 Containment Heat Removal System

The EHR [CHRS] performs the following chemistry related functions to satisfy the chemistry specifications:

- a) During refuelling period, the reactor pit flooding tank will supply boron water to the IRWST;
- b) The reactor pit flooding tank can be purified by the PTR [FPCTS];
- c) Obtain liquid samples in the containment from IRWST after accidents;
- d) Obtain liquid samples from the reactor pit flooding tank through PTR [FPCTS].

The supplied boron water to the IRWST and purification of the reactor pit flooding tank are required to be performed during normal operation, and the IRWST sampling function is required to be performed after accidents. To fulfil the function of sampling for the IRWST and the reactor pit flooding tank, the EHR [CHRS] is designed to connect with REN [NSS] and PTR [FPCTS].

Detailed information of EHR [CHRS] can be founded in Chapter 7.

21.8 Sampling and Monitoring

21.8.1 Sampling Principle

21.8.1.1 Normal Operation Sampling

In order to maintain the primary water chemistry regime, the following chemistry parameters will be monitored during the normal operation. According to sampling characteristic from the different locations, the samples can be sampled and monitored though the on-line meters and laboratory located in the nuclear auxiliary building or the site laboratory.

- a) Primary water chemistry parameters

Primary water chemistry parameters include pH, boron, dissolved hydrogen, dissolved oxygen, lithium, nickel (during start-up), silica, calcium, aluminium, magnesium, sulphates, chlorides, fluorides, and sodium.

- b) Secondary water chemistry parameters

Secondary water chemistry parameters include pH, conductivity, cation conductivity, suspended solids, hydrazine, ammonia, oxygen, iron, silica, sulphates, chlorides, fluorides and sodium.

- c) Auxiliary water chemistry parameters

Auxiliary water chemistry parameters include pH, conductivity, suspended solids, boron, iron, silica, phosphates, sulphates, chlorides, fluorides, calcium, aluminium, magnesium and sodium.

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21.8.1.2 Accident and Post-accident Sampling

In accident conditions, the normal operation sampling lines for the primary coolant and secondary coolant can be used if it is needed if sampling can be implemented due to the radiological conditions of the sampling room.

The post-accident sampling requirement is from the fault studies and accident analysis, including gaseous samples from containment atmosphere and liquid samples from IRWST for the purpose of confirming the sample activity.

21.8.2 Chemistry Sampling and Monitoring

21.8.2.1 Nuclear Sampling System

The Nuclear Sampling System (REN [NSS]) mainly enables centralised analysis and determination of the chemical and radio-chemical characteristics of samples taken from Reactor Coolant System (RCP [RCS]), the Steam Generator (SG), nuclear auxiliary systems and liquid waste and gaseous waste treatment system.

a) Primary sampling system

During normal operation, the REN [NSS] collects liquid and gaseous samples from the following locations:

- 1) RCP [RCS];
- 2) RCV [CVCS];
- 3) Safety Injection System (RIS [SIS]);
- 4) Other primary auxiliary systems;
- 5) Liquid and gaseous waste treatment systems.

These samples are categorised into primary liquid, radioactive liquid, slightly radioactive liquid, corrosion product and gaseous ones, and the sampling feature present in the T-21.8-1.

b) Secondary sampling system

During normal operation, the secondary sampling system collects liquid samples from SG feedwater, APG [SGBS] blowdown lines as well as APG [SGBS] purification. The sampling feature is present in the T-21.8-2.

T-21.8-1 Sampling categories, Location and Specific Features for Primary
Sampling System

Sampling Categories	Sampling Location	Specific Feature
Primary coolant	<ul style="list-style-type: none"> • RCP hot leg loop 2/3; • Liquid phase of the pressuriser; • Downstream of the three trains of RIS [SIS] RHR exchangers; • RCV [CVCS] downstream the high pressure charging pumps and upstream purification. 	<p>On-line analysers: boron, hydrogen, oxygen and phase separator</p> <p>Grab sampling for on-line checking in the glove box</p>
Radioactive liquid	<ul style="list-style-type: none"> • Upstream of the RCV [CVCS] mixed bed demineralisers; • TEP [CSTS] coolant storage tanks; • Downstream of the TEP [CSTS] resin trap, TEP [CSTS] boric acid evaporation unit, REA [RBWMS] boric acid pumps and RCV [CVCS] the resin traps. 	<p>Grab sampling in the glove box</p>
Slightly radioactive liquid	<ul style="list-style-type: none"> • Liquid phase of accumulators; • The RPE [VDS] drainage sump; • Downstream of the PTR [FPCTS] heat exchangers, the reactor pool purification loop, the spent fuel pool purification loop, TEP [CSTS] degasser column and cooler. 	<p>Grab sampling in the glove box</p>
Corrosion product	<ul style="list-style-type: none"> • Upstream and downstream of the RCV [CVCS] mechanical filters and PTR [FPCTS] mechanical filters. 	<p>Grab sampling in the glove box</p>
Gaseous	<ul style="list-style-type: none"> • Upstream of the TEG [GWTS] gas drier; • Upstream and downstream of the TEG [GWTS] recombiner and delay beds; • The RPE [VDS] tanks. 	<p>Grab sampling</p>

T-21.8-2 Sampling categories, location and Specific features
for Secondary Sampling System

Sampling Categories	Sampling Location	Specific Feature
SG	<ul style="list-style-type: none"> • On the SG close to the inlet nozzle of RCP [RCS]; • On the SG blowdown lines of APG [SGBS]. 	<p>The secondary sampling lines used for automatic analysis run continuously. Samples can also be routed to the sample room for grab sampling without the glove box.</p>
APG [SGBS] purification	<ul style="list-style-type: none"> • Downstream the cation demineralisation bed; • Downstream the resin trap filters of anion demineralisation bed. 	<p>Each sampling line of SG and APG [SGBS] blowdown water is equipped with a pH meter, a conductivity meter and an activity measurement which are out of scope of this system. A sodium meter is connected to the three SG and APG [SGBS] blowdown sampling lines.</p> <p>Each sampling line of APG [SGBS] purification is equipped with a conductivity meter. A sodium meter is connected to the two APG anion demineralisation beds sampling lines.</p>

c) Post-accident sampling system

The post-accident sampling system obtains gaseous samples from containment atmosphere and liquid samples from IRWST in post-accident situation for the purpose of confirming the sample activity.

More information about nuclear sampling is described in Chapter 10. In order to ensure the sampling management satisfy the safety requirement, a report on sampling and monitoring arrangement will give more detailed information.

21.8.2.2 Feedwater Chemical Sampling System

The SIT [FCSS] monitors and takes samples of water or steam from the secondary circuit systems with the exception of the SGs and Steam Generator Blowdown System (APG [SGBS]).

The sampling system delivers representative samples of fluids from secondary systems to sample analysers. Secondary sampling monitors send control signals to the

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Conventional Island Chemical Feed System (SIR [CIS]) that automatically injects chemicals into the condensate and feedwater systems to control pH and dissolved oxygen concentration. The on-line sampling location and parameters are present in the T-21.8-3. All the on-line sampling points grab samples can be collected in the sampling room. In addition, some sampling points in the turbine hall are grab sampling by the SIT [FCSS] primary cooling rack.

T-21.8-3 On-line Sampling Location and Parameters for SIT [FCSS]

Sampling Location	On-line Parameter
Condensate extraction pump outlets	<ul style="list-style-type: none"> ▪ Dissolved oxygen (At condenser outlet) ▪ Sodium (At condensate polisher outlet) ▪ Cation conductivity (At condensate polisher outlet) ▪ pH (At condensate polisher outlet) ▪ Specific conductivity (At condensate polisher outlet)
Drains of HP heaters, LP heaters and MSRs drain	<ul style="list-style-type: none"> ▪ Cation conductivity
Deaerator downcomers and recirculation pump outlets	<ul style="list-style-type: none"> ▪ Dissolved oxygen ▪ pH
Main feedwater manifold	<ul style="list-style-type: none"> ▪ pH ▪ Cation conductivity ▪ Hydrazine ▪ Dissolved oxygen ▪ Turbidity
Main steam lines	<ul style="list-style-type: none"> ▪ Cation conductivity ▪ Sodium

21.9 ALARP Assessment

Following the ALARP methodology presented in Chapter 33, it is required to identify RGP and OPEX within the reactor chemistry topic area and to identify potential improvements based on the review against RGP and OPEX.

This sub-chapter presents a review of UK HPR1000 against the reactor chemistry

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RGPs to establish optimum control regimes, reducing the corrosion risk to the level ALARP, Reference [15].

The followings are sources of RGP and OPEX for reactor chemistry:

- a) IAEA safety standards
 - 1) IAEA Safety Standards, Chemistry Programme for Water Cooled Nuclear Power Plants. Specific Safety Guide No. SSG-13. IAEA. July 2011;
 - 2) IAEA Safety Standards, Design of the Reactor Core for Nuclear Power Plants. Safety Guide No. NS-G-1.12. IAEA. April 2005.
- b) SAPs and TAGs
 - 1) ONR, Safety Assessment Principles for Nuclear Facilities, Revision 0, 2014;
 - 2) ONR, Nuclear Safety Technical Assessment Guide, Chemistry of operating civil nuclear reactor. NS-TAST-GD-088 Revision 0. April 2017;
 - 3) ONR, Nuclear Safety Technical Assessment Guide, Chemistry Assessment. NS-TAST-GD-089 Revision 0. February 2018.
- c) Codes and standards
- d) OPEX from other GDA projects

The RGPs and OPEX adopted in the design are listed in T-21.9-1 and T-21.9-2.

T-21.9-1 Identification of RGP & OPEX for the Primary Water Chemistry

NO.	RGP and OPEX	Source	Applicability
1	Use of lithium hydroxide for pH control of reactor coolant	According to Reference [6] <i>“4.27. Addition or removal of alkaline compounds should be used in order to maintain the optimum pH_T value (pH at operating temperature) at all times during operation. In PWRs, generally, lithium hydroxide is added.”</i>	Applicable
2	Use of hydrogen for oxygen control of reactor coolant	According to Reference [6] <i>“4.28. The concentration of hydrogen should be maintained at an optimal level in order to suppress the production of oxygen via radiolysis and to keep the electrochemical potential at a sufficiently low level to prevent the stress corrosion cracking of stainless steel.”</i>	Applicable

NO.	RGP and OPEX	Source	Applicability
3	Use of enriched boric acid for reactivity control	According to Reference [11] <i>“IV.7. Because of the higher excess reactivity of the core in a high burnup core, a higher concentration of soluble boron in the coolant may be needed. Such a higher concentration may cause problems relating to the coolant chemistry such as increased corrosion in the primary circuit. Enriched ¹⁰B may be used to reduce the concentration of soluble boron.”</i>	Applicable
4	Use of zinc for radiation field and stress corrosion cracking control	According to Reference [4] <i>“A4.14. There are many on-going developments in primary coolant chemistry for PWRs which are aimed at having positive effects on one or more of the detriments highlighted above.”</i>	Applicable

T-21.9-2 Identification of RGP and OPEX for the Secondary Water Chemistry

NO.	RGP & OPEX	Source	Applicability
1	Use of volatile alkaline reagents for pH control of secondary circuit	According to Reference [6] <i>“4.42. The secondary circuit should be operated according to an ‘all volatile treatment’ or an ‘all volatile treatment with high pH’. All volatile treatment means the use of only volatile alkaline reagents such as ammonia and/or amines (e.g. morpholine, ethanolamine, dimethylamine). A reducing agent should also be added when necessary.”</i>	Applicable
2	Use of reducing reagent for oxygen control of secondary circuit	According to Reference [4] <i>“A5.15. These design choices and potential corrosion and degradation threats limit the feedwater chemistry to an All Volatile Treatment (AVT) with redox control and minimised impurity levels.”</i>	Applicable

RGP gap analysis has been undertaken and identified gaps will be addressed during GDA Step 3 and Step 4. ALARP is a continuous process. From the gap analysis, some new

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potential improvements may be identified and analysed in the GDA process. The ALARP analysis for the new potential improvements will be conducted according to the approach of ALARP, and the document will be updated.

21.10 Concluding Remarks

For UK HPR1000 design, the development of the chemistry control and related material selections are based upon proven RGP and OPEX.

The material selection of SSCs is a key parameter for ensuring the safe operation. Based on this point, chemistry controls that are developed in terms of the material corrosion risk, assisting in the integrity of SSC important to safety and minimisation of the source term, are holistically and sufficiently met in the generic UK HPR1000.

The key chemistry parameters have been generically described and justified, and system design can provide the means to maintain in the limits and conditions of operation, achieving the balance of chemistry related safety objectives, whilst demonstrating the risks at a level ALARP.

To achieve the goal of maintaining plant integrity and minimising of radiation field, the appropriate chemistry strategy for UK HPR1000 is prevention, control, and mitigation, thereby resulting in a safe design, which incorporates:

- a) Material selections based on lessons learned, customer inputs, and good practices;
- b) Chemistry regime defined according to the standards, good practices and OPEX;
- c) Chemistry regime controlled through comprehensive related systems to improve the performance of plant operation;
- d) Chemistry effects considered in the accident analysis to reduce the risk;
- e) Chemistry monitoring and control equipment and on-line instrumentation.

21.11 References

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