REGULATORY OBSERVATION Resolution Plan	
RO Unique No.:	RO-UKHPR1000-0031
RO Title:	Control of Boron during Normal Operations and Faults
Technical Area(s)	Reactor Chemistry
Revision:	0
Overall RO Closure Date (Planned):	2021-03-31
Linked RQ(s)	n/a
Linked RO(s)	n/a
Related Technical Area(s)	9. Fault Studies 10. Fuel & Core 17. RadWaste, Decommissioning & Spent Fuel Management 21. Environmental
Other Related Documentation	
Scope of Work	

Background

Boron, in the form of boric acid, is dissolved in the primary coolant of the UK HPR1000 to regulate rates of nuclear reaction at-power and as a backup to the shutdown control-rods at other times. Stocks of coolant for use in emergencies, shutdowns and the Spent Fuel Pool are also held with a sufficiently high Boron concentration to completely suppress nuclear chain reaction. At-power, the concentration of Boron in the circulating primary coolant is modified to compensate for variations in the fissile content of the fuel and contraction of the coolant in a shutdown. The amount of Boron required at any given time is determined by nuclear physics. This means that the operators must have rigorous control over Boron at all times. The main nuclear safety risks associated with a loss of control of Boron relate to dilution events, covering both heterogeneous and homogeneous dilution events.

For UK HPR1000 the Requesting Party (RP) has specified that Enriched Boric Acid, (EBA), will be used rather than natural Boron. In natural boric acid, only around 21% of the Boron is the effective ^{10}B isotope but this percentage is increased in EBA. While the use of EBA offers some potential safety benefits, it does require additional controls as, in addition to the overall concentration of Boric acid, the enrichment must be strictly controlled to ensure that there is no inadvertent reduction in the ^{10}B content. Such a process also happens throughout the fuel cycle by the poisoning effect of the Boron. The UK HPR1000 will recycle the EBA that is used, which involves the interaction of several different systems. A key part of the safety case is therefore the control of Boron concentration, (both chemical and isotopic), within all the relevant systems, and a justification that the systems that control Boron chemistry are adequate.

As well as the PCSR [1], during Step 3 of GDA, ONR has continued to receive and assess the RP's suite of supporting documentation which defines and justifies the chemistry for UK HPR1000, including [2]. To support the safety arguments presented in [1], and to be able to provide an adequate demonstration of how Boron is controlled in UK HPR1000, ONR expect this suite of documents to provide information on the Boron recycling system and the control of Boron, the choice and justification of the enrichment level of Boron, the monitoring, control and handling of Boron, and the prevention of Boron dilution events, (both chemical and isotopic, during normal operations and in fault conditions). This should cover the full range of systems where a claim is made on the Boron to provide nuclear reactivity control, and over all relevant operating modes.

Scope of work

EBA is selected for the UK HPR1000, and the boric acid is stored, transported in different systems, such as the Chemical and Volume Control System (RCV[CVCS]), the Reactor Boron and Water Makeup System (REA [RBWMS]), the Safety Injection system(RIS[SIS]), the Coolant Storage and Treatment System (TEP [CSTS]). Both boron enrichment and boric acid concentration should be controlled during power operation, startup and shutdown and refuelling, and necessary monitoring and sampling should be provided. A holistic view of boron chemistry will be provided recognising the following four items:

- Item 1: Normal chemistry - the boron enrichment and concentration of boric acid required is identified.
- Item 2: Normal chemistry process - the chemical process systems that store and distribute boric acid during all the operation modes, such as power operation, startup and shutdown, refuelling, are identified, and risks of chemical process, such as the dilution and enrichment depletion are identified and evaluated.
- Item 3: Accident chemistry - DBC and DEC events that boron may affect the accident consequence are identified, and the effects are evaluated through fault studies, e.g. the boron concentration is the input for the IRWST post accident pH evaluation. The chemical requirements for the safety systems that perform the safety function (reactivity control) are identified.
- Item 4: Accident chemistry process - the system requirements for the systems that mitigate the consequence of DBC or DEC events, such as the RIS[SIS] system, the RBS[EBS] system, EHR[CHRS] system, are identified. Risks of the chemical process are also identified and evaluated.

The design of the process systems are assigned with many functions other than boron managenment or control, the scope in the resolution of this RO will concentrate on the functions that related to boron.

Deliverable Description

RO-UKHPR1000-0031.A1 – Demonstrate that Boron can be adequately controlled during normal operations

- **ROA1-1:** Provide a suitable and sufficient safety case to demonstrate that Boron can be controlled in all systems where a nuclear safety claim is made on it, and covering all operating modes.
- **ROA1-2:** Provide a description of all systems that are involved in controlling Boron in the UK HPR1000. This should be a rigorous review detailing how Boron is controlled in all aspects of the systems during normal operation. This should include a description of how the concentration is controlled, and how the normal dilution process is governed. In addition to the Primary Circuit this

review should include the following systems:

- Chemical Volume and Control System
- Condensate Storage and Treatment System
- Reactor Boron Water Make-up System
- Emergency Boration System
- Safety Injection System
- Spent Fuel Pool
- In-Containment Refuelling Water Storage Tank
  This review should also identify relevant control parameters, and any limits and conditions that should be applied. Where aspects of the substantiation is provided in existing documents, clear links should be identified to justify that the systems have been substantiated to fulfill the requirements that have been placed upon them.
- **ROA1-3:** Justify the use of Enriched Boric Acid, and the choice of enrichment level. This should consider the effect this choice has on the operating pH throughout the fuel cycle, any impacts the use of EBA has on the production of radioactivity, and any impact on refuelling activities.
- **ROA1-4:** Identify the specific operating and handling requirements associated with the use of EBA, including make-up and preparation of EBA.
- **ROA1-5:** Describe how Boron enrichment will be controlled, and identify the different scenarios that may have an impact on Boron depletion. Identify the necessary actions that will be required to control Boron enrichment throughout the fuel cycle.
- **ROA1-6:** Demonstrate that the monitoring and sampling systems have been designed to achieve representative sampling of all relevant locations within the primary circuit and other relevent systems.

Resolution Plan for ROA1

The safety case will be developed from the four items described above that are normal chemistry (demonstration of the enrichment and concentration of boric acid during normal operation), normal chemistry process (demonstration of the engineering process systems that include storing, distributing and recycling of boric acid during normal operation), accident chemistry (demonstration of the enrichment and concentration of boric acid during and after DBC and DEC accident conditions) and accident chemistry process (demonstration of the boron related engineering process systems that mitigate the consequence of DBC and DEC events).

- From the normal chemistry aspect (item 1), a new document *Selection of Enriched Boric Acid for UK HPR1000* will be developed. The total boron concentration requirement according to pH and lithium limit is described in the *Topic Report of pH Control in the Primary Circuit of UK HPR1000*. The ^{10}B concentration requirement according to reactivity control is described in *Fuel Management Report*. In the document *Selection of Enriched Boric Acid for UK HPR1000*, the use of Enriched Boric Acid, and the choice of enrichment level will be justified, the impacts of use of EBA, such as pH control, waste minimization, system capacity, impact on Crud Included Power Shift (CIPS), radioactivity release and economics will also be analysed. Further detail of the contents of this report and the RO sub-actions it addresses are detailed below.
- From the normal process aspect (item 2), a new document *Boron Management and Risk Evaluation*

during Normal Operation will be developed to give a holistic view of how boron is managed in the UK HPR1000. The detailed descriptions of the boron related systems, which operate in different operation modes, are described in the relevant *System Design Manuals*. A brief introduction of each of the systems will be given in this new document, the interface between the systems will be given, the risks identified during the design will be described, and the risks that impact each of the systems normal functions (such as boric acid crystallization) will be evaluated in this new report. For the risks that affect the plant safety (such as dilution accidents), these will be evaluated in the specific reports developed in response to ROA-2. Control parameters, and limits and conditions related to boron management and control will be given in the *Boron Management and Risk Evaluation during Normal Operation* report. The system design has considered the risks, and detailed information is in the *System Design Manuals.* Boron monitoring and sampling requirements will also be described in the *Boron Management and Risk Evaluation during Normal Operation* report. Further detail of the contents of this report and the RO sub-actions it addresses are detailed below.

- From the accident chemistry aspect (item 3), the chemical requirements for the safety systems that perform safety functions relating to reactivity control are identified. The DBC and DEC events that boron may affect the accident consequence of are identified. The descriptions are given in Safety Functional Requirement of Safety Systems (including RIS [SIS], RBS [EBS] and EHR [CHRS] system). The effects that boron may affect the accident consequence are evaluated through fault analysis.
- From the accident process aspect (item 4), the systems that mitigate the consequence of DBC or DEC events, such as the RIS[SIS] system, the RBS [EBS] system, EHR [CHRS] system, requirements are identified. In normal operation, the safety systems are in a standby state. The description of boron management of these systems will also be included in the *Boron Management and Risk Evaluation during Normal Operation report.*

The reports that will be developed are as follows:

New documents

- *Selection of Enriched Boric Acid for UK HPR1000*
- *Boron Management and Risk Evaluation during Normal Operation*
- *Safety Functional Requirement of Safety Injection System (RIS[SIS]) System*
- *Safety Functional Requirement of Emergency Boration System (RBS[EBS]) System*

The existing reports are as follows:

Existing documents

To ROA1,the following existing documents need to be updated.

- *Topic Report on Power Operation Chemistry(GHX00100104DCHS03GN, Rev. B)*
- *Topic Report on Startup and Shutdown Chemistry (GHX00100105DCHS03GN, Rev. C)*
- *ALARP Demonstration Report of PCSR Chapter 21(GHX00100063KPGB03GN, Rev. B)*

The following documents also used to support ROA1, don't need to be updated.

- *Topic Report of pH Control in the Primary Circuit of UK HPR1000(GHX00100007DCHS03GN, Rev. D)*
- *Fuel Management Report(GHX00600009DRDG03GN, Rev. B)*

- *System Design Manuals (RCV [CVCS], REA [RBWMS], TEP [CSTS], RIS[SIS], EHR[CHRS], RCP[RCS], RBS[EBS], PTR [FPCTS], REN [NSS], etc.)*

The contents of each report and how they address each RO action (and sub-actions) are given as follows.

- *Selection of Enriched Boric Acid for UK HPR1000*

Selection of Enriched Boric Acid for UK HPR1000 links to ROA1-3. This report will introduce the purpose of boron chemistry control, the reason for selecting enriched boron, the basis for determining the boron enrichment, and the evaluation process applied for selecting enriched boric acid.

An optioneering between natural and enriched boric acid selection will be demonstrated. The optioneering will systematically review advantages and disadvantages of using enriched boric acid, including:

- In terms of waste minimization, the volume of boric acid injected into the primary circuit for boron concentration regulation is decreased, i.e. boration in shutdown condition, thus the waste water that the TEP [CSTS]) treats is reduced due to the selection of enriched boric acid. The use of enriched boric acid also facilitates a higher pH during power operation which reduces corrosion, the release of corrosion products and in turn, the volume of solid waste generated.
- In terms of radioactivity release, tritium discharged to the environment is decreased through the use of enriched boric acid.
- In terms of accident mitigation, the volume of boric acid injected into the primary circuit for reactivity control in accident by RBS[EBS] is decreased, and thus reduces the opening risk of the pressurizer safety valves.
- In terms of process design, the volume of boric acid storage tanks is decreased, the lower concentration of boric acid in pipelines reduce requirement of environment temperature in the room.
- In terms of fuel design, the effect on Crud Induced Power Shift (CIPS) will be evaluated. This part links to RO0015.
- In terms of economics, selection of enriched boric acid and the impact this has on the overall cost will be analysed relative to normal boric acid.
- In terms of refuelling operation, it is necessary to ensure concentration and enrichment consistency between primary loop and connecting systems (such as IRWST and RHR) during refuelling.

The level of enrichment will be given in this report according to the pH strategy and ^{10}B concentration needed by reactivity control during power operation.

- *Boron Management and Risk Evaluation during Normal Operation.*

This report (*Boron Management and Risk Evaluation during Normal Operation*) will describe how boric acid is managed in the primary circuit, auxiliary systems and spent fuel pool during power operation, reactor start up, shutdown and refuelling conditions. Recognising that detailed information for each of the systems that are involved in controlling boron in the UK HPR1000 is currently detailed in the respective *System Design Manuals*, a holistic summary of how each of the systems interface will be provided in this report for each operating mode. This is in addition to a brief introduction to each of the systems explaining how they operate. This report will also identify the risks in each operation and explain the countermeasures in place in the design of normal operation systems to mitigate these risks. For risks that affect the plant safety (such as dilution accidents), these will be evaluated in the specific reports developed in response to ROA-2. This report is linked to ROA1-1, ROA1-2, ROA1-4, ROA1-5 and ROA1-6.

The main contents of this report are as follows:

- Preparation and distribution of boric acid

  Enriched boric acid may obtained by mixing with a higher enrichment and natural boric acid. This report will introduce the calculation of the addition amount of boric acid with different enrichment.

  Preparation and distribution function are implemented by the REA system. The report will describe the specific operation during the preparation (including the handling of boric acid powder) and distribution process, identify the risks in the operation and provide countermeasures, for example, during the distribution operation, the risk of crystallization is prevented by the HVAC system or Boron Heating System (RRB[BHS]).

- Boron cycle during power operation

  The circulation of boric acid during power operation will be introduced with a diagram which gives a holistic view of the boron cycle. The systems involved are the *RCP [RCS],* RCV [CVCS], REA [RBWMS] and TEP [CSTS]. Their function includes providing boration, dilution, make-up and re-cycle. The concentration of boron in the primary circuit over the duration of the power operation mode will be illustrated and how the systems integrate to achieve this concentration will be described. This report will also describe the normal operation risks identified and their countermeasures. For example, form the control logic of REA [RBWMS] system to make the injecting boric acid concentration is consistent with the concentration of boric acid in primary loop.

- Boron management during startup and shutdown

  During startup and shutdown, the boric acid concentration is adjusted according to the reactivity control. In addition, the enrichment of RCP and the connected systems (such as spent fuel pool) may be slightly different after power generation. To avoid any decrease in enrichment, the consistency of the boric acid enrichment of the connected systems will be considered and the adjustment approach will be demonstrated.

- Boric acid consumption and supplement during normal operation

  During normal operation the boron enrichment will decrease due to the reaction of ^{10}B atom with neutrons. The enrichment of primary circuit will be sampled periodically by REN. The volume of boric acid will decrease due to drainage before equipment maintenance and resin absorption. The decrease of boric acid volume will be measured by primary loop leakage periodic test. This report will introduce the causes and quantities of boric acid consumption and describe how it is supplemented.

- Boron management of spent fuel pool

  The report will outline how boric acid is controlled and managed in the spent fuel pool, and explain how the risk of events such as boric acid crystallization are minimised. The enrichment of the spent fuel pool may be slightly different to the RCP after power generation. The consistency of the boric acid enrichment of the RCP and connected systems will be considered and the adjustment approach will be demonstrated.

- Management of boric acid stored in safety systems during normal operation

Due to the requirements of reactivity control and heat removal, safety systems inject boric acid into the primary circuit during accident scenarios, systems such as RIS[SIS] (including IRWST), RBS[EBS] and EHR [CHRS] system. During normal operation, the boric acid stored in these systems needs to be managed to ensure that the concentration, enrichment and volume meet the safety functional requirements of such systems. This report will describe how boric acid is effectively managed in these safety systems during normal operation. The information relating to boric acid storage for safety systems is linked with the information provided in response to ROA2-5.

- Control parameters

  Control parameters will be identified according to the importance of the parameter, several aspects, such as reactiovity control, fault study, process design, will be considered. Why they are selected as control parameters will be provided.

- Sampling

  The sampling requirements for boron control will be given according to the safety aspect or the normal operation aspect. Boron related systems mentioned above are required to sampling and designed with sampling interface. This report will state the sampling locations and measurement used for each of the control parameters identified.

- *Safety Functional Requirement of RIS[SIS] System*

Safety Functional Requirement of RIS[SIS] System report will identify the relevant DBC and DEC events where the RIS[SIS] is required to be used. It will detail the safety functional requirements of the RIS [SIS], including the control of sub-criticality through boric acid injection after accident events. The requirements of boron concentration, volume of accumulators and IRWST will be provided in this report. These values are managed as limits during normal operation. This report links to ROA1-2.

- *Safety Functional Requirement of RBS[EBS] System*

Safety Functional Requirement of RBS[EBS] System report will identify the relevant DBC and DEC events where the RBS[EBS] is required to be used and the related safety functional requirements. RBS [EBS] performs reactivity control function via injecting borated water to Reactor Coolant System (RCP [RCS]) Under Design Basis Condition (DBC) and Design Extension Condition A (DEC-A) events. RBS [EBS] performs borated water injection function to ensure that the plant can reach safe shutdown state. The minimum boron concentration and minimum volume requirement of Emergency Boric Acid Tank will be given in this report. These values are managed as limit values during normal operation. This report links to ROA1-2.

- *System Design Manuals (RCV [CVCS], REA [RBWMS], TEP [CSTS], RIS[SIS], EHR[CHRS], RCP[RCS], RBS[EBS], PTR [FPCTS], REN [NSS], etc.)*

These documents support the *Boron Management and Risk Evaluation during Normal Operation* report. These documents are already present in the safety case and aren't required to be updated. They provide the detailed system design descriptions for each of the relevant systems and explain how the risks relating to boron management are eliminated.

- *Topic Report on Power Operation Chemistry*

The Limiting Condition for pH_T and the associated concentration of enriched boric acid when co-ordinated with enriched lithium hydroxide is included in this report. The next revision of this report (GHX00100104DCHS03GN, Rev. C) will be updated to reflect the information presented on boron control in the *Boron Management and Risk Evaluation during Normal Operation* report in response to ROA1-2.

- *Topic Report on Startup and Shutdown Chemistry*

In this report, it defines the Limiting Condition of boron during startup and shutdown operation. The current version of the report is temporarily missing boric acid-related content and will be added in the next version(GHX00100105DCHS03GN, Rev. D). The report links to ROA1-2.

- *Topic Report of pH Control in the Primary Circuit of UK HPR1000*

This report provides the justification for the pH control regime proposed for the UK HPR1000 and defines the primary coolant high-temperature pH_T. The maximum total boron concentration and associated enrichment requirement is derived based on reactivity control requirements as well as pH control requirements. This report supports to the *Selection of Enriched Boric Acid for UK HPR1000* report (linked to ROA1-3) and isn't required to be updated.

- *Fuel Management Report*

This report states the requirement for ^{10}B concentration for different cycles and stages of operation in the UK HPR1000. This report supports to the *Selection of Enriched Boric Acid for UK HPR1000* report (linked to ROA1-3) and isn't required to be updated.

- *ALARP Demonstration Report of PCSR Chapter 21*

This report presents the preliminary information on the ALARP demonstration for the use of enriched boric acid linked with ROA1-3. It will be updated (GHX00100063KPGB03GN, Rev. C) to maintain consistency with the newly published document *Selection of Enriched Boric Acid for UK HPR1000*.

The reports and the relationship to ROAs are demonstrated as below.

Boron Items	Requirements	Reports	ROAs
Normal chemistry	Boron enrichment Boric acid concentration	• *Selection of Enriched Boric Acid for UK HPR1000* •*Topic Report of pH Control in the Primary Circuit of UK HPR1000* • *Fuel Management Report* • *ALARP Demonstration Report of PCSR Chapter 21*	ROA1-3
Normal chemistry process	RCV[CVCS]	• *Boron Management and Risk Evaluation during Normal Operation*	ROA1-1 ROA1-2

			• Topic Report on Power Operation Chemistry *•Topic Report on Startup and Shutdown Chemistry* *• RCV system design manual*	ROA1-4 ROA1-5
		REA [RBWMS]	*• Boron Management and Risk Evaluation during Normal Operation* *• Topic Report on Power Operation Chemistry* *•Topic Report on Startup and Shutdown Chemistry* *• REA system design manual*	ROA1-1 ROA1-2 ROA1-4 ROA1-5
		TEP [CSTS])	*• Boron Management and Risk Evaluation during Normal Operation* *• Topic Report on Power Operation Chemistry* *•Topic Report on Startup and Shutdown Chemistry* *•TEP system design manual*	ROA1-1 ROA1-2 ROA1-4 ROA1-5
		PTR [FPCTS]	*• Boron Management and Risk Evaluation during Normal Operation* *• Topic Report on Power Operation Chemistry* *•Topic Report on Startup and Shutdown Chemistry* *• PTR system design manual*	ROA1-1 ROA1-2 ROA1-4 ROA1-5
		REN [NSS]	*• Boron Management and Risk Evaluation during Normal Operation* *• REN system design manual*	ROA1-6
	Accident chemistry	Boron enrichment boric acid concentration	*• Safety Functional Requirement of RIS[SIS] System* *• Safety Functional Requirement of RBS[EBS] System*	ROA1-2
	Accident chemistry process	RIS[SIS] (including IRWST)	*• Safety Functional Requirement of RIS[SIS] System* *• Boron Management and Risk Evaluation during Normal Operation* *• RIS system design manual*	ROA1-1 ROA1-2 ROA2-5
		RBS[EBS]	*• Safety Functional Requirement of RBS[EBS] System* *• Boron Management and Risk Evaluation during Normal Operation* *• RBS system design manual*	ROA1-1 ROA1-2 ROA2-5
		EHR[CHRS]	*• Boron Management and Risk Evaluation during Normal Operation*	ROA1-1 ROA1-2

		• *EHR system design manual*	ROA2-5

RO-UKHPR1000-0031.A2 – Demonstration that the risks associated with Boron Dilution Faults have been reduced SFAIRP

Provide a suitable and sufficient justification that the risks associated with Boron dilution faults have been reduced SFAIRP in the generic UK HPR1000 design. This should include:

- **ROA2-1:** Identification of the fault scenarios that could lead to a Homogeneous Boron Dilution of the expected Boron concentration, and the consequences of such events.
- **ROA2-2:** Identification of the fault scenarios that could lead to a Heterogeneous Boron Dilution of the expected Boron concentration, and the consequences of such events.
- **ROA2-3:** Justification that the systems that are employed to detect a Boron dilution fault are adequate.
- **ROA2-4:** Demonstration that the processes and systems that are designed to protect against Boron dilution faults are capable of delivering the required safety functions with sufficient reliability.
- **ROA2-5:** A description of the measures that are necessary to prevent the inadvertant use of Boric acid with insufficient enrichment.

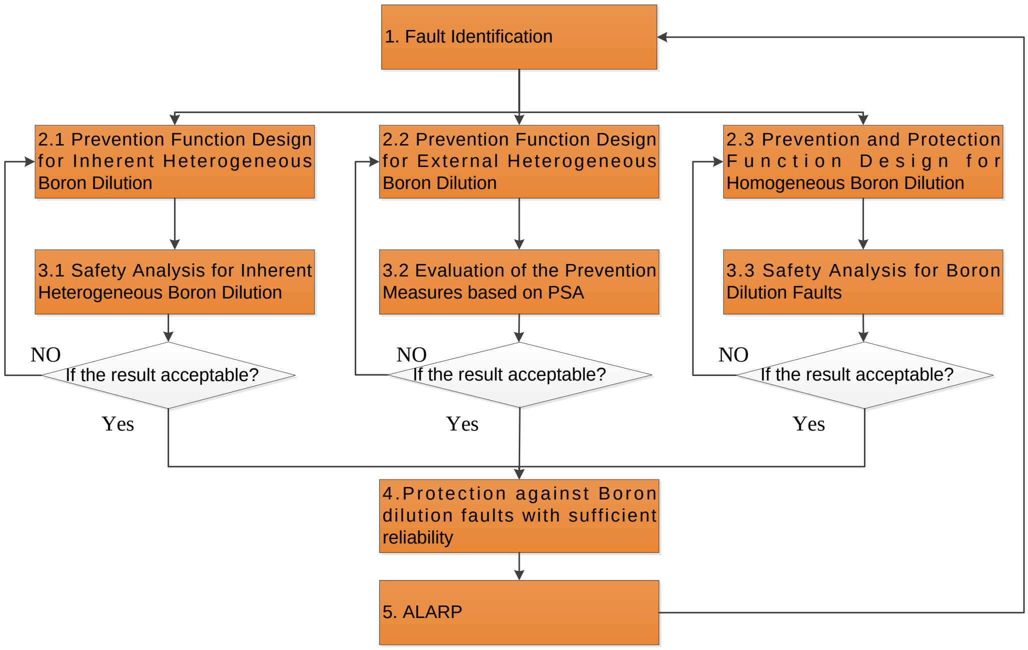
The response to this Action should consider all systems where a nuclear safety claim is made on Boron, and cover all operating modes.

Resolution Plan for ROA2

In order to respond the questions in ROA2, the following work should be done:

1) Identification of homogeneous and heterogeneous boron dilution faults (related to ROA2-1 and ROA2-2);
2) Development of functional requirements for the prevention and protection against boron dilution (related to ROA2-3 and ROA2-4).
3) Safety analysis for the dilution faults and evaluation of the adequacy of prevention and protection functions (related to ROA2-3 and ROA2-4).
4) Demonstration that the required safety functions protecting against Boron dilution faults will be delivered with sufficient reliability (related to ROA2-4).
5) Justification that the risk of dilution has been reduced SFAIRP (related to ROA2-3 and ROA2-4).

The work process is shown in the follwing flow chart:



The reports that will be developed are as follows:

New documents

- *Functional Requirements for Prevention and Protection against Boron Dilution*
- *Inherent heterogeneous boron dilution analysis*
- *Boron Management and Risk Evaluation during Normal Operation*
- *CFD Analysis of Critical Water Slug Size for External Heterogeneous Dilution Scenarios*
- *Demonstration of the Elimination of External Heterogeneous Boron Dilution*

The existing reports are as follows:

Existing documents

To ROA2,thess existing documents need to be updated.

- *ALARP Demonstration Report of Fault Studies (GHX00100055KPGB03GN, Rev. A)*

These documents also used to support ROA2, and aren’t required to be updated.

- *PIE List of UK HPR1000 of Internal Event (Except for Loss of Support System) (GHX00100110DOZJ03GN, Rev. D)*
- *PIE Grouping and Bounding Analysis for the PIE of Internal Event (Except for Loss of Support System) (GHX00100007DRAF03GN, Rev. D)*
- *Identification of DBC list from PIE Grouping Results (GHX00100056DRAF03GN, Rev. B)*
- *Functional requirements of the RPS – Core Related (GHX00100011DRAF03GN, Rev. B)*
- *Functional requirements of the RPS – PS Related (GHX00100010DRAF03GN, Rev. B)*
- *Decrease in Boron Concentration in Reactor Coolant due to malfunction of RCV [CVCS], REA [RBWMS] and TEP [CSTS] (GHX00600002DRDG02GN, Rev. D)*
- *Boron Dilution due to Rupture of One Heat Exchanger Tube (GHX00600008DRDG03GN, Rev. C)*
- *UK HPR1000 Fault Schedule (GHX00600276DRAF02GN, Rev. B)*
- *Small Break – Loss of Coolant Accident (State A) (GHX00100043DRAF03GN, Rev. B)*

- *Intermediate Break and up to Surge Line Break – Loss of Coolant Accident (GHX00100042DRAF03GN, Rev. B)*

The activites showed in the flow chart are introduced as following part:

1) Fault Identification (related to ROA2-1 and ROA2-2)

A systematic and comprehensive PIE identification for all potential dilution events (including Homogeneous Boron Dilution as well as Heterogeneous Boron Dilution) has been carried out. The identification process and the PIE list are presented in the section 5.1 of the *PIE List of UK HPR1000 of Internal Event (Except for Loss of Support System)* (GHX00100110DOZJ03GN, Rev. D).

Basing on the PIE list, a grouping and bounding analysis has been carried out. The grouping process and results are presented in the *PIE Grouping and Bounding Analysis for the PIE of Internal Event (Except for Loss of Support System)* (GHX00100007DRAF03GN, Rev. D) and the *Identification of DBC list from PIE Grouping Results* (GHX00100056DRAF03GN, Rev. B). The homogeneous boron dilution faults are grouped into two DBC events (see the following point 2.3 and 3.3), and the external heterogeneous boron dilution faults are grouped together for prevention functions design.

2.1) Prevention and Protection Function Design against Inherent Heterogeneous Boron Dilution (related to ROA2-2, ROA2-3 and ROA2-4)

For a limited range of break sizes, inherent boron dilution may occur during SB/IB-LOCA. The main safety functions to reach safe state in SB/IB-LOCA are presented in the *Small Break – Loss of Coolant Accident (State A)* (GHX00100043DRAF03GN, Rev. B) and the *Intermediate Break and up to Surge Line Break – Loss of Coolant Accident* (GHX00100042DRAF03GN, Rev. B). There are no additional prevention or protection functions specially against inherent heterogeneous boron dilution.

2.2) Prevention Function Design against External Heterogeneous Boron Dilution (related to ROA2-2, ROA2-3 and ROA2-4)

Multiple prevention functions have been designed to reduce the risk of heterogeneous boron dilution. An existing document in the reference design FCG3, the *Functional Requirements for Prevention and Protection against Boron Dilution*, presents the functional requirements (including the actions, corresponding plant state and classifications). An English version of this document will be submitted in 31/08/2020 to address the action.

2.3) Prevention and Protection Function Design against Homogeneous Boron Dilution (related to ROA2-1, ROA2-3 and ROA2-4)

The Homogeneous Boron Dilution PIEs are grouped into two DBC events. The functional requirements of the protection signals against the Homogeneous Boron Dilution events are presented in the *Functional requirements of the RPS – Core Related* (GHX00100011DRAF03GN, Rev. B) and the *Functional requirements of the RPS – PS Related* (GHX00100010DRAF03GN, Rev. B). The protection measures used in the dilution accident are also in the *UK HPR1000 Fault Schedule,* (GHX00600276DRAF02GN, Rev. B).

In addition to the protection functions, a set of prevention functions have been designed to reduce the risk of boron dilution. These preventive functional requirements will be presented in the *Functional Requirements for Prevention and Protection against Boron Dilution.* As stated in point *2.2,* it is an existing document in FCG3 and will be translated in English. It will present in a systematic way the prevention functions against homogeneous boron dilution as well as heterogeneous boron dilution, and also the protection functions against homogeneous boron dilution (which is consistent with the two Functional Requirements of the RPS mentioned in the above paragraph).

3.1) Evaluation of the Prevention and Protection Functions for Inherent Heterogeneous Boron Dilution Faults (related to ROA2-1, ROA2-3 and ROA2-4)

The analysis of relevant phenomena and the demonstration of a safety margin to re-criticality under current protection function design will be presented in the document *Inherent heterogeneous boron dilution analysis* (to be submitted in 31/07/2020).

3.2) Evaluation of the Prevention Functions for External Heterogeneous Boron Dilution Faults (related to ROA2-1, ROA2-3 and ROA2-4)

With the consideration of the prevention measures, the frequency of the external Heterogeneous Boron Dilution is so low that it is excluded from the DBC list. A brief justification is presented in the *Identification of DBC List from PIE Grouping Results* (GHX00100056DRAF03GN, Rev. B). A new document titled *Demonstration of the Elimination of External Heterogeneous Boron Dilution* will be submitted in 30/09/2020 to present the detailed demonstration process, including the reliability analysis and modeling of the prevention functions. To evaluate the maximum volume of water slug (critical water slug) injected into the reactor core without the risk of core re-criticality, a new document titled *CFD Analysis of Critical Water Slug Size for External Heterogeneous Dilution Scenarios* will be submitted before 30/09/2020.

3.3) Safety Analysis for Homogeneous Boron Dilution Faults (related to ROA2-1, ROA2-3 and ROA2-4)

The criteria and results of the safety analysis for these two events are respectively presented in the *Decrease in Boron Concentration in Reactor Coolant due to malfunction of RCV [CVCS], REA [RBWMS] and TEP [CSTS]* (GHX00600002DRDG02GN, Rev. D) and the *Boron Dilution due to Rupture of One Heat Exchanger Tube* (GHX00600008DRDG03GN, Rev. C). Analysis results show that for each initial condition the acceptance criteria are met with conservative assumptions and the most penalizing single failure.

In addition, the DBC-2 dilution event is classified as a frequent fault and the diverse protection lines of this event are presented in *UK HPR1000 Fault Schedule* (GHX00600276DRAF02GN, Rev. B).

4) Demonstration that the required safety functions protecting against Boron dilution faults will be delivered with sufficient reliability (related to ROA2-4)

As explained in point 3.3, safety analysis show that safety functions protecting against Homogeneous Boron dilution faults can be delivered with sufficient margin and redundancy.

RP will also respond to this action by the report *UK HPR1000 Fault Schedule* (GHX00600276DRAF02GN, Rev. B), which specifies the diverse protection lines against Homogeneous Dilution event, including classification for each diverse protection line.

Besides, the submitted reports *Functional requirements of the RPS – Core Related*

(GHX00100011DRAF03GN, Rev. B) and *Functional requirements of the RPS – PS Related* (GHX00100010DRAF03GN, Rev. B) describe the requirements for reactor protection functions of the RPS [PS] against boron dilution, including the protection channel, measurement parameters, voting logics, measurement range, accuracy requirements, delay time and the permissive signals.

5) Justification that the risk of dilution has been reduced SFAIRP (related to ROA2-3 and ROA2-4)

Boron Concentration in Reactor Coolant due to malfunction of RCV [CVCS], REA [RBWMS] and TEP [CSTS], Boron Dilution due to Rupture of One Heat Exchanger Tube, Inherent heterogeneous boron dilution analysis, these reports present the acceptance criteria and safety analysis results for the faults. Considering the safety margin existing in current design and analysis, the risk for fuel failure is considered to be ALARP.

The existing *ALARP Demonstration Report of Fault Studies* (GHX00100055KPGB03GN, Rev. A) will be updated (end of Nov. in 2020) to present the outcome and conclusion of the ALARP assessment for fault studies including boron dilution.

This new version of the document will reference several reports, in which the optioneering process will be presented to demonstrate that the option which reduces the risk of dilution So Far As Is Reasonably Practicable (SFAIRP) has been selected.

6) Boron management and control (related to ROA2-5)

The boron management with process systems during normal operation is described in ROA1.The change of enrichment B10 in the core is due to its absorption of neutrons. The enrichment of B10 is changed a little during one cycle from experience of CPR1000. So the enrichment of B10 is not changed during the boron dilution accidents, since the time of boron dilution accident is much shorter than one fuel management cycle. So boric acid with insufficient enrichment is not considered in the boron dilution accidents. This part of work refers to the ROA1. The following table presents the link between ONR expectations and RP response to get an easy understanding.

No.	ONR expectation	RP respond/Report
1	Fault Identification	*PIE List of UK HPR1000 of Internal Event (Except for Loss of Support System);* *PIE Grouping and Bounding Analysis for the PIE of Internal Event (Except for Loss of Support System);* *Identification of DBC list from PIE Grouping Results.*
2	Risk Mitigation	*Functional requirements of the RPS – Core Related;* *Functional requirements of the RPS – PS Related;* *Functional Requirements for Prevention and Protection against Boron Dilution.*

3	Safety Analysis	*Decrease in Boron Concentration in Reactor Coolant due to malfunction of RCV [CVCS], REA [RBWMS] and TEP [CSTS];* *Boron Dilution due to Rupture of One Heat Exchanger Tube;* *UK HPR1000 Fault Schedule;* *Inherent heterogeneous boron dilution analysis;* *Small Break – Loss of Coolant Accident (State A);* *Intermediate Break and up to Surge Line Break – Loss of Coolant Accident;* *Demonstration of the Elimination of External Heterogeneous Boron Dilution;* *CFD Analysis of Critical Water Slug Size for External Heterogeneous Dilution Scenarios.*
4	Safety function reliability	*UK HPR1000 Fault Schedule;* *Functional requirements of the RPS – Core Related;* *Functional requirements of the RPS – PS Related.*
5	ALARP	*ALARP Demonstration Report of Fault Studies*

Impact on the GDA Submissions

Relevant information will be incorporated into the final version of Reactor Chemistry submission during Step 4. The submissions that are impacted by this resolution plan include:

Document No.	GDA Submission Document	Revision	Related ROAs	Planned Submission Date
1	*Selection of Enriched Boric Acid for UK HPR1000*	A	ROA1-3	2020-06-30
2	*Boron Management and Risk Evaluation during Normal Operation*	A	ROA1-1 ROA1-2 ROA1-4 ROA1-5 ROA1-6 ROA2-5	2020-07-30
3	*Safety Functional Requirement of RIS[SIS] System*	A	ROA1-2	2020-06-30
4	*Safety Functional Requirement of RBS[EBS] System*	A	ROA1-2	2020-08-31
5	*Topic Report on Power Operation Chemistry*	C	ROA1-2	2020-11-30
6	*Topic Report on Startup and Shutdown Chemistry*	D	ROA1-2	2020-11-30

7	*ALARP Demonstration Report of PCSR Chapter 21*	C	ROA1-3	2020-10-30
8	*Functional Requirements for Prevention and Protection against Boron Dilution*	A	ROA2-1 ROA2-2 ROA2-3 ROA2-4	2020-08-31
9	*Inherent heterogeneous boron dilution analysis*	A	ROA2-2	2020-7-31
10	*Demonstration of the Elimination of External Heterogeneous Boron Dilution*	A	ROA2-2 ROA2-4	2020-9-30
11	*CFD Analysis of Critical Water Slug Size for External Heterogeneous Dilution Scenarios*	A	ROA2-2	2020-9-30
12	*ALARP Demonstration Report of Fault Studies*	B	ROA2-3 ROA2-4	2020-11-30

Timetable and Milestone Programme Leading to the Deliverables

Attach a Gantt chart to present the timetable and milestone of the RO resolution in APPENDIX A.

Reference

[1] Pre-Construction Safety Report, Chapter 21, Reactor Chemistry, HPR/GDA/PCSR/0021, Rev. 000, GNS, November 2018.

[2] Topic Report on Power Operation Chemistry, GHX00100104DCHS03 GN, Rev B, CGN. April 2019. CM9 Ref: 2019/152125.

APPENDIX A RO-UKHPR1000-0031 Gantt Chart

Tasks	**Steps**	**2020**												**2021**			
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**
RO Action 1																	
Selection of Enriched Boric Acid for UK HPR1000 (Revision A)	Development																
	Submission																
Boron Management and Risk Evaluation during Normal Operation (Revision A)	Development																
	Submission																
Topic Report on Power Operation Chemistry (Revision C)	Development																
	Submission																
Topic Report on Startup and Shutdown Chemistry (Revision D)	Development																
	Submission																
Safety Functional Requirement of RIS[SIS] System (Revision A)	Development																
	Submission																
Safety Functional Requirement of RBS[EBS] System (Revision A)	Development																
	Submission																
ALARP Demonstration Report of PCSR Chapter 21 (Revision C)	Development																
	Submission																

Tasks	Steps	2020												2021			
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**
RO Action 2																	
Functional Requirements for Prevention and Protection against Boron Dilution (Revision A)	Development																
	Submission																
ALARP Demonstration Report of Fault Studies (Revision B)	Development																
	Submission																
Inherent Heterogeneous Boron Dilution Analysis (Revision A)	Development																
	Submission																
Demonstration of the Elimination of External Heterogeneous Boron Dilution (Revision A)	Development																
	Submission																
CFD Analysis of Critical Water Slug Size for External Heterogeneous Dilution Scenarios (Revision A)	Development																
	Submission																
Regulator assessment																	
Target RO closure Date																	